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Effects of saline irrigation water and proline applications on yield, vegetative and physiological characteristics of potato crop (*Solanum tuberosum* L.)

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Abstract

Potato (*Solanum tuberosum* L.) is one of the most important starch crops grown extensively. In this study, the effects of saline water and proline content on yield and some characteristics of potato were determined. Proline concentrations of 0 mM (control), 10 mM, and 20 mM were applied to potato crop irrigated with water with electrical conductivities of 0.2 dSm^{-1} (control), 3.5 dSm^{-1}, 7 dSm^{-1} 10 dSm^{-1} and 13 dSm^{-1}. Different levels of saline irrigation water were obtained by adding NaCl into the tap water with an EC of 0.2 dSm^{-1}. In the saline water treatments, a leaching fraction about 20% was applied. The study was conducted between January-June 2010 in the pots located in a greenhouse under the Eastern Mediterranean (Hatay, Turkey) conditions. Compared to the control treatment, the amount of irrigation water and crop water use decreased by 4.5%-18.9% and 3.0%-16.0% depending on soil salinity, respectively. Soil salinity caused a decrease in total tuber yield, mean tuber weight, total dry weight, harvest index, and number of potatoes classified as Grade A, whereas it caused an increase in total dry matter content. No distinct effects of proline on tuber yield were observed in the treatments of higher salt stress. The effect of increasing proline concentration was mostly pronounced in the vegetative and gas exchange parameters.

Keywords: Potato, Salinity, Proline, Tuber yield, Photosynthesis rate, Stomatal conductance

Tuzlu sulama suyu ve prolin uygulamalarının patatesin (*Solanum tuberosum* L.) verim, vejatatif ve fizyolojik özellikleri üzerine etkileri

Öz

Patates (*Solanum tuberosum* L.) yaygın olarak yetiştirilen önemli nişasta bitkilerinden biridir. Bu çalışmada tuzlu su ve prolin içeriğinin verime ve bazı patates özelliklerine etkileri belirlenmiştir. Araştırmada, elektriksel iletkenliği 0.2 dSm^{-1}, 3.5 dSm^{-1}, 7 dSm^{-1}, 10 dSm^{-1} ve 13 dSm^{-1} olan sulama suları ile sulanan bitkiye 0 mM, 10 mM, 20 mM konsantrasyonlarında prolin uygulanmıştır. Elektriksel iletkenliği 0.2 dS m^{-1} olan musluk suyuna NaCl ilave edilerek farklı seviyelerde tuzlu sulama suyu elde edilmiştir Tuzlu su uygulamalarında %20 civarında yıkama suyu eklenmiştir. Çalışma Ocak-Haziran 2010 tarihleri arasında Doğu Akdeniz (Hatay-Türkiye) koşullarında sera içinde yerleştirilen saksılarda yürütülmüştür. Kontrol konusuna kıyasla, sulama suyu ve bitki su tüketimi, toprak tuzluluğuna bağlı olarak, sırasıyla, %4.5-18.9 ve % 3.0-16.0 oranında azalmıştır. Toprak tuzluluğu toplam yumru veriminde, ortalama yumru ağırlığında, toplam kuru ağırlıkta, hasat indeksinde ve A Sınıfı olarak sınıflandırılan patates sayısında azalmaya neden olurken, toplam kuru madde içeriğinde artışa neden olmuştur. Yüksek tuz stresi konularında prolinin yumru verimi üzerindeki belirgin etkileri gözlenmemiştir. Artan prolin konsantrasyonunun etkisi vejatatif ve gaz değişim parametrelerinde daha çok belirgin olduğu belirlenmiştir.

Anahtar Kelimeler: Patates, Tuzluluk, Prolin, Yumru verimi, Fotosentez hızı, Stoma iletkenliği

1. Introduction

Because of the importance in human diet, potato growth and development have received considerable scientific attention, especially the regulation of tuber development. The trend of potato production has been toward greater acreage in warm climates using cultivars that were developed for production in cool climates (Levy and Veilleux, 2007). Major limitations for potato production are high temperature and the scarcity of fresh water resources for irrigation, necessitating the use of alternative water resources such as saline water.

Potato crop can be grown without any reduction in tuber yield in soils whose electrical conductivity (EC_e) is less than 1.7 dSm^{-1} (Levy and Veilleux, 2007). After this threshold value, tuber yield decreases such that the decrease in tuber yield is 10% at EC_e of 2.5 dSm^{-1}, 50% in 5.9 dSm^{-1} and when EC_e is 10 dSm^{-1}, no tuber yield is obtained at all (FAO, 2002). As soil salinity increases, mean tuber weight and tuber yield decreases but the number of tuber increases (Kirk et al., 2006). Especially, early development stage is the most vulnerable stage for potato crop in terms of salinity (Nadler and Heuer, 1995). Fidalgo et al. (2004) reported that salt stress negatively affected relative water content, leaf stomatal conductance and transpiration rate of potato. Changes to the chloroplast structure presumably affect photosynthesis, resulting in increased starch in leaves, suppression of nitrate reductase and reduced growth and dry matter production in tubers (Ghosh et al., 2001). Levy and Veilleux (2007) stated that salinity reduced yield components such as number of tuber and tuber weight by 27% and 40%, respectively. The adverse effects of salinity stress on potato plant can be a) reduced growth of stems (stunting), leaves and tubers b) leaf chlorosis (yellowing), tip burn and leaf burn, c) restricted water uptake by roots, d) enhanced plant senescence, e) reduced tuber yield, f) browning and cracking of tuber surface (Levy and Veilleux, 2007).

Crops are secreting proline as a first physiological reaction when they are exposed to stress factors such as salinity (Chen et al., 1999), draught (Arvin and Donnelly, 2008), cold (Sluc et al., 1991), heavy metals (De and Mukherjee, 1996), and temperature (Rahman et al., 2003). Proline accumulation depends on crop species as well as crop varieties within a certain crop species under different stress condition (Yürekli et al., 1996). Proline is accumulated at most in crops under stress condition. Increase of proline concentration in the vacuole inside the cell is a measure of how long the crop is under stress and how the crop is tolerant to that stress factor. This constitutes the first stage in metabolic activity. Although researches indicate that proline is occurred during protein decay resulting an increase in its concentration in the cell, the general opinion is that it is synthesized inside the cell (Avcıoğlu et al., 2003). Researches on proline are mostly concentrated on how crops synthesize proline and the amount of concentration of synthesized amino acid. It is reported that proline has significant function in stabilizing osmotic effects by balancing of ion concentrations such as Na, K, Mg and Ca, in strengthening the cell wall and in other enzymatic actions (Iba, 2002).

As a result of higher Na concentration, proline is produced and accumulated in the cells (Avcıoğlu et al., 2003). Crops are producing proline under salt stress condition to survive by adjusting osmotic pressure in the cell for balancing higher osmotic pressure occurred in the nutritional environment. As a result of Cl ions arisen from ionization of NaCl accumulated on the cell membrane under salt stress condition, pH decreases sharply. Hence, hydrogen bonding of membrane proteins are decomposed, resulting higher free ion concentration in the medium (Öztürk and Demir, 2002).

The aim of this study is to determine the effects of foliar applied proline and saline irrigation water applications on tuber yield, vegetative and physiological characteristics of potato crop (*Solanum tuberosum* L.) grown under arid and semi-arid climatic conditions.

2. Material and Method

The experiment was carried out between January and June 2010 in a greenhouse located in the research area of department of field crops, Mustafa Kemal University, Hatay, Turkey. The greenhouse used in the experiment is located at latitude of 36º19' North, longitude of 36º11' East and an altitude of 28 m. The climate of the region is typically Mediterranean, i.e. mild and rainy in winter, dry and hot in summer. Potato variety called Marfona which is moderately tolerant to salt (Khrais, 1998) and grown extensively in Turkey was used in the study. The crops were grown in plastic containers filled with the mixture of sand and loamy soil at a ratio of 1:1 (v:v), obtaining a sandy loam soil. The diameter and height of the containers were 26 cm and 42 cm, respectively. Containers were filled with soil-sand mixture such that each of them weighted 18 kg on an electronic scale. One tuber is planted at 10 cm depth in each container on 15 January 2010. NaCl was used as a salt source to obtain the desired electrical conductivity level by adding into the tap water. The chemical properties of water and soil are given in Table 1 and 2, respectively. The pH of pure proline (Sigma P5607) was 6.3.

Potato crop was irrigated ten times as much as 50% of the available water capacity of the soil with water having electrical conductivities (EC_w) of 0.20 (T0, tap water, control), 3.50 (T3.5), 7.00 (T7), 10 (T10) and 13 dS m^{-1} (T13) and proline foliar applied having concentration of 0 (P_0), 10 (P_{10}) and 20 (P_{20}) mM. The experiment was designed statistically according to split-plot design in CRD or RCBD with three replications such that each treatment had 15 pots. Proline applications were formed as main plots and saline water applications as sub-plot. The volume of irrigation water was given manually to the containers. Proline was applied to the treatments one day after saline water application as much as 10 mM (P_{10}) and 20 mM (P_{20}). Control treatment where non-saline water used for irrigation was excluded proline application.

Different level of saline irrigation water was accumulated in a tank whose volume is 1 ton. The saline water was prepared such that Na/(Na+Ca) ratio is between 0.1 and 0.7 for low to moderate salinity as suggested by Grattan and Grive (1999). To prevent the effect of higher Sodium Adsorption Ratio (SAR), gypsum was also added to the irrigation water. The amount of irrigation water was determined by weighing three pots used for observation. As much as 50% of the available water capacity of the soil was allowed to be used by potato plant. Before the irrigation, the pots were weighed and the amount of water to bring soil water in those pots was determined. The same amount of water (liter) to bring the soil water in the observation pots up to field capacity was applied to the other pots. In addition to the required water, 20% leaching water was also applied to the pots except control treatment. The amount of leaching water was collected on the base plates of the bottom-perforated pots. Crop water use between two irrigations was determined by taking the difference in weight of observation pot before every irrigation. At the end of the experiment, the seasonal crop water use was computed by subtracting the weight of potato in the observation pots from cumulative water use.

The effect of saline irrigation water, soil salinity, and proline concentration on stomatal conductivity, transpiration and photosynthesis rate were measured in three plants in each treatment. Photosynthesis (μmol m^{-2} s^{-1}) and transpiration rate (μmol m^{-2} s^{-1}) were measured by portable photosynthesis device (LCA-4), stomatal conductance (mmol m^{-2} s^{-1}) was measured by leaf porometer (model SC-1, LPS0881), total leaf area was measured by leaf area meter (LICOR 3100C). The HH-2 moisture meter (Delta T, WET sensor, Water, Electrical Conductivity, Temperature) was used to measure soil water content (cm^3 cm^{-3}), soil salinity (dSm^{-1}) and soil temperature (^oC). Measurements were taken between 11:00 and 14:00 when the sky was clear and sunny. Stomatal conductance, photosynthesis and transpiration rate were taken on 45 (preliminary period of tuber formation), 60 (period of tuber formation) and 75 (period of tuber maturation) days after planting (DAP). To determine the effects of saline water and proline applications on the yield and yield components of potato, all of the crops at the harvesting time were separated and counted. In each plot, number of tuber and tuber fresh weight per plant as well

Table 1. Chemical properties of irrigation water

Irrigation water	pH	ECw (dSm^{-1})	Na (meL^{-1})	K (meL^{-1})	Ca+Mg (meL^{-1})	HCO_3 (meL^{-1})	CO_3 (meL^{-1})	Cl (meL^{-1})	SO_4 (meL^{-1})	SAR
T_0	7.6	0.2	1.55	0.13	1.35	1.23	-	1.78	0.02	1.89
$T_{3.5}$	7.5	3.5	27.11	0.75	12.14	3.87	-	27.13	9.00	11.00
T_7	7.6	7.0	55.60	1.23	13.55	5.36	-	56.88	8.14	21.36
T_{10}	7.6	10.0	91.24	1.00	13.55	3.57	-	97.61	4.61	35.05
T_{13}	7.6	13.0	118.24	1.22	14.20	4.30	-	123.94	5.42	44.37

Table 2. Chemical properties of soil

pH	ECe (dS m^{-1})	Na (me 100 g^{-1})	K ($me100g^{-1}$)	Ca+Mg ($me100g^{-1}$)	HCO_3 ($me100g^{-1}$)	CO_3 ($me100g^{-1}$)	Cl ($me100g^{-1}$)	SO_4 ($me100g^{-1}$)	SAR
7.4	0.19	1.1	0.09	1.14	1.31	0.15	0.85	0.02	1.46

as mean tuber weight was determined. Having measured these parameters, the samples were separately put in paper bags and dried in oven at 70ºC until they reach constant weight to determine dry weight of the same samples. Biological yield (gplant^{-1}) was computed by adding dried leaf, stem, stolon, tubers belonging to one plant. Harvest index (%) was computed as the ratio of dry tuber weight to biological yield. Tubers obtained from each plot were classified according to their sizes and each group percentages were determined. Tuber diameter more than 45 mm, between 28-45 mm, and less than 28 mm was graded as Grade A, Grade B and Cull, respectively. Also, cull yield and number of tuber was determined to find marketable yield. Pre-sprouting was done on tubers and tubers containing one sprout were chosen to plant so that variation as a result of sprouting was diminished. After emergence, each pot was fertilized weekly using solution containing as much as 120 mgL^{-1} N, 120 mgL^{-1} P, 170 mgL^{-1} K and 20 mgL^{-1} Mg (Schittenhelm et al., 2004). The data were analyzed statistically by using SAS and the means were compared using Tukey test (Bek and Efe, 1988).

3. Result and Discussion

3.1. Water budget components, salinity of drainage water (EC_d) and soil saturation extract (EC_e)

Components of water budget, average salinity of drain water and soil saturation extract are given in Table 3. The amount of water applied to T_0, $T_{3.5}$, T_7, T_{10}, and T_{13} treatments were 23.3, 22.3, 21.3, 20.9, and 18.9 liters, respectively. Total tuber yield (TTY) ranged from 317.38 in T_0 to 167.49 g pot^{-1} in T_{13} treatment. Average soil salinity (EC_e) was found to be 3.23, 4.98, 7.69, 9.60 and 18.21 dS m^{-1} whereas EC of drain water (EC_d) was 4.97, 9.29, 15.20, 19.25, and 21.62 dS m^{-1}, for T_0, $T_{3.5}$, T_7, T_{10}, and T_{13}, respectively (Table 3). The values of EC_d were always higher than that of EC_e. The leaching water applied as much as 20% of irrigation water helped to prevent the increase in soil salinity. As the soil salinity (EC_e) increased irrigation water requirement decreased. This decrease was about 4.5%, 9.4%, 14%, and 18.9% for $T_{3.5}$, T_7, T_{10}, and T_{13}, respectively, compared to non-saline (control) irrigation water treatment. An empirical linear relationship between irrigation water salinity (EC_w) and average soil salinity (EC_e) and drainage water salinity (EC_d) was established as ($EC_e=1.1EC_w+1.45$, $r^2=0.87^*$) and ($EC_d=1.38EC_w+4.88$ $r^2=0.99^{**}$), respectively. Since the main restricting parameter is soil salinity rather than irrigation water salinity, the results are presented hereafter in terms of soil salinity (EC_e).

Although it depends on variety, potato crop is moderately tolerant to salinity. Studies showed that tuber yield of potato is not affected by soil salinity less than 1.7 dSm^{-1} and no yield is obtained when soil salinity exceeds 10 dSm^{-1} (FAO, 2002). Irrigation water salinity was set up as 0.2 dSm^{-1} in control treatment (T_0). The soil salinity in the control treatment increased up to 3 dSm^{-1} in the harvest. Soil salinity and drain water salinity increased in the treatments where saline irrigation water was applied although they received 20% leaching water. As a result of increasing salinity, irrigation water decreased 4.5%, 9.4%, 14.0%, 18.9%, in $T_{3.5}$, T_7, T_{10} and T_{13} while crop water use decreased about 3%, 5%, 6%, and 16% in $T_{3.5}$, T_7, T_{10}, T_{13}, respectively. Salts accumulated in irrigated field soils are one of the factors limiting crop growth as well as evapotranspiration (Prathapar and Qureshi, 1999). In a study conducted in pots, it was reported that crop water use of potato decreased about 37% and 60% when irrigated with water having EC of 3 and 12 dSm^{-1}, respectively, (Demirel, 2012). Because the growing medium is restricted in pot experiment, the effects of irrigation methods and climatic conditions are assessed as relative differences to each other.

Table 3. Components of water budget (WU=I-Dp±ΔS) and salinity

Treatments	I (L)	Dp (L)	ΔS (L)	CWU (L)	ECe (dSm^{-1})	ECd (dSm^{-1})	TTY (g pot^{-1})
T_0	23.3	4.66	4.68	23.32	3.23	4.97	317.38
$T_{3.5}$	22.3	4.46	4.52	22.36	4.98	9.29	287.02
T_7	21.3	4.46	4.96	21.80	7.69	15.20	242.32
T_{10}	20.9	4.46	5.30	21.74	9.60	19.25	187.77
T_{13}	18.9	4.46	4.84	19.28	18.21	21.62	167.49

Higher differences among treatment in terms of amount of irrigation water and crop water use can be attributed to the limiting size of growing medium. Salinity threshold value is an important issue in saline irrigation-yield studies. In this study, the threshold values in terms of tuber characteristics were found to be different when compared to control treatment. In studies where only tuber yield was taken into consideration, salinity threshold value was differentiated depending on variety and irrigation method. Katerji et al. (2003) reported that crop growth and tuber yield of potato significantly decreased when EC_w is 2.3 dSm^{-1}. Zhang et al. (1993) stated that threshold value depends on variety and was about 1-2 dSm^{-1} when irrigated by surface irrigation. On the other hand, the threshold value in drip irrigation was found to be about 3-4 dS m^{-1} (van Hoorn et al., 1993).

3.2. The effects of soil salinity and proline applications on yield and vegetative growth parameters

The **v**ariance analyzes results with respect to yield and vegetative growth parameters are given in Table 4**.** Soil salinity (EC_e) affected all of the yield parameters statistically except harvest index (HI), while proline applications has effects on number of tubers (Tnum), mean tuber weight (MTW), harvest index (HI), number of tuber classified as grade A and cull at different levels. ECe*Proline interaction was found to be statistically significant at $p<0.001$ for all other yield parameters except total dry matter content (TDMC), harvest index (HI) and tuber dry weight (TDW). Soil salinity (EC_e) and proline applications affected statistically all of the vegetative growth parameters at different levels. ECe*Proline interaction was also found to be statistically significant for all of the vegetative growth parameters except plant height (Table 4).

Mean values of yield parameters in proline and saline water applications at harvest are presented in Table 5. The number of tuber (Tnum) decreased depending on increasing salinity levels and proline concentrations. The highest Tnum was obtained from P_oT_o treatment while the lowest was obtained from $P_{10}T_{10}$ and $P_{20}T_0$ treatments. Similarly, total tuber yield (TTY) is also decreased with respect to increasing salinity. However, an increase in TTY in P_{10} treatments was observed. This is caused by higher mean tuber weight (MTW) obtained from P_{10} treatments. Higher MTW was obtained in P_{10} and P_{20} treatments compared to Po treatments. The effect of proline was mostly pronounced in MTW out of tuber characteristics. While the highest amount of tuber classified as first class was obtained from $P_{20}T_0$ treatment followed by $P_{10}T1_0$, the highest amount of cull was obtained from $P_{20}T_{13}$ followed by $P_{10}T_{13}$.

Mean values of vegetative growth parameters in proline and saline water applications at harvest are given in Table 6. Plant height, leaf area, biomass, leaf plus stolon dry weight and root dry weight decreased with increasing salinity levels. The highest leaf area, biomass, leaf plus stolon dry weight and root dry weight were obtained from P_oT_o treatment while the lowest ones from $P_{20}T_{13}$ treatment. A study conducted in potato by Demirel (2012) showed

Table 4. Variance analysis with respect to yield parameters

Yield parameters	Variation source		
	ECe	Proline	ECe x Proline
Number of tubers (Tnum)	***	***	***
Total tuber yield (TTY)	***	NS	***
Mean tuber weight (MTW)	***	***	***
Total dry matter content (TDMC)	***	NS	NS
Harvest index (HI)	NS	**	NS
Tuber dry weight (TDW)	***	NS	NS
Tuber classified as first class (Grade A)	**	***	***
Tuber classified as a second class (Grade B)	***	NS	***
Cull	***	*	**
Plant height	***	*	NS
Leaf area	***	***	***
Biomass	***	***	**
Leaf+stolon dry weight (L+SDW)	***	***	**
Root dry weight (RDW)	**	***	***

NS: Not significant; * Significant at P<0.05; ** Significant at P<0.01; *** Significant at P<0.001

Table 5. Mean values of yield parameters in proline and saline water applications (at harvest)

Proline level	Salinity level	Tnum	TTY ($g\ pot^{-1}$)	MTW ($g\ tuber^{-1}$)	TDMC (%)	HI (%)	TDW ($g\ pot^{-1}$)	Grade A ($g\ pot^{-1}$)	Grade B ($g\ pot^{-1}$)	Cull ($g\ pot^{-1}$)
P_0	T_0	8.53 a	309.04 ab	36.22 c	23.91	32.00	47.18	190.20 ab	104.15 bf	14.69 cd
	$T_{3.5}$	8.40 ab	289.37 b	34.53 c	26.08	32.35	40.68	182.64 b	91.09 bf	15.64 bd
	T_7	7.97 ab	229.65 de	28.86 de	26.39	31.16	38.03	108.56 d	102.08 bef	19.01 bd
	T_{10}	7.53 ac	209.95 ef	27.85 e	26.25	33.02	35.01	80.38 e	106.05 be	23.52 ad
	T_{13}	6.87 ce	167.59 g	24.46 e	25.58	36.78	26.99	63.75 ef	85.28 cf	18.55 bd
P_{10}	T_0	6.80 ce	332.80 a	48.95 a	21.56	35.24	44.87	185.90 b	128.73 ab	18.17 bd
	$T_{3.5}$	7.53 ac	287.79 b	38.27 c	25.39	33.80	44.08	203.81 ab	67.31 f	16.66 bd
	T_7	7.40 bd	250.09 dc	33.88 cd	26.61	33.77	40.67	77.59 e	146.04 a	26.46 ab
	T_{10}	6.00 e	169.54 g	28.27 e	26.79	31.95	33.37	70.92 ef	76.57 ef	22.05 ad
	T_{13}	6.40 de	153.50 g	23.98 e	26.30	38.18	27.51	22.79 g	105.27 bf	25.45 ac
P_{20}	T_0	6.00 e	310.26 ab	51.82 a	22.21	39.14	46.17	211.97 a	84.06 def	13.48 d
	$T_{3.5}$	6.50 ce	283.97 bc	43.67 b	25.42	37.88	41.51	143.77 c	123.61 ac	16.60 bd
	T_7	6.87 ce	247.23 d	36.00 c	27.08	35.64	38.93	116.21 d	115.83 ad	15.18 bd
	T_{10}	6.40 de	183.84 fg	28.72 de	27.15	32.32	36.66	51.61 f	116.20 ad	16.02 bd
	T_{13}	6.40 de	181.33 fg	28.41 e	26.18	32.00	26.97	60.17 ef	90.40 bf	30.78 a

Tnum: Number of tubers, TTY: Total tuber yield ($g\ pot^{-1}$), MTW: mean tuber weight ($g\ tuber^{-1}$), TDMC: Total dry matter content (%), HI: Harvest index (%), TDW: Tuber dry weight ($g\ pot^{-1}$), Grade A: tuber classified as first class, Grade B: tuber classified as a second class.

Table 6. Mean values of vegatative growth parameters in proline and saline water applications (at harvest)

Proline level	Salinity level	Plant height (cm)	Leaf area (cm^2)	Biomass ($g\ pot^{-1}$)	L+SDW ($g\ pot^{-1}$)	RDW ($g\ pot^{-1}$)
P_0	T0	36.77	3596.47 a	147.52 a	87.37 a	12.97 a
	T3.5	42.23	3028.87 b	125.49 b	73.63 b	11.44 ab
	T7	42.43	2830.10 bc	122.00 bc	73.37 b	10.33 abc
	T10	36.77	2333.80 de	106.21 cd	63.53 bcd	7.91 cde
	T13	31.20	1788.57 f	91.51 def	56.62 cde	7.66 abcd
P_{10}	T0	39.43	2580.33 cd	121.94 bc	71.42 b	9.92 bcde
	T3.5	43.43	2486.33 d	125.23 b	71.23 b	8.34 bcde
	T7	42.63	2443.87 d	120.43 bc	68.77 bc	8.31 bcde
	T10	38.57	2133.33 e	98.54 def	57.08 cde	8.09 bcde
	T13	34.67	1611.23 f	86.27 ef	51.46 de	7.30 cde
P_{20}	T0	41.67	2810.33 bc	121.08 bc	68.50 bc	8.22 bcde
	T3.5	43.43	2277.43 de	105.68 cd	57.92 cde	6.66 de
	T7	42.57	2356.77 de	102.77 ed	57.45 cde	6.59 de
	T10	40.77	2104.13 e	102.32 ed	57.17 cde	6.41 de
	T13	34.77	1793.67 f	83.41 f	49.85 e	6.24 e

L+SDW: Leaf+stolon dry weight, RDW: Root dry weight

that tuber yield, number of tuber, total tuber yield, hardness, dry matter, leaf area and plant height decreasing while Karakuş (2008) reported that number of leaves, stem diameter, tuber yield per plant, tuber weight, and tuber diameter decreased depending on increasing salt concentration. Levy (1992) pointed out that saline water (6.5 dSm^{-1}) caused a decrease in both tuber number and tuber weight by 27% and 40%, respectively.

Different results were published in literature in terms of the effect of proline. Karakuş (2008) studied the effect of salt stress (0, 25, 50, 100 mM NaCl) and proline concentration (0, 5, 15 mM) on potato variety of Agria and concluded that increasing salt concentration caused a significant decrease in vegetative characteristics, tuber yield and chlorophyll content while foliar applied proline had a positive effect to reduce the negative effect caused by salt stress. Martinez et al. (1996) reported that salt stress and proline content of leaves in potato varieties of *S. juzepczuckii* and *S. curtilobum* were positively correlated and concluded that proline content of leaves could be used to determine whether the variety is salt tolerant or not. However, Velasquez et al. (2005) found no relation between proline accumulation and salt tolerance among 12 Argentine potato cultivars, although considerable variation was observed among these varieties in an in vitro screen. Likewise, Rahnama and Ebrahimzadeh (2004) found no clear relationship between accumulation of proline and salt tolerance in potato seedlings. It was clear that the effect of foliar applied proline is not understood well. Time of proline application (before and after irrigation as well as different time in a day), and proline concentration are subject to study.

3.3. The change in photosynthesis, transpiration rate and stomatal conductance with respect to growing stages

The change in photosynthesis rate with respect to soil salinity is presented in Figure 1. More tolerant photosynthesis rate towards harvest was observed. Photosynthesis rate measured in T_0 treatment on 45., 60., and 75. DAP was found to be 12.33 μmol m^{-2} s^{-1}, 11.66 μmol m^{-2} s^{-1} and 3.39 μmol m^{-2} s^{-1}, respectively. The decrease in photosynthesis rate in T_{13} compared to T_0 was 53%, and 52% on 45 and 60 DAP, respectively, and equal to each other on 75 DAP, (3.39-3.40 μmol m^{-2} s^{-1}). One dS m^{-1} increase in EC_e decreases photosynthesis rate about 0.50 μmol m^{-2} s^{-1} and 0.01 μmol m^{-2} s^{-1} on 45 DAP and at harvest, respectively. Higher values of photosynthesis rate were measured in $T_{3.5}$ and T_7 treatments on 45 DAP compared to T_0 treatment. Additionally, the highest value was measured in T_7 treatment on 75 DAP (Figure 1).

The change in transpiration rate with respect to soil salinity is depicted in Figure 2. Trend observed for photosynthesis rate was similar to transpiration rate. While the transpiration rate decreased gradually depending on soil salinity on 45 and 60 DAP, it was relatively stable on 75 DAP (tuber maturation stage). Transpiration rate on 45 DAP in T_0 treatment was measured as 2.80 μmol m^{-2} s^{-1}, it increased in $T_{3.5}$ and T_7 (3.09-3.70 μmol m^{-2} s^{-1}). In the same stage, transpiration rate in T_{13} decreased as much as 67.5% compared to T_0 treatment.

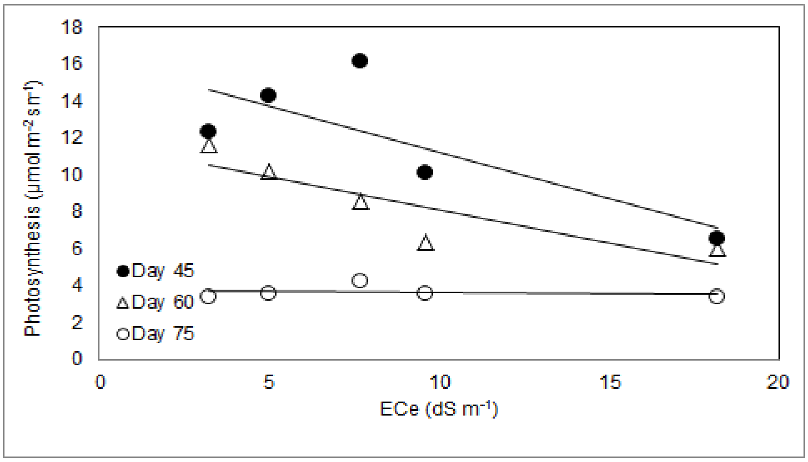

Figure 1. The relationships between photosynthesis and ECe on different growth stage

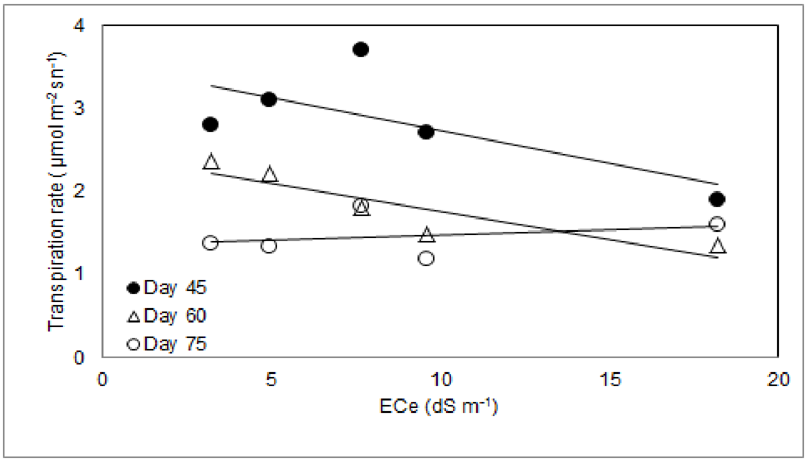

Figure 2. The relationships between transpiration rate and EC_e on different growth stage

The most stable transpiration rates were measured on tuber formation stage (60 DAP). In this stage, the rate decreased from 2.36 (T_0) to 1.35 µmol m^{-2} s^{-1} (T_{13}) (57%). On the other hand, at the harvest time, the rate increased, but not steadily, from 1.37 (T_0) to 1.82 (T_7) and 1.59 µmol m^{-2} s^{-1} (T_{13}).

Stomatal conductance, similar to transpiration and photosynthesis rate, decreased depending on growth stage, as seen in Figure 3. Stomatal conductance ranged from 107.78 mmol m^{-2} s^{-1} (T_0) to 56.67 mmol m^{-2} s^{-1} (T_{13}) in 45 DAP and from 92.5 mmol m^{-2} s^{-1} (T_0) to 45 mmol m^{-2} s^{-1} (T_{13}) depending on irrigation water salinity. Towards the harvest stage, the response of the crop to irrigation water salinity became more unstable. Stomatal conductance was measured as 65.56, 68.89, 97.22, 55.00, and 70.56 mmol m^{-2} s^{-1} in T_0, $T_{3.5}$, T_7, T_{10}, T_{13}, respectively. Stomatal conductance decreased about 50% on 45 and 60 DAP while the decrease was not stable on 75 DAP. Among the three parameters, the highest decrease was determined in stomatal conductance. Generally, all of the three parameters increased in T_7 treatment. It is important which of the parameters (stomatal conductance, photosynthesis and transpiration rates) are affecting the yield on which of the growing stages.

The most important period on yield was determined 60 DAP in the experiment. The effects of the applications after this date were more limited. Photosynthesis and transpiration rates are more effective (r^2=0.99**) than that of the stomatal conductance (r^2=0.96**) on yield measured at harvest stage. In the study, it was also observed that the irrigation water salinity differentiated the aging of leaves. In T_{13} treatment, a sharp decrease in leaf area together with aging of leaves was observed clearly. The increase in osmotic pressure caused the crop to use more energy to survive resulting in decreased leaf area and accelerated aging.

Photosynthesis, transpiration, and stomatal conductance changed with respect to salinity at different tuber development stages resulting in lower values towards the end of tuber development. Cumulative effect of salinity beginning from leaf forming until harvest was more pronounced on leaf aging causing a decrease in vapor transport from roots to leaves and water use (Table 4). Yeo et al., (1991) and Elkhatib et al. (2004) also pointed out that salt stress usually causes early aging in leaves and decreases water uptake of water by roots as a result of increasing osmotic potential. Similar symptoms were also observed when water stress occurred (Rosenthal et al., 1987).

Salt stress decreased photosynthesis rate about 53%-52%, transpiration rate about 67.5%-57%, and stomatal conductance about 50% in 45 and 60 DAP. Salt stress was pronounced mostly in early development stage. Backhausen et al. (2005) reported that NaCl application at 60% relative humidity decreased transpiration rate from 2.4 mmol m^{-2} s^{-1} to 0.8 mmol m^{-2} s^{-1} two hours later. NaCl concentration in leaves reached its maximum level after 28 hours and transpiration rate almost vanished after 150 hours.

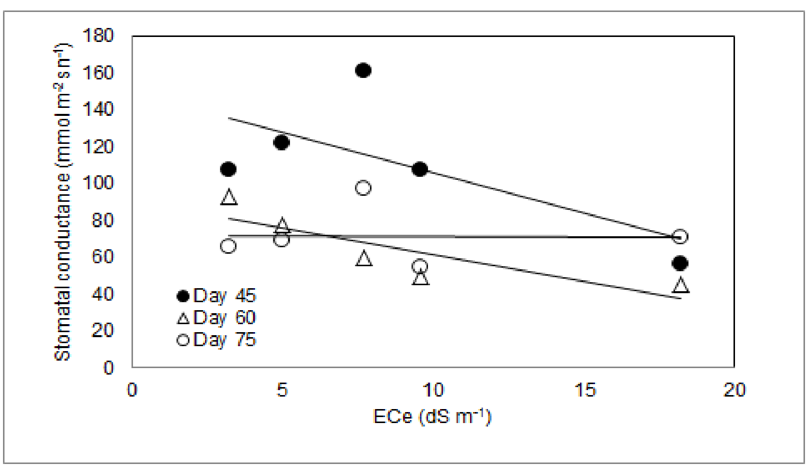

Figure 3. The relationships between stomatal conductance and EC_e on different growth stage

4. Conclusions

Salinity is one the obstacles in sustainable agriculture. Saline water is being used in irrigation as a result of global warming. Potato is one of the most important foods in human diet. Therefore, it is important to study the effects of saline irrigation water on potato yield. The studies regarding genetic application to create salt tolerant potato cultivars are important with no doubt next to the studies to determine the effect of foliar applied proline to select salt tolerant potato cultivars. Not only under laboratory conditions but also studies in pot as well as in field need to be conducted to determine the confidence of the studies. Tuber yield and yield characteristics were qualitatively and quantitatively affected significantly depending on salinity. Depending on salinity, TTY, MTW, Grade A, TDW and HI decreased while cull yield increased. The variety Marfona classified as salt sensitive (Aghaei et al., 2008) was found to be as salt tolerant in this study based on the result obtained. The decrease in yield was not more than 48% even in the treatment where the irrigation or soil salinity was the highest. The decrease in yield classified as grade A (75.9%) was the characteristic affected at most. However, the variety seems to be more tolerant in terms of characteristics such as TDMC, HI and TDW. Proline content affected tuber yield and characteristics partially whereas it affected vegetative development parameters and vapor transport completely. It was determined that foliar applied proline is affecting vegetative characteristics and vapor transport, except plant height, in all measurement phases. However, when average values with respect to tuber yield are evaluated it was determined that the contribution of proline on tuber yield is doubtful economically. Proline has a negative effect on Grade A which is an important parameter commercially.

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