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Water Use - Production Relationship of Maize under Tekirdag Conditions in Turkey

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Abstract: The study was conducted to investigate times of irrigation, seasonal evapotranspiration, water use-production function and yield response of maize (*Zea mays*) to water under Tekirdag climatic conditions in Turkey. Sandoz-PX 74 variety of maize was used. Eight irrigation treatments were designed considering different combinations of irrigation application at three growth stages, vegetative (V), tasseling (T) and cob (T) together with no irrigation application (NoI). VTC treatment (irrigation at vegetative, tasseling and cob stages) was the control treatment. The highest seasonal evapotranspiration was calculated in VTC treatment, with the least water stress, as 586 mm. The highest monthly evapotranspiration was 217 mm in July. Maize yield for this treatment was 9920 kg ha^{-1}. The seasonal yield response factor, k_y, was 0.76 and tasseling stage was the most sensitive to water stress. Control treatment might be practiced to realize the highest yield however TC treatment, with two irrigations, can be applied without major yield reduction instead of three. By this way, 26.3 % of irrigation water is saved against only 2.7 % yield reduction.

Key words: Maize, irrigation, evapotranspiration, water-production and yield response factor

Introduction

Irrigation is one of the major practices among others to increase the yield. In Turkey, having continental climatic characteristics, irrigation is necessary in the periods when precipitation is insufficient during the growth stages.

Continuous population growth and industrial development, leading to the contamination of fresh water resources, put enormous pressure on the use of limited water resources. Increasing the productivity of existing water resources is needed to produce more food, fight poverty, reduce competition for water and to the enough water for nature. The productivity of water may be increased by deficit irrigation of the crops during the stages that are not very sensitive to water. In this way, more area is irrigated and despite of small reduction in the yield of unit area total production will be optimized.

Thrace region of Turkey has a great agricultural potential due to its climatic characteristics and soil properties. Except horticultural production, dry farming system has been practiced in the region. Present water resources in the region are insufficient for irrigation of all agricultural land. However, investments on tourism and building summer houses at the cost and industrial development inside the region without taking any precautions has caused a decrease in agricultural lands and shared limited water resources. This obliged to practice the deficit irrigation and field study on this subject. Maize is one of the main crops grown in Thrace region. Many studies were conducted to investigate water use-production relationship of maize. It is evaluated the crop growth simulation model EPICphase and the model CROPWAT on their ability to simulate maize grain yield reduction caused by water stress under semi-arid conditions. Simultaneous optimization of deficit irrigation and nitrogen input was investigated in the field study by Pandey *et al.* (2000). They concluded that optimizing these inputs at the farm level would maximize biomass production and harvest index. Influence of tassel on crop water stress index and its components were investigated. It is compared irrigation scheduling methods for maize under field conditions. The aim of this study is to investigate the seasonal evapotranspiration, irrigation water requirement, time and number of irrigations, water use-production functions and yield response factor of maize that is predominantly grown in Thrace region.

Materials and Methods

Field experiments were conducted on a private farm area at Topagac district of Tekirdag Province located at Thrace part of Marmara Region in Turkey during the years 1994 and 1995. The experimental area, distanced 500 m from Marmara sea and altituded 50 m, located at 40°57′ N latitude, 27°28′ E longitude. The climate of Tekirdag is characterized by Mediterranean type with mild and rainy winters and hot and dry summer at the coast while continental type prevails inside. The averages of annual temperature, relative humidity, wind speed, sunshine duration and total annual precipitation are 13.7 °C, 75 %, 3.1 m/s, 6.5 h and 579.7 mm, respectively (Anonymous, 1984).

Soil chemical and some other important properties are presented in Table 1. Soil moisture characteristics such as field capacity, wilting point, bulk density, available water holding capacity at the experimental site are presented in Table 2. The area does not have boron, salt, sodium and drainage problems. Irrigation water quality is C_2S_1 (electrical conductivity: 0.5 dS/m and sodium adsorption rate: 7.0 meq/l).

In the selection of irrigation treatment three different growth stages of maize, vegetative, tasseling and cob stages, were considered. The treatments were as follows: no irrigation (NoI), irrigation at vegetative stage (V), irrigation at tasseling stage (T), irrigation at cob stage (C), irrigations at vegetative and tasseling stages (VT), irrigations at vegetative and cob stages (VC), irrigations at tasseling and cob stages (TC) and irrigations at vegetative, tasseling and cob stages (VTC). VTC treatment was the control.

All treatments were irrigated at the same time with the control treatment (VTC). Soil moisture deficit of 90 cm soil depth of control treatment was filled to field capacity (Howell, 1988) and the same amount of irrigation water was applied to other plots as suggested by Kanber *et al.* (1989). Soil moisture content in the plots was determined gravimetrically in the soil layers 0-30 cm, 30-60 cm and 60-90 cm during the whole growing season. The amount of water applied to the plots were measured with a flowmeter. The plots were irrigated by furrow irrigation method. Each experimental plot occupied an area of 25.2 m^2 (4.2 x 6.0 m), including 144 plants with 0.7 x 0.25 m^2 plant spacing. The gap between the plots was 3.0 m and plots were situated on furrow-irrigated land having a uniform slope of about 0.5 %. Sandoz-PX 74 hybrid maize seed was used since it performed well in the region (Baser, 1993). Nitrogen and Phosphorous were applied at the rate of 100 kg per hectare N and 50 kg per hectare P_2O_5 before sowing. Winter wheat had been grown in the experimental site before the experiment.

The seeds were sown in the plots on 9th April 1994 and 4th April 1995. Plant stem length and leaf area index (LAI) were measured in each plot. This was performed in each irrigation treatment at three different growth stages and at harvest. After physiological

Table 1: Some chemical properties of the soil at the experiment site.

Year	Soil layer (cm)	Soil reaction pH	EC 10^3 25°C	Total salt (%)	Lime $CaCO_3$ (%)	Organic matter (%)	Available (kg ha^{-1})	
							P_2O_5	K_2O
1994	0-20	6.4	1.8	0.047	-	1.10	61	475
	20-40	6.2	1.6	0.030	-	0.95	78	400
1995	0-20	6.3	1.3	0.032	0.48	1.16	41	434
	20-40	6.5	1.2	0.032	0.96	0.89	43	556

Table 2: Moisture characteristics of the soils at the experiment site.

Soil layer (cm)	Field capac.		Wilting point		Bulk dens. (g/cm^3)	Available water		Texture
	Pw	mm	Pw	mm		Pw	mm	
0-30	19.46	96.91	11.13	55.43	1.66	8.33	41.48	SCL
30-60	20.11	100.75	10.75	53.86	1.67	9.36	46.89	SCL
60-90	20.37	103.28	11.16	56.58	1.69	9.21	46.70	SCL
0-90		300.94		165.87			135.07	

Pw: weight basis moisture percentage; water height as mm in the defined layer; SCL: sandy clay loam.

maturity, cobs for yield were harvested from three rows per plot on 16th August 1994 and 15th August 1995. The cobs were dried under open-air during 7-10 days and then the grains were separated from the cobs, oven dried at 65 °C and weighed to determine total dry matter. Total grain yield and 1000 grain weight were measured (Kun, 1985). Yields were adjusted to 15 % moisture content.

Evapotranspiration (ET) for ten-days periods was calculated according to the water balance method (Heerman, 1985). The relationships between grain yield and evapotranspiration (yield response factor) was determined according to Stewart model (Stewart, 1977). While total water use efficiency (TWUE) was calculated from grain yield and total water use. Irrigation water use efficiency (IWUE) was calculated from grain yield and irrigation water use (Unger, 1982). Data were analyzed by analysis of variance and relationship between water use and grain yield was evaluated by regression analysis. First variance analyses and classification of Duncan tests were done on the data for the treatments of each year separately. Then, the same procedure was repeated for both trial years together after the homogeneity test showing that there were no statistically significant difference between them.

Results and Discussion

Grain yield: The average of two years grain yield data showed that the highest yield was obtained in VTC treatment that was classified as the first group alone with 9920 kg ha^{-1}. This was followed by TC treatment that was placed in the second group with 9650 kg ha^{-1}. Irrigating twice in TC treatment instead of three times in VTC treatment caused 270 kg ha^{-1} (2.7 % only) grain yield reduction. Table 3 also reveals that, although, these two treatments were put into different groups, a and ab, according to the average of two years, they were placed in the same group considering the two trial years separately after the Duncan test. This implies that TC treatment may be applied without serious grain yield losses when water is scarce.

Twice irrigated VT treatment and once irrigated T and V treatments were in the third group. These were followed by C and Nol treatments in the fifth group.

The main inference from the grain yield result is that it is possible to obtain satisfied grain yield applying two irrigations instead of three times in this region. But one of these two irrigations should be applied at tasseling stage. The other one is at the vegetative stage when the plant heights reach 40-50 cm, the last week of May or the first week of June, if the beginning of the growth stage is drought. On the other hand, if the beginning of the growth stages is wet, it is applied at cob stage. This is confirmed by many studies on the investigation of critical stages of maize against water stress. Kanber *et al.* (1990); Rhoads and Bennett (1990); Ul (1990); Uzunoglu (1991); Yildirim (1993); Bakanogullari (1995); Yildirim *et al.* (1995) and Evren and Istanbulluoglu (1995) obtained in their research that water stress at the tasseling stage,

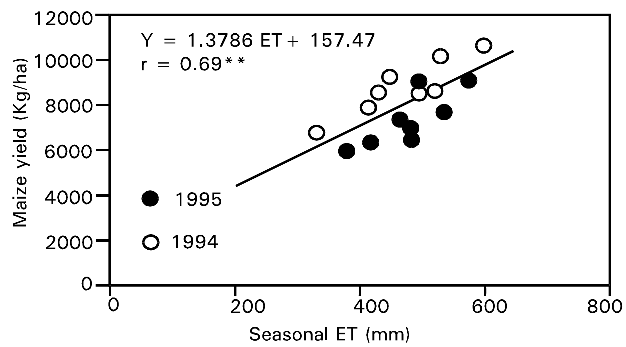

Fig. 1: Seasonal water use-production function of maize

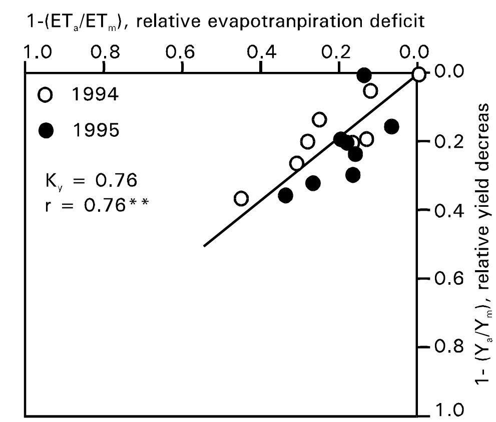

Fig. 2: Yield response of maize to water for total growth period.

that was the pollination time, decreased the number of grains through preventing fertilization and therefore reduced the grain yield.

1000 grains weight: The highest 1000 grains weight was obtained in VTC and TC treatments. The 1000 grains weights of the treatments irrigated at tasseling and cob stages were more than that of the others. It increased with the number of irrigations. This is probably because irrigation increased the grains size. This was also stated by Kanber *et al.* (1990); Ul (1990); Yildirim (1993) and Ogretir (1994).

Cob length: The longest cobs were recorded in TC, VTC and TC treatments, statistically placed in the same group, three of which contained irrigation at tasseling stage. However, in treatment VC

Table 3: The yield, vegetative growth, amount of irrigation water (I), seasonal evapotranspiration (ET) and water use efficiencies (WUE) for the treatments in the trial years (T means total).

Year	Treatments	Grain yield (kg ha^{-1})	1000 grain weight(g)	Plant height (cm)	Cob length (cm)	I (mm)	Seasonal ET (mm)	TWUE kg ha^{-1} mm	IWUE kg ha^{-1} mm
1994	VTC	10690a**	342.6a**	240	20.3a*	306	599	17.8	34.9
	TC	10200a**	343.3a**	230	20.4a**	235	528	19.3	43.4
	VC	8550abc	309.4ab**	230	19.0ab	183	496	17.2	46.7
	VT	8660abc	319.4a*	240	19.7a*	194	519	16.7	44.6
	C	8570abc	307.6ab	220	19.2a*	112	430	19.9	76.5
	T	9270ab	322.3a*	230	20.2a*	123	466	20.8	75.4
	V	7880bc	281.7bc	235	18.7ab	71	414	19.0	111.0
	NoI	6760c	260.3c	220	16.9b	-	328	20.6	-
1995	VTC	9150a**	332.5a**	234	20.5a**	264	573	16.0	34.7
	TC	9100a**	322.8ab	220	20.4a**	184	493	18.5	49.45
	VC	6490b	293.5ab	228	18.2ab	149	479	13.5	43.6
	VT	7730ab	295.2ab	234	19.1ab	195	533	14.5	39.6
	C	6280b	296.5ab	210	17.8ab	69	418	15.0	91.0
	T	6970ab	295.6ab	220	17.9ab	115	481	14.5	60.6
	V	7420ab	280.5ab	227	18.7ab	80	461	16.1	92.8
	NoI	5920b	267.4b	210	16.4b	-	378	15.7	-
Ave.	VTC	9920a**	337.6a**	237	20.4a**	285	586	16.9	34.8
	TC	9650ab	333.1a*	225	20.4a**	210	511	18.9	46.5
	VC	7520bc	301.5abc	229	18.6ab	166	488	15.4	45.2
	VT	8200abc	307.3ab	237	19.4a*	195	526	15.6	42.1
	C	7430c	302.0abc	215	18.5ab	91	424	17.5	83.8
	T	8120abc	309.0ab	225	19.1ab	119	464	17.7	68.0
	V	7650abc	281.1bc	231	18.7ab	76	438	17.6	101.9
	NoI	6340c	263.9c	215	16.7b	-	353	18.2	-

-*, ** Significant at 0.05 and 0.01 confidence level, respectively.

Table 4: The leaf area index (LAI) values for irrigation treatments in trial years

Treatments	Observation dates							
	1994				1995			
	28 May	27 June	13 July	25 July	03 June	28 June	13 July	26 July
VTC	0.44	4.05	3.90	2.62	0.42	3.80	3.72	2.51
TC	0.44	3.50	3.30	2.09	0.42	3.40	3.22	2.02
VC	0.44	4.05	3.62	2.15	0.42	3.80	3.33	2.19
VT	0.44	4.05	3.90	2.24	0.42	3.80	3.72	2.21
C	0.44	3.50	3.17	1.19	0.42	3.40	3.09	1.90
T	0.44	3.50	3.35	1.81	0.42	3.40	3.21	1.99
V	0.44	4.05	3.62	1.88	0.42	3.80	3.55	1.81
NoI	0.44	3.50	3.17	1.69	0.42	3.40	3.09	1.64

that was also irrigated two times as TC and VT were and contained no irrigation at tasseling stage was the last group, according to the Duncan's classification test. This implies that irrigation has a great influence on cob length formation. Therefore, it should be applied at the stages of tasseling and cob.

Plant height: The treatments affected plant heights significantly. The development of height of the plants was slow from emergence to the formation of 3-4 leaves, but quite fast from this stage to the tasseling stage. After the tasseling stage, vegetative development was replaced by the cob formation.

The highest plants were recorded in VTC and VT treatments with the value of 237 cm. Because plants experienced less water stress at these stages. This was followed by V treatment with 231cm, VC treatment with 229 cm, and T and TC treatments with 225 cm and NoI and C treatments with 215 cm. The most effective irrigation treatments on plant heights were at vegetative and tasseling stages, respectively. Irrigation at cob stage has no effect on plant height while it is very affective on grain yield.

Irrigation water amounts: The amount of irrigation water in V, T and C treatments, irrigated only once, varied between 71 and 123 mm in 1994, 69 and 115 mm in 1995. Water demand during the tasseling stage was more than that of the other stages.

Similarly, the amount of irrigation water in the treatments VT, VC, TC, irrigated two times, were found between 183 and 235 mm, in 1994 and between 149 and 195 mm in 1995. The difference between the two years was because of the difference in the magnitude of precipitation. The total precipitation in July 1994 was 5.6 mm only while it was 92.8 mm in July 1995.

The highest amount of irrigation water with three applications was to VTC treatment during the whole growth period. The total water applied was 306 mm in 1994 and 264 mm in 1995. The highest grain yield and plant water use value were also obtained in this treatment.

Evapotranspiration (ET): Seasonal and monthly ET of the treatments in the trial years were calculated using soil moisture measurements, irrigation water quantity and effective precipitation.

ET of the trials increased with the increase in amount of irrigation water. Because there was no irrigation in April and May, the amount ET of all treatments were the same in these months. Introduction of the irrigation in June was effective in the deviation of the ET values between the treatments after this month.

The least ET value was observed in the NoI treatment with 353 mm. This was followed by the treatments irrigated ones C, V and T being 424 mm, 438 mm and 464 mm, respectively. The ET of twice irrigated treatments VC, TC and VT were found to be, respectively, 488, 511 and 526 mm. The ET value of control treatment irrigated three times VTC was 586 mm. Comparing the two trial years with each other, no statistical difference was seen. The highest monthly ET values were realized in June for NoI, V and VC treatments and in July for other treatments. The highest

monthly ET was obtained in VTC treatment with 217 mm (around 7.0 mm/day) in July, followed by TC treatment with 202 mm (6.5 mm/day). This high ET values fell in flowering period that contained T and C stages. Similar results were also observed by Kanber *et al.* (1990); Ul (1990); Uzunoglu (1991); Yildirim (1993); Bakanogullari (1995); Yildirim *et al.* (1995) and Evren and Istanbulluoglu (1995).
The seasonal ET of maize varied between 373-964 mm depending upon the differences in climate, soil conditions and plant species.

Water use efficiency: The irrigation water use efficiencies (IWUE) of the treatments in the experiments were higher than the total water use efficiencies (TWUE). The reason for this is that the amount of total water use is greater than the amount of irrigation water.
Using average values, the highest TWUE was obtained in TC treatment with 18.9 kg ha^{-1} mm while the lowest TWUE was observed in VC treatment with 15.4 kg ha^{-1} mm. This was because no irrigation was applied at the tasseling stage in VC treatment.
As for the IWUE, the highest and lowest rates were recorded as 101.9 kg ha^{-1} mm in V treatment and 34.8 kg ha^{-1} mm in VTC treatment, respectively. This shows that, as stated by Tulucu (1985), after a certain amount of irrigation water and soil moisture level, crop production can not be increased and maize equally benefits from the water during all growth stages.

Leaf area index: Leaf area index (LAI) increased continuously from the emergence to the tasseling stage (Table 4). This increase was accelerated with irrigation. When the number of leaves reached 13 the LAI took the maximum value.
The highest LAI was 3.93 in VTC, VC, VT and V treatments, while the smallest LAI was observed in C and NoI treatments. This may be explained by the irrigation water applied at V stage. The number of irrigation, in the other words less water stress led to increases in leaf area and therefore LAI. Similar results were also reported by many researchers referring to Ogretir (1994). Also, A positive linear relationship between the number of the irrigation and LAI was found.

Seasonal water use function: The seasonal water use function obtained using ET and grain yield of maize is presented in Fig. 1. There was a positive linear relationship between ET and grain yield (Y) such that Y = 1.3786 ET + 157.47 (r = 0.69**). Using this relationship, grain yield of maize in this region can be predicted from ET. But, when using the produced equation, the upper limit of the independent variable should not be exceeded. Previous investigations show that the ET-grain yield relationship may be either linear or non-linear referring to Tulucu (1985). However, many studies on this issue showed that a linear relationship may be used for Turkey's conditions (Kanber *et al.*, 1990; Yildirim, 1993; Ogretir, 1994 and Yildirim *et al.*, 1995).

Yield response factor (ky): Using ET and grain yield of the treatments, ky which explain the relationship between the relative water use deficit and relative yield reduction was calculated as explained by Stewart (1977).

$$\left(1-\frac{Ya}{Ym}\right) = 0.7626\left(1-\frac{ETa}{ETm}\right) + 0.404 \qquad r = 0.76^{**}$$

The value 0.0404 may be omitted because it is too small. Then this relation becomes:

$$\left(1-\frac{Ya}{Ym}\right) = 0.76\left(1-\frac{ETa}{ETm}\right)$$

The slope of the line curve of above equation is taken as yield response factor (ky), being 0.76 in Fig. 2.
The ky values for the trial years of 1994 and 1995 were 0.75 and 1.01, respectively. Different ky values for maize were reported by different authors; for example: Yildirim *et al.* (1995) as 0.94 and Evren and Istanbulluoglu (1995) as 0.77. Our observation is consistent with the one obtained by Evren and Istanbulluoglu (1995) while it was smaller than that of Yildirim *et al.* (1995). This was probably because maize was grown under more favorable conditions in this study than that of the other researchers. Under Tekirdag condition, achieving 6340 kg ha^{-1} grain yield from NoI treatment and obtaining an amount that is very close to the maximum yield from two times irrigated treatments has proved this. It shouldn't be misled from this result that maize is not sensitive to water but regional conditions are very effective on this.
According to the results obtained, VTC treatment might be practiced to realize the highest yield. The irrigation schedule of this treatment may be as follows: The first irrigation is when the plant height reached 40-50 cm, that is the end of May or the beginning of June; the second irrigation is at the tasseling stage, that is the last weak of June; and the third irrigation is at the cob stage, that was in the middle of July. The effect of omitting irrigation that should be applied at a certain time on maize grain yield varies with treatments. Irrigation at the vegetative stage is not as effective as the one at tasseling and cob stages. Therefore, TC treatment, with two irrigations, can be applied without major yield reduction instead of three in VTC treatment in the years that water resources are limited. By this way, 26.3 % of irrigation water is saved against only 2.7 % yield reduction. If the water resources permit irrigation only once, then it should be supplied at T stage. The calculated ky value of maize for Thrace Region is 0.76 which may be used to predict yield from ET according to Stewart model.

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