Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2010 8(S2), S66-S75
ISSN: 1695-971-X
eISSN: 2171-9292

Evaporative demand and water requirements of the principal crops of the Guadalentín valley (SE Spain) in drought periods

M. I. Sanchez-Toribio[1]*, R. Garcia-Marin[2], C. Conesa-Garcia[2] and F. Lopez-Bermudez[2]

[1] *Departamento de Riego. Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC). Apdo. 164. 30100 Murcia. Spain*

[2] *Departamento de Geografía. Universidad de Murcia. Campus de La Merced. 30001 Murcia. Spain*

Abstract

The drought periods that affect the province of Murcia, especially the Guadalentín Valley, are aggravated by an increase in evaporative demand. The aim of the present study was to characterize the increased water demand of woody and herbaceous crops during drought periods in the Guadalentín Valley, an agricultural zone with an excellent climate for specialty crops, which is of great economic importance for Murcia. After defining the drought periods of the last three decades in time and space by means of the standard index of rainfall drought (IESP), several methods were used to determine the reference evapotranspiration (ETo): the Penman-Monteith model (ASCE and FAO models for grass), the Hargreaves method (ETo-ASCE for alfalfa), and ETo using the FAO Radiation method. Finally, the crop water requirements for each to crop type and area of cultivation were estimated using monthly crop coefficients (K_c) and the mean monthly evaporative demand values were obtained by the best fitting method. The increase in the evaporative demand reflected the increased water deficits that occur in the drought years, both in summer and winter (1.23 hm^3 yr^{-1}). Drought periods are also responsible for reducing the areas dedicated to horticultural crops, because of their high water demands and the additional costs involved, resulting an aggravated socioeconomic position and increased unemployment.

Additional key words: crop coefficients (K_c); lysimetric measurements; standardized index of rainfall drought; woody and herbaceous crops.

Resumen

Demanda evaporativa y necesidades hídricas de los principales cultivos del valle del Guadalentín (SE España) en períodos de sequía

La carencia pluviométrica e hídrica que sufre la Región de Murcia, sobre todo en zonas como el Valle del Guadalentín, se halla agravada por una mayor demanda evaporativa durante periodos de sequía. El objetivo del presente trabajo fue determinar, en estos episodios secos, y en función de su superficie, el incremento de la demanda hídrica de los cultivos leñosos y herbáceos predominantes en el Valle del Guadalentín, zona agrícola de excelentes condiciones térmicas para cultivos de alto rendimiento, y por tanto de gran importancia socioeconómica en la Región de Murcia. En primer lugar se definen, mediante el índice estandarizado de sequía pluviométrica (IESP), las rachas secas de las tres últimas décadas. Una vez delimitadas dichas secuencias en el tiempo y el espacio, se aplican los modelos ETo, ETo Penman-Monteith (modelos ASCE y FAO para gramíneas), ETh de Hargreaves Samani, ETr (ASCE para alfalfa) y ETr (Radiación FAO) para evaluar las necesidades hídricas asociadas a la evapotranspiración, según cultivos y áreas. Las necesidades hídricas de cada tipo de cultivo son estimadas a partir de los coeficientes de cultivo (K_c) mensuales y las demandas evaporativas medias mensuales obtenidas por el método de mejor ajuste. El aumento de la demanda evaporativa reflejó los aumentos en el déficit hídrico que sucedieron en los años de mayor sequía, tanto en verano como en invierno (1,23 hm^3 por año). La sequía fue también responsable de la reducción en el área dedicada al cultivo de hortícolas, por el elevado consumo de agua y los costes adicionales, lo que agrava la situación socioeconómica y el desempleo en la zona.

Palabras clave adicionales: coeficientes de cultivos (K_c); cultivos leñosos y herbáceos; índice estandarizado de sequía pluviométrica (IESP); medidas lisimétricas.

* Corresponding author: toribio@cebas.csic.es
Received: 20-10-09; Accepted: 22-07-10.

Abbreviations used: AEMET (State Agency of Meteorology), APA (accumulated rainfall anomaly), ETo (reference evapotranspiration), ETP (potential evapotranspiration), IESP (standardized index of rainfall drought), IMIDA (Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario), K_c (crop coefficient), LAI (leaf area index).

Introduction

Due to the great importance of the agricultural sector in the province of Murcia (SE Spain), especially in the Guadalentín Valley, where the intensive cultivation of horticultural crops has replaced traditional dry land agriculture, there is great concern about the lack of water and the constant need for the same (Gil-Olcina, 2004).

The principal use of water in the area for woody crops is to irrigate citrus trees (17%), almond trees (13%) and table grapes (5.2%), stone fruit trees and grapevines for wine hardly present in this district. Among herbaceous plants, alfalfa is the main receives of water (14%), while lettuce (7%) and tomato (5%) are also important in this respect (Portero-Faus, 2000).

The yields of these crops are continuously affected by a pronounced annual water deficit (about 600 mm) as a result of the scant rainfall the area receives (annual mean of 350 mm) and the high rate of potential evapotranspiration (annual ETP > 900 mm) (Sánchez-Toribio *et al*., 1996). To these scant resources we can add other factors, both physical (geological, hydromorphological and edaphological) and socioeconomic, which render the area particularly sensitive to the twin processes of degradation and desertification (López-Bermúdez *et al*., 1996).

The sequences of drought occurring between 1980 and 2009 were defined by reference to the Standardized Index of Rainfall Drought (IESP in Spanish) (Pita-López, 2001). The overall and per sector evaporative demands were calculated for this whole period, but especially during the severe bouts of drought experienced, The climatological data used were those of the Murcia/Alcantarilla, Librilla, Alhama «Huerta Espuña», Totana, Lorca, Puentes and Puerto Lumbreras meteorological stations belonging to the Spanish Meteorological Agency (AEMET) and the Murcia Institute of Investigation and Agrarian Development (IMIDA, Comunidad Autónoma de la Región de Murcia) (Fig. 1). To calculate evapotranspiration the Penman-Monteith-FAO method (Monteith, 1965) was used after checking the goodness of its fit for the ET of grass in this region by lysimeter (Sánchez-Toribio *et al*., 1990). In other geographical locations, especially the USA, it is more common to apply the Penman Monteith ASCE equation using alfalfa as crop reference (ASCE-EWRI, 2005). Although the use of gramineae or alfalfa as reference crop has been widely discussed (ASCE 28), the advantage of the former is that it is easy to maintain a green surface throughout the year, with a LAI (leaf area index) of about 3 (De Santa Olalla, 2005), which is particularly useful when using lysimeters. Among the most used species are ryegrass (*Lolium perenne* L.) or festuca (*Festuca arundinacea* L.), and among the least suitable those which exercise strong biological control over transpiration, such as Bermuda (*Cynodon dactylon* L.).

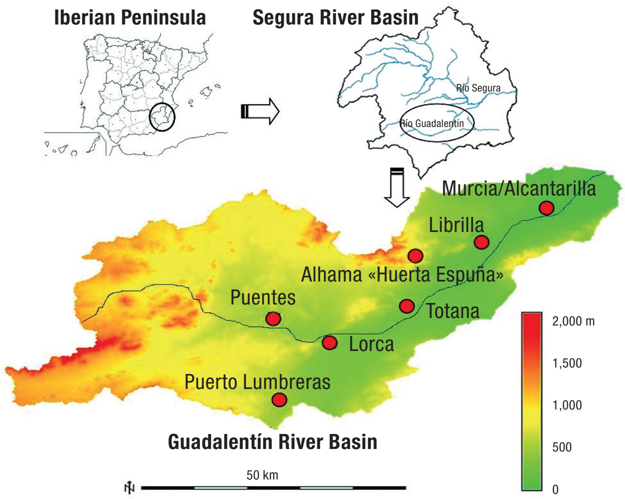

Figure 1. Guadalentín Basin: location of the weather stations.

In normal stress conditions, the value of the plant cover is low, so the crop coefficient (K_c) will be less affected by the conditions of the soil in which these crops and natural cover grow. Equations that express the fit as a function of the plant cover fraction and LAI are described in Allen *et al*. (1998).

The values of K_c are equally necessary to establish, in conjunction with the ETo, the water requirements of the different crops and covers. The usefulness of the «$K_c \cdot$ ETo» method has already been demonstrated at a regional scale (ASCE28) (Allen *et al*., 1998). In this case, the applications correspond basically to the field of hydrology and the management of water resources, and are usually directed at ascertaining the water balance at aquifer or hydrographical basin scale. This type of analysis is strongly conditioned by the level of detail of the knowledge we have of the area and soils at the scale used in each study. In the case of the Guadalentin Valley, the K_c values comes from the Irrigation Assessment Programme of IMIDA, the results of which form part of a specific data base which can be managed by a Geographic Information System.

The objective of the present study was to determine, as a function of the cultivated area, the evaporative demand and the different crop coefficients, the increase in water requirements of the main woody and herbaceous crops of the Guadalentin Valley, an agricultural zone with excellent temperatures for high yield crops and of great economic importance for the province, even during droughts. The frequent occurrence of such events, with the severe water stress that they involve, makes these drought periods ideal states for applying and comparing methods such as those proposed.

Material and methods

Study area

The Guadalentin Valley was chosen as study area because of the constant water stress it suffers, which is aggravated by frequent drought periods. The valley begins near the middle of the Guadalentín river/wadi and lies within the province of Murcia. The upper reaches (205 km^2), drained by the Viznaga wadi, include a small ENE-WSW corridor of tectonic origin between Puerto Lumbreras and Lorca. It is separated from the coast by the Carrasquilla and Almenara Sierras Downstream of Totana, the valley follows the tectonic control of the Bajo Guadalentín, bounded to the north by the mountain ranges of Espuña, El Cura y La Muela, and to the south by the Sierra de Carrascoy. Although the great geographical diversity of the Guadalentín basin implies climatic diversity (Navarro-Hervás, 1991; Martín-Vide and Olcina-Cantos, 2001), its situation in the south east of the Iberian Peninsula and the orographic shelter conferred by the Bettics give the whole valley a semiarid Mediterranean character.

Delimitation of the drought sequences

The dry sequences, present in all climatic dominions, particularly affect semiarid regions marked by a strong inter-annual variation in rainfall patterns. Special attention to dry period lasting more than one year has been taken, since they produce the most important damage in zones like the Iberian Peninsula, familiar with this type of event and adapted to shorter periods with almost total impunity.

Sequences of drought need to be translated into a numerical format if their characteristics are to be determined. From a social-economic point of view, which is what determines whether an extreme climatic event (drought) is counted a natural risk, several parameters should be mentioned: magnitude, duration, frequency, time taken to impose itself, extension and spatial dispersion. To quantify such parameters mathematical calculations are necessary to establish in detail to what extent there has been drought and what the temporal limits of the drought episode are (Marcos, 2001).

Several indices exist (percentage of mean rainfall, quantiles, Palmer PDSI etc.). In this work the standardised index of rainfall drought derived from rainfall but applicable to identifying drought sequences has been applied, since it precisely reflects the beginning and end of each sequence, its duration and intensity at any given moment. The index is the result of standardising accumulated monthly rainfall anomalies, interrupting the accumulation when a negative rainfall anomaly appears, that is, the beginning of each drought sequence. In this way, the effect of minimizing droughts as a consequence of the accumulation of preceding excess (positive) rainfall is avoided. The IESP has been shown to be effective for analyzing the long drought sequences that characterize Mediterranean dominions (Pita-López, 2000, 2001). The index is based on the calculation of accumulated monthly rainfall anomalies following these steps:

i) Calculate the rainfall anomaly of each month of the series (AP_i) using the expression:

$$AP_i = P_i - P_{MED}$$

where AP_i = monthly rainfall anomaly; P_i = monthly rainfall and P_{MED} = mean of the corresponding month.

ii) Obtain accumulated rainfall anomalies from the first month when there is a negative anomaly ($AP_i < 0$) to —as a result of the accumulations— a positive accumulated rainfall anomaly occurs ($AP_i > 0$). This is when the drought ends ($APA > 0$ marks the end of the rainfall deficit). The following drought sequence begins when a month showing a negative rainfall anomaly occurs:

$$APA_i = \Sigma AP_i$$

from i = negative AP to i = positive APA, where APA_i = accumulated rainfall anomaly of the month.

iii) Standardize the accumulated anomalies by converting into Z scores. This reveals the intensity of the drought and will be used to identify the drought sequences:

$$ZAPA_i = APA_i - \overline{APA}) / \sigma APA$$

where $ZAPA_i$ = standardised rainfall anomaly of the month; $\overline{APA}$ = mean of the accumulated rainfall anomalies for all the months of the series and σAPA =

typical deviation of the accumulated rainfall anomalies for all the months of the series.

The method can be applied to long time series and, simultaneously, to different observatories, so that the risk of drought can be analysed for different sectors of the Valley.

Estimation of evapotranspiration

The concept of evapotranspiration has always been considered slightly ambiguous due to the type of vegetal cover being considered. In the 1970s, the concept of «reference evapotranspiration» (ETo) was developed and the term «potential evapotranspiration» (ETP) was coined, since when many calculation systems have been developed.

To fit the estimations of FAO methods (Doorenbos an Pruitt, 1977), there are numerous procedures for calculating ETo with parameters adapted or modified in accordance with local conditions. To confirm the validity of these models in the USA, the American Society of Civil Engineers (ASCE) compared the results of 20 widely used methods using alfalfa as reference crop (Jensen *et al*., 1990). A similar study for the European Commission evaluated different methods of calculating ET_0 using lysimetric measurements. Both studies confirmed the excellent behavior of the model adapted by Penman-Monteith for the FAO, both in humid and arid climates (Allen *et al*., 1998). Such were the conclusions of the FAO in a report published in 1990 in collaboration with the *International Commission on Irrigation and Drainage* (ICID) and the *World Meteorological Organization* (WMO). The report recommended adoption of the Penman-Monteith (ETo-PM, FAO) method for reference ETo and included calculation procedures revised and normalized in Smith *et al*. (1996).

In our case, the reference cover is a hypothetical cover of grass with a height of 0.12 m, a constant value of the canopy resistance of 70 s m^{-1} and an albedo of 0.23. This fixed resistance of 70 s m^{-1} implies a moderately dry soil with a weekly irrigation frequency (Allen *et al*., 1998):

$$ETo = \frac{0.408(R_n - G) + \gamma \dfrac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$

where ETo = ET of the reference crop; R_n = net radiation calculated (MJ m^{-2} d^{-1}); G = heat flux in the soil (MJ m^{-2} d^{-1}); T = mean temperature for the period at a height of 1.5 -2.5 m (°C); U_2 = mean wind speed (m s^{-1}); e_s = vapor pressure at saturation (kPa), calculated at height of 1.5 to 25 m; e_a = present vapour pressure at 1.5-2.5 m (kPa); Δ = slope of the vapour pressure at saturation-temperature (kPa °C^{-1}); γ = psicrometric constant (k Pa °C^{-1}).

The method described above enables us to predict the effects of climate on the evapotranspiration of the reference crop (ET). However, to relate ETo with crop evapotranspiration, ET (crop), it is possible to use coefficients of culture (K_c), which represent the evapotranspiration of a crop in optimal conditions. From the product ETo · K_c the ET representing the water needs can be obtained for different crops of the area.

Obtaining suitable values of K_c is a complex task since many factors intervene: crop characteristics, planting or sowing date, crop growth rhythms and length of vegetative period, soil and climatic conditions, especially during growth, rainfall frequency or supply of irrigation water. The values used are those of the Irrigation Assessment Program from IMIDA, which were obtained indirectly in field experiments and from the bibliography referring to area similar to those of the Valley Guadalentín (Jiménez-Montesinos and De-Luna, 1984; Fereres, 1987; Faci and Martínez-Cobb, 1999).

Results and discussion

Delimitation of drought sequences by IESP

Although drought is a widespread phenomenon, inter-territorial comparisons may serve to better manage the consequences of the same, as long as compensatory mechanisms exist between sectors. However, a small spatial co-variation in the case of drought does not guarantee in itself that amendment mechanisms can be established. For this to be possible, the areas which supply water must always be in a situation of excess so that they can temporarily export water.

Application of the IESP to the weather stations of the Guadalentín Valley (Fig. 2) identified various drought sequences (negative Z values) that approximately coincide (García-Marín and Conesa-García, 2006). As regards their most significant characteristics and, especially, their spatial extension, the drought periods of the 1980s and 1990s are of note, followed by the drought phase at the turn of the millennium (1999-

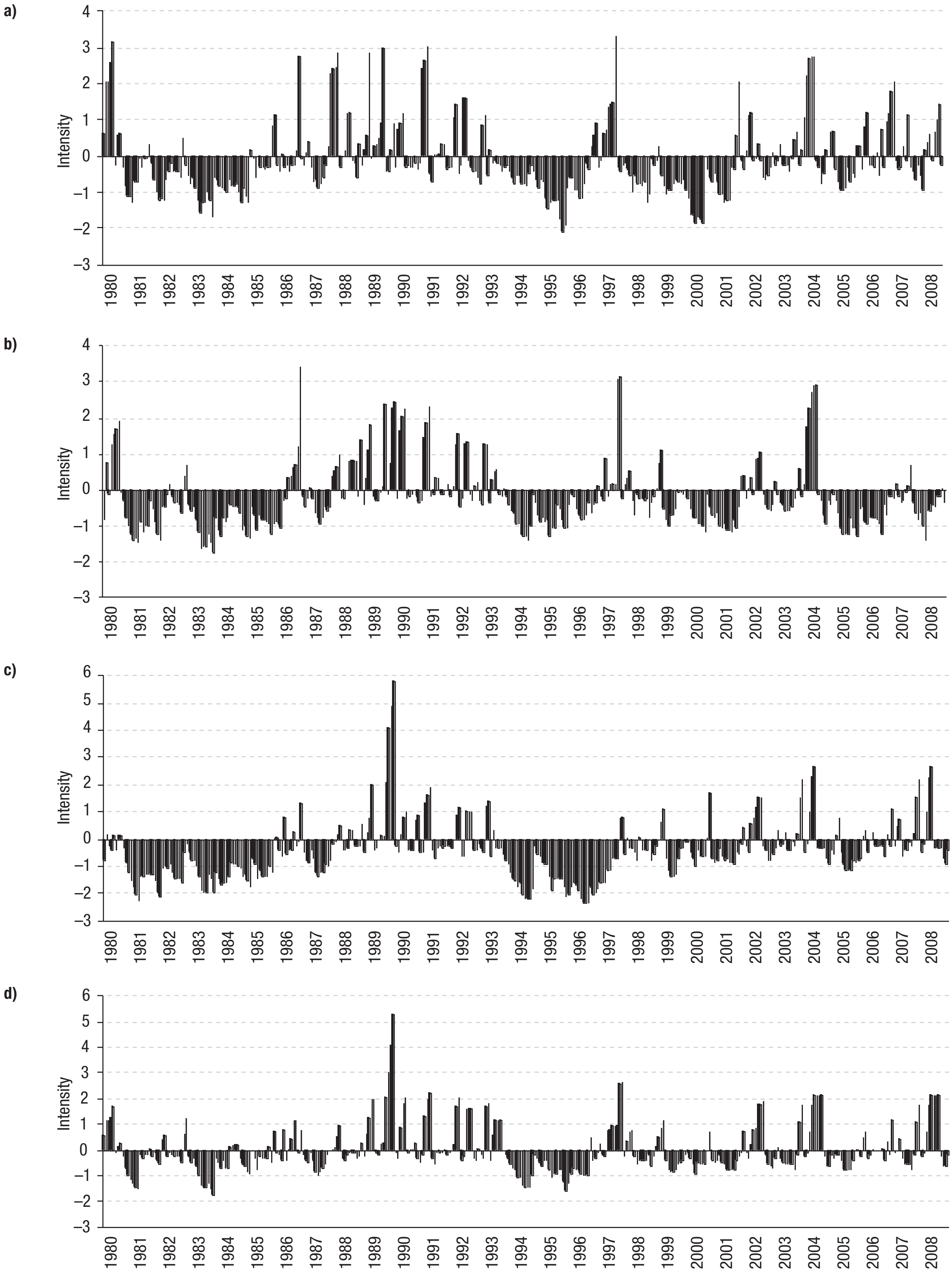

Figure 2. Standardized index of rainfall drought (IESP). a) Murcia/Alcantarilla. b) Alhama de Murcia. c) Lorca. d) Puerto Lumbreras (1980-2009 period).

2001) and middle of the first decade of the XXI century (2004-2006).

Droughts of the 1980s (1981-1985)

According to both integral and regional studies, the 1980s began with one of the longest drought periods of the XX century throughout mainland Spain. In the Guadalentín Valley, rainfall deficits exceeding four years were recorded (*e.g.* in Lorca from September 1980 to October 1985), and Z values below –2 and even below –3 were recorded due to the accumulation of an extraordinary number of consecutive months with a rainfall deficit. The severity of this prolonged drought was evident in the strong impact observed on the water ecosystems of the river Segura and the socioeconomic repercussions generated, especially as regards agricultural production (Zapata-Nicolás *et al.*, 1990).

Droughts of the 1990s (1993-1997)

The first part of the last decade of the XX Century was marked by an intense period of drought through most of the Iberian Peninsula, although it reached the southeast slightly later, but lasted longer. Certain stations (*e.g.* Lorca) registered more than 50 months of drought, while others registered between 30 and 50. The intensity was quite pronounced in most of the basin even though it lasted less than the previous drought. Suffice to give one example, that of Murcia/Alcantarilla, which registered 41 consecutive months (June 1993-October 1996) of strong intensity (–2.04).

Despite lasting less time, this drought was especially harsh in several areas. After the summer of 1905, one of the driest of the XX century, the Spanish government put into effect the so-called *«Plan Metasequía»*, which included emergency measures to guarantee the immediate and future water supply to several Spanish cities. These included the drilling of wells, the use of depurated water and the construction of desalination plants (Morales-Gil and Olcina-Cantos, 1999).

Both droughts effects (April 1999-October 2001 and August 2004-March 2007) were felt along the Guadalentín Valley although with differing degrees of intensity, the most severely affected being Alhama followed by Alcantarilla.

Evaluation of evaporative demand

The rainfall drought and, as a consequence, water shortage was aggravated by increased evaporative demand (Fig. 3). An increase in evaporation over the extensive surface area of exposed water in the region (regulation reservoirs, and the water stored behind small dams and retention dykes for storing occasional water), together with irrigation reservoirs, led to the loss of a considerable amount of water, seriously damaging the potential yields of the abundant forced crops fed by drip irrigation.

Behaviour of the different methods for measuring evapotranspiration

The ETo, ETo Penman-Monteith models (ASCE and FAO models for grass) and Hargreaves Samani's ETh model show very similar daily mean evapotranspiration values, while the results of the ETr model (ASCE for

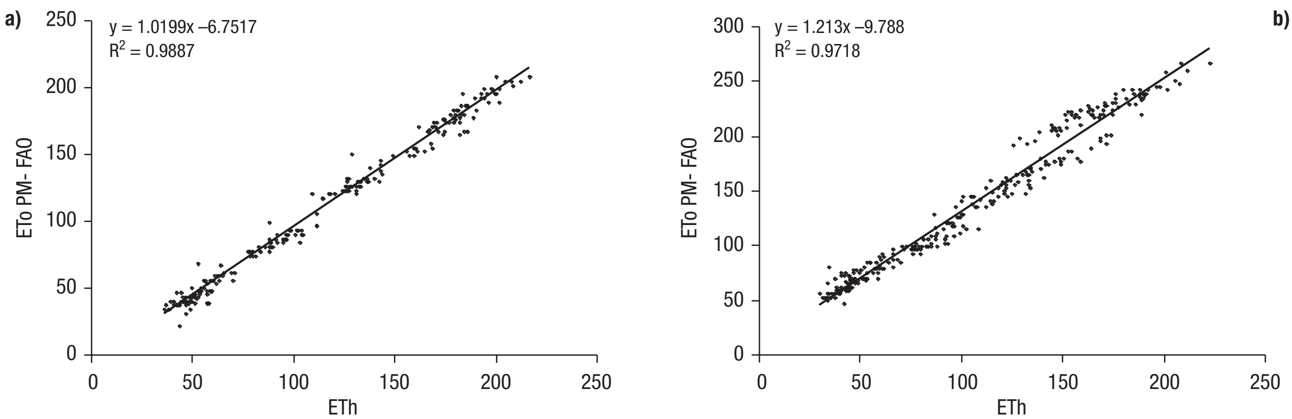

Figure 3. Relation between ETh and ETo-PM (mm month^{-1}) in two weather stations. Alcantarilla (a) and Lorca (b).

Table 1. Mean evaporation (mm day^{-1}) in drought periods, calculated by different methods[1]

	ETh	ETo	ETr	ETo PM	ETo P	ETo R	ETo BC
Puerto Lumbreras							
1980-81	2.7	2.8	3.6	3.2	2.9	3.1	3.1
1982-84	3.1	2.6	3.5	3.3	3.1	3.7	3.8
1993-96	3.0	2.9	3.7	3.4	3.2	3.7	3.9
1999-01	3.2	2.9	3.6	3.4	3.3	3.9	3.9
$\overline{X}$	3.0	2.8	3.6	3.3	3.1	3.6	3.7
Murcia- Alcantarilla							
1981-84	3.8	3.3	4.2	3.6	3.5	4.0	4.3
—	—	—	—	—	—	—	—
1993-96	3.9	3.5	4.5	3.8	3.8	4.3	4.2
1997-01	3.8	3.3	4.2	3.7	3.6	4.2	4.7
$\overline{X}$	3.8	3.4	4.3	3.7	3.6	4.2	4.4

ETh: Hargreaves-Samani. ETo: ASCE-EWRI gramineae. ETr: ASCE-EWRI alfalfa. ETo PM: Penman-Monteith-FAO, gramineae. ETo P: Penman-FAO. ETo R: Radiation-FAO. ETo BC: Blaney-Criddle-FAO.

alfalfa) are closer to obtained with ETr (Radiation FAO) (Table 1).

The Blaney-Criddle-FAO, Radiation-FAO and ETr (ASCE alfalfa) equations show higher values of ET, especially during summer months. Sánchez-Toribio (1990) demonstrated the overestimations that result from using the Radiation and Blaney-Criddle-FAO models compared with lysimetric measurements made in the lower stretches of the Guadalentín Valley. A comparison of the theoretical values of the models used confirms the good fit of ETh, based only on temperature, with the physical ETo method of Penman-Monteith (Fig. 3).

Comparing the evapotranspiration between a rainy period (1989-93) and a dry period (1994-95) in the Alcantarilla station (Lower Valle of Guadalentín) (Fig. 4), the annual evapotranspiration rate gradually increased in inverse relation with rainfall, although not at the same rhythm.

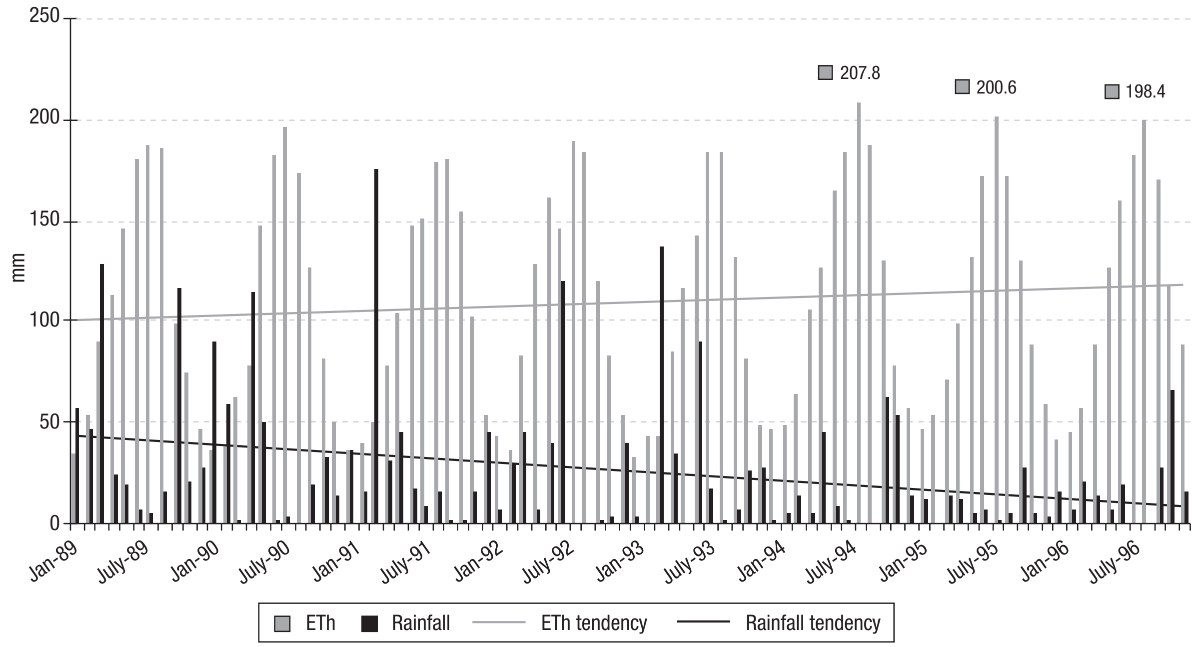

Figure 4. Comparison of ETh and rainfall considering a drought period (1994-95) following a drought period (1989-93). Alcantarilla, Lower Guadalentín Valley.

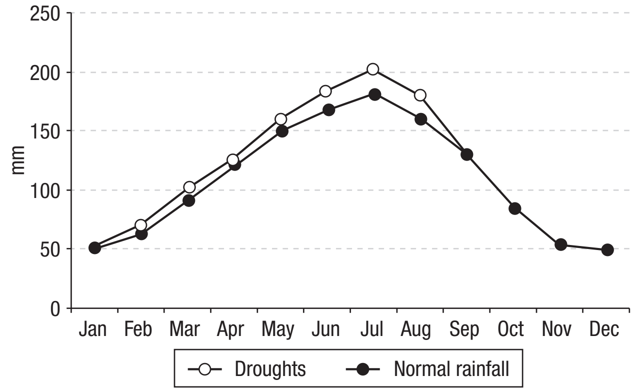

Figure 5. Monthly ETo-PM values in periods of normal rainfall and droughts. Guadalentín Valley.

The values of ETo Penman-Monteith during the dry periods exceeded those of wet or normal periods (Fig. 5). The differences were especially evident after the spring months, and reach a maximum in July. From September to February the values of both the dry and normal months evened out.

Estimation of overall water demand

The traditional methods for calculating the water requirements of a plant are based on ETo values. All microclimatic methods have been developed for total cover crops and their use in fruit and citrus trees presents problems of accuracy: representativity, leaf area gradients, crown density, etc. Such estimates of the water requirements are also limited because they are not directly related with the water functioning of the plants, especially in deficit irrigation situations. Consideration of the monthly crop coefficient (K_c) for different plant cover types obtained from IMIDA and the bibliography, together with the mean monthly evaporative demand values, permitted us to determine the water requirements of the irrigated areas of the zone. Given the importance of agriculture in the same, this will be of undoubted interest for the regional government. The formula used (monthly ETo · monthlyK_c), taking the K_c as suggested by the FAO (2006) (0.75 during rainy months and 0.8 during dry months) provides good estimates both in normal periods and droughts. Among the crops of the area that show greatest vulnerability to water stress are citrus trees, which are particularly sensitive during flowering. Given that the K_c of this crop with most of the trees in full cover is around 0.8-0.9, the irrigation in this semiarid area needs to count on a daily application of 5-10 mm.

The water requirements of each crop, multiplied by the respective areas they covered, will provide the overall water demands for the zone. The final result for the water requirements is expressed in hm^3 in order to simplify and improve the interpretation of possible comparisons. From the values obtained, it is inferred that the overall water demand for the principal crops of the Guadalentín Valley should be increased by 8.35 hm^3 during drought periods, tomato, pepper, artichoke, cauliflower and broccoli being the crops that need the greatest amount (Table 2). The same data point to quite different increased water requirements. In peppers grown to produce paprika, for example, an increase of 290 m^3 ha^{-1} $year^{-1}$ is assumed, while the figure for lettuce and cauliflower does not exceed 12 m^3 ha^{-1} $year^{-1}$.

Woody crops increase their water demands during drought to a lesser extent (6.15 hm^3) (Table 2). Citrus (lemon and orange) and table grapes suffer most during low rainfall periods, especially given the higher evaporative demand as a result of increased insolation.

In total, the increased annual demand estimated for the main crops of the Guadalentín Valley during drought periods is some 14.5 hm^3, a volume of water that will be difficult to provide, given the surface water deficit and already overexploited aquifers. This explains the decrease in the areas devoted to certain crops, especially herbaceous crops, that have been recorded when the persistence of rainfall drought gives way to a situation of hydrological drought (Fig. 6).

The area devoted to agriculture during the different stages of drought closely reflects the insufficient capacity of the Guadalentín Valley to survive increased annual water deficits. This is particularly clear in the reduction in the number of hectares dedicated to irrigated herbaceous crops.

Conclusions

As computed for other zones of the province of Murcia (Sánchez-Toribio and López-Bermúdez, 1996; Sánchez-Toribio and Romero-Díaz, 2006), the reference alfalfa and grass evaporation models, especially the exclusively temperature-based model of Hargreaves-Samani (1995), showed a good fit with the physical based models (ETr, ETo-Penman-Monteith). The increase in the evaporative demand reflected the increased

Table 2. Main horticultural crops and irrigated woody crops of Guadalentín Valley and their annual water requirements during normal and drought periods (hm^3). Data were calculated following the model of ETo-Penman Monteith

	Area (ha)	Normal periods	Drought periods	Differences
Horticultural crops				
Pepper (paprika)	416	2.57	2.90	0.33
Flowers	240	2.48	2.60	0.12
Artichoke	3,375	26.80	27.90	1.10
Cauliflower and broccoli	12,555	29.51	31.40	1.89
Lettuce	7,610	24.86	26.60	1.74
Melon	2,472	8.73	9.40	0.67
Watermelon	1,150	4.06	4.40	0.34
Tomato	3,631	25.96	27.30	1.34
Potato	231	0.92	1.00	0.08
Cotton	871	6.25	6.50	0.25
Other herbaceous	1,850	7.40	7.90	0.50
Total	34,401	139.55	147.90	8.35
Irrigated woody crops				
Lemon	4,020	24.27	25.80	1.53
Mandarin	736	4.89	5.20	0.31
Orange	2,463	16.37	17.40	1.03
Almond	1,710	9.18	9.80	0.62
Plum	461	2.31	2.50	0.19
Peach	790	4.42	4.70	0.28
Olive grove	2,309	10.10	10.80	0.70
Vineyard (grape table)	3,338	16.50	17.50	1.00
Others windbreaks	1,702	7.47	7.98	0.50
Total	17,529	95.53	101.68	6.15

water deficits that occur in the drought years, both in summer and winter. An increase in evaporation over the extensive surface area of exposed water in the studied zone (regulation reservoirs, irrigation dams and retention dykes) led to the loss of a considerable amount of water, which lay an even greater threat to the irrigation of forced crops, economically important for the region (León *et al*., 1986). Drought periods are also responsible for reducing the areas dedicated to horticultural crops, because of their high water demands and the additional costs involved, resulting an aggravated socioeconomic position and increased unemployment.

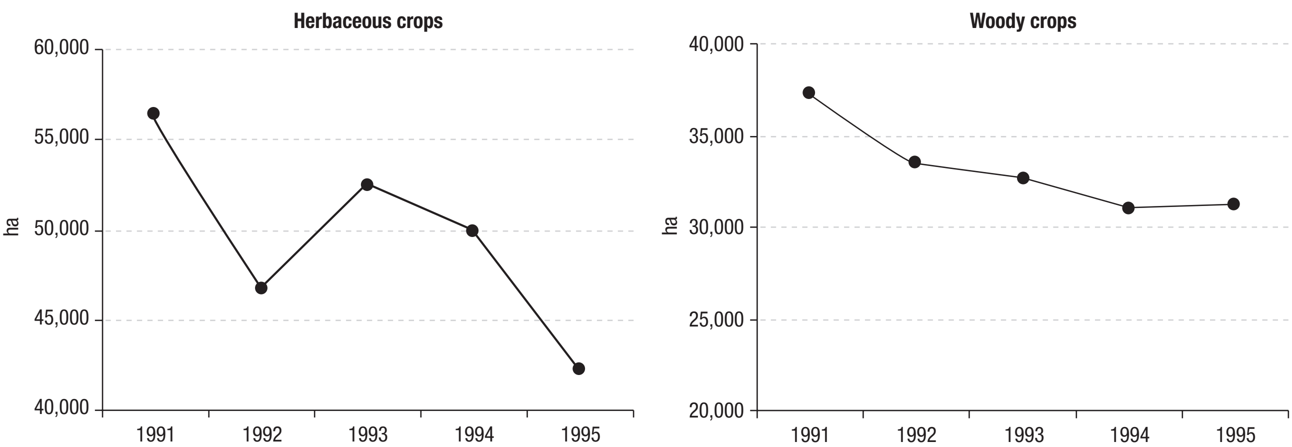

Figure 6. Evolution of total cultivated area dedicated to herbaceous and woody crops in Guadalentín Basin. Note the sharp decline during the drought period (1994-95). Data coming from CARM (1996).

Acknowledgements

This study was supported by Instituto Euromediterráneo de Hidrotecnia (PI/17) grant to the authors.

References

ALLEN R.G., PEREIRA L.S., RAES D., SMITH M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements. FAO Irrig & Drain, Paper 56. Roma. 323 pp. Available in: http://www.fao.org. [October 2009].

ASCE-EWRI, 2005. The ASCE standardized reference evapotranspiration equation. Task Committee on Standardization of Reference Evapotranspiration of the Environmental and Water Resources. Institute of the American Society of Civil Engineers. 173 pp.

DE-SANTA-OLALLA-MAÑAS F.M., 2005. Agua y agronomía. Mundi-Prensa, Madrid. 606 pp.

DOORENBOS J., PRUITT W.O., 1977. Guidelines for predicting crop water requirements. FAO Irrig and Drain Paper 24 (Rev), Roma. 156 pp.

CARM, 1996. Estadística agraria regional. Consejería de Agricultura y Agua, Comunidad Autónoma de la Región de Murcia. 158 pp. [In Spanish].

FACI J.M., MARTÍNEZ-COBB A., 1999. Necesidades de riego. Determinación en las plantaciones del Valle del Ebro. Horticultura 4, 47-52. [In Spanish].

FERERES E., 1987. Necesidades hídricas de los cultivos. Eficiencia de los métodos de aplicación y consumos totales de agua a nivel de parcela. Comité Español de Riegos y Drenajes. Simposio sobre Necesidades Hídricas de los Cultivos y su Abastecimiento. Madrid 3-4 de noviembre. 40 pp. [In Spanish].

GARCÍA-MARÍN R., CONESA-GARCÍA C., 2006. Secuencias pluviométricas secas de larga duración en la cuenca del Guadalentín (Murcia-Almería). In: Clima, sociedad y medio ambiente (Cuadrat Prats *et al.,* eds). Publ Asociación Española de Climatología (AEC) Serie A, nº 5. Zaragoza. pp. 371-382. [In Spanish].

GIL-OLCINA A., 2004. El campo de Lorca. Estudio de geografía agraria, 2nd ed. Ayuntamiento de Lorca, Murcia, Spain. 204 pp. [In Spanish].

JENSEN M.E., BURMAN R.D., ALLEN R.G. (eds), 1990. Evapotranspiration and irrigation water requirements. Amer Soc Civil Eng, New York.

JIMÉNEZ-MONTESINOS M., DE-LUNA J., 1984. Fertilización por goteo en los cítricos. Fertilización 95, 18-27. [In Spanish].

LEÓN-MARTÍNEZ-CAMPOS A., DEL AMOR F., TORRECILLAS A., 1986. El riego en la región de Murcia. Apuntes para una historia reciente. Consejería de Agricultura, Ganadería y Pesca, Murcia. 28 pp. [In Spanish].

LÓPEZ-BERMÚDEZ F., ROMERO-DÍAZ A., CABEZAS-CALVO-RUBIO F., MARTÍNEZ-FERNÁNDEZ J., BÖER M., DEL BARRIO G., 1996. The Guadalentín basin, Murcia, Spain. In: Atlas of Mediterranean environments in Europe (Mairota P., Thornes J.B., Geeson N., eds). John Wiley and Sons, Chichester. pp. 130-142.

MARCOS O., 2001. Sequía: definiciones, tipologías y métodos de cuantificación. Investigaciones Geográficas nº 26. Instituto Universitario de Geografía de Alicante. pp. 59-80. [In Spanish].

MARTÍN-VIDE J., OLCINA-CANTOS J., 2001. Climas y tiempos de España. Alianza editorial SA, Madrid. 288 pp. [In Spanish].

MONTEITH J.L., 1965. Evaporation and the environment. Proc Soc Exp Biol 19, 205-234.

MORALES-GIL A., OLCINA-CANTOS J., 1999. Diferentes percepciones de la sequía en España: adaptación, catastrofismo e intentos de corrección. Investigaciones Geográficas 22, 5-46. [In Spanish].

NAVARRO-HERVÁS F., 1991. La aridez en la Cuenca del Guadalentín: prácticas y técnicas para suplir el déficit hídrico. Papeles de Geografía 17, 61-78. [In Spanish].

PITA-LÓPEZ M.F., 2000. Un nouvel indice pour les domaines méditerranéens. Application au bassin du Guadalquivir (sud-ouest de l'Espagne). Publications de l'Association Internationale de Climatologie 13, 225-233. [In French].

PITA-LÓPEZ M.F., 2001. Sequías en la cuenca del Guadalquivir. In: Causas y consecuencias de las sequías en España (Gil-Olcina A., Morales-Gil A., eds). Caja de Ahorros del Mediterráneo e Instituto Universitario de Geografía, Alicante. pp. 303-343. [In Spanish].

PORTERO-FAUS M., 2000. Contribución al estudio de las necesidades hídricas del regadío en la región de Murcia. Trabajo fin de carrera. Universidad Miguel Hernández, Elche, Alicante. 253 pp. [In Spanish].

SÁNCHEZ-TORIBIO M.I., 1990. La evaporación en la región de Murcia en relación a sus aplicaciones en hidrología y agricultura. Publicaciones. Universidad de Murcia. 285 pp. [In Spanish].

SÁNCHEZ-TORIBIO M.I., LÓPEZ-BERMÚDEZ F., DEL AMOR F., LEÓN-MARTÍNEZ-CAMPOS A., 1996. Assesment of referente evapotranspiratión (ETo) in semiarid mediterranean climate conditions. ICID Journal 45(1), 1-10.

SMITH M., ALLEN R.G., PEREIRA L., 1996. Revised FAO methodology for crop water requirements. Proc ASAE Int Conf Evapotranspiration and Irrigation Scheduling. November 1996. San Antonio, Texas, USA, ASCE. pp. 116-123.

ZAPATA-NICOLÁS M., CORTINA J., CAPEL J.J., GRIS J., 1990. Repercusiones económicas de la sequía 1980-1983 en el sector agrario de la Cuenca del Segura. CEBAS-CSIC, Murcia. 237 pp. [In Spanish].