

Determination of Irrigation Performance of Water User Associations in the Vicinity of Sarıgöl and Alaşehir Using Remote Sensing Techniques

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Abstract: The aim of this research was to determine the irrigation performance of Sarıgöl, Bağ, and Üzüm Water User Associations (WUAs) in the vicinity of Sarıgöl and Alaşehir using remote sensing techniques. For this purpose, the performance of the irrigation system for the 2004 irrigation season (May to September) was determined according to 5 indicators, namely overall consumed ratio (ep), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET). Potential and actual evapotranspiration parameters used in determining these indicators were estimated according to the SEBAL (Surface Energy Balance) method using NOAA-16/AVHRR images. Seasonal averages of Sarıgöl, Bağ, and Üzüm WUAs calculated from the results were, respectively, 0.82, 0.88, and 1.26 for ep; 1.21, 1.13, and 0.94 for RWS; 0.53, 0.59, and 0.68 for DF; 45.61, 42.44, and 45.81 mm month⁻¹ for CWD; and 0.64, 0.67, and 0.64 for RET. According to the seasonal average values of all the performance indicators, the irrigation performance of all WUAs was usually poor, and only the depleted fraction indicator for Üzüm WUA was within the range of acceptability. Thus, performance indicators showed that less irrigation water was supplied to WUAs than was needed.

Key Words: Irrigation performance, remote sensing, SEBAL

Uzaktan Algılama Tekniklerinden Yararlanarak Sarıgöl ve Alaşehir Yöresi Sulama Birliklerinde Sulama Performansının Belirlenmesi

Özet: Bu araştırmada, uzaktan algılama tekniği kullanılarak, Sarıgöl ve Alaşehir yöresindeki Sarıgöl, Bağ ve Üzüm Sulama Birliklerinin (SB) sulama performansının belirlenmesi amaçlanmıştır. Bu amaçla, 2004 yılı sulama sezonu (Mayıs-Eylül ayları) için sistemlerin sulama performansı, proje tüketim randımanı (ep), rölatif su temini (RWS), su tüketim oranı (DF), bitki su açığı (CWD) ve rölatif evapotranspirasyon (RET) olmak üzere beş ayrı performans göstergesine göre belirlenmiştir. Bu göstergelerin belirlenmesinde kullanılan potansiyel ve gerçek evapotranspirasyon parametreleri, NOAA-16/AVHRR uydu görüntüleri kullanılarak SEBAL (Yüzey Enerji Dengesi) yöntemiyle hesaplanmıştır. Araştırmada, Sarıgöl, Bağ ve Üzüm SB'nin sırasıyla mevsimlik ortalama ep değerleri, 0.82, 0.88 ve 1.26; RWS değerleri, 1.21, 1.13 ve 0.94; DF değerleri, 0.53, 0.59 ve 0.68; CWD değerleri, 45.61, 42.44 ve 45.81 mm ay⁻¹; RET değerleri, 0.64, 0.67 ve 0.64 olarak bulunmuştur. Bu değerlere göre, tüm sulama birliklerinin performansı genellikle kötü çıkmıştır. Ancak su tüketim oranı göstergesinin yalnızca Üzüm SB için izin verilebilir aralıkta olduğu belirlenmiştir. Sonuç olarak, tüm bu performans göstergeleri, tüm sulama birliklerinin ihtiyaç duyulandan daha az sulama suyu temin edebildiğini ortaya koymuştur.

Anahtar Sözcükler: Sulama performansı, uzaktan algılama, SEBAL

Introduction

Turkey has a total area of 78 million ha, of which 28.05 million ha is arable. A total of 25.75 million ha of agricultural area can be irrigated. Turkey's potential surface and groundwater resources are sufficient for irrigating a land area of 8.50 million ha economically,

while the total land area opened to public and private irrigation presently stands at 4.89 million ha (DSİ, 2006). However, more agricultural land should be opened to irrigation, and the use of the limited soil and water resources must be improved. In order for this to happen, the current condition and performance of irrigated agriculture must first be determined.

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Many authors have proposed indicators to measure irrigation system performance. Much of the work to date in irrigation performance assessment has been focused on the internal processes of irrigation systems, a major purpose of which is to assist irrigation system managers in improving water delivery service. Other performance indicators are external. These indicators help policy makers and managers make long-term and strategic decisions, and they are also useful for researchers investigating relative differences between irrigation systems (Molden et al., 1998).

In addition, agricultural, social, economic, and environmental performance indicators have been developed. However, none of these performance indicators deals with crop water consumption because the actual (ET_a) and potential evapotranspiration (ET_p) across a region cannot be determined using traditional methods (Roerink et al., 1997).

Measurement of crop evapotranspiration (ET) based on both conventional methods or the use of climate data is difficult especially on a project or basin basis. Because of the lack of detail on the spatial distribution of ET, studies based on conventional field data collection are often limited. A complete and objective analysis of an entire irrigation system is difficult to achieve using traditional data-collection techniques because of their piecemeal nature and their reliance on the individual and subjective opinions inherent in these approaches. Remote sensing (RS) has the advantage of providing objective information over a large area. Combined with ground information, RS can be an extremely effective tool in analyzing the performance of large irrigated areas (Bastiaanssen et al., 1999).

Several models for the derivation of ET using satellite data are used. One type is the empirically based model, which directly relates the daily ET or sensible heat flux to an instantaneous surface temperature. Although these models are simple, they mostly deal with homogeneous surfaces (Ambast et al., 2002). Another model is based on the surface energy balance (SEBAL) on an instantaneous time basis, integrated over the day for the estimation of ET on a daily basis. This model overcomes the dependency on detailed meteorological measurements, information on crop types, and application to small areas. Hemispherical surface albedo, surface temperature, and vegetation index that are needed to solve the model are derived from satellite measurements (Bastiaanssen et al., 1998).

The aim of this study was to determine the irrigation performance of Sarıgöl, Bağ, and Üzüm Water User Associations (WUAs) in the vicinity of Sarıgöl and Alaşehir using remote sensing techniques. The SEBAL method was used to derive the parameters of ET_a and ET_p that are needed to estimate performance indicators using NOAA-AVHRR images.

Materials and Methods

Materials

The Gediz Basin, which contains Sarıgöl, Bağ, and Üzüm WUAs, is located in the west of Turkey, and covers an area of 17,200 km², with 140,000 ha under irrigation. Annual precipitation ranges from 1000 mm on the mountains to 500 mm in the coastal areas, and the area has a Mediterranean climate (Droogers et al., 2000). Sarıgöl, Bağ, and Üzüm WUAs are indicated in Figure 1. Information about them is given in Table 1.

The study made use of flow records the General Directorate of State Hydraulic Works of Turkey (DSİ), along with low resolution (1.1 km at nadir) raw NOAA-16/AVHRR images. These images were obtained on cloud-free days (May 12, June 15, July 3, 12, and 28, August 14 and 25, and September 2 and 20 in 2004) at about 16:00 local time. The images were downloaded free of charge from <http://www.class.noaa.gov>.

Method

Irrigation performance was determined according to the indicators of overall consumed ratio (e_p) (Bos and Nugteren, 1990), relative water supply (RWS) (Perry, 1996), depleted fraction (DF), crop water deficit (CWD) (Bastiaanssen et al., 2001), and relative evapotranspiration (RET) (Roerink et al., 1997), which were calculated using parameters of ET_a and ET_p derived from remote sensing.

Estimation of Performance Indicators

Overall consumed ratio

The overall consumed ratio (e_p) quantifies the degree to which crop irrigation requirements are met by irrigation water in the irrigated area. The ratio is defined as (Bos and Nugteren, 1990):

$$e_p = \frac{ET_p - P_e}{V_c}$$

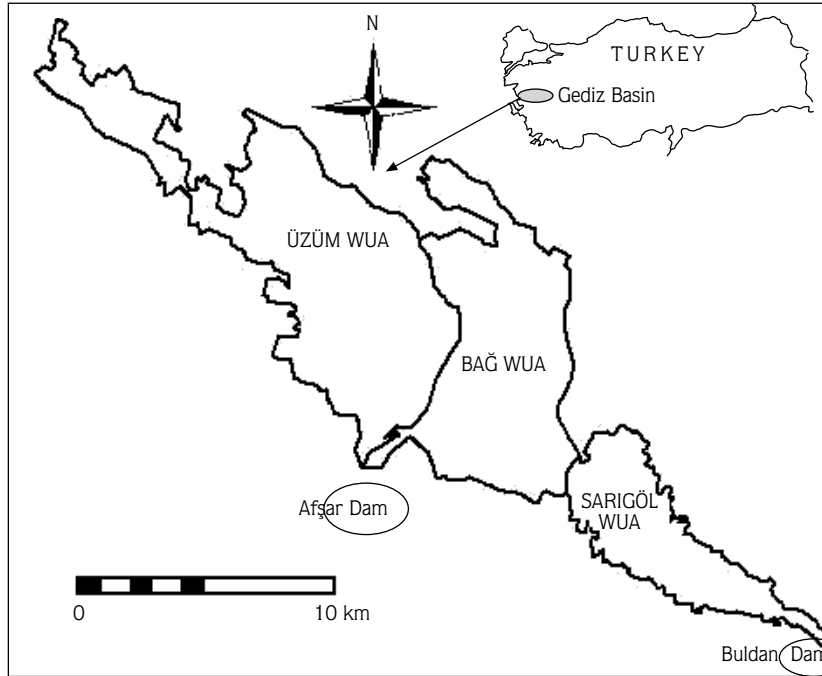


Figure 1. General view of the command areas of the Sarigöl, Bağ and Üzüm WUAs.

Table 1. Principle characteristics of water user associations (DSİ, 2004).

WUAs	Construction year of system	Year transferred	Command area (ha)	Main crops	Water source
Sarigöl	1969	1994	1 927	Grapes, Maize	Buldan dam
Bağ	1979	1995	4 486	Grapes	Afsar dam
Üzüm	1979	1995	6 930	Grapes	Afsar dam and groundwater

where ET_p is potential evapotranspiration in millimeters, P_e is effective precipitation in millimeters, and V_c is volume of irrigation water diverted from resource and/or groundwater in millimeters.

The value of $ET_p - P_e$ for the irrigated area is entirely determined by the crop, the climate, and the interval between water applications. Hence, the actual value of the overall consumed ratio varies with the actual volume of irrigation water supplied to the considered command area (Bos et al., 2005). A target overall consumed ratio should be set within an existing irrigated area, and compared to the actual ratio on a monthly and seasonal basis. Considering the values of water application efficiency (0.60) and conveyance efficiency (0.85)

accepted by the DSİ (1977) when WUAs were preparing overall irrigation plans, the product of these 2 figures, 0.51, can be accepted as the target value at the field level in the conditions of study area.

Relative water supply

The relative water supply (RWS), used as an indicator of adequacy of irrigation water delivery, compares the amount of the water supply with that of water demand. It is calculated as follows (Perry, 1996):

$$RWS = \frac{V_c + P_g}{ET_p}$$

where P_g is gross precipitation in millimeters. The target value of the RWS indicator was considered 2.0 (Molden et al., 1998).

Depleted fraction

The depleted fraction (DF) is the fraction of available water that is depleted and no longer available for other water consumption processes. The depletion in an irrigation scheme is governed by ET_a . DF is defined as follows (Molden, 1997):

$$DF = \frac{ET_a}{V_c + P_g}$$

where ET_a is actual evapotranspiration in millimeters. DF should be considered a function of time. For semi-arid and arid regions, the critical value of the depleted fraction averages about 0.6 (Bos et al., 2005). The acceptable range of DF was considered 0.6-1.1 (Bastiaanssen et al., 2001).

Crop water deficit

Crop water deficit (CWD) over a period is defined as the difference between ET_p and ET_a of the cropping pattern within an area. A common period is 1 month. An average CWD of 30 mm month⁻¹ is acceptable. CWD is defined as follows (Bastiaanssen et al., 2001):

$$CWD = ET_p - ET_a$$

Relative evapotranspiration

To evaluate the adequacy of irrigation water delivery to a selected command area as a function of time, the dimensionless ratio of ET_a over ET_p gives valuable information to the water manager and is described as relative evapotranspiration (RET). RET is defined as follows (Roerink et al., 1997):

$$RET = \frac{ET_a}{ET_p}$$

A value of $RET \geq 0.75$ is quite acceptable for irrigated agriculture in the growing season, although this is not constant over time (Roerink et al., 1997).

In the equations, ET_a and ET_p were derived from satellite RS. The values of V_c and P_g were obtained from

the DSI (2004) and Turkish State Meteorological Service (Meteoroloji Genel Müdürlüğü, 2004) records, respectively. P_e was estimated according to the US Bureau of Reclamation Method (Smith, 1992).

Estimation of Evapotranspiration Using Remote Sensing

NOAA-16 AVHRR images used in the study were preprocessed in order to correct geometric distortions, to calibrate the data radiometrically, and to eliminate the noise and clouds present in the data (Gautam et al., 2006). WinCHIPS software was used for this process. After the images were preprocessed, ET_a and ET_p maps were obtained using AHAS and ILWIS software according to SEBAL.

A major disadvantage of the use of satellite images is the temporal resolution. Since the satellites circumnavigate the earth, they cannot be used for continuous observations. And even if a satellite passes over certain areas more than once every day, the captured images may be useless because of the presence of clouds. Therefore it is still necessary to have ground data that cover the time period in which no satellite images are captured. The value obtained from satellite images is an instantaneous value that has to be scaled up to a daily value (Schipper, 2005).

To obtain ET_a for the entire irrigation season from values of daily ET_a , daily ET_a was integrated. The value obtained from these images for a period between 2 afterimages cannot be used to represent an average periodic condition because of varying weather conditions, especially cloud formations, within this period. Therefore, reference ET (ET_0) was calculated by the Penman Monteith method (Allen et al., 1998) for the entire irrigation season, first on a daily basis. A ratio of ET_a/ET_0 was calculated for each pixel on each of the 9 NOAA images. After that the ET_a/ET_0 ratio for each pixel was assumed to remain constant for that particular period. Next, this ratio was multiplied by total ET_0 for the period to obtain periodic ET_a . The periodic ET_a was adjusted for the month to get a total seasonal ET_a (Bastiaanssen et al., 1999).

In order to estimate the daily ET_p , a simplified Penman-Monteith approach approved by Priestley and Taylor (1972) was used, taking the ratio of the actual rate of evapotranspiration and the potential rate as constant for certain periods (Schipper, 2005). Periodic ET_p was adjusted for the month to get the total seasonal ET_p , and it is performed in the same way as for ET_a .

Results

The values of the ET_a , ET_p , V_c , P_g , and P_e parameters that are needed to determine irrigation performance indicators are given in Table 2 for the 2004 irrigation season.

Performance indicators for the evaluation of the irrigation performance (field application ratio (e_a), overall consumed ratio (e_p), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET)) are given in Tables 3-5 for Sarıgöl, Bağ, and Üzüm WUAs, respectively. As an example, daily ET_a and ET_p maps of WUAs for July 28 and August 25 when irrigation applications were heavy are indicated in Figures 2 and 3.

It can be seen that there are no values of e_p and DF indicators for some months because the values of the parameters V_c and P_g used to calculate these indicators are zero. These months were not considered when calculating the values of the coefficient of variation (CV).

Discussion

Overall consumed ratio

Because the total water supply to a command area is among the very first values that should be measured, the overall consumed ratio is the first indicator that should be available for each irrigated area (Bos, 1997). For waterlogging and salinity, the critical groundwater depth

Table 2. Values of actual evapotranspiration (ET_a), potential evapotranspiration (ET_p), volume of irrigation water diverted from resource (V_c), gross precipitation (P_g), and effective precipitation (P_e) needed for estimating performance indicators (mm).

Months	Sarıgöl WUA			Bağ WUA			Üzüm WUA			All WUAs	
	ET_a	ET_p	V_c	ET_a	ET_p	V_c	ET_a	ET_p	V_c	$P_g^{(a)}$	$P_e^{(a)}$
May	50.2	111.5	5.5	55.8	122.7	0.0	50.2	117.1	0.0	18.4	17.9
June	92.2	134.3	255.5	89.5	129.0	255.3	89.5	134.3	238.2	11.4	11.2
July	96.2	156.5	299.1	99.4	153.3	294.0	96.2	155.4	265.1	0.2	0.2
August	89.5	122.5	178.2	100.5	122.5	141.5	92.7	120.9	65.0	0.0	0.0
September	81.1	112.4	0.0	82.5	112.4	0.0	78.2	108.1	0.0	0.0	0.0
Total	409.2	637.2	738.2	427.7	639.9	690.8	406.9	635.9	568.4	30.0	29.3

^a For all WUAs, the same values were considered.

Table 3. Values of overall consumed ratio (e_p), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET) for the Sarıgöl WUA.

Months	e_p	RWS	DF	CWD (mm month ⁻¹)	RET
May	17.18	0.21	2.10	61.4	0.45
June	0.48	1.99	0.35	42.1	0.69
July	0.52	1.91	0.32	60.3	0.61
August	0.69	1.45	0.50	33.0	0.73
September	-	-	-	31.3	0.72
Total				228.1	
Seasonal Average	0.82	1.21	0.53	45.61	0.64
CV* (%)	176	85	105	32	18

* Coefficient of variation.

Table 4. Values of overall consumed ratio (e_p), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET) for the Bağ WUA.

Months	e_p	RWS	DF	CWD (mm month ⁻¹)	RET
May	-	0.15	3.03	66.9	0.45
June	0.46	2.07	0.34	39.5	0.69
July	0.52	1.92	0.34	53.9	0.65
August	0.87	1.15	0.71	22.0	0.82
September	-	-	-	29.9	0.73
Total				212.2	
Seasonal Average	0.88	1.13	0.59	42.44	0.67
CV* (%)	35	91	117	43	20

* Coefficient of variation.

Table 5. Values of overall consumed ratio (e_p), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD) and relative evapotranspiration (RET) for the Üzümlü WUA.

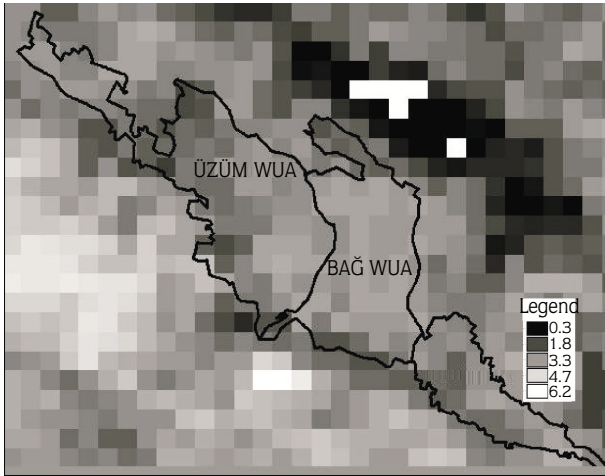
Months	e_p	RWS	DF	CWD (mm month ⁻¹)	RET
May	-	0.16	2.73	66.9	0.43
June	0.52	1.86	0.36	44.8	0.67
July	0.59	1.71	0.36	59.2	0.62
August	1.86	0.54	1.42	28.3	0.77
September	-	-	-	29.9	0.72
Total				229.1	
Seasonal Average	1.26	0.94	0.68	45.81	0.64
CV* (%)	77	103	92	38	20

* Coefficient of variation.

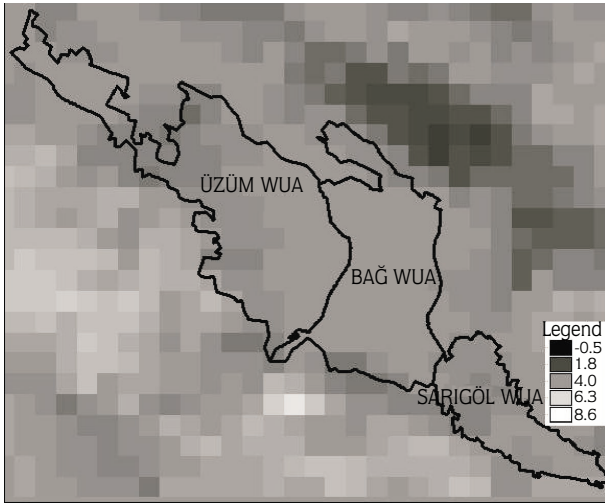
mostly depends on the effective rooting depth of the crop, the overall consumed ratio of irrigation water use and the hydraulic characteristics of the unsaturated soil (Bos et al., 2005). During the periods with low ratios, the non-consumed fraction of the water will cause the groundwater table to rise (only if this water is applied to the field) (Bos et al., 1991), while during the periods with a ratio above 0.51, groundwater must be pumped and stored to avoid water shortage.

In the 2004 irrigation season, when this study was carried out, average seasonal e_p values for Sarıgöl, Bağ,

and Üzümlü WUAs were 0.82, 0.88, and 1.26, respectively (see Tables 3-5). The e_p performance indicator for the month of May could not be calculated because no water was delivered to the Bağ and Üzümlü WUAs, both of which get their water from Afşar Dam. The e_p indicator for the 3 WUAs was well above the target value of 0.51. This is a clear indicator of water insufficiency for all 3 WUAs. The WUA with the biggest sufficiency problem was Üzümlü. It can be said that this WUA did not receive even half of the water it needed. The other 2 WUAs were close to each other with regard to water insufficiency, but they were not as low as Üzümlü.

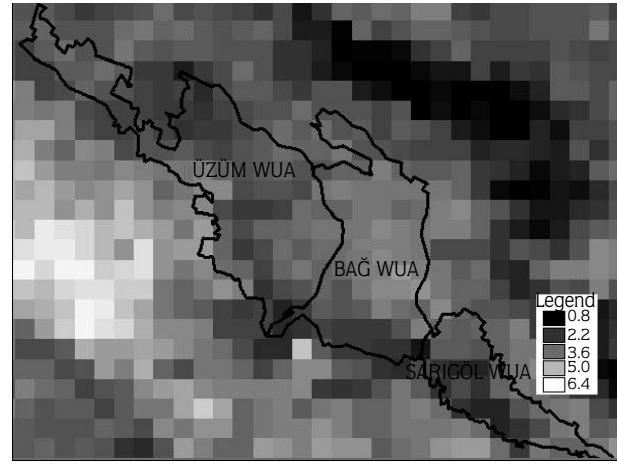


(a)

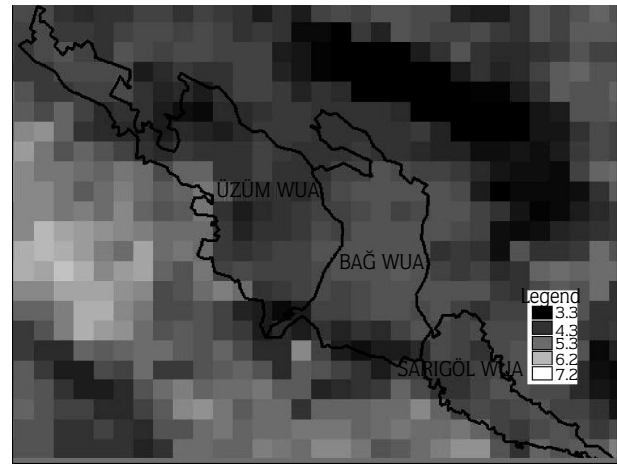


(b)

Figure 2. Daily actual evapotranspiration (ET_a) (a) and potential evapotranspiration (ET_p) (b) maps of WUAs for July 28 (mm).



(a)



(b)

Figure 3. Daily actual evapotranspiration (ET_a) (a) and potential evapotranspiration (ET_p) (b) maps of WUAs for August 25 (mm).

e_p indicators are not homogeneous from month to month. That is, there is a month-to-month inconsistency in the ratio between monthly water requirements and the amounts actually obtained (Tables 3-5). This inconsistency is a result of the fact that CV values for all WUAs, which show changes in the e_p indicator over time, were high. For all WUAs, in the period of June-August, August was the month when the demand for water was the least met, and the values for June and July are close to each other. This is thought to be related to the fact that, although grapes, the main product of the region,

require water in August almost as much as in June and July, farmers reduce the amount of irrigation water before the August harvest in order to keep the sugar content of the grapes high.

The e_p indicator for Sarıgöl WUA in May was very high because the amount of water delivered from the source was much less than needed. However, if the May figure (176%) is excluded, the seasonal CV value for Sarıgöl WUA is 19% (Table 3). This shows that, apart from May, Sarıgöl WUA was more homogeneous than the others with regard to the supply and demand ratio.

In a previous study carried out in the Gediz Basin, where our study area is located, the e_p values for the Menemen Left and Right Bank WUAs for the 2001 irrigation season were found to be 1.37 and 1.41, respectively (Karataş, 2006). These values are higher than the seasonal averages obtained in this study for all 3 WUAs. Thus, it may be said that the WUAs in our study experienced fewer water supply problems than the other WUAs of the Menemen Left and Right Bank systems. However, the fact that the average e_p values of all 3 WUAs in our study were higher than those determined for the 31 pumped irrigation units of the Nilo Coelho irrigation system in Brazil (0.71) (Bastiaanssen et al., 2001) shows that the irrigation systems in our study experienced greater water supply problems.

Relative water supply

Relative water supply is a suitable indicator to inform the irrigation manager whether sufficient water is being supplied to a large area of cropped land in order to meet the total crop water demand. RWS and e_p have an inversely proportional relationship (Bastiaanssen et al., 2001).

Average values of the RWS indicator for Sarigöl, Bağ, and Üzümlü WUAs for the 2004 irrigation season were 1.21, 1.13, and 0.94, respectively (Tables 3-5). These values are well below the target value of 2.0. This also shows that there is a big problem with water supply.

When compared with the average value (0.92) for the Menemen Right Bank system in the same basin for the 5-year period between 1995 and 1999 (Akkuzu, 2001), RWS indicators for all 3 WUAs in our study are better. In addition, it can be seen that the values found in the present study are close to the value (1.08) given by Merdun and Degirmenci (2004) for the Menemen irrigation system as a whole for 2001, and much lower than the average value (2.66) that they gave for the 239 irrigation systems in Turkey for the same year. Furthermore, a study performed on the Menemen Left and Right Bank WUAs in 2001 found RWS values for both WUAs to be 0.81 (Karataş, 2006). RWS values for all WUAs in our study were higher than these values.

Thus it can be seen that there was a significant difference between monthly RWS indicators for all 3 WUAs in our study, that is, there was an imbalance between months in water supply. Indeed, it can be seen that this variability in monthly values comes from the fact

that the CV values were high (85%-103%, Tables 3-5). When evaluated on a monthly basis, it can be seen that all WUAs experienced a great water supply problem in May, and in June and July there was an over-supply. In August, even though the need for water was almost as great as in June, much less water could be obtained compared to June. This may be because of an insufficiency in the water source as shown by the e_p indicator, or because less water was given on purpose to keep the sugar content of the grapes high.

Depleted fraction

The seasonal average DF indicators for the Sarigöl, Bağ, and Üzümlü WUAs for the 2004 irrigation season were 0.53, 0.59, and 0.68, respectively. DF indicator values (0.60-1.10) were outside permissible limits in the Sarigöl and Bağ WUAs. A study carried out in 1999 on the Menemen Left Bank WUA in the Gediz basin found DF values of 0.60 and 0.72 for cotton and grapes, respectively (Droogers and Bastiaanssen, 2002). In the Menemen Left Bank WUA, regarding the DF value (0.72) of grapes, the most dominant crop of all the WUAs in the present study, it can be said that it is better than those of all 3 WUAs. Bastiaanssen et al. (2001) found the average DF value of 0.6 in a study on the Nilo Coelho irrigation system in Brazil. This value was higher than the seasonal average values of the DF indicator for Sarigöl and Bağ WUAs, and lower than that of Üzümlü WUA.

Monthly DF values for all WUAs were observed to be all outside the permissible limits for almost all months. The DF values of all WUAs were especially high in May, showing that much more water was consumed than supplied. This value may be affected by the use of winter precipitations stored around the roots of the crop or groundwater (Tables 3-5). Except for the Bağ and Üzümlü WUAs in the month of August, monthly DF values for all WUAs were very low. This shows that a large amount of the water delivered from the source in these months could not be consumed by the plants. This may explain the low irrigation efficiency. After the communication with the WUA managers, we think that physical problems (collapses, reversed slopes, or cracks) or operational problems (not irrigating at night, unscheduled irrigation, etc.) may play an important part in this.

A critical value of DF (0.6) implies that if ET_a is less than about 0.6 ($P_g + V_c$), a portion of the available water goes into storage, causing the groundwater table to rise,

while storage decreases if ET_a is greater than 0.6 (P_g+V_c) (Bastiaanssen et al., 2001). The DF values for all 3 WUAs that are located in a semi-arid area were generally lower than the critical value (0.6), and the unused portion of the water delivered from the source in these months may feed the groundwater. The fact that even though no water was delivered from the source in September, the plants consumed almost as much water as in the other months is a clear indication of this.

Even though a large proportion of the water needed for September in all 3 WUAs had been consumed (Table 2), DF could not be calculated because there was neither rain nor water supplied from the source. CV values for all WUAs were quite high (92%-117%) and DF values were temporally very variable, which shows that neither good planning nor good water distribution was achieved.

Crop water deficit

Seasonal average values of CWD indicators for Sarıgöl, Bağ, and Üzüm WUAs in the study period were 45.61, 42.44, and 45.81 mm month⁻¹, respectively, while seasonal total values were 228.1, 212.2, and 229.1 mm (Tables 3-5). These average values are above the permissible level (30 mm month⁻¹).

In a study on the Nilo Coelho irrigation system in Brazil, Bastiaanssen et al. (2001) found the average CWD value of 30.3 mm month⁻¹. In our study, the CWD indicators for Bağ and Üzüm WUAs in the months of August and September were the only ones that were at an acceptable level. The biggest deficit in all 3 WUAs was in May. The lack of month-to-month homogeneity in the CWD indicator can also be observed in CV values (Tables 3-5). However, if the total crop water requirements (ET_p) in Table 2 are evaluated along with the CWD values, it can be said that about one-third of the water demand was not met in any of all 3 WUAs over the whole season.

Relative evapotranspiration

Seasonal average values of the RET indicator for Sarıgöl, Bağ, and Üzüm WUAs were 0.64, 0.67, and 0.64, respectively. Thus, seasonal RET performance of all the WUAs was poor. In a study using remote sensing techniques, an average RET value of 0.77 was found (Bastiaanssen et al., 2001). The RET averages for the WUAs in our study were lower, and thus it can be said that they had a greater problem with water supply. As

was also shown with the CWD indicator, about one-third of the water needed was not met for any of the 3 WUAs.

The lowest RET value for all 3 WUAs was in May. This is because no water was supplied in May, except for Sarıgöl WUA, and about half of the crop water requirement was met. In September, although (as in May) no water was given, a large proportion of the crop water requirement was met (Table 2). This result shows that the water that was stored in the crop root area from rain or irrigation may have been used when there was little or no rain. Taken on a monthly basis, RET did not reach the recommended value for irrigated agricultural land (≥ 0.75) (Roerink et al., 1997) in any WUA, except for Bağ and Üzüm WUAs in August (Tables 3-5).

Conclusion

Whether taken on a monthly or a seasonal basis, the irrigation performance of all the WUAs was poor. At the same time, the performance in the months when irrigation was not intensive (May and September) and in the months when it was most intensive (July and August) was different. The basic factor in this poor performance is the insufficiency of water. Moreover, we think that operational and physical deficiencies in the system may also be to blame.

Another important finding is that while the irrigation performance of the Bağ and Üzüm WUAs, both of which are supplied from Afşar Dam, was similar, it was different for the Sarıgöl WUA, which is supplied from Buldan Dam. This result shows that a water source can have an important effect on irrigation performance.

When calculating performance indicators, the amount of irrigation water delivered to the system from the water source was taken into account. However, there was no information about whether or not groundwater had been used and, if it had been used, when and in what quantities. When aiming to provide more accurate performance indicators, it should not be forgotten that this kind of data deficiency may have a great effect. Only when these problems are solved will it be possible to evaluate more accurately the reasons for high or low performance in this area.

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