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Irrigation Water Management for Sprinkler Irrigated Corn using Rooting Data Obtained by the Minirhizotron Technique

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ABSTRACT

The research, aiming to evaluate possibilities for irrigation scheduling of corn using root development data obtained by minirhizotron technique, was carried out during 2008 and 2010 on experimental fields belonging to Çanakkale Onsekiz Mart University. Line source sprinkler irrigation was applied for irrigation of the experimental plots and irrigation water amount determination was based on water deficits of the actual effective root depth obtained prior to the irrigation application using the minirhizotron technique. Results of the 2 year study show that the effective root depth of the crop is around 70-75 cm until the 3rd or 4th irrigation application. Using data for root development restricted overwatering and excessive water loss compared to 90 cm root depth traditionally assumed for corn irrigation in the region. The highest grain yields were obtained from the treatment under favorable moisture conditions and yield decreased with increasing distance from the sprinkler irrigation lateral. There a linear relationship between seasonal evapotranspiration rates and grain yield, and seasonal evapotranspiration deficit and relative yield reduction, during each of the experimental years. Average value of the yield response factor (ky) for the research period was 1.34. © 2012 Friends Science Publishers

Key Words: Irrigation; Minirhizotron; Corn; Roots; Water management

INTRODUCTION

In crop plants, root system development is not as much studied as rest of the plant parts (Lamm & Troojen, 2003). However, roots are important for the uptake of nutrients and water (Liedgens *et al.*, 2000). Among crops, maize (*Zea mays* L.) is known to be very sensitive to water and nitrogen availability and limitation of these factors causes reduction of yield and it is commonly grown in Turkey. Development of plant root systems, which depend on the genetic characteristics of the plant (Klepper, 1990) are affected by soil physical properties as well as water availability, plant nutrients and carbon content (Bathke *et al.,* 1992; Ball-Coelho *et al.*, 1998; Olivera *et al.,* 1998; Pardo *et al.*, 2000).

The pattern of root production can vary depending on plant species and genetic characteristics under similar growing conditions (Entz *et al.*, 1992; Dardaneli *et al.*, 1997). Root morphology determines the ability of the plant to acquire water and nutrients, and root length density and diameter are the most frequently estimated parameters (Vamerali *et al.,* 2003). Roots serve as a bridge between plant and soil physical, chemical and biological properties and they have a significant influence on plant growth and yield. Knowledge of rooting depth patterns is essential to irrigation and fertilizer management, and consequently to yield and quality (Machado *et al.*, 2003).

Effective rooting depth is an important parameter to determine the amount of irrigation water needed. The distribution of water within the soil profile as a result of the level of irrigation affects the development of horizontal and vertical root growth as well as transportation and uptake of nutrients by plant roots in the soil (Sperry *et al.,* 1991; Hai-xing & Sheng-xiu, 2006; Hu *et al.*, 2008). Frequent light irrigation results in shallow root systems, which cause plants to become stressed even during short periods of water

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deficit. On the other hand, excessive irrigation consumes more water and is not economically viable. Machado *et al.* (2003) used a minirhizotron camera to compare surface *vs* subsurface drip irrigation on the root distribution of two processing tomato cultivars. They found that root growth occurs preferentially in the 0–40 cm soil layer and is independent of the drip irrigation depth used (surface or subsurface). Passioura (1982) reported that, for adequate nitrogen and water uptake, a certain critical value of root length density (RLD) (1 cm cm^{-3} in wheat) should be exceeded. Higher root density does allow plants to take up water at a lower matric potential (Shein & Pachepsky, 1995).

There are many techniques to remove roots from the soil. Excavation is useful to determine biomass, architecture and root morphology of individual plants but not useful for larger areas. Coring is based on sampling undisturbed soil with a sampling cylinder and is a valuable approach to root research, but it requires a very large amount of processing time. It is generally used to determine root biomass, root nutrient contents and root tips research (Upchurch & Taylor, 1990; Kavdir, 2000). All of these methods are based on destruction of natural soil samples. Development of plant roots of the same plants over a period of time can be measured by rhizotron and minirhizotron (MR) techniques. MR is based on observing and recording roots in situ through a transparent tube. This method enables observation of root growth and turnover non-destructively over a period of time (Polomski & Kuhn, 2002; Gregory, 2006).

There are many studies in the literature about plant root systems. Most of them are about the effect of soil physical properties and water content on root development and root density (Bathke *et al.*, 1992; Smith *et al.*, 1999; Gao *et al.*, 2010; Kage *et al.*, 2000; Quanqi *et al.*, 2010; Yang *et al.,* 2010), root uptake (Green *et al*., 2005), and uptake of nitrogen (N) by plant roots (Thorup-Kristensen, 2006; Hai-xing & Sheng-xiu, 2006; Zotarelli *et al.*, 2009). However, almost no available literature sources exist in terms of irrigation management or in the determination of the amount of irrigation water to be applied on the basis of actual root depth.

In general, literature values for effective rooting depth of corn are used without consideration of applied water level. Sometimes this can cause excessive irrigation of plants. The purpose of the present study was to investigate the rooting pattern of corn using the minirhizotron technique and to seek possibilities to use the actual rooting depth for the purposes of irrigation.

MATERIALS AND METHODS

Research area and cultivation: Research was conducted between 2008-2010 in Çanakkale Onsekiz Mart University (ÇOMU) Dardanos research fields in Çanakkale, Turkey. Weather conditions in the research area are presented in Table I. Soil was classified as typical Haploxererts, according to Soil Survey Staff (USDA, 1998) and as Eutric Vertisol according to FAO-UNESCO (1974) and Özcan *et al.* (2004). Some chemical and physical properties of the research soils are presented in Table II.

GS 308 (AYB 936) corn variety which has 120 day vegetation term was used in the research plots. Corn was planted on May 9 and May 4, with a two-row small planter with 0.7 m row spacing in 2008 and 2010, respectively. Corn plants were thinned giving a plant density of 72000 plants/ha after emergence. Fertilization amount and types were determined after soil testing; 200 kg N ha^{-1} N, 100 kg P ha^{-1} and 100 kg K ha^{-1} was added to soil.

Irrigation of the experimental plots was done using a line source sprinkler irrigation technique (Fig. 1) providing a gradual decrease of the irrigation water amount from irrigation line to the outer part of the plot. Thus, treatment with different water supply levels, including that of full irrigation, was formed in each experimental replication. Sprinkler heads were placed at a distance of 6 m in order to ensure the homogeneity of water applied along the irrigation lateral. Water applied to experimental plots was measured using catch can technique as described by Hanks *et al.* (1976) and Köksal *et al*. (2001).

The experimental plots were designed to be 10 m long by 2.1 m wide. Each plot consisted of three plant rows (3 x 0.7 m = 2.1 m), of which the central row was used for observation and measurements. Rooting depth observations were made using minirhizotron tubes placed at both ends of the central row, while soil moisture content from each soil depth of the experimental plots was monitored (from sowing to harvest) with a neutron probe (CPN, 503 DR), using one access tube located at the central part of the observational row in each experimental plot (Fig. 1). The neutron probe was calibrated using gravimetric soil analyses simultaneously with the neutron readings at all tubes over the experimental site before the first irrigation application.

Irrigation application and measurements: Pre-emergence irrigation (90 mm) was applied after sowing seeds for more uniform emergency in 2008. Application of the first irrigation was based on plant growth measurements and was started when the plant height reached 35 cm in each experimental year. Initially, all plots were irrigated to reach field capacity at 0-90 cm soil depth on June 20, 2008 and June 15, 2010. The following irrigation applications were performed at 10 day intervals with water amounts as predicted for any of the treatments.

The irrigation water amount to be applied to the control treatment (SD1) was determined using data for soil water content and effective root depth of the crop obtained just prior to the irrigation application. Data related to root development obtained prior to any irrigation were evaluated using WinRhizo Tron MF 2007b program. Water amount required to replenish the water deficit in the effective rooting depth of the control treatment was calculated using equation 1 given below.

$$d_n = \frac{Pw}{100}\gamma_t D \qquad (1).$$

Where d_n is irrigation water amounts in mm, Pw is water deficit in the effective root depth of the control treatment (SD1), γ_t is bulk density of the soil (gr cm^{-3}) and D is effective rooting depth.

Irrigation water amount was applied through single line source sprinkler irrigation system providing decreasing levels of water supply from 100% supply at the plot nearest to the irrigation line to 0% water supply in the farthest experimental plot.

Irrigation duration was calculated using the following equation (2):

$$T = \frac{dn}{E_a . I_y} \qquad (2).$$

Where, T is irrigation duration (hour), I_y is water discharge of the head (mm h^{-1}), and Ea is irrigation application uniformity (%).

Control of the irrigation application duration was provided by collecting and measuring water depths in the catch cans located over the experimental plots. In order to determine irrigation application uniformity wind speed was monitored during all the irrigation events. Water applications were ceased at the milk stage of corn grain.

Soil water content measurement started at sowing and ended at harvest. Water contents of soil were monitored between 0-30, 30-60, 60-90 and 90-120 cm depths with a neutron probe (CPN, 503 DR), using one access tube located at the center of each plot. The neutron probe was calibrated using gravimetric soil water content data simultaneously with the neutron readings at all tubes over the experimental site before the first irrigation application. A large number of readings and gravimetric samples have been taken for various depths and levels of moisture content, and strong ($P < 0.01$) linear relationships between water content and count ratios were derived for each experimental year.

Evapotranspiration (ET) from each plot was determined using the soil water balance equation (3) published by James (1988).

$$ET = P + I \pm R + SD - DP \qquad (3).$$

Where, P is precipitation amount during the experimental period (mm), I is irrigation water amount (mm), R is runoff/run-on (mm), SD is soil water depletion (mm), and DP is deep percolation (mm) below the rooting zone. Runoff/run-on was considered zero because the experimental plots were surrounded by dikes. Soil water depletion was calculated as the difference between soil water content values at the beginning and end of each period for a soil depth of 1.2 m. Drainage below the root zone was assumed to be zero, since water applied with each irrigation was equal to water deficit in the effective rooting depth of the fully irrigated control treatment, and no water leaching below 1.2 m depth was observed from neutron measurements taken to a 1.5 m soil depth.

Experimental data obtained from the treatments during the years of study were subjected to an analysis of variance. Statistical procedures were conducted using SAS statistical software (SAS Institute Inc., 1987), and the Duncan mean separation test was also applied. Data related to the experimental years were subjected to an ANOVA test and year x treatment interactions were evaluated. Regression was used to evaluate water use-yield relationships, using seasonal irrigation water or evapotranspiration amounts, and grain yield data obtained from the experiment. Seasonal values of the yield response factor (ky) for each experimental year were determined following the procedure described by Köksal *et al.* (2001) based on the Stewart model (Stewart *et al.,* 1977).

$$\left(1 - \frac{Ya}{Ym}\right) = ky\left(1 - \frac{ETa}{ETm}\right) \qquad (4).$$

Where; Ya = actual harvested yield (obtained from all the treatments).

Ym = maximum harvested yield (obtained from irrigated control).

ky = yield response factor.

ETa = actual evapotranspiration.

ETm = maximum evapotranspiration.

Irrigation water use (IWUE) and water use (WUE) efficiencies of the experimental treatments were evaluated using equations 5 and 6 below, published by Howell *et al.* (1990) and Kanber *et al.* (1992).

$$IWUE = \frac{Y_a}{IR} \qquad (5).$$

$$WUE = \frac{Y_a}{ET} \qquad (6).$$

Where, IWUE is irrigation water use efficiency in kg m^{-3}, Ya is grain yield of the treatment in kg ha^{-1}, IR is seasonal irrigation water amount applied to the treatment in mm, WUE is water use efficiency in kg m^{-3}, and ET is seasonal evapotranspiration value of the treatment in mm.

Minirhizotron measurements: Root growth, demographics and dynamics were monitored *in situ* by minirhizotrons (Upchurch & Ritchie 1983; Smucker *et al.*, 1987). Two minirhizotron tubes (0.063 x 1.82 m) were inserted in the soil, directly under the corn row, to depths of 120 cm at 60° angles Micro-video color camera (CI-600 root scanner, Regent Instruments Inc.) equipped with an index handle and color monitor, were used to video record root images intersecting the upper 1.8 x 1.35 cm region at each stop along the MR tube. Root images were digitized and processed by Winrhizotron 2007b.

RESULTS

Root development: Root picture measurements started before the first irrigation date to a soil depth of 120 cm (Figs. 3 & 4). Monitoring of roots continued until the last irrigation date in 2008 (06.08.2008). The last MR picture could not be taken due to trouble with MR camera and data from August 8 was used in 2008. Total root length was 4.76 m m^{-2} before the first irrigation date and the highest root distribution was between 69-86 cm soil depth (26%, 1.26 m m^{-2}). Root distribution within the soil profile was different at each measurement date (Figs. 2 & 3). Corn roots started to develop immediately before 2nd irrigation and most of them accumulated between 17-34 cm soil depth (31%, 69.68 m m^{-2}). Roots were between 34-52 cm (20%, 130.19 m m^{-2}) depths before 3rd and 69-86 cm depths (19%, 201.03 m m^{-2}) before 4th irrigation in 2008 (Table III; Fig. 2). The lowest root length density was observed at 103-121 cm depths. Similar results were also obtained in 2010. Maximum root distribution was observed at different soil layers before each irrigation time, while the lowest root length density was observed at 103-121 cm depths in 2010.

Total root length was 33.05 m m^{-2} before the first irrigation date and the highest root distribution was between 34-52 cm soil depth (28%, 9.43 m m^{-2}) (Table IV; Fig. 3). Most of the corn roots were between 52-69 cm soil depth before the 2nd, 3rd and 4th irrigation dates (Table IV; Fig. 3). The lowest root length density was observed at 103-121 cm depths. Maximum total root length density was 610.28 m m^{-2} in 2010 compared to 1066.25 m m^{-2} in 2008.

Seasonal irrigation water requirements and seasonal evapotranspiration: The amount of irrigation water to be applied to the fully irrigated control treatment was based on effective rooting depth data determined by minirhizotron camera (Table V).

Root observation data showed that roots were present in all soil layers up to 121 cm as early as the time of the first irrigation application during both years of study (Table V). Effective rooting depths (ERD) were 70 and 75 cm before 3rd and 4th irrigations applied on 25.07.2008 and 30.07.2010 respectively (Table V). Thus ERD of 70 and 75 cm were accepted for the first two and first three irrigation applications both years, instead of 90 cm which is traditionally used in the process of irrigation water amount calculation for corn in the region in order to avoid over watering and excessive water loss.

Irrigation amounts and seasonal water consumption values of the experimental treatments during 2008 and 2010 experimental years are presented in Table VI. Results of the 2 years study showed that total irrigation water amounts applied to any of the treatments was closely dependant on the distance of the experimental plot from the sprinkler irrigation line. Thus, the highest seasonal water amounts of 511 mm and 494 mm were applied to SD1 treatment located closest to the sprinkler source, while lowest water amounts of 160 and 40 mm were given to the farthest SD6 plots, respectively for the first and second experimental years. Irrigation water amounts applied to the remainder of the experimental treatments gradually decreased with increasing distance from the line irrigation source. SD6 plots received more water in 2008 compared to 2010 in order to ensure germination and emergence of the plant during 2008.

Similar results were obtained with regard to the seasonal evapotranspiration rate of the experimental treatments, which gradually decreased with increasing distance from the sprinkler irrigation lateral. As in the case of seasonal irrigation water amount, the highest and lowest seasonal ET amounts of 674 and 756 mm, and 526 and 574 mm were determined for SD1 and SD6 treatments during 2008 and 2010, respectively.

Grain yields, yield response factor and water use efficiencies: Grain yields decreased with increasing distance from the irrigation lateral and decreasing levels of water supply (Table VI). Statistical evaluation of the experimental data obtained from the 2-years study showed that grain yield was significantly ($P < 0.05$) affected by water supply levels. The visual effect of irrigation on grain yield of corn was observed among treatments. Thus, the highest yields of 7753 and 9352 kg ha^{-1} were obtained from plots located closest to the irrigation water source and receiving most water (SD1). On the other hand lowest gain yields of 392 and 2409 kg ha^{-1} were recorded for the treatment receiving

Table I: Climate data during the research period

	Years	Months				
		May	June	July	August	September
Precipitation	**2008**	**-**	**8.30**	**-**	**34.10**	**38.00**
(mm)	2010	3.0	86.2	13.0	-	30.0
Temperature	2008	17.8	21.8	25.8	26.3	20.5
(°C)	2010	17.5	22.0	25.2	27.5	21.2
Relative	2008	65	83	59	58	82
humidity (%)	2010	70	74	64	62	66
Evaporation	2008	139	195	219	210	153
(mm)	2010	129	148	178	183	110
Wind speed	2008	3.12	2.82	3.51	3.62	2.01
(m s^{-1})	2010	1.78	1.52	1.94	2.37	2.31

Table II: Some chemical and physical properties of research plots before the experiment (2008)

Depth (cm)	Soil texture class	Bulk density (g cm^{-3})	Field capacity (mm)	Wilting point (mm)	pH	EC (dS m^{-1})	Organic matter (%)
0–30	CL	1.36	122	69	7.7	0.177	2.29
30–60	CL	1.55	149	93	8.0	0.255	1.71
60–90	CL	1.55	144	102	8.0	0.122	0.81
90–120	CL	1.43	137	90	8.1	0.137	1.41

Table III: Root length before irrigation in 2008

Soil depth (cm)	Root length before irrigation (m m^{-2}) in SD1			
	02.07.2008	11.07.2008	25.07.2008	06.08.2008
0-17	0.87 ± 0.59	32.72 ± 10.19	39.30 ± 11.43	27.15 ± 12.07
17-34	0.60 ± 0.34	69.68 ± 20.07	105.58 ± 13.10	138.41 ± 74.14
34-52	0.63 ± 0.25	49.42 ±8.41	130.19 ± 13.69	175.14 ± 37.02
52-69	0.80 ± 0.45	39.04 ± 8.24	115.81 ±15.09	178.66 ± 15.78
69-86	1.26 ± 0.64	23.55 ± 3.64	101.45 ± 12.63	201.03 ± 11.12
86-103	0.50 ± 0.38	8.64 ± 1.96	93.33 ± 15.55	192.83 ± 4.32
103-121	0.10 ± 0.02	2.06 ± 0.66	62.83 ± 11.64	153.03 ± 14.98
Total	4.76 ± 1.22	225.12 ± 34.83	648.50 ± 59.26	1066.25± 182.98

*Numbers after ± indicates the standard error of the mean (n=3)

Table IV: Root length before irrigation in 2010

Soil depth (cm)	Root length before irrigation (m m^{-2}) in SD1					
	24.06.2010	09.07.2010	19.07.2010	30.07.2010	09.08.2010	18.08.2010
0-17	3.01 ± 0.84	61.90 ± 10.91	50.43 ± 10.18	29.03 ± 4.73	30.23 ± 6.16	22.34 ± 5.11
17-34	6.48 ± 1.02	102.32 ± 16.30	98.86 ± 11.76	72.08 ± 8.49	70.26 ± 9.73	53.06 ± 6.05
34-52	9.43 ± 2.05	108.02 ± 8.08	117.58 ± 6.97	97.40 ± 13.13	98.53 ± 11.80	77.84 ± 8.84
52-69	6.37 ± 2.14	141.18 ± 21.91	125.45 ± 18.50	107.81 ± 7.85	102.96 ± 14.57	89.22 ± 8.66
69-86	3.49 ± 1.02	110.89 ± 30.15	110.51 ± 23.12	95.67 ± 12.41	127.27 ± 79.51	85.42 ± 12.31
86-103	2.09 ± 0.47	51.20 ± 20.53	65.32 ± 16.30	74.90 ± 12.31	55.56 ± 12.28	64.43 ± 11.70
103-121	2.17 ± 0.94	14.52 ± 8.67	42.14 ± 17.88	51.01 ± 15.66	36.07 ±1 9.82	49.67 ± 17.20
Total	33.05 ± 3.88	590.03 ± 93.92	610.28 ± 84.84	527.91 ± 43.48	520.86 ± 140.44	441.99 ± 53.00

*Numbers after±indicates the standard error of the mean (n=3)

Table V: Maximum and effective rooting depths under fully irrigated treatment

	2008				2010			
Irrigation number	Irrigation application date	Maximum Rooting Depth, (cm)	Effective Rooting Depth, (cm)	Irrigation water amount (mm)	Irrigation application date	Maximum Rooting Depth, (cm)	Effective Rooting Depth, (cm)	Irrigation water amount (mm)
I	Pre-emergence irrigation		-	90			-	-
1	20 June		-	70	15 June.			40
2	3 July	121	70	70	1 July.	121	75	99
3	15 July.	121	70	75	10 July.	121	75	100
4	26 July.	121	90	54	21 July	121	75	90
5	6 August.	121	95	100	2 August.	121	90	91
6	17 August.	121	95	52	12 August	121	90	74
Total				511 mm				494 mm

Table VI: Irrigation water amounts, seasonal evapotranspiration and grain yield values of the experimental treatments during the years of study

Year of study	Experimental treatment	IR (mm)	ET (mm)	Grain yield* (kg ha^{-1})
2008	SD1	511	674	6753^{A}
	SD2	445	626	4044^{B}
	SD3	381	572	3450^{B}
	SD4	241	441	1694^{C}
	SD5	173	384	861^{DC}
	SD6	160	377	392^{D}
2010	SD1	494	756	9352^{A}
	SD2	405	665	6623^{B}
	SD3	285	541	4797^{CD}
	SD4	197	471	5327^{C}
	SD5	86	347	3940^{D}
	SD6	40	321	2409^{E}

*Means within columns not followed by the same letter are significantly different at the P < 0.05 level of Duncan's Multiple Range Test

Table VII: Water use efficiency (WUE) and irrigation water use efficiency (IWUE) of the experimental treatment

Irrigation Treatments	2008		2010	
	WUE (kg m^{-3})	IWUE (kg m^{-3})	WUE (kg m^{-3})	IWUE (kg m^{-3})
SD1	1.00	1.32	1.24	1.89
SD2	0.65	0.91	1.00	1.64
SD3	0.60	0.90	0.89	1.68
SD4	0.38	0.70	1.13	2.70
SD5	0.22	0.50	1.13	4.58
SD6	0.10	0.24	0.75	6.02

the lowest irrigation water rates (SD6) in 2008 and 2010, respectively. Grain yields were different in 2008 and 2010 (Table VI). Yields were higher in all treatments in 2010 compared to the first year, because of much higher precipitation during 2010 when precipitation events continued until mid July.

The relationships between seasonal irrigation water amounts applied to the experimental plots and grain yield on one hand, and between seasonal evapotranspiration and grain yield on the other, have also been evaluated for each experimental year (Fig. 4 & 5). Results of the regression statistical analysis showed that a close relationship ($P<0.05$) exists between the mentioned parameters for each experimental year.

The response of yield to water supply can be quantified using the yield response factor (ky), relating relative yield decrease to relative evapotranspiration deficit. The average value of seasonal crop response factor (ky) for corn plotted in Fig. 6 was derived from data related to seasonal evapotranspiration and grain yield value recorded during the experimental years, using the procedure described by Köksal *et al.* (2001) based on the Stewart equation (Stewart *et al.*, 1977).

The slope of the curve plotted in Fig. 6 presents the seasonal value of the yield response factor (ky) for corn valid for the region of the study. As can be implied from the figure, the average value of the mentioned parameter for the research period was 1.34.

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) values determined for treatments with various water supply levels during the experimental years are summarized in Table VII. In general, WUE and IWUE

Fig. 1: Layout of the experimental field

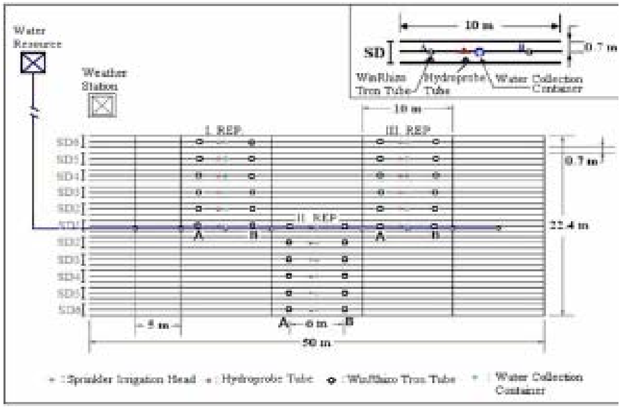
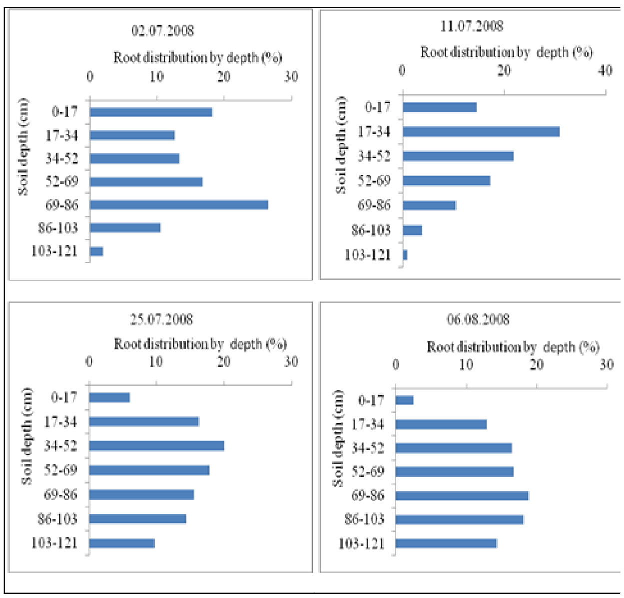


Fig. 2: Percentage root length distribution in 2008



gradually decreased with decreasing amounts of irrigation water applied or with increasing distance from the sprinkler irrigation line, during the dry experimental year (2008). The highest values of 1.00 WUE and 1.32 kg m^{-3} IWUE were determined for SD1 for the mentioned year, while lowest values of 0.10 and 0.24 kg m^{-3} were recorded for SD6, the farthest treatment from the irrigation lateral.

DISCUSSION

Root distributions by depth were similar in both years. The greatest root distribution was between 69-86 cm soil depth before the first irrigation date however, these roots belong to plants from the previous season, previously observed by Kavdir (2000). Root distribution within the soil profile was different at each measurement date (Figs. 2 & 3). The lowest root length density was observed at 103-121 cm depths. Similar results were also obtained in 2010. Maximum root distribution was observed at different soil layers before each irrigation time while the lowest root length density was observed at 103-121 cm depths in 2010.

Effective rooting depths (ERD) were 70 and 75 cm before 3rd and 4th irrigations applied on 25.07.2008 and 30.07.2010, respectively (Table V). Thus ERD of 70 and 75 cm were accepted for the first two and first three irrigation applications both years, instead of 90 cm, which is traditionally used in the process of irrigation water amount calculation for corn in the region in order to avoid over watering and excessive water loss.

Seasonal water amounts of 511 and 494 mm applied to the fully irrigated control treatment in 2008 and 2010 were higher than the average values of 285 mm published for the coastal part of the Thrace region (Istanbulluoglu *et al.*, 2002). Application of higher amounts of water in our study, carried out also in the coastal part of Marmara region, could be easily explained by differences in the growing characteristics of the varieties used in the two experiments. Moreover four and six irrigation applications were done in our study vs. three irrigations applied in the other study. On the other hand, seasonal irrigation water amounts applied in our study are considerably higher than those of 420 mm reported for the Black Sea region of our country, receiving much more seasonal precipitation compared to our region (Bayrak, 1979).

The results for seasonal irrigation water requirements obtained in our research are in agreement with those of 490 and 525 mm published for the years of normal precipitation of the non-coastal part of the Thrace region (Çakir, 2004). Higher seasonal water requirements of 568 mm and 581 mm were reported by Cavero *et al.* (2000) and Yazar *et al.* (2002), respectively, for the semiarid region of Spain and dry climatic conditions of south east Turkey.

Grain yields were different in 2008 and 2010 (Table VI). Significantly higher corn yields were obtained in 2010. These differences may have resulted from higher rainfall when precipitation events continued until mid July. Rainfall supplied enough water to the soil for high corn yield. Conversely, rainfall during the corn growing season was low and below normal rainfall in July reduced corn grain yields in 2008. Similar findings in corn yield differences among years were also reported by Varsa *et al.* (1997).

Yields were higher in all treatments in 2010 compared to the first year, because of much more precipitation during 2010. Results of the study concerning the drastic decrease of the yields due to unfavourable climatic conditions of 2008 supports the concept of Çakir (2004) of an approximately 30-35% decrease of yield under full irrigation conditions during the dry experimental year. Though yields obtained from the recent study were much lower than those of 13100 and 13840 kg ha^{-1} reported by the same author for fully irrigated corn during wet years in the non-coastal part of Thrace region of Turkey. The grain yield of 9352 kg ha^{-1} recorded for the year with more favourable precipitation distribution (2010) is comparable with the yields of 10015 and 10035 kg ha^{-1} published earlier by Gençoğlan and Yazar

Fig. 3: Percentage root length distribution in 2010

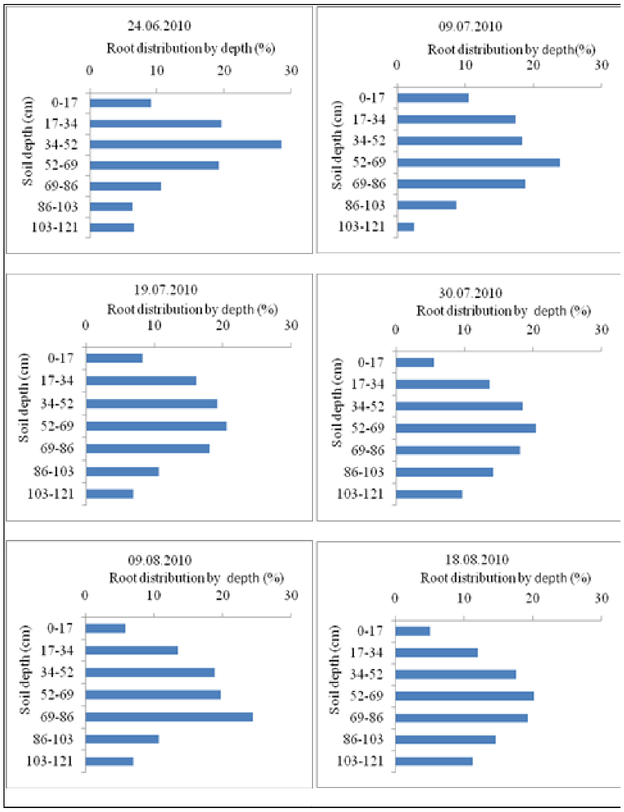
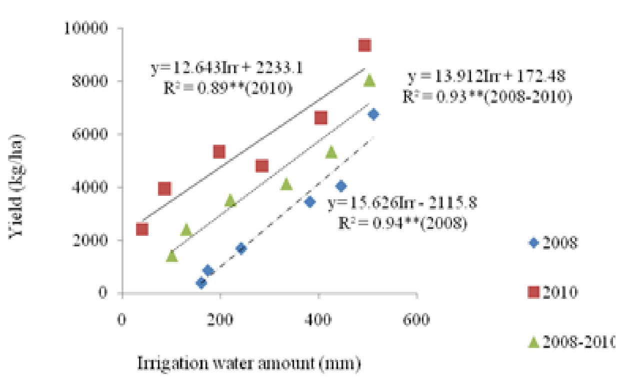


Fig. 4: Relationship between seasonal irrigation water and grain yield during the study

** Statistically significant at the P < 0.05 level



(1999) for Çukurova in Turkey.

Seasonal value of the yield response factor (ky) for corn is valid for the region of the study. As can be implied from the figure, the average value for the research period was 1.34.

The average seasonal value of yield response factor derived in this study is much higher than that of 0.76 published for a second crop of corn grown in the region of Çukurova (Kanber *et al.*, 1990). However, it is consistent with the value of 1.25 published by Doorenboos and Kassam (1979). Çakir (2004) evaluated years of various climatic

Fig. 5: Relationship between seasonal evapotranspiration values and grain yield during the study

**Statistically significant at the P < 0.05 level

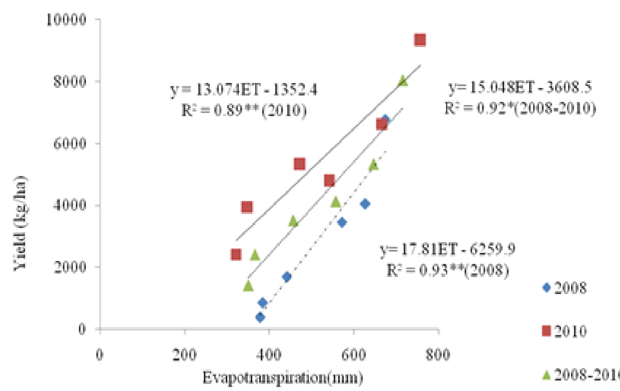
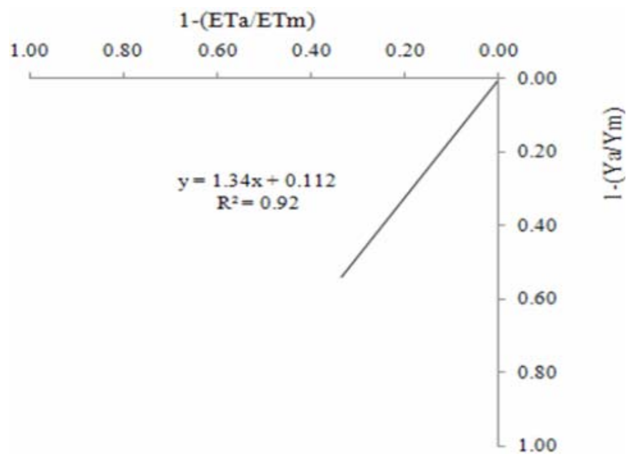


Fig. 6: Relationship between seasonal evapotranspiration deficit and relative yield reduction



characteristics of the non-coastal part of Thrace and determined that the seasonal value of the yield respond factor varies from 0.81 in a wet year to 1.22 and 1.36 for normal and extremely dry years respectively. Relatively high values of 1.47 and 1.39 are reported respectively by Howell *et al.* (1997), and Retta and Hanks (1980) for different regions of USA. Relatively high average value of 1.51 is determined for silage maize grown under semiarid conditions of eastern Anatolia in Turkey (Kiziloglu *et al.*, 2009).

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) values determined for treatments with various water supply levels during the years of experiment are summarized in Table VII. In general, WUE and IWUE gradually decreased with decreasing amounts of irrigation water applied or with increasing distance from the sprinkler irrigation line, during the dry experimental year (2008). The highest values of 1.00 WUE and 1.32 kg m^{-3} IWUE were determined for SD1 for the mentioned year, while lowest values of 0.10 and 0.24 kg m^{-3} were recorded for SD6, the farthest treatment from the irrigation lateral.

CONCLUSION

The effects of irrigation water amount, calculated according to actual rooting depth (MR camera), on seasonal water consumption and water use efficiency were determined. Plants were irrigated 4 times in 2008 and 6 times in 2010. Total root lengths were 4.76 m m^{-2} and 33.05 m m^{-2} before the first irrigations and 1066 m m^{-2} and 441.99 m m^{-2} before the last irrigations in 2008 and 2010, respectively. Distribution of roots in soil profile changed after each irrigation. Effective rooting depth was 70 cm until the third irrigation in the first year of the experiment (25.07.2008). ERD was 75 cm until 4^{th} irrigation (30.07.2010) in the second year. Therefore, it can be concluded that ERD can be assumed to be 75 cm for calculation of irrigation water amount until the end of July in Canakkale. Use of higher values can cause excessive use of irrigation water. The average value of the seasonal yield response factor was 1.34.

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