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Deficit Irrigation Programs Effects on Yield in Millet (*Panicum miliaceum* L.) in Thrace Region Conditions

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ABSTRACT

Millets are indigenous to many parts of the world and are more widely grown, especially in areas where water is limited. The most widely grown millet type is sorghum (*Sorghum bicolor* L.). A field study was carried out to determine the effect of deficit irrigation regimes on grain yield and seasonal evapotranspiration of proso millet (*Panicum miliaceum* L.) in the Thrace Region of Turkey. The field trials were conducted on a loam Entisol soil, on Öğretmenoğlu and Beydarı, the most popular varieties in the research area. In the study, the split plots experimental design with three replications was used. Eight different irrigation issues are considered, including combinations of the vegetative (V), flowering (F) and grain formation (Y) phases of the plant (including dry conditions, NoI). Results showed that proso millet was significantly affected by water stress during the sensitive flowering stage. The highest grain yield was obtained with 4.09 t ha-1 from Öğretmenoğlu and 4.03 t ha-1 from Beydarı, which was rinsed (VFY) in all development periods. Seasonal irrigation water use and evapotranspiration of the irrigated (VFY) in all development periods were 318 and 579 mm, respectively, for the non-stressed treatment. The seasonal water yield function was calculated as Y = 0.4087 ET + 144.03, and the seasonal yield-water response factor value was calculated as 0.57'.

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Trakya Bölgesi Koşullarında Kısıntılı Sulama Programlarının Darıda (*Panicum miliaceum* L.) Verim Üzerine Etkileri

ÖZET

Darılar dünyanın pek çok yerine özgüdür ve özellikle suyun kısıtlı olduğu alanlarında daha yaygın olarak yetiştirilmektedir. En yaygın olarak yetiştirilen darı türü sorgumdur (*Sorghum bicolor* L.). Darı (*Panicum miliaceum* L.)'nın su-verim ilişkilerinin belirlenmesi amacıyla yapılan bu araştırma 2018-2019 yıllarında Tekirdağ Namık Kemal Üniversitesi deneme alanında (40°59'K-27°34'D; 20 m) yürütülmüştür. Öğretmenoğlu ve Beydarı çeşileri kullanılarak tesadüf parselleri deneme desenine göre üç tekerrürlü planlanan araştırma, tınlı-killi bünyeli Entisol toprak grubu üzerinde kurulmuştur. Bitkinin vejetatif (V), çiçeklenme (F) ve dane oluşum (Y) dönemlerinin kombinasyonları içeren (kuru koşullar dâhil, NoI) sekiz farklı sulama konusu yer almıştır. Araştırma sonuçlarına göre, darının topraktaki nem eksikliğine duyarlı bir bitki olduğu, en fazla duyarlı olduğu dönemin ise çiçeklenme (F) dönemi olduğu görülmüştür. En yüksek darı dane verimi, tüm gelişme dönemlerinde sulanan (VFY) konusunda Öğretmenoğlu'dan 4.09 t ha^{-1} ve Beydarı'dan 4.03 t ha^{-1} elde edilmiştir. Bu konunun mevsimsel sulama suyu kullanımı ve bitki su tüketimi sırasıyla 318 ve 579 mm olmuştur. Mevsimsel su verim fonksiyonu Y = 0.4087 ET + 144.03 , Mevsimsel verim-su tepki faktörü değeri ise 0,57' olarak hesaplanmıştır.

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Anahtar Kelimeler
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Su üretim fonksiyonu
Su verim ilişkisi faktörü

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INTRODUCTION

The usage areas of Sorghum [*Sorgum bicolor* (L.) Moench] has changed over time, but it remains a primary staple food, especially for arid regions. Sorghum also plays a significant role in human consumption; in terms of production area, it ranks fifth after maize, rice, wheat and barley among the cereal crops (Paterson, 2008). It has been reported that 21 sweet sorghum genotypes have high yield and silage quality potential under Çukurova conditions (Yucel et al. 2017). The global climate change, which is being experienced more and more each year, the increasing world population and the increasing need for food require solutions to the universal problems in the agricultural sector. The importance of growing sorghum is increased by the fact that it does not require as intensive plant protection and nutrient replenishment as maize (Tsuchihashi & Goto, 2004).

The possible agricultural drought resulting climate change necessitates effective water management to increase and maintain productivity with irrigated agriculture.

In plant production, instead of obtaining maximum efficiency from the unit area with full irrigation, by limiting the number of irrigation or the amount of irrigation water, more areas can be irrigated with the same amount of irrigation water, and thus water use can be optimized (Anonymous, 2018).

Millet (Panicum miliaceum L.), subsidized to meet quality forage deficiencies in Turkey, has recently become increasingly embedded in the crop pattern of the Thrace Region. Therefore, the need for information on millet cultivation and water use efficiency in irrigated conditions has become critical. It has a water demand of 500–580 mm/year and a transpiration coefficient of 150–250 l/kg dry matter (Assef et al., 2010). In the case of limited watering of the plants, with the change of soil moisture, the plant reacts differently in different development periods. This means that the sensitivity of plants to water deficiency in each development period is different.

Few studies on millet in Turkey and the world reveal that millet is a water-sensitive product (Ibrahim et al. 1993; Turgut et al. 2006). Similarly, it was stated by Prasad et al. (1986), Seghatoleslami et al. (2008), Okant (2014) and Gong et al. (2019) that irrigations at different growth stages cause very other effects on plant growth and yield.

In this study, it is aimed to contribute to the agriculture of the region by determining the water-yield relationship of millet.

MATERIAL and METHOD

Research Site

The research was carried out in the experimental area of Tekirdağ Namık Kemal University Faculty of Agriculture in 2018 and 2019. The trial area is 2 km from the sea, at an altitude of 20 m, and is located at 40°59' north latitude and 27°34' east longitude.

Climatic Conditions

Tekirdağ province has a semi-terrestrial climate type. Winters are cool and rainy; summers are dry and hot. For many years (1975-2019), the annual average precipitation is approximately 581.8 mm, the temperature is 14 °C, the relative humidity is 77%, the evaporation amount is 987.3 mm, and the wind speed is around 2.7 m s^{-1} (State Meteorology Bulletin, 2020). The monthly temperature, relative humidity, wind speed, precipitation and sunshine duration values measured during the trial years (2018-2019) are given in Table 1.

Experimental Plan

Experiment area did not form a pedogenetic horizon, very young, clayey textured (average 46.2% clay, 27.9% silt, 25.9% sand in 0-90 cm soil profile), located on Entisol soil order. (Boyraz and Sarı, 2012). There is no problem with boron, salinity, sodium, calcification, drainage and erosion. Irrigation water quality is T2S1 (electrical conductivity 0.5 dS m^{-1}, sodium absorption rate 7.0). Soil moisture constants of the experimental area are given in Table 2, and some chemical analysis values of the soil are shown in Table 3.

The research was carried out as two separate experiments with three replications, using the Öğretmenoğlu and Beydari seed varieties (Panicum miliaceum L.) according to the split plots experimental design. The sowings were made on 16 April 2018 and 12 April 2019. Trial plots were 2.1 x 4.0 m in size, 0.35 m between rows and 0.20 m above rows. A total of six rows were created in each plot. With the planting, all plots were given 20-20-0 fertilizer with 100 kg ha^{-1} and urea fertilizer with the analaysis of 50 kg ha^{-1} when the plant height reached 40-45 cm. In both years, winter wheat was planted as a preliminary plant in the experimental area.

Irrigation Applications

In selecting irrigation topics, three developmental periods with high sensitivity in water-yield relations were taken as stated in Doorenbos and Kassam (1979) and Allen et al. (1998).

The amount of irrigation water to be given to the subjects to be irrigated is based on the principle of increasing the amount of missing moisture in the soil samples taken from the adequate root depth (0-90 cm) of the relevant plots before each development period (Howell et al., 1988) to the field capacity (Howell et al.,1988).

Table 1. Meteorological values measured during the trial years
Çizelge 1. Deneme yıllarında ölçülen meteorolojik değerler

Aylar (Months)	Meteorolojik değerler (Meteorological values)											
	Sıcaklık (Temperature) (°C)		Nisbi nem (Relative humidity) (%)		Rüzgar hızı (Wind speed) (m s^{-1})		Yağış (Precipitation) (mm)		Güneşlenme (Sunbathing) (h)			
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019		
January	6.6	5.6	85.6	76.3	2.9	3.2	76.5	63.9	101.2	49.9		
February	7.3	5.8	86.1	74.3	3.5	2.9	95.3	44.8	49.0	104.5		
March	9.8	9.3	85.8	70.8	3.0	2.9	76.8	30.2	92.0	199.8		
April	14.0	11.6	76.4	71.9	2.2	2.6	10.6	42.9	240.3	162.4		
May	18.5	17.9	79.2	70.5	2.8	2.3	27.4	31.2	183.7	191.7		
June	22.3	24.1	72.6	64.8	3.0	2.8	75.4	7.5	199,1	237.1		
July	25.1	23.9	69.5	65.0	2.6	2.7	87.7	18.8	259.5	293.0		
August	26.0	25.3	63.1	62.7	3.8	3.5	-	-	228.4	293,3		
September	21.8	21.6	67.7	65.1	3.1	3.3	18.7	9.6	132.8	223.3		
October	16.7	17.5	75.9	73.3	2.8	2.3	48.2	46.2	125.8	184.1		
November	12.1	15.5	76.7	75.7	3.6	2.6	48.2	17.4	52.5	130.2		
December	6.2	9.2	76.3	75.5	2.6	2.7	115.2	22.3	59.9	71.1		
Yıllık (Annual)	15.5	15.6	76.2	70.5	3.0	2.8	680.0	334.8	143.7	178.4		

Table 2. Field capacity and wilting point values of the research area soil
Çizelge 2. Araştırma alanı toprağının tarla kapasitesi ve solma noktası değerleri

Toprak derinliği (Soil depth) (cm)	Tarla kapasitesi (Field capacity)		Solma noktası (Wilting point)		Hacim ağırlığı (Volume weight) (gr cm^{-3})	Faydalı su (Useful water) (mm)
	Pw	mm	Pw	mm		
0 - 30	19.70	96.9	10.23	50.3	1.64	46.6
30 - 60	20.21	101.3	9.97	50.0	1.67	51.3
60 - 90	21.26	107.8	11.18	56.7	1.69	51.1
Toplam (Total)		306.0		157.0		149.0

Table 3. Some chemical analysis values of the research area soil
Çizelge 3. Araştırma alanı toprağının bazı kimyasal analiz değerleri

Yıl (Year)	Toprak derinliği (Soil Depth) (cm)	Toprak doygunluğu (Soil Saturation) (cm)	Potansiyel hidrojen (Potential hydrogen)	Elektiriksel iletkenlik (Electrical conductivity) $10^3 * 25°C$	Toplam tuz (Total Salt) (%)	Kireç (Lime) $CaCO_3$	Organik madde (Organic Matter) (%)	Mevcut (Available) (kg da^{-1})	
								P_2O_5	K_2O
2018	0 – 20	58	6.9	492	0.021	0.92	0.93	11.2	128.9
	20 – 40	59	6.9	484	0.018	0.84	0.87	6.8	126.8
2019	0 – 20	59	7.1	551	0.022	0.86	0.90	12.8	137.5
	20 – 40	61	7.0	520	0.021	0.82	0.70	8.0	139.9

Soil moisture levels of the plots were determined by gravimetric method with soil samples taken from 0-30, 30-60 and 60-90 cm depths. Necessary irrigation water was applied to the plots together with the ponded furrow method in both trials. $ETa = P + I \pm \Delta S$ water balance equation was used to calculate plant water consumption (Beyce & Madanoğlu, 1980). Inequality, ETa: crop water consumption, P: precipitation, I: irrigation water, and ΔS: moisture change in soil profile between the sowing and harvesting period. All precipitation values were accepted as effective in the experiment. According to the specified equation, cumulative plant water consumption amounts were obtained by using soil samples taken at the beginning of each irrigation period (Istanbulluoğlu, 1996). The first year of the trial was terminated on 18 September 2018, and the second year was on 14 September 2019. Grain yields obtained from the trial subjects were evaluated statistically by analysis of variance and Duncan classification.

The water-production function was obtained, which gives the relationship between the grain yields obtained from the experiments and the seasonal plant water consumption values. In addition, the water-yield relationship factor (ky), which gives the relationship between proportional plant water consumption deficits and proportional yield reductions, was determined. For this, the following equation was used based on the model of Stewart et al (1977) (Doorenbos and Kassam, 1979).

$$\left(1-\frac{Y_a}{Y_m}\right)=ky\left(1-\frac{ET_a}{ET_m}\right)$$

In equality; Ya: actual yield, Ym: maximum yield, ETa: actual plant water consumption, ETm: maximum plant water consumption, and ky: water-yield relationship factor.

The grain yields obtained from each irrigation application; total water use activities (TWUE) with its ratio to total evapotranspiration and irrigation water usage activities (IWUE) with its ratio to total irrigation water amount were calculated (Musıck and Dusek, 1980).

RESULTS and DISCUSSION

Effect of Irrigation on Grain Yield

The results of the combined analysis of variance and significance test (Duncan) as a result of positive homogeneity test results in millet grain yield values obtained in both cultivars are given in Table 4.

According to the variance analysis of the grain yields obtained from the two-year study, it is understood that the soil moisture level has a significant ($p < 0.01$) effect on the product yield. The sensitivity of the plant to water at different growth stages was markedly different. The order of susceptibility was listed as flowering (F), vegetative development (V) and grain formation (Y). All subjects involving irrigation during the flowering period were included in the first four classifications in both years.

Table 4. Millet grain yields obtained from in irrigation applications (t ha^{-1})
Çizelge 4. Sulama uygulamalarında elde edilen darı dane verimleri (t ha-1)

Sulama konusu (Irrigation subject)	Çeşitler (Varieties)					
	Öğretmenoğlu			Beydarı		
	2018	2019	Average	2018	2019	Average
NoI	2.13 d ±0.24	2.31 d ±0.14	2.22 d ±0.13	2.06 c ±0.10	1.94 e ±0.05	2.00 e ±0.06
V	3.15 bc ±0.16	3.01 bcd ±0.03	3.08 bc ±0.08	3.20 ab ±0.07	2.26 de ±0.09	2.73 cd ±0.22
F	3.25 abc ±0.23	3.29 abc ±0.21	3.27 abc ±0.14	3.29 ab ±0.14	2.59 cd ±0.07	2.94 bcd ±0.17
Y	2.61 cd ±0.34	2.81 cd ± 0.11	2.71 cd ±0.16	2.88 bc ±0.22	2.04 e ±0.05	2.46 de ±0.21
VF	3.73 ab ±0.29	3.39 abc ±0.20	3.56 ab ±0.15	3.25 ab ±0.16	2.85 bc ±0.11	3.05 bc ±0.12
VY	3.14 bc ±0.18	2.96 bcd ±0.06	3.05 bc ±0.09	2.91 b ±0.15	2.05 e ±0.06	2.48 d ±0.20
FY	3.93 ab ±0.17	3.63 ab ±0.12	3.78 ab ±0.12	3.70 ab ±0.11	3.42 ab ±0.06	3.56 ab ±0.08
VFY	4.13 a ±0.09	4.05 a ±0.13	4.09 a ±0.05	3.99 a ±0.09	4.07 a ±0.05	4.03 a ±0.05
Average (Standard error)	3.26 ±0.15	3.18 ±0.11	3.22 ±0.14	3.16 ±0.14	2.65 ±0.12	2.91 ±0.18

As can be seen from the examination of the average grain yields for two years, the highest yield was obtained from the VFY subject. The highest yields were obtained with 4.09 t ha^{-1} grain from Öğretmenoğlu and 4.03 t ha^{-1} grain from Beydari. These were followed by FY and VF subjects in the Öğretmenoğlu variety, and the FY subject in the Beydari variety.

In cases where water shortage or water economy problems are experienced in the region, FY or VF issues can be applied according to the order of priority. In cases where water shortage is high and single irrigation can be done, there should be a flowering (F) period. This period is approximately the first week of July, 75-85 days after planting the plant. If there is a drought at the beginning of the plant growing season, irrigation should be done in the last week of May or the first week of June, as an approximate date when the plant height is 40-45 cm. Studies conducted by Seghatoleslami et al. (2008), Okant (2014) and Gong et al. (2019) in studies conducted to determine the critical development periods of millet against water deficiency support in the results.

Plan Seasonal Irrigation Water Requirement and Plant Water Consumption

The amounts of irrigation water applied to the trial subjects, the obtained irrigation water saving, irrigation water usage activities, total water usage activities and seasonal plant water consumption values are given in Table 5.

During the years of in this study, the amount of precipitation and its distribution affected the amount of irrigation water applied to irrigation issues. Due to the rainy season in the first year, there was a decrease in irrigation water application compared to the second year. The highest irrigation water was applied during the flowering (F) and grain formation (Y) periods.

Seasonal plant water consumption values in both years were significantly affected by falling precipitation, soil moisture content and applied irrigation water amounts. The amount of irrigation water applied to the subjects most affected the plant water consumption values. The lowest plant water consumption of 261 mm, was obtained from the NoI subject without irrigation. This was followed by subjects V, Y and F, respectively. The highest crop water consumption was 579 mm for the three times irrigated VFY. There was no statistically significant difference in ET values over the years.

Table 5. Seasonal irrigation water amounts, water savings, water use activities and plant water consumption values obtained from the trial subjects
Çizelge 5. Deneme konularından elde edilen mevsimsel sulama suyu miktarları, su tasarrufu, su kullanım faaliyetleri ve bitki su tüketim değerleri

Sulama konuları (Irrigation Subjects)	Sulama sayısı (Irrigation number)	Sulama suyu miktarı (Irrigation water amount) (mm)	Sulama suyu tasarrufu (Irrigation water saving) (%)	Sulama suyu kullanım verimliliği (Irrigation water use efficiency) (kg ha^{-1} mm^{-1})	Toplam su kullanım verimliliği (Total water use efficiency) (kg ha^{-1} mm^{-1})	Bitki su tüketimi (Plant water consumption) (mm)
NoI	-	-	100	-	9.0	261
V	1	79	75	39.2	9.3	340
F	1	123	61	26.7	8.7	384
Y	1	117	63	23.3	7.3	378
VF	2	201	37	17.7	7.7	462
VY	2	195	39	15.6	6.7	456
FY	2	239	25	13.7	6.6	500
VFY	3	318	0	12.9	7.1	579

The highest monthly plant water consumption was realized in other months due to irrigation water application in further development periods due to irrigation issues. The tallest plant water consumption was obtained in June for NoI, V and VF subjects and in July for other issues. In FY and VFY subjects, this value was 180 mm.

In addition, the most significant savings in irrigation water for both years were realized in V, Y and F subjects, which were irrigated once. The moisture content in the soil profile during irrigation determined the amount of water saved

Using the average values, the highest total water use efficiency was obtained from the V subject with 9.3 kg ha^{-1} mm^{-1}, and the lowest were obtained from the FY and VY subjects with 6.6 and 6.7 kg ha^{-1} mm^{-1}, respectively. Regarding irrigation water usage efficiency, the highest and lowest values were obtained from V subject with 39.2 kg ha^{-1} mm^{-1} and VFY matter with 12.9 kg ha^{-1} mm^{-1}, respectively. This confirms the statements by Fereres and Soriano (2007), Geerts and Raes (2009) and Pereira, Oweis and Zairi (2002) that there will be no increase in plant yield after a certain amount of irrigation water and soil moisture content. As a result, it shows that the plant does not benefit from water equally in all development periods.

Water-Production Function and Water-Yield Relationship Factor (Ky)

The water usage function obtained using seasonal evaporation and millet yield for all applications is given in Figure 1. The relationship between ET and grain yield (Y) Y = 0.4087 ET + 144.03 (r = 0.77**) was statistically significant at the 0.01 level($p<0.01$). Using this relationship, millet grain yield in this region can be estimated from ET. However, when using the above equation, the upper limit of the independent variable (ET) should not be exceeded.

Using the seasonal plant water consumption and grain yield of the trial subjects, the water-yield relationship factor (ky), which explains the relationship between the proportional lack of plant water consumption and the proportional yield decrease, was calculated as 0.57 in Figure 2. The ky values for 2018 and 2019 were 0.56 and 0.58, respectively.

CONCLUSION

In both years, grain yield decreased in Y subject without irrigation (33.7%) in the first two growing periods compared to VFY subject. Watering is essential during the F growing season. The least reduction in yield occurred in treatments irrigated only at this stage. A 45.7% yield reduction in yield was found in the rain-fed treatment compared to the VFY application. The highest seasonal ET was calculated as 579 mm in VFY-treatment of non-water stress conditions, the highest monthly ET was 180 mm in July. 4,09 tons ha-1 grain yield was obtained from this subject

According to the results, irrigated VFY in all growth periods can be recommended to obtain the highest yield. The irrigation schedule of this subject can be as follows: the first irrigation is in the vegetative period, 40-50 days after planting, the end of May; the second watering is during the flowering period, 75-85 days after planting, that is, in the first week of July; the third irrigation is during the grain transport period, that is, in the last week of July.

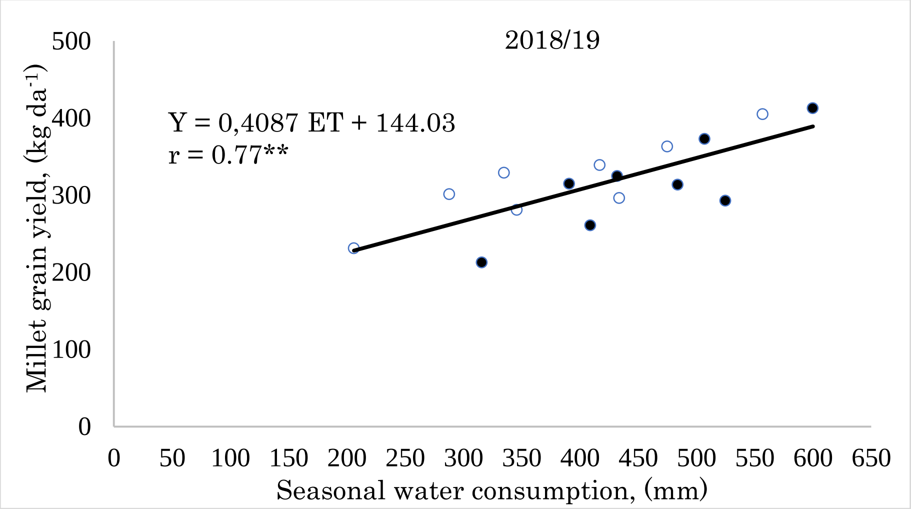

Figure 1. Water-production function giving the relationship between millet grain yields and seasonal plant water consumption values

Şekil 1. Darı dane verimleri ile mevsimlik bitki su tüketim değerleri arasındaki ilişkiyi veren su üretim fonksiyonu

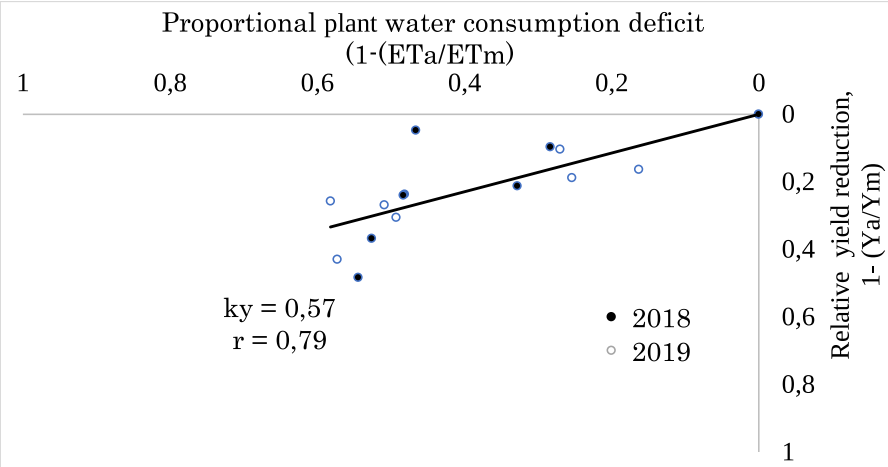

Figure 2. Water-yield relationship factor (ky) that gives the relationship between proportional yield reductions and proportional plant water consumption deficits in millet

Şekil 2. Darıdaki orantılı verim düşüşleri ile orantılı bitki su tüketimi açıkları arasındaki ilişkiyi veren su-verim ilişki faktörü (ky)

The relationship between seasonal ET and grain yield was statistically significant ($p < 0.01$) and was defined by the equation Y = 0.4087 ET + 144.03 (r = 0.77 **). The water-yield relationship factor (ky), which explains the relationship between the proportional ET deficit and proportional yield decrease, was calculated as 0.57. The ky values for 2018 and 2019 were 0.56 and 0.58, respectively. Using the mean values, the highest TWUE was obtained from the V subject with 9.3 kg ha^{-1} mm^{-1}, while te lowest TWUE was obtained from the FY and VY subjects with 6.6 and 6.7 kg ha^{-1} mm^{-1}, respectively.

Author's Contributions

The authors contributed equally to the article.

Statement of Conflict of Interest

The authors declare that they have no conflicts of interest.

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