Salinity Distrubution, Water Use Efficiency and Yield Response of Grafted and Ungrafted Tomato *(Lycopersicon esculentum)* Under Furrow and Drip Irrigation with Moderately Saline Water in Central Anatolian Condition*

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Abstract: A field study with tomato was carried out at Ankara University, Horticultural Research Station in two consecutive years. The aim of the study is to determine the effects of grafting and irrigation methods on yield and water use of tomato and salinity distribution within the soil. Grafted and ungrafted tomato cultivars were grown using drip and furrow irrigation methods. Salinity of irrigation water (electrical conductivity) was 1.9 dS/m and the SAR (sodium adsorption ratio) was below 1.0. The mean fruit yields were 4671, 4391, 4109 and 3457 g/plant for drip-grafted, drip-ungrafted, furrow-grafted and furrow-ungrafted treatments, respectively. Seasonal total evapotranssprations were 810.0 and 771.5 mm under drip irrigation, 957.0 and 928.2 mm under furrow irrigation in 2005 and 2006, respectively. Total irrigation water requirement (applied water) were 731 and 714 mm under drip irrigation, 881 and 871 mm under furrow irrigation in 2005 and 2006, respectively. Water use efficiencies (WUE) were 12.92, 12.14, 9.38 and 7.90 kg/m^3 for drip-grafted, drip-ungrafted, furrow-grafted and furrow-ungrafted treatments, respectively. Monthly soil samplings indicated that the salinity distribution decreased towards the root zone (wetted area beneath the emitters and plants) with drip irrigation and increased towards the root zone (furrow ridges and plants) with furrow irrigation.
Keywords; *Tomato, Lycopersicon esculentum, Grafting Vegetable, Salinity, Drip Irrigation, Furrow Irrigation.*

Orta Anadolu Koşullarında Aşılı ve Aşısız Domateste *(Lycopersicon esculentum)* Damla ve Karık Yöntemlerinin Toprakta Tuz Dağılımı, Meyve Verimi ve Su Kullanım Etkinliği Üzerine Etkileri

Özet: Ankara Üniversitesi, Ayaş Bahçe Bitkileri Araştırma İstasyonunda, 2005 ve 2006 yıllarında yürütülen bu çalışmada, aşılı ve aşısız fide kullanılan domates, damla ve karık yöntemleri ile sulanmıştır. Çalışmanın amacı, aşılı ve aşısız domateste sulama yöntemlerinin, verim, su kullanım etkinliği ve toprak profilindeki tuzluluk dağılımına etkilerinin belirlenmesidir. Bu amaçla aşılı ve aşısız domates bitkileri damla ve karık yöntemleri ile sulanmıştır. Sulama suyunun elektriksel iletkenliği 1.9 dS/m ve SAR değeri 1.0'dan küçüktür. Ortalama meyve verimi, damla-aşılı, damla-aşısız, karık-aşılı ve karık-aşısız için sırasıyla, 4671, 4391, 4109 ve 3457 g/bitki olarak belirlenmiştir. Sırasıyla, 2005 ve 2006 yıllarında, toplam mevsimlik bitki su tüketimi, damla yönteminde 810. ve 771.5 mm, karık yönteminde ise 957.0 ve 928.2 mm olarak bulunmuştur. Toplam sulama suyu ihtiyacı (uygulanan sulama suyu miktarı) 2005 ve 2006 yılları için sırayla, damla yönteminde, 731 ve 714 mm, karık yönteminde, 881 ve 871 mm olarak bulunmuştur. Su kullanım etkinliği, damla-aşılı, damla-aşısız, karık-aşılı ve karık-aşısız için sırasıyla, 12.92, 12.14, 9.38 ve 7.90 kg/m^3 olarak ölçülmüştür. Her ay alınan toprak örnekleri sonucunda elde edilen profil tuzluluk dağılımları, damla yönteminde damlatıcılardan ıslak çepere doğru, karık yönteminde ise karıklardan bitki köklerine doğru artış gösterdiği belirlenmiştir.
Anahtar kelimeler: *Domates, Lycopersicon esculentu), Aşılı Sebze, Tuzluluk, Damla Sulama, Karık Sulama*

1. Introduction

The limited quality and quantity of water and thus the need to save water is of growing concern throughout the world but especially in arid and semi arid regions. This concern forces irrigated agriculture to meet 'more yield per drop', which is technically called water use efficiency. By means of water saving irrigation techniques like drip, this problem is alleviated to some extent.

Increasing the salt tolerance of crops through plant breeding could increase the sustainability of irrigation with low quality water by reducing the need for leaching and

*Bu çalışma Ekim 2009'da savunulan 'Karık ve Damla Sulama Yöntemlerinin Aşılı Domateste (*Lycopersıcon esculentum)* Meyve Verimi, Kalitesi İle Toprak Tuzluluğuna Etkileri' isimli doktora tezinin özetidir.

allowing the use of poorer quality water. The selection of the appropriate irrigation method can increase water use efficiency and reduce the demand on fresh water (Gawad et al., 2005). Tomato could act as a model crop for saline land recovery and use of poor-quality water as there is a wealth of knowledge on the physiology and genetics of this species (Cuartero and Fernandez-Munoz, 1999). Tomato is one of the most important horticultural crops in the world, and its production is very concentrated in semi-arid regions, where saline waters are frequently used for irrigation., It is thus of great interest to know whether the grafting technique is a valid strategy for improving the salt tolerance in tomato (Santa-Cruz and Cuartero, 2002).

The cultivated area of grafted Solanaceous plants has increased in recent years. The main objective of grafting is to obtain cultivars with a higher fruit production and quality (Lee, 1994). However, grafting has also been carried out to reduce infection by soil-borne diseases caused by pathogens (Biles et al., 1989) and to increase low-temperature resistance (Tachibana, 1982, 1988, 1989). Salinity is an increasingly expansive problem for agriculture, as it reduces growth and development of salt-sensitive plants (Greenway and Munns, 1980). There are several studies conducted in greenhouse and sand tanks reporting the interaction between salinity and grafting tomato yield (Santa-Cruz and Cuartero, 2002; Fernandez-Garcia et al, 2002; Fernandez-Garcia et al., 2003; Fernandez-Garcia et al., 2004; Estan et al., 2005; Khah et al., 2006; Qaryouti et al., 2007; Martorana et al., 2007; Öztekin et al., 2009). These authors all agree that grafted tomato has higher yield than ungrafted tomato cultivars. Therefore, there are several studies on the effects of irrigation methods on ungrafted tomato yield and fruit quality (Ayars et al., 2001; Çetin et al., 2001; Ashcroaft et al., 2003; Singandhupe et al., 2003; Hanson and May, 2004; Malash et al., 2005; Sutton et al., 2006; Kahlon et al., 2007; Malash et al., 2008). Yet, there is no report, to our knowledge, comparing the effects of irrigation methods on grafted and ungrafted tomato yield, water requirement and use efficiency, under moderate salinity field conditions. The aim of the study is thus to address this need and better understand the role of grafting in irrigated agriculture.

2. Material and Methods

The experiment was conducted in two consecutive years (2005-2006) in Ayas, Ankara (Turkey) region where tomato is economically the most important crop. Half of the field was utilized in 2005 and other half in 2006, thus the uniformity of variables was maximized. For both study years, water source and pipes were the same. Initial soil physical and chemical parameters are shown in Table 1 and 2, respectively. Texture of the experimental soil was clay loam and initial soil was not saline and SAR (sodium adsorption ration, defined as $Na/(Ca+Mg)^{0.5}$ where concentration is expressed in mmol/L) was less than 1.0. Monthly sampled irrigation water composition is shown in Table 4. Grafted and ungrafted tomato seedlings were commercially purchased from a seedling company. The shoot of grafted and ungrafted plants was the same genotype.

The distance between drip lines and furrow beds was one meter. The length of each drip line and furrow bed was 8 meters. Tomato seedlings were sown 0.5 m apart in each row. Soil moisture content at a depth of 30-120 cm was monitored by neutron probe (CPN 503 DR Hydroprobe) and the moisture in the 0-30 cm interval was monitored gravimetrically. At the begining of the experiment a calibration equation was developed for the measurements and statistical analyses were performed. The obtained calibration equation (eq. 1) and regression coefficient is;

$P_v = - 6.52 + 32.31\,(SO)\ ;\quad r = 0.912 \qquad (1)$

Pv= Volumetric water content, %

Probes were installed 30 cm away from plants for both soil moisture measurement methods. Every other day, soil samples and neutron readings were taken to monitor water content. Irrigations were performed when 40-50% and 30-40% of readily available water content was depleted for drip and furrow irrigation respectively. Irrigation water requirements were calculated for drip (eq. 2) and furrow (eq. 3) by means of the following equations.

$$d = \left(\frac{FC_{0-30} - MC_{0-.30}}{100} + \frac{FC_{30-60} - MC_{30-60}}{100} + \frac{FC_{60-90} - MC_{60-90}}{100} \right) D\,P \qquad (2)$$

$$d = \left(\frac{FC_{0-30} - MC_{0-.30}}{100} + \frac{FC_{30-60} - MC_{30-60}}{100} + \frac{FC_{60-90} - MC_{60-90}}{100} \right) D \qquad (3)$$

d : Irrigation water depth, mm.
FC : Field capacity at addressed soil layer, %.
MC : Moisture content at addressed soil layer, %.
D : Depth of each layer, 300 mm.
P : The ratio of wetted area, %.

For drip irrigation, P (the ratio of wetted area) was measured at the begining of the experiment. The value of P was 0.750 and equal for both study years. The same amounts and source of fertilization and pesticides were applied uniformly to the field.

Seasonal evapotranspration was determined by means of the following equation (Jensen et al., 1989);

$$ET = d_b + d + R_e - d_s - d_r \qquad (4)$$

ET : Seasonal evapotranspration, mm.
d_b : Soil moisture at the beginning of the experiment, mm.
d : Total irrigation water, mm.
R_e : Total effective rainfall, mm.
d_s : Soil moisture at the end of the experiment, mm.
d_r : Runoff, mm.

Table 1. Soil physical parameters.

Depth (cm)	**Texture**	**Bulk density (g/cm^3)**	**Field Capacity** P_w **(%)**	**Wilting point** P_w **(%)**	**$CaCO_3$ (%)**
			2005		
0-30	SCL	0.94	40.99	27.46	13.41
30-60	CL	1.21	36.63	24.87	12.87
60-90	CL	1.32	38.00	26.36	13.27
90-120	CL	1.29	35.23	24.44	15.35
			2006		
0-30	CL	1.21	40.39	26.65	13.10
30-60	CL	1.25	38.50	26.67	13.55
60-90	CL	1.21	37.34	25.54	14.71
90-120	CL	1.11	36.52	26.03	15.65

Table 2. Initial soil chemical parameters.

Depth (cm)	Cations (me/L)			Anions (me/L)			pH_e	EC_e (dS/m)
	Na	K	Ca+Mg	Alk.	Cl	SO_4		
2005								
0-30	1.46	0.40	4.7	4.00	1.24	1.30	8.19	0.64
30-60	2.11	0.58	11.0	7.68	1.51	4.45	8.20	1.37
60-90	2.48	0.49	13.6	8.26	2.09	6.22	8.60	1.67
90-120	2.62	0.23	11.0	7.78	2.00	4.05	8.20	1.39
2006								
0-30	1.64	0.57	10.6	5.28	2.78	4.76	8.38	0.96
30-60	1.85	0.62	11.1	6.96	2.38	4.23	8.27	1.14
60-90	1.92	0.61	11.2	6.50	2.18	6.05	8.26	1.00
90-120	1.97	0.52	14.9	8.50	2.80	6.08	8.39	1.23

Some meteorological data of the study years was shown in Table 3. Water use efficiency (WUE) has been defined as the ratio of economical yield (kg) to total amount of applied water (m^3). Soil samples to determine the salinity distribution were taken monthly at 2 locations for drip and 2 locations for furrow irrigation, for each of the grafted and ungrafted treatments. The samples were taken at the depth intervals of 0-30, 30-60, 60-90 cm and at 0-25, 25-50, 50-75 and 75-100 cm laterally.

Table 3. Some meteorological data of the study years.

	Months												Annually
	1	2	3	4	5	6	7	8	9	10	11	12	
2005													
Prec. (mm)	29.2	48.2	69.4	62.7	27.5	47.6	18.7	1.8	4.8	15.9	43.9	17.0	386.2
Temp.(°C)	3.6	3.0	6.8	12.5	17.6	20.9	26.3	26.6	20.3	12.2	7.1	3.6	13.4
Rel. Hum. (%)	73	66	66	56	49	51	46	50	54	60	70	74	60
Wind Speed (m/s)	0.9	1.2	1.3	1.2	1.2	1.3	1.4	1.2	1.0	0.9	0.8	0.6	1.1
Sunshine Hours (h/day)	2.9	4.0	5.6	6.7	8.4	10.8	11.9	11.3	9.2	6.6	2.9	2.7	6.9
2006													
Prec. (mm)	60.9	84.7	43.0	14.1	13.3	9.2	39.1	0.3	82.8	19.9	17.5	1.8	386.6
Temp.(°C)	-0.8	-0.4	8.1	14.3	18.1	23.1	24.7	28.7	19.5	14.9	6.3	1.3	13.2
Rel. Hum. (%)	72	81	62	49	49	45	44	42	54	67	69	70	58
Wind Speed (m/s)	0.7	0.6	1.0	1.2	1.3	1.5	1.4	1.4	1.0	0.6	0.8	0.6	1.0
Sunshine Hours (h/day)	2.8	2.3	5.7	8.2	8.9	10.6	12.0	11.7	7.7	5.3	5.2	4.3	7.1

Table 4. Irrigation water composition.

Sample Date	EC dS/m	SAR	Cations (me/L) Na	K	Ca+Mg	Anions (me/L) Alk	Cl	SO_4
2005								
May	1.9	0.76	2.2	0.22	16.9	13.1	2.43	3.75
June	1.9	0.88	2.5	0.35	15.6	13.3	2.5	2.86
July	1.9	0.95	2.7	0.33	16.2	13.4	2.5	3.27
August	1.9	0.87	2.5	0.38	16.6	12.8	2.7	3.96
2006								
May	1.9	0.89	2.51	0.39	15.7	12.5	2.1	3.97
June	1.89	0.96	2.67	0.41	14.8	11	2.4	4.45
July	1.91	0.91	2.62	0.37	16.7	13.2	2.3	4.17
August	1.93	0.90	2.54	0.38	15.9	12.8	2.8	3.21

3. Results

3.1. Yield

Statistical analyses revealed that a three-way interaction of year, irrigation and grafting did not exist for yield data. However, the interaction of grafting and irrigation method on yield was found significant, $p<0.005$. The highest mean yield (4671 g/plant) was obtained from the drip-grafted treatment (Table 5).

Comparing the irrigation methods, drip irrigation had the higher yield in both grafted and ungrafted cultivars. Under drip irrigation, the yield difference between grafted and ungrafted plants was 6%, while under furrow irrigation it was 18.9%. Comparing drip-grafted to the other treatments, the yield differences were 6%, 13.7% and 35.1% for drip-ungrafted, furrow-grafted and furrow-ungrafted, respectively. These results indicate that under furrow irrigation, the yield of grafted plants were still lower than drip irrigation, but the magnitude of the yield decrease was more severe in ungrafted plants. The results are in general agreement with Estan et al, (2005) who stated that the positive effect of grafting on the fruit yield was not found under favorable growth conditions but only under saline conditions. Correspondingly, our results shows that under environmentally ‘good’ conditions for tomato like drip irrigation practices, the yield difference between grafted and ungrafted plants is as little as 6%, but under furrow irrigation, which we consider not as good as drip irrigation, (salinity built up, ineffective fertilization utilization, lower irrigation interval etc), the yield difference is as high as 18.9%. We suggest that grafted tomato is beneficial under severe stress conditions.

Table 5. Yield (g/plant) and statistical results.

	Years (Y)			
	2005		2006	
	Cultivar (C)			
	Grafted	Ungrafted	Grafted	Ungrafted
Drip	4404	4269	4939	4513
Furrow	3447	2971	4771	3942

Interaction of Y x I

(A↓) (b→)	2005	2006
Drip	4337 b A(1)	4726 a A
Furrow	3209 b B	4357 a B

Interaction of C x I

(A↓) (b→)	Grafted	Ungrafted
Drip	4671 **a A**(2)	4391 **b A**
Furrow	4109 **a B**	3457 **b B**

Sources	DF	SS	dj SS	Adj MS	F	P
Year (Y)	1	21294379	21294379	21294379	80,77	0,000**(3)
Cultivar (C)	1	7838600	7838600	7838600	29,73	0,000**
Irrigation method (I)	1	20163842	20163842	20163842	76,49	0,000**
Y x C	1	934928	934928	934928	3,55	0,062^{ns}
Y x I	1	5179038	5179038	5179038	19,65	0,000**
C x I	1	1248993	1248993	1248993	4,74	0,031*
Y x C x I	1	8479	8479	8479	0,03	0,858^{ns}
Error	136	35853248	35853248	263627		
Total	143	92521507				

(1) Lowercases show Duncan groups of years in each irrigation method and capitals show Duncan groups of irrigation method in each year.

(2) Bold lowercases show Duncan groups of cultivars in each irrigation method and bold capitals show Duncan group of irrigation methods in each cultivar.

^{ns} , *, ** : Difference is not significant, $P<0.05$, $P<0.001$.

3.2. Water requirement and seasonal evapotranspration

Irrigation practices are shown on Figures 1-4. On the figures, the depths of applied water, target initial water content for each method, amount of water at field capacity and wilting point are presented. Soil moisture contents were not allowed to drop below the target levels set for initiation of irrigations. Total amounts of irrigation water for furrow were 881 and 871 mm and for drip 731 and 714 mm, in 2005 and 2006, respectively. Water quantities saved by means of drip method were 17% and 18%, in 2005 and 2006 respectively. Accordingly, comparing drip to furrow irrigation, seasonal evapotranspration (Table 6) was 15% and

21.5% lower, in 2005 and 2006, respectively. The main reason for this is likely the coefficient representing the wetted area (eq. 1). Because of the nature of the drip technique, the cropped area is not completely wetted, so the water requirement is lower than for surface methods where there is more surface evaporation.

Table 6. Seasonal evapotranspration.

Study years	Irrigation methods	Soil moisture (mm 120 cm^{-1}) At the planting date	At the last harvest	Irrigation water (mm)	Effective rainfall (mm)	Evapotranspration (mm)
2005	Drip	510.2	515.7	731	84.5	810.0
	Furrow		518.7	881		957.0
2006	Drip	520.3	513.3	714	50.5	771.5
	Furrow		513.6	871		928.2

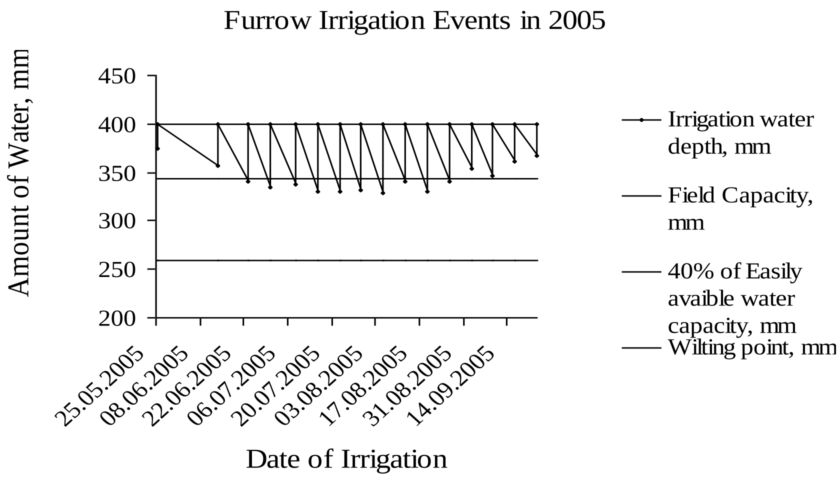

Figure 1. Irrigation events for furrow method in 2005.

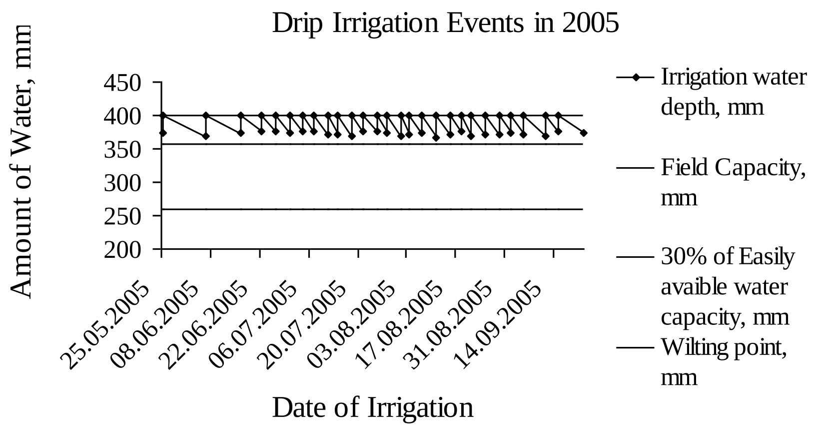

Figure 2. Irrigation events for drip method in 2005.

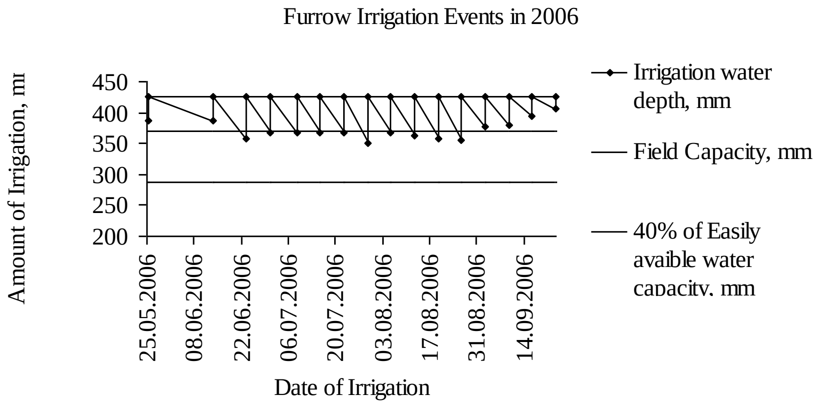

Figure 3. Irrigation events for furrow method in 2006.

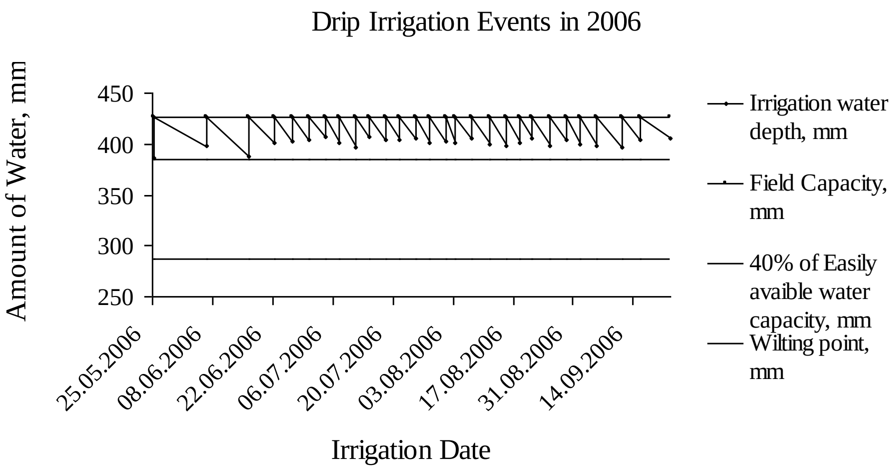

Figure 4. Irrigation events for drip method in 2006.

3.3 Water use efficiency

Water use efficiency (WUE) has been defined as the ratio of economical yield to total amount of applied water. Figure 5 shows water use efficiencies of the treatments. The mean WUE values for both years, for drip-grafted and drip-ungrafted treatments were 12.92 and 12.14 kg/m^3, respectively. The mean WUE values for both years for furrow-grafted and furrow-ungrafted were 9.38 and 7.90 kg/m^3, respectively. Comparing drip-grafted to other treatments, WUE were 6%, 27% and 38% higher than drip-ungrafted, furrow-grafted and furrow-ungrafted treatments, respectively. WUE under drip irrigation is higher than that of furrow irrigation, which is very expected because of the water saving feature of the drip method. Under furrow irrigation WUE is 18.7% higher with grafted than ungrafted tomato, while under drip irrigation WUE is 6.4% higher with grafted than ungrafted tomato. The differences in WUE are more notable under furrow irrigation as compared to drip irrigation. Our interpretation is that the benefits of grafting increase when unfavorable growing conditions occur, again confirming the results of Lykasand et al, (2007) who reported that in an open hydroponic system, grafted tomato had higher WUE relative to ungrafted tomato.

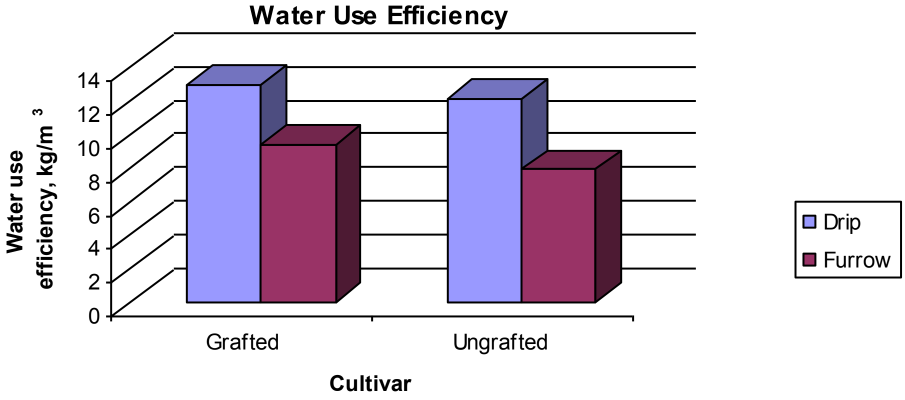

Figure 5. Water use efficiency of grafted and ungrafted tomato under furrow and drip irrigation.

3.4 Salinity Distribution

Soil salinity was monitored with monthly sampling (and measurement of EC in an extract with a soil: water ratio of 1:2.5). Figures 6 and 7 represent seasonal mean EC distributions for furrow and drip method in mS/m, respectively. Plants were located at 12.5 cm away from the position 0 (Figure 6 and 7) in the row where drip lines and furrow ridges were placed. Soil salinity increased towards the furrow ridges and decreased towards the drip lines. These Figures show that the drip method provides a more favorable salinity distribution for plants as compared to the furrow method.

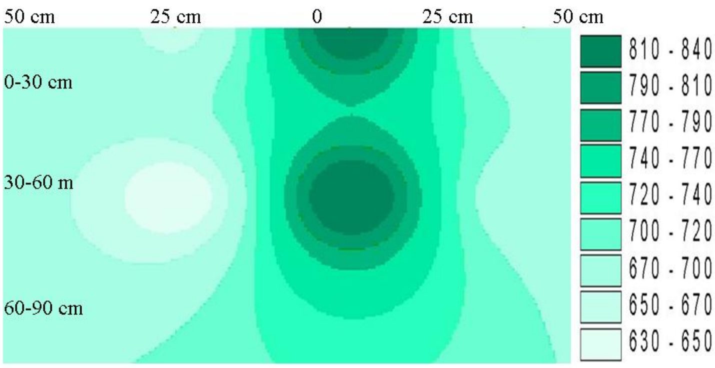

Figure 6. The mean salinity ($EC_{1:2.5}$ in mS/m) distribution for furrow irrigation.

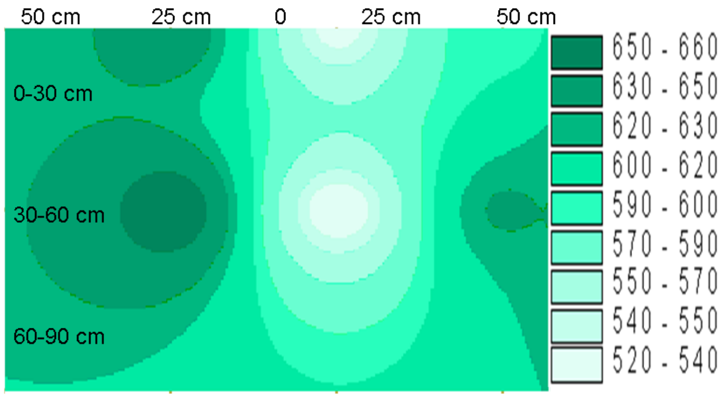

Figure 7. The mean salinity ($EC_{1:2.5}$ in mS/m) distribution for drip irrigation.

4. Conclusion

We conclude that the advantages of the grafting technique appear better when the environmental conditions for the plant are less than ideal. The current study revealed that the yield increase with the drip-grafted combination versus furrow-ungrafted combination is 35% in the semi-arid central Anatolian climatic condition. While, the yield of grafted plants is 6% higher than ungrafted plants under drip irrigation, it is 18.9% higher under furrow irrigation. In spite of the fact that the yield of grafted tomato under furrow irrigation is lower than under drip irrigation (13.6%), the yield decrease is more notable for furrow when comparing grafted to ungrafted (27%). Irrigation water requirement and seasonal mean evapotranspration are 722.5-876 mm and 790-942.6 mm for drip and furrow irrigation, respectively. With drip irrigation, saved irrigation water is 21% of the total. Water use efficiencies of grafted tomatoes are higher than ungrafted tomatoes under both drip (6%) and furrow (18.7%) irrigation, however the difference is greater for furrow irrigation. Actual salinity which plants experience alters between EC at field capacity and moisture level where irrigation starts. Actual soil water salinity increases with decreasing water content in the root zone, but EC_e value of sampled soil from root zone stays constant, since the water content at saturation or reference water content does not change. It is also important to know salinity distribution to understand the severity of salinity experienced by plants. Consequently, we consider that salinity reports should maintain irrigation intervals which directly represent moisture content for allowed driest period. In brief, soil salinity at a moisture level of either saturated or any soil-water ratio alone may not give an exact idea about severity of salinity experienced by the plant.

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