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The Impact of Water Deficit on Yield Response Factors: A Case Study of Cotton and Silage-Maize in İslahiye

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ABSTRACT

Understanding the effects of water deficit on crop yield is essential for growers and researchers, as it represents a crucial uncertainty in agriculture, along with factors such as sales price, tenure, input costs, and input quality. This study compares and analyzes the yield response factors of two crops, cotton and silage maize, to water deficit using data from Islahiye town of Gaziantep Province in Türkiye. The primary data source is the 2016 Türkiye Plant Water Consumption Guide, prepared by TAGEM and DSI using the FAO Penman-Monteith method. The yield response factor Ky indicates the sensitivity of the crop yield to the potential evapotranspiration (PET) deficit in ten-day periods, t. Their yield response factors change depending on the growth stage and percentage of water deficit. Our model is based on water production function and the soil moisture balance equation, and the model can be applied to all crops, including herbaceous, trees, and vines. The water shortage rate is the same for each t. The solution of the maximization model by a Mixed-Integer Programming (MIP) Solver revealed that both crop yields are considerably affected by water deficits, with similar sensitivities observed. However, while cotton is more sensitive until a 15 per cent deficit, silage maize becomes more sensitive beyond this value. The findings will have a significant impact on decision-making for water allocation, ensuring optimal use of this essential resource. This model and its solution use optimization algorithms to provide new knowledge and perspectives to manage water deficits better and optimize crop yields.

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Kısıntılı Sulamanın Verim Tepki Faktörleri Üzerindeki Etkisi: İslahiye'de Pamuk ve Silajlık Mısır Üzerine Bir Vaka Çalışması

ÖZET

Su kıtlığının bitki verimi üzerindeki etkilerini anlamak, tarımda satış fiyatı, mülkiyet süresi, girdi maliyetleri ve girdi kalitesi gibi unsurlarla birlikte önemli bir belirsizliği temsil ettiğinden, yetiştiriciler ve araştırmacılar için hayati bir öneme sahiptir. Bu çalışma, Türkiye'nin Gaziantep ilinin İslahiye ilçesinden alınan verileri kullanarak pamuk ve silajlık mısırın kısıntılı sulamaya verdiği verim tepki faktörlerini karşılaştırmayı ve analiz etmeyi amaçlamaktadır. Verim tepki faktörü Ky, on günlük periyotlarda (t), potansiyel bitki su tüketimindeki azalmaya karşı bitki veriminin duyarlılığını gösterir. Ana veri kaynağı, TAGEM ve DSI tarafından FAO Penman-Monteith yöntemi kullanılarak hazırlanan 2016 Türkiye Bitki Su Tüketimi Rehberi'dir. Verim tepki faktörleri, büyüme aşamasına ve kısıntılı sulama yüzdesine bağlı olarak değişmektedir. Modelimiz su üretim fonksiyonu ve toprak nem dengesi denklemine dayalı olup, otsu bitkiler, ağaçlar ve asmalar dahil tüm bitkilere uygulanabilir. Kısıntılı sulama oranı her bir t için aynıdır. Karma Tamsayılı Programlama (MIP) Çözücü ile maksimizasyon modelinin çözümü, her iki ürünün veriminin de

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benzer duyarlılıklar göstererek kısıntılı sulamadan önemli ölçüde etkilendiğini ortaya koymuştur. Ancak, pamuk %15 kısıntılı sulama oranına kadar daha duyarlı iken, silajlık mısır bu değerin ötesinde daha duyarlı hale gelmektedir. Bulgular, su tahsisi karar alma sürecinde önemli bir etkiye sahip olacak ve bu temel kaynağın optimum şekilde kullanılmasını sağlayacaktır. Bu model ve çözümü, kısıntılı sulamayı daha iyi yönetmek ve ürün verimlerini optimize etmek için yeni bilgi ve bakış açılarıyla optimizasyon algoritmalarını kullanmaktadır.

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Nomenclature

$AREA_c$	The cultivated area of crop c per unit area	FC	Critical soil water depletion fraction	n	Number of time slots	SMW_c	Soil moisture wilting point for crop c, in mm per unit depth
AET_0^t	Reference evapotranspiration in time slot t, in mm	GW	Groundwater resources	QWT	QWT is the known amount of water (volume) available for the entire season, m3 ha-1	$SMINIT_c$	The constant soil water content of deeper layers before the cultivation of crop c, in mm per unit depth
AET_c^t	Actual evapotranspiration of crop c in time slot t, in mm	DP_c^t	Deep percolation for crop c in time slot t in mm	PET_0^t	Potential evapotranspiration of reference crop c in time slot t, in mm	$SMAv_c^t$	Average soil moisture is the arithmetic mean of the sum of added irrigation water at the end and soil water content at the beginning of time slot t.
c	Type of crop	IRR_c^t	Irrigation water in time slot t for crop c, in mm	PET_c^t	Potential evapotranspiration of crop c in time slot t, in mm	TAGEM	General Directorate of Agricultural Research and Policies
CE	Conveyance efficiency of irrigation water, dimensionless	IAE_c	Irrigation water application efficiency for crop c, dimensionless	$RAIN^t$	Rainfall in time slot t, in mm	t	Time period or time slot (10 days)
CWR	Crop Water Requirement	Ky_{ass}	Crop yield response factor to water deficit, dimensionless, assumed in the beginning	$Root_c^t$	Root depth of crop c at the beginning of time slot t, in cm	Ya_c	Actual yield of crop c in kg per unit area
DSI	General Directorate State Hydraulic Works	Ky_c	Crop yield response factor to water deficit, dimensionless	SMA_c^t	Soil moisture at the beginning of time slot t for crop c, in mm per unit depth	Ym_c	Maximum yield of crop c in kg per unit area
FAO	Food and Agricultural Organization of the United Nations	m	Number of crops	SMF	Soil moisture field capacity, in mm per unit depth	Yr	Yield Ratio of crop c (Ya_c/Ym_c)

INTRODUCTION

Approximately 70 % of freshwater resources are used for agriculture globally (UN-Water, 2023). While the supply of freshwater resources has been diminishing over time because of global warming and environmental pollution, the demand for freshwater has been increasing depending on population growth and living standards. Countries may be considered water-stressed if they withdraw more than 25 percent of their renewable freshwater resources. They approach physical water scarcity when more than 60 percent is withdrawn, and face severe physical water scarcity when more than 75 percent is withdrawn (FAO, 2017) (IPCC, 2021).

In the next few decades, water sharing among countries that use the same resources may become a global problem, especially in the Eastern Mediterranean region. Additionally, water deficits are linked to 10% of the rise in global migration, and climate change is accelerating the global water crisis (Worldbank, 2021). For this reason, agricultural water should be used effectively and safely to increase the production and yield of crops. Since agriculture uses the most available fresh water, conservation or optimization of water usage in this sector will be more impactful than managing water consumption in other areas like domestic and industrial use. Water-saving irrigation systems should be followed to save water and maximize yield. To ensure the sustainable development of water resources, it is essential to consider effective utilization and management methods, and to develop scientific and reasonable systems for crop irrigation (Jia, et al. 2024).

The most important guide is the guides published by FAO, the Food and Agricultural Organization of the United Nations. FAO Irrigation and Drainage paper, No. 33, Yield response to water (Doorenbos and Kassam 1979) published in Rome, is a milestone. FAO Irrigation and Drainage Paper No. 56 (Allen, et al. 1998) and FAO Irrigation and Drainage Paper No. 66, Crop yield response to water (Steduto, et al. 2012) contribute to agricultural irrigation. The books Water Sources System Planning and Management (Loucks and Van 2017), and Water Resources Systems Modelling Techniques and Analysis (Vedula and Mujumdar 2016) are other valuable references. The linear or nonlinear models for optimizing irrigation water and crop pattern determination problems for a limited amount of water (reservoir), especially in arid or semi-arid regions, have been studied. The research studies conducted by Ghahraman and Sepaskhah in (2002) and (2004) serve as notable examples.

Biotic and abiotic stresses negatively affect the growth and development of plants, and water stress is a prominent abiotic stress factor (Akcay and Dagdelen 2016). The impact of water deficit on crop yield is considerable, and understanding its effects is crucial for growers and researchers. The yield response factor Ky quantifies the reduction in yield due to inadequate water availability. The specific impact can vary based on factors such as the severity and duration of the water deficit, crop variety, and growth stage. This study compares yield response factors of cotton and summer-planted silage maize to water deficit. This comparison determines which and how to prioritize in case of drought and water deficit when both plants consume the most water in July-September. To optimize water consumption and allocation, it is necessary to analyze the water sensitivity of plants if a limited amount of water is shared by different crops competing for water. Ky is not the only factor determining the allocation of a limited water source. However, other criteria, such as cost-benefit relationships, food security, and social-economic subventions, also contribute to this decision-making.

The study used the data from Islahiye town of Gaziantep Province in Türkiye. Nearby this town, Tahtaköprü Dam, which irrigates Islahiye and the Amik Plain, is available. The source of almost all parameters of Islahiye is the Türkiye Water Consumption Guide of Crops (TAGEM, DSİ, 2016). This guide is prepared using the FAO Penman-Monteith method, making it a unique and valuable source for irrigation studies related to the Eastern Mediterranean region affected by global warming and migration.

The paper is organized as follows. The second section of this study is about material and methods. Firstly, linear models and formulas are introduced. Then summarized definitions of evapotranspiration and crop yield factor Ky were given. Model sets and parameters are detailed in cotton and silage maize potential water demand, evapotranspiration, PET for İslahiye were given. Cotton and silage maize (second product) are spring and summer crops, respectively. The result section discusses the solution of a linear model focusing on crop yield sensitivities and water deficits at different ratios for cotton and silage maize. Comparison of water deficit ratio [1-AET(t)/PET(t)] in per cent concerning Ky crop yield factor is finalized the discussion of the results. The findings of the study are discussed in the conclusion section.

To the best of the authors' knowledge, this research addresses a spatial gap in the existing literature by focusing on the Eastern Mediterranean region. The limitations of linear solutions, which fail to adequately capture the dynamic nature of climatic data, highlight the urgent need for our proposed advanced forecasting models and AI algorithms. These innovative approaches, with their stimulating capabilities, are crucial in addressing the water stress in this region.

MATERIAL and METHODS

Models and Formulas

Evapotranspiration And The Penman-Monteith Method

Evapotranspiration is the process that combines water loss from the soil through evaporation and from plants through transpiration, playing a crucial role in the water cycle, especially in regions with arid and semiarid climates where irrigation is needed for plant growth and yield due to a lack of enough precipitation (Irmak, 2008). The amount of evapotranspiration depends on climatic variables, crop characteristics, management, and environmental aspects (Allen, et al. 1998). Potential (PET) or maximum evapotranspiration refers to the amount of water that would evaporate and transpire from a specific area if there were always enough water available for plants and soil. Reference evapotranspiration (ET_0) is a measure of how much water evaporates and transpires from a standardized surface, not from the actual crops but from an ideal grass field under specific conditions (Irmak, 2008). AET represents the actual evapotranspiration-water consumption in given conditions. The Blaney-

Criddle method has found wide use to calculate the evapotranspiration in Turkiye instead of the Penman-Monteith method because it requires fewer meteorological elements and the calculation steps are easier. However, the literature states that methods based on more climate parameters, such as the Penman-Monteith method, give more realistic results (Allen, et al. 1998), (Droogers and Allen 2002) and (Xing, et al. 2023). Turkiye Water Consumption Guide of Crops (TAGEM and DSI 2016) uses the FAO Penman-Monteith method.

Crop yield response factor (Ky)

It is important to understand crop yield response factor (Ky) when dealing with irrigation, especially when limited water resources are available. Ky is an indicator of a crop's sensitivity to water deficits. Plants require water for various functions, including nutrient uptake, photosynthesis, and cell growth. Water shortages can negatively impact these processes, causing crop loss. As a result of water shortage, actual crop yield (Ya) decreases relative to actual evapotranspiration (AET). The Ky values are crop specific and vary over the growing season according to growth stages (Steduto, et al. 2012). Ky bigger than 1 indicates high crop sensitivity. These crops need a steady and sufficient water supply throughout the entire growing season. Ky values less than one indicates that the crop is more tolerant to water deficit. These crops can withstand some level of water stress and might recover partially. Finally, when Ky equals 1, it indicates that the reduction in yield is proportional to the water deficit. The following linear relationship (Eq.1) (Doorenbos and Kassam 1979) between relative yield and relative evapotranspiration is presented as follows:

$$\left(1-\frac{\mathrm{Ya}}{\mathrm{Ym}}\right)=\ 1-\mathrm{Ky}\ \left(1-\frac{\mathrm{AET}}{\mathrm{PET}}\right) \quad (1)$$

Where Ya and Ym are actual and maximum crop yields, correspond to AET and PET, actual and maximum evapotranspiration, respectively, and Ky is the crop yield response factor. In this equation, referred to as the FAO 33 method, Ky varies depending on species, variety, irrigation method and management, and growth stage when deficit evapotranspiration is imposed. Rao et al. (1988) proposed a multiplicative form of equation (Eq.2) that covers all growth stages simultaneously and is an extended form of one growth stage of water production function developed by the FAO 33 method (Doorenbos and Kassam 1979). The FAO 33 method proposed a multiplicative equation that covers all growth stages simultaneously, and is an extension of one growth stage of water production function for single crop:

$$\frac{\mathrm{Ya}}{\mathrm{Ym}}=\ 1-\prod_{\mathrm{i}}^{\mathrm{n}}\ \mathrm{Ky_i}\left(1-\frac{\mathrm{AET_i}}{\mathrm{PET_i}}\right) \quad (2)$$

where i is an index for the growth stages and it corresponds to time slot t in our notation, and n is the total number of crop growth stages. In addition to the multiplicative form of the above-given equation, it also has been addressed in an additive form as follows:

$$\frac{\mathrm{Ya}}{\mathrm{Ym}}=\ 1-\sum_{\mathrm{i}}^{\mathrm{n}}\ \mathrm{Ky_i}\left(1-\frac{\mathrm{AET_i}}{\mathrm{PET_i}}\right) \quad (3)$$

It was reported that both equations, multiplicative (Eq.2) and additive (Eq.3) forms, bring similar results. In our model, the additive form gives more feasible results.

Modelling of irrigation water allocation

Crop yield optimization for multiple crops

The goal of irrigation water management is to maximize crop production while considering the crop's response to irrigation. This is typically achieved through mathematical programming techniques using crop production functions. A simple additive form of the production function given in Eq.4 is used to discuss the formulation of the optimization problems (Vedula and Mujumdar 2016). This is :

$$\left[\frac{\mathrm{Ya_c}}{\mathrm{Ym_c}}\right]=1-\sum_{\mathrm{t}}^{\mathrm{n}}\sum_{\mathrm{c}}^{\mathrm{m}}\ \left\{\mathrm{Ky}_{\mathrm{c}}^{\mathrm{t}}\left(1-\frac{\mathrm{AET}_{\mathrm{c}}^{\mathrm{t}}}{\mathrm{PET}_{\mathrm{c}}^{\mathrm{t}}}\right)\right\} \quad (4)$$

Where, n is the number of time slot, m is the number of crops, Ky^t_c is the yield response factor for the growth stages t (10 days time slot) of crop c, ya_c is the actual yield of the crop c, AET^t_c is the actual evapotranspiration at time slot t and PET^t_c is the potential evapotranspiration at time slot t for the crop c.

Soil moisture balance

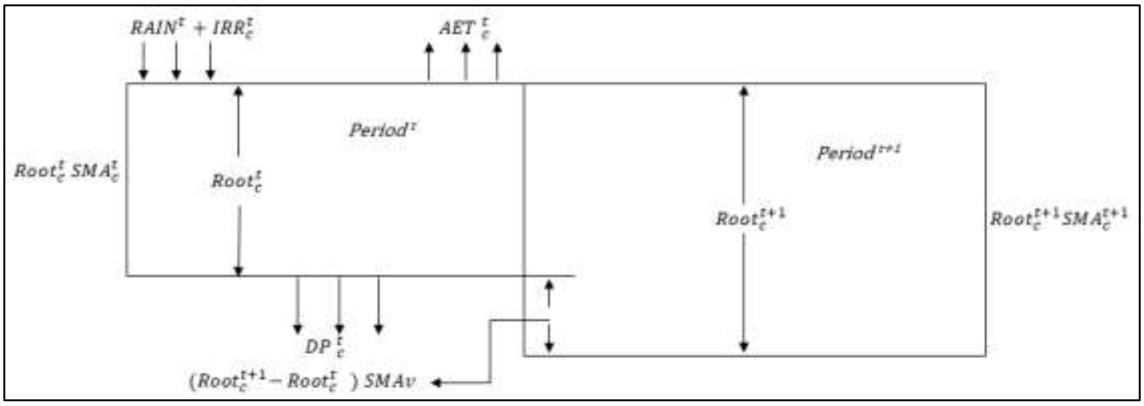


Figure 1 Schematic Diagram for Soil Moisture Balance (Vedula and Mujumdar 2016)
Şekil 1 Toprak Nem Dengesi Şematik Diyagram (Vedula and Mujumdar 2016)

In Eq.5, SMA^t_c is the soil moisture of crop c at the beginning of the period t, $Root^t_c$ is the root depth of crop c during period t, $RAIN^t$ is the effective rainfall (contribution of rainfall to soil moisture) in the command area in period t, IRR^t_c is the irrigation application to crop c in period t, AET^t_c is the actual evapotranspiration of crop c in period t, SMI_c is the initial soil moisture in the soil zone into which the crop root extends at the beginning of period t + 1, GW^t groundwater in time slot t and DP^t_c is the deep percolation. The soil moisture values SMA^t_c, SMI_c and $SMAv^t_c$ are in units of depth per unit root depth (mm/cm), and all other terms are in-depth units, namely mm. Schematic Diagram for Soil Moisture Balance (Vedula and Mujumdar 2016) figured out in Figure1.

Actual Evapotranspiration AET^t_c is equal or less than Potential Evapotranspiration (Eq.6). The field capacity of soil, SMF, represents the maximum amount of water that can be held in soil after excess water has percolated out through gravity. Actual Soil Moisture SMA^{t+1}_c is equal or less than soil field capacity SMF (Eq.7 and Eq.13).The permanent wilting point of soil, SMW, represents the point at which roots cannot absorb water remaining in the soil. If the soil's moisture reaches this point, plants die. Eq.8 and Eq.14 are to meet this constraint. For use in linear models, the AET constraint is written as:

$$AET^t_c \leq \left(SMA^t_c + IRR^t_c + RAINt - SMW \right) PET^t_c / (SMF\_SMW) \ \forall t, c \quad (5)$$

$$AET^t_c \leq PET^t_c \ \forall t, c \quad (6)$$

$$SMA^{t+1}_c \leq SMF \ \forall t, c \quad (7)$$

$$SMW \leq SMA^t_c \leq SMF \ \forall t, c \quad (8)$$

The optimization model for single crop

The optimization problem for single crop (c) may be formulated as follows:

$$\text{Max} \quad \left[\frac{Ya}{Ym}\right] = 1 - \sum_{t}^{n} \left\{ Ky^{\,t} \left(1 - \frac{AET^{\,t}}{PET^{\,t}} \right) \right\} \ \forall t, \text{where } t = 1,2, \ldots n \quad (9)$$

Subject to:

$$(SMA^{\,t+1} Root^{t+1}) = (SMA^t \, Root^t) + RAIN^t + IRR^t - AET^t - DP^t \, SMAv \, (Root^{t+1} - Root^t) \ \forall t \quad (10)$$

$$AET^t \leq \frac{(SMA^t + RAIN^t + IRR^t - SMW)(PET^t)}{SMF - SMW} \quad \forall t \quad (11)$$

$$\frac{AET^t}{PET^t} \geq 0.5 \quad \forall t \quad (12)$$

$$SMA^{t+1} \leq SMF \ \forall t \quad (13)$$

$$SMW \leq SMA^t \leq SMF \ \forall t \quad (14)$$

$$DP^t \geq IRR^t (1 - IAE) \ \forall t \quad (15)$$

$$\sum \mathrm{IRR}^{t}\,\mathrm{AREA} \quad \leq \mathrm{QWT}\ \ \forall\, t \tag{16}$$

Eq.9 is the objective function of optimization problem to maximize the yield ratio Ya/Ym. QWT is the known amount of water (volume) available for the entire season, IRR^t is the amount of water (depth) allocated in period t, and AREA is the crop area. Eq.16 constraints that total irrigation water should be equal or less than total avaibla water, QWT. The problem is formulated for a constant root depth so that the soil moistures, SMF and SMW in the above formulation are in-depth units.

The amount of irrigation water was found for a predetermined cultivation area. The amount of water supply was accepted as constant, although it was not. However, this model can be considered a core model running correctly. It should be enhanced, revised, and some additional constraints or subtractions of some assumptions to adapt it to real-world conditions, overcoming the handicaps of uncertainties of this problem. The number of crops is limited to a single. The time slots are 10 days. If one crop is modelled, it starts from the sowing or planting time to the final harvesting. For example, while the number of time slots is 18 for cotton, it is 10 for silage maize. Irrigation application efficiency (IAE) of less than 100% causes some water percolation below the root zone. Therefore, the model structure needs to include a constraint (Eq.15). If water application efficiency is 100 %, then DP is taken as zero. If the soil water content is less than or equal to FC, then DP becomes zero. For simplicity, 100% irrigation uniformity is assumed. In the soil water balance equation (Eq.10), the initial soil water content is considered constant through the deeper layers of the soil. As the roots deepen, this extra soil water contributes to the equation. Surface runoff water was ignored under the water deficit. The amount of groundwater (GW) is considered negligible. The variation of soil water content between time slot t is considered linear. Eq.1 is taken as a sum of addition. The water deficit ratio is restricted to 50 per cent (Eq.12) since the model is not reliable below this value. Average root length is 100 cm for all crops at all vegetation periods. This study does not consider the other factors which improve the yield including weather conditions, soil type, and fertilizer application. Considering the amount and intensity of rainfall during the summer in the region, this study does not require calculating the effective rainfall.

Model Sets and Parameters

Islahiye town is located in Gaziantep Turkiye, with Latitude 37.0253 (N), Longitude: 36.6311 (E), and Elevation in 518 m (TAGEM and DSI 2016). A study (Asil, 2018) examined the changes in plant patterns in irrigation areas during dry years. Droughts occurred in Islahiye in 2007, 2008, 2011, 2014, and 2016. The plant patterns of the irrigation areas of these years were examined, and it was observed that the planting rates of cotton, wheat, corn, vineyards, and carrots in the irrigation areas varied from year to year due to drought. The selection of cotton and silage maize is not a coincidence; they were selected on purpose.

Turkiye has 29 different climate regions, and Islahiye is located in the region numbered 22 and named the Eastern Mediterranean and Southeastern Anatolia corridor (TAGEM and DSI 2016). It is primarily influenced by the Mediterranean climate. The total annual average rainfall of Islahiye town is 797 mm. When Figure 2 is examined, it is seen that the global maximum points of rainfall are 62 mm in mid-December and 54 mm in mid-February. The driest period starts in mid-June and lasts until mid-September. There is no precipitation at all during this period.

Cotton and water demand

Cotton is primarily cultivated as a raw material for the global textile industry, including in Turkiye. A research study conducted by the Kahramanmaras Eastern Mediterranean Transition Zone Agricultural Research Institute found that the average yield of cotton was 3,450 kg per hectare during the 2012-2013 period (Gonen and Tanriverdi 2021). As the world cotton production in 2022/23 is 24.62 million tons, Turkey is the 6th largest producer with a production of 0.87 million tons (Ozudogru and TEPGE 2024).

The growth stages of cotton for Islahiye are given in Table 1. Cotton needs 700 to 1300 mm of water to meet its PET requirements depending on climate and the length of the total growing period. In the early vegetative period, crop water requirements are low, about 10 per cent of the total. They are high during the flowering and boll formation period when the leaf area is at its maximum or about 50 to 60 per cent of the total. In the growing period, the requirements decline.

Water consumption of cotton, the potential evapotranspiration PET(t) mm of cotton, 882 mm per year for Islahiye is given in Figure 3 (TAGEM and DSI 2016). Figure 3 shows the maximum amount of water consumed by cotton from planting in the first ten days of May (t=1) to harvesting in the second 10 days of October (t=18). This vegetation period lasts approximately 180 days. Based on the data presented in Figure 3, there appears to be a significant lack of rainfall from mid-June to mid-September, a crucial period for cotton crop growth and maintenance. During this timeframe, approximately 80% of irrigation water is utilized. While there is a small amount of rainfall in May and October, totaling approximately 110 mm, it is dispersed and does not contribute greatly to irrigation efficacy, particularly for cotton crops. The maximum water consumptions of cotton is from July-11-20 to August 21-31. The study does not require calculating effective rainfall, considering rainfall amount and intensity in summer season of Islahiye.

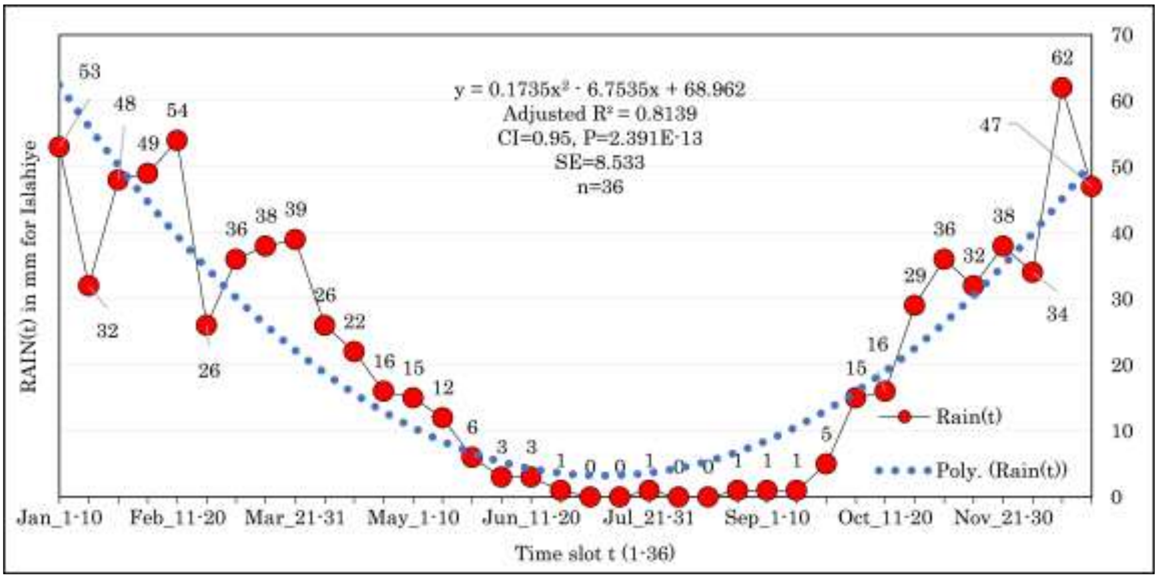


Figure 2 Region 22: Eastern Mediterranean and Southeastern Anatolia corridor region, Rainfall in Islahiye, Annually 797 mm (TAGEM and DSI 2016)

Şekil 2 Bölge 22: Doğu Akdeniz ve Güneydoğu Anadolu geçit bölgesi, İslahiye'de yıllık yağış miktarı 797 mm (TAGEM and DSI 2016)

The values in Figure 2 were used directly without additional calculations to find the net amount of rainfall. Almost half of the total irrigation need is consumed in the period from July II to August III. Crop water requirement, IRR(t), is 82, 94, 83, 82, and 83 mm on July 10-21, July 21-31, August 1-10, August 11-20, and August 21-31, respectively. The maximum amount of water is needed in the third ten days period of July.

The adjusted R^2 of the quadratic trendline in Figure 2 is 0.8025. This indicates that the relationship between time slot t and RAIN(t) is relatively strong, as the adjusted R^2 value is above 70%. The p-value for x^2 is 2.391E-13. Since the p-value for x^2 is less than 0.05 ($p < .05$), the null hypothesis H_0 is rejected. The high adjusted R^2 (0.8025) and low p-value for x^2 together suggest that the model is statistically significant and practically meaningful. In other words, a statistically significant quadratic relationship between time slot t and RAIN(t) exists. Since the range of RAIN(t) is 0 to 54 mm, SE = 8.53 is moderate relative to the range of RAIN(t), as it accounts for 15.8% of the total range. In many fields, an SE that is between 10-20 % of the range is considered moderate.

Table 1 Region 22: Eastern Mediterranean and Southeastern Anatolia corridor region crop growing periods for cotton and silage maize (TAGEM and DSI 2016)

Çizelge 1 Bölge 22: Doğu Akdeniz ve Güneydoğu Anadolu geçit bölgesi, pamuk ve silajlık mısır için ürün yetiştirme dönemleri

Crop	*Sowing (Planting time)*	*First period (Germination)*	*Second period (Vegetation)*	*Third period (Flowering and fruit growing)*	*Fourth period (Maturity and harvesting)*	*Total Vegetation period*
Cotton	Apr_11-20	30 days (t=1-3)	46 days(t=4-8)	60 days(t=9-14)	43 days (t=15-18)	179 days
Silage maize (summer)	Jul_I-10	20 days (t=1-2)	30 days(t=3-5)	40 days(t=6-9)	10 days(t=10)	100 days

Maize and water demand

Maize is the crop with the largest cultivation area after wheat and barley in Turkiye (Koc, ve diğerleri 2022). It is an essential plant that considerably contributes to human and animal nutrition and is cultivated over vast areas. It is highly valued as a green crop and for silage production. Maize can be cultivated as either a primary or secondary crop. In Turkiye, approximately 70% of the maize produced is utilized for livestock feed, including cattle, sheep, and poultry (Ozturk ve Orak 2020). Maize variety is widely grown as silage feed worldwide and in Turkiye due to its high dry matter production per unit area. According to a research study carried out by Kahramanmaras Eastern Mediterranean Transition Zone Agricultural Research Institute, it was determined that the average forage yield of maize was 63,630 kg ha-1 in the years 2019-2020 (Kizilsimsek, Gunaydin and Akbay 2024). In the 2022/23 season, world maize production is 1.16 billion tons, while it is 8.5 million tons for Turkey (Tasdan and TEPGE 2024).

The growth stages of silage maize for Islahiye are given in Table 1. Silage maize needs 400 to 700 mm of water to meet its PET requirements depending on climate and the length of the total growing period. In the early vegetative period, crop water requirements are low, or about 25 percent of the total. They are high during the flowering and grain formation period. Approximately ten days before harvesting the requirements decline. Water consumption of silage maize, the potential evapotranspiration PET(t) mm of cotton, 487 mm per year for Islahiye is given in Figure 4 (TAGEM and DSI 2016). According to Figure 4, there seems to be a notable lack of precipitation from July to October. This timeframe is essential for cultivating and maintaining silage maize crops, with almost all irrigation water being utilized during this period. Although a meagre quantity of rainfall, around 20 mm, is observed in the last ten days of September and the first ten days of October. It is scattered and does not contribute to irrigation efficacy for silage maize. The maximum water consumption of silage maize is from Aug_1-1 to Sep_11-20, which is almost 70% of the total consumption of 487 mm or 4,870 m^3 ha-1. In this study, effective rainfall was not calculated. Crop Water Requirement CWR, is 55, 74, 83, 64, and 57 mm for the time slots of Aug_1-10, Aug_11-20, Aug_21-31, Sep_1-10, and Sep_11-20, respectively. The highest water requirement is during the third ten days of August (Aug_21-31).

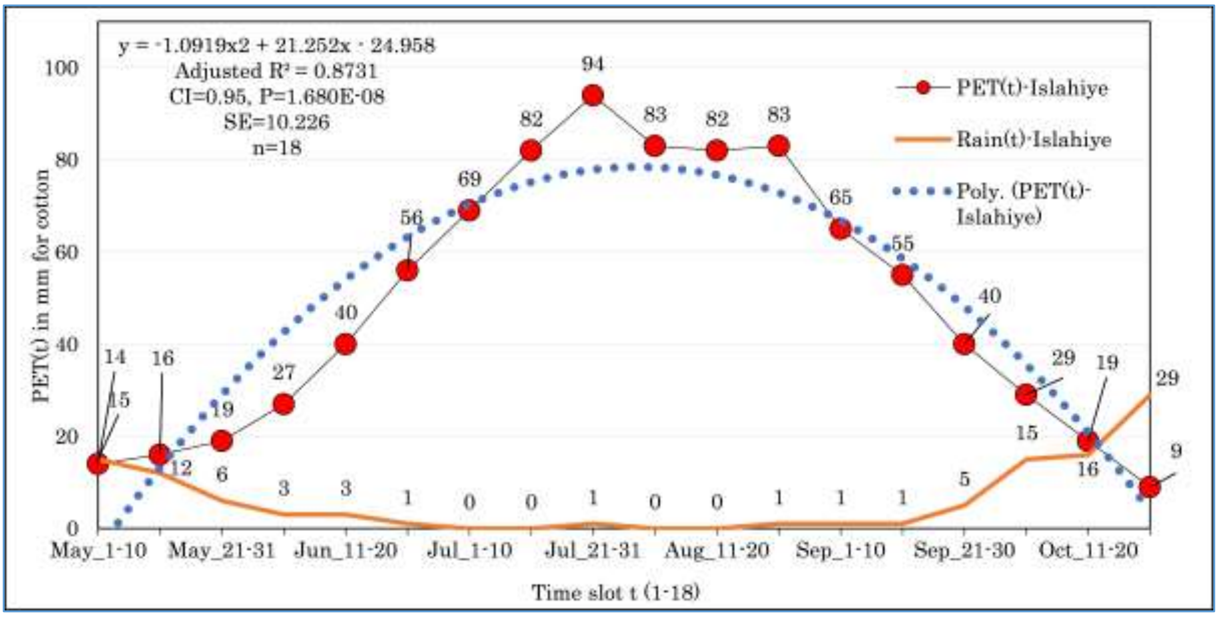


Figure 3 Potential Evapotranspiration PET(t) mm of cotton, 882 mm per year for Islahiye and RAIN(t) (TAGEM and DSI 2016)

Şekil 3 Pamuğun Potansiyel Evapotranspirasyon PET(t) mm değeri, İslahiye için yıllık 882 mm ve yıllık yağış miktarı RAIN(t) (TAGEM and DSI 2016)

The adjusted R^2 of the quadratic trendline in Figure 3 is 0.8731. This indicates that the relationship between time slot t and PET(t) is relatively strong, as the adjusted R^2 value is above 70%. The p-value for x^2 is 1.680E-08. Since the p-value for x^2 is less than 0.05 ($p < .05$), the null hypothesis H_0 is rejected. The high adjusted R^2 (0.8731) and low p-value for x^2 together suggest that the model is statistically significant and practically meaningful. In other words, a statistically significant quadratic relationship between time slot t and PET(t) exists. Since the range of PET(t) is 9 to 94 mm, SE = 10.22 is moderate relative to the range of RAIN(t), as it accounts for 12.0% of the total range. In many fields, an SE that is between 10-20 % of the range is considered moderate.

Statistical Analysis

MS Excel 2016 TOOLPAK for the Regression analysis tool which performs linear regression analysis (Output: Analysis of Variance, ANOVA) by using the "least squares" method to fit a line/curve through a set of observations by a single dependent one or more independent variables was used to analyze the data of Figures 2, 3, 4, 5, 7 and 9 (CI=0.95, p<.05).

Since we have more than one (five) dependent variables or predictors, STATGRAPHICS Centurion v16, multiple sample comparison analysis (Output: Analysis of Variance, ANOVA) was used to analyze the data of Figures 6 and 8.

RESULTS and DISCUSSION

Crop Yield Calculation of Cotton

The optimization model in equations 11-16 was solved to maximize the objective function yield ratio (Ya/Ym) by a Mixed-Integer Programming (MIP) Solver. Variable IRR(t), AET(t), SMA(t) and DP(t) were calculated. The time slot set t is valued 1-18 and corresponds to May_1-10 to Oct_21-31. Scalar values: SMF, Soil field capacity maximum soil moisture is 3.2 mm per cm, SMW, Soil wilting point is 1.6 mm per cm, AE, Irrigation application efficiency is 0.85, DF, Critical soil water depletion fraction is 0.5, SMAINIT, Initial soil moisture at time t=1 is 2.8mm per cm, and AREA, Total command area is 10,000 m^2 or one hectare.

Parameters: RAIN(t), Rainfall in time slot t for Islahiye in mm is given in Figure 2, PET(t), Standard potential evapotranspiration for cotton in time slot t for Islahiye is given in Figure 3 in mm, $Ky_{ass}(t)$, Yield factor values for cotton in time slot t from 1 to 18 are assumed as 0.2, 0.2, 0.25, 0.25, 0.25, 0.25, 0.35, 0.45, 0.5, 0.5, 0.45, 0.4, 0.3, 0.25, 0.25, 0.25, 0.2, and 0.20, respectively. While the Actual yield over maximum yield, Ya/Ym is free variable;

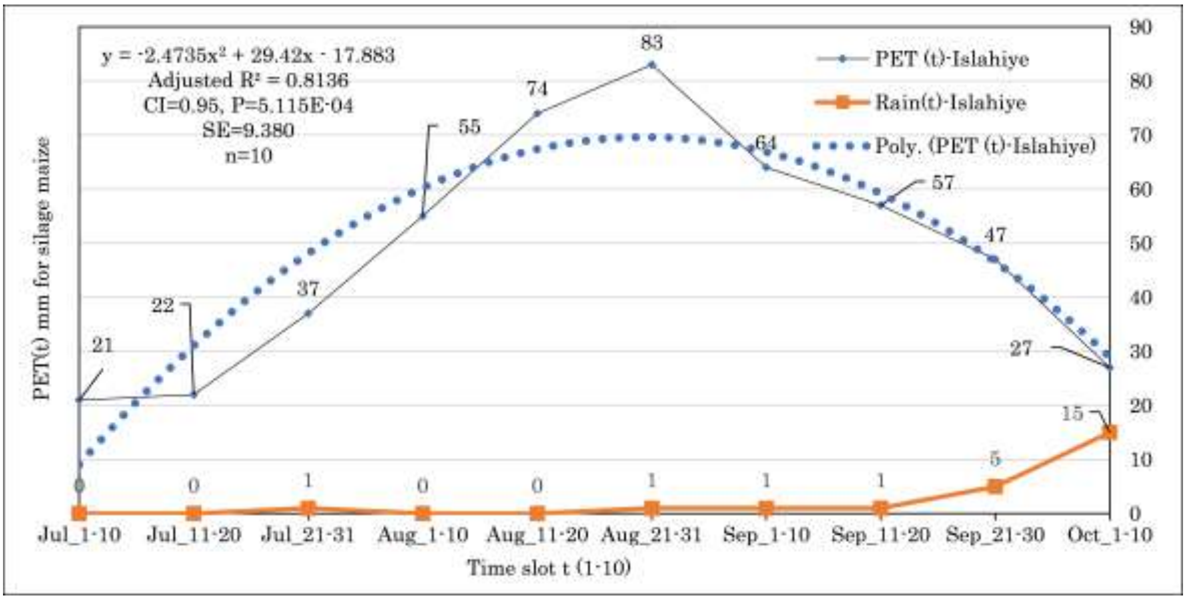


Figure 4 Potential Evapotranspiration PET(t) mm of silage maize, 487 mm per year for Islahiye and RAIN(t) (TAGEM and DSI 2016)

Şekil 4 Silajlık mısırın Potansiyel Evapotranspirasyon PET(t) mm değeri, İslahiye için yıllık 487 mm ve yıllık yağış miktarı RAIN(t) (TAGEM and DSI 2016)

The adjusted R^2 of the quadratic trendline in Figure 4 is 0.8136. This indicates that the relationship between time slot t and PET(t) is relatively strong, as the adjusted R^2 value is above 70%. The p-value for x^2 is 5.115E-04. Since the p-value for x^2 is less than 0.05 ($p < .05$), the null hypothesis H_0 is rejected. The high adjusted R^2 (0.8136) and low p-value for x^2 together suggest that the model is statistically significant and practically meaningful. In other words, a statistically significant quadratic relationship between time slot t and PET(t) exists. Since the range of PET(t) is 21 to 83 mm, SE = 9.380 is moderate relative to the range of RAIN(t), as it accounts for 15.1% of the total range. In many fields, an SE that is between 10-20 % of the range is considered moderate.

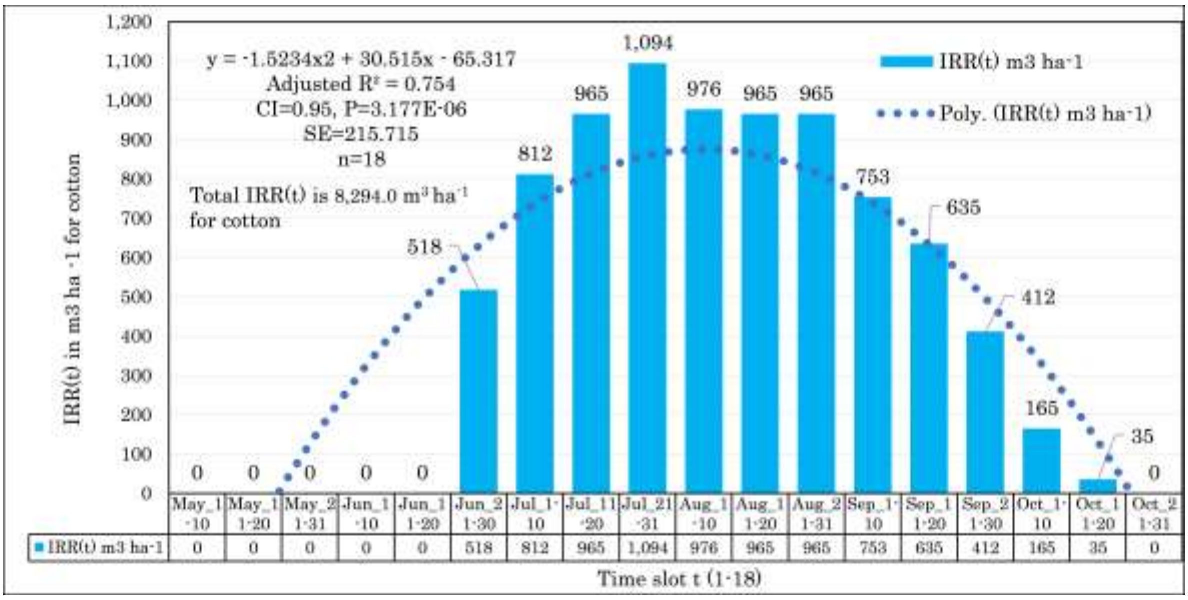


Figure 5 IRR(t) Irrigation amount of water in time slot t of cotton in m3 ha-1 for Islahiye
Şekil 5 IRR(t) İslahiye'de t zaman diliminde pamuk için m3 ha-1 olarak sulama suyu miktarı

Actual Soil moisture SMA(t), Actual evapotranspiration AET(t), Deep Percolation DP(t) and Allocated amount of water IRR(t) are positive variables. According to Figure 5, the crop water requirement of cotton starts at time t equals 6 (The third ten-day of June) with 517.7 m3 ha-1 and ends at t equals 17 (The second ten-day of October) with 35 m3 ha-1. The irrigation water requirement of cotton for the maximum yield is 8,294 m3 ha-1 for Islahiye for the whole vegetation season, 180 days. Maximum yield means actual yield Ya equals Ym, and then Ya/Ym= 1.

The adjusted R^2 of the quadratic trendline in Figure 5 is 0.754. This indicates that the relationship between time slot t and IRR(t) is relatively strong, as the adjusted R^2 value is above 70%. The p-value for x^2 is 3.177E-06. Since the p-value for x^2 is less than 0.05 ($p < .05$), the null hypothesis H_0 is rejected. The high adjusted R^2 (0.754) and low p-value for x^2 together suggest that the model is statistically significant and practically meaningful. In other words, a statistically significant quadratic relationship between time slot t and IRR(t) exists. Since the range of IRR(t) is 0 to 1.094 mm, SE = 215.71 is moderate relative to the range of IRR(t), as it accounts for 19.7 % of the total range. In many fields, an SE that is between 10-20 % of the range is considered moderate.

Table 2 gives the amount of IRR(t) for different percentages of water deficit, starting from 0% up to 20%, incrementing 5% per step, applied to the whole vegetation period of cotton. The content of Table 2 is graphically represented in Figure 6. In this study, the efficiency of the ideal irrigation amount was compared with the efficiency at various water shortage rates. Water scarcity rates were 95%, 90%, 85% and 80%. At higher rates of water scarcity, the model does not work properly. Yield ratio Ya/Ym and water deficit per cent relationship of cotton for Islahiye were given in Table 2. Comparison of water deficit ratio [1-AET(t)/PET(t)] in per cent with respect to water consumption of cotton.

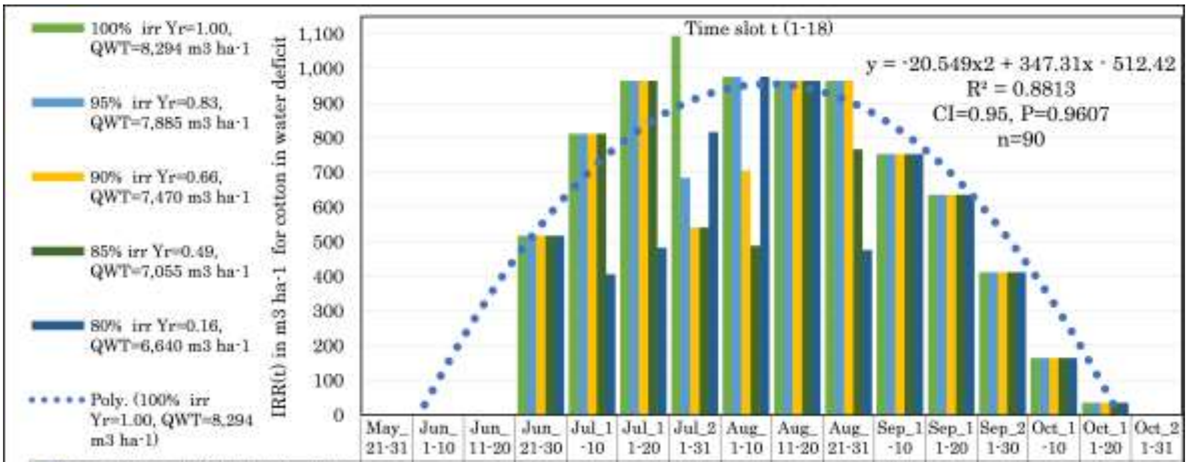
Table 2 Cotton yield response factor (water deficit sensitivity) Ky for Islahiye for water deficit 5 %, 10%, 15% and 20%
Çizelge 2 Pamuğun verim tepki faktörünün (Kısıntılı Sulama hassasiyeti), %5, %10, %15 ve %20 kısıntılı sulamaya bağlı olarak değişen değerleri

	Cotton water sensitivity			*Total IRR(t) in m³ per hectare (Islahiye)*
AET(t) PET(t)⁻¹	*Water Deficit %*	*Ya Ym⁻¹*	*Ky*	
1.00	0%	1.00	1.00	8,300
0.95	5%	0.83	3.36	7,890
0.90	10%	0.66	3.40	7,470
0.85	15%	0.48	3.47	7,060
0.80	20%	0.30	3.50	6,640

Crop Yield Calculation of Silage Maize

The optimization model in equations 11-16 was solved to maximize the objective function yield ratio Yr (Ya/Ym) by a Mixed-Integer Programming (MIP) Solver. Variable IRR(t), AET(t), SMA(t) and DP(t) were calculated. The time period set t is valued 1-10 and corresponds to Jul_1-10 to Oct_1-10. Scalar values: SMF, Soil field capacity maximum soil moisture is 3.2 mm per cm, SMW, Soil wilting point is 1.6mm per cm, IAE, Irrigation application efficiency is 0.85, DF, Critical soil water depletion fraction is 0.5, SMAINIT, Initial soil moisture at time t=1 is 2.8 mm per cm, and AREA, Total command area is 10,000 m^2 or one hectare.

Parameters: RAIN(t), Rainfall in time slot t for Islahiye in mm is given in Figure 2, PET(t), Standard potential evapotranspiration for silage maize in time slot t for Islahiye are given in Figure 4. Kyass(t), Yield response factor values for silage maize in time slot t from 1 to 10 are assumed as 0.4, 0.4, 0.9, 1.5, 1.5, 1.5, 0.9, 0.5, 0.20 and 0.2, respectively. While Actual yield over maximum yield, Ya/Ym is free variable; SMA(t), Actual Soil moisture, AET(t),



	May_ 21-31	Jun_ 1-10	Jun_ 11-20	Jun_ 21-30	Jul_1 -10	Jul_1 1-20	Jul_2 1-31	Aug_ 1-10	Aug_ 11-20	Aug_ 21-31	Sep_1 -10	Sep_1 1-20	Sep_2 1-30	Oct_1 -10	Oct_1 1-20	Oct_2 1-31
100% irr Yr=1.00, QWT=8,294 m3 ha-1	0	0	0	518	812	965	1094	976	965	965	753	635	412	165	35	0
95% irr Yr=0.83, QWT=7,885 m3 ha-1	0	0	0	518	812	965	685	976	965	965	753	635	412	165	35	0
90% irr Yr=0.66, QWT=7,470 m3 ha-1	0	0	0	518	812	965	541	705	965	965	753	635	412	165	35	0
85% irr Yr=0.49, QWT=7,055 m3 ha-1	0	0	0	518	812	965	541	488	965	767	753	635	412	165	35	0
80% irr Yr=0.16, QWT=6,640 m3 ha-1	0	0	0	518	406	482	816	976	965	476	753	635	412	165	35	0

Figure 6 Yield ratio Ya/Ym and water deficit per cent relationship of cotton for Islahiye for water deficit 5 %, 10%, 15%, and 20%

Figure 6 İslahiye'de pamuk için Ya/Ym verim oranıyla, %5, %10, %15 ve %20 kısıntılı sulama arasındaki ilişki

For the data of Figure 6, one dependent (time slot t) and 5 independent variables (irrigation amount in 5 different deficit ratios), the ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F ratio, which in this case equals 0,154065, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is greater than or equal to 0,05, there is not a statistically significant difference between the means of the 5 variables at the 95,0% confidence level.

Actual evapotranspiration, DP(t), Deep Percolation and IRR(t), Allocated amount of water in cubic meter are positive variables. According to Figure 7, the crop water requirement of silage maize starts at time slot t number 1(The first ten-day of July) with 271 m3 ha-1 and ends at t number 10 (The first ten-day of October) with 142 m3 ha-1. The irrigation water requirement of silage maize for one hectare for Islahiye is 5,470 m3 for the whole vegetation season, 100 days, for the maximum yield. Maximum yield means actual yield Ya equals Ym, and then Ya/Ym = 1.

The adjusted R^2 of the quadratic trendline in Figure 7 is 0.797. This indicates that the relationship between time slot t and IRR(t) is relatively strong, as the adjusted R^2 value is above 70%. The p-value for x^2 is 5.124E-04. Since the p-value for x^2 is less than 0.05 ($p < .05$), the null hypothesis H_0 is rejected. The high adjusted R^2 (0.797) and low p-value for x^2 together suggest that the model is statistically significant and practically meaningful. In other words, a statistically significant quadratic relationship between time slot t and IRR(t) exists. The range of IRR(t) is 141.18 to 964.71mm and SE = 12.375 is regarded as a good fit to the range of IRR(t), as it accounts for 1.50 % of the total range. In many fields, an SE that is less than 10% of the range is considered a good fit.

Yield ratio Ya/Ym and water deficit per cent relationship of silage maize for Islahiye were given in Table 3. Comparison of water deficit ratio [1-AET(t)/PET(t)] in per cent with respect to water consumption of silage maize. Table 3 gives the amount of IRR(t) for different percentages of water deficit, starting from 0% up to 20%, incrementing 5% per step, applied to the whole vegetation period of silage maize. The content of Table 3 are graphically represented in Figure 8. In this study, the efficiency of the ideal irrigation amount was compared with the efficiency at various water shortage rates. Water scarcity rates were 95%, 90%, 85% and 80%. At higher rates of water scarcity, the model does not work properly.

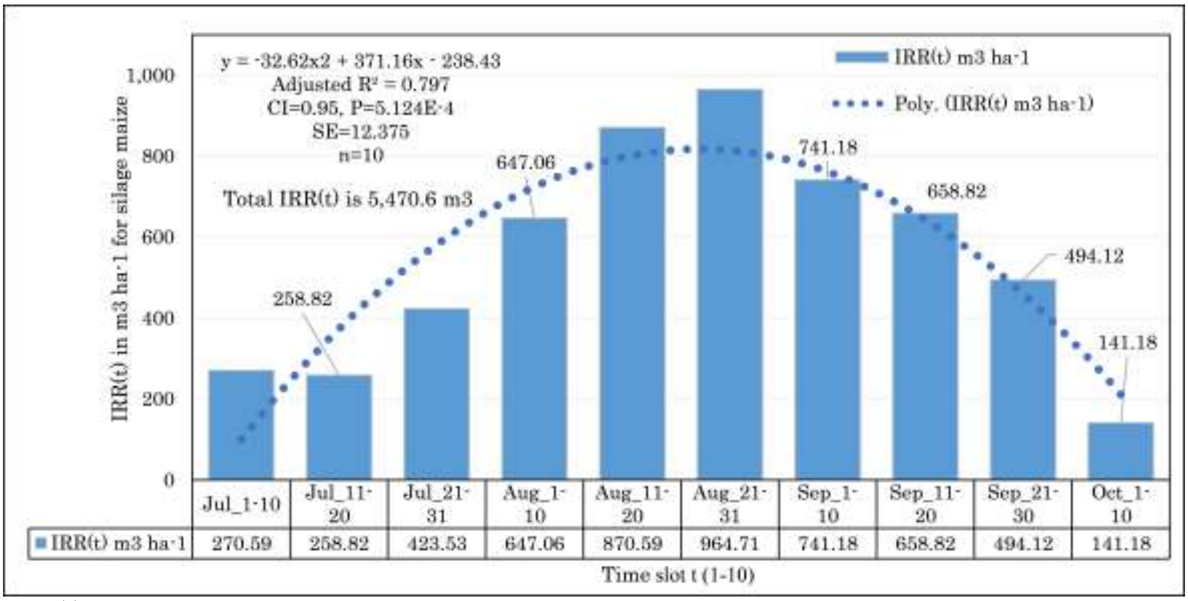


Figure 7 IRR(t) Irrigation amount of water in time slot t in m3 ha-1 of silage maize for Islahiye
Şekil 7 IRR(t) İslahiye'de t zaman diliminde silajlık mısır için m3 ha-1 olarak sulama suyu miktarı

Table 3 Silage maize yield response factor (water deficit sensitivity) Ky for Islahiye for water deficit 5 %, 10%, 15% and 20%
Çizelge 3 Silajlık mısırın verim tepki faktörünün (su kıtlığı hassasiyeti) %5, %10, %15 ve %20 kısıntılı sulama oranlarına bağlı olarak değişen değerleri

Silage-maize yield response factor to water deficit				*Total IRR(t) in m^3 ha-1 (Islahiye)*
AET(t) $PET(t)^{-1}$	*Water Deficit*	*Ya Ym^{-1}*	*Ky*	
1.00	0%	1.00	0	5,470
0.95	5%	0.90	2	5,210
0.90	10%	0.72	2.8	4,930
0.85	15%	0.50	3.34	4,660
0.80	20%	0.17	4.14	4,380

Water deficit concerning Ky

Analyzing the yield water sensitivities of cotton and silage maize at different water deficit rates needs to be clarified. The Average Ky of cotton and silage maize given in Table 2 and Table 3 are 3.43 and 3.07, respectively. If the water deficit sensitivities of these two crops are compared, the average Ky of cotton is higher than that of silage maize's. According to Figure 9 the silage maize with a regression (trendline) line y = 0.696x + 1.33, R^2= 0.9944 comparing with regression line of cotton y = 0.0487x + 3.31, R^2 = 0.9841 are considered, the silage maize is more sensitive to water deficit than cotton beyond water deficit per cent more than 15%.

For the data of Figure 8, one dependent (time slot t) and 5 independent variables (irrigation amount in 5 different deficit ratios), the ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F ratio, which in this case equals 0,208587, is a ratio of the between-group estimate to the within-group estimate. Since the P-value (0.9321) of the F-test is greater than 0,05, there is not a statistically significant difference between the means of the 5 variables at the 95,0% confidence level.

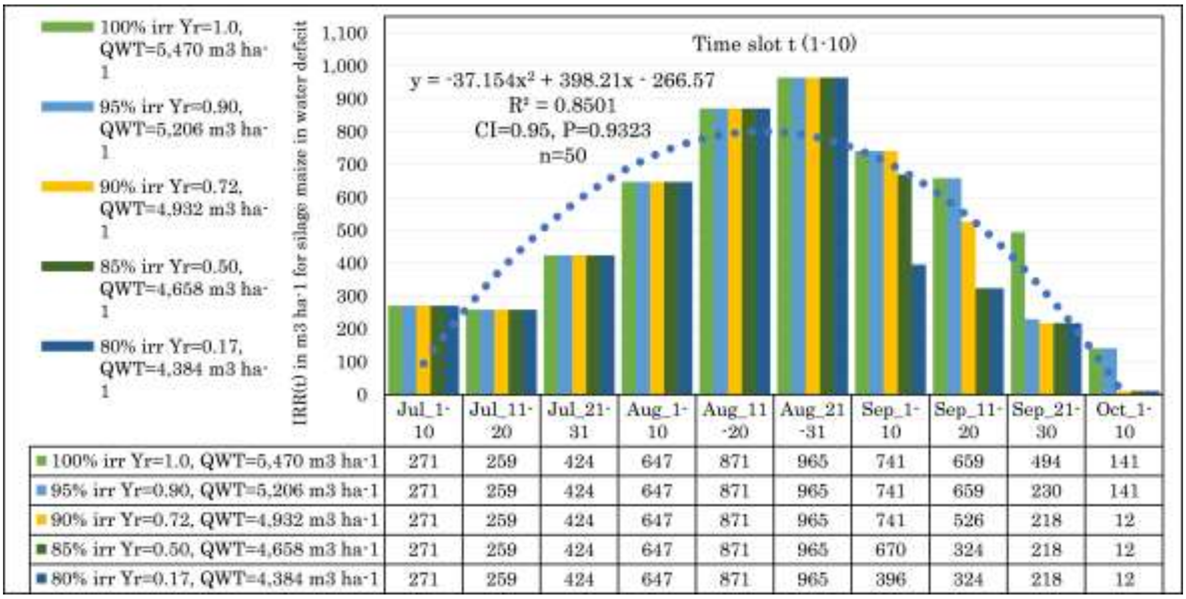


Figure 8 Yield ratio Yr= Ya/Ym and water deficit percent relationship of silage maize for Islahiye for water deficit 5 %, 10%, 15% and 20%

Şekil 8 İslahiye'de silajlık mısır için Ya/Ym verim oranıyla, %5, %10, %15 ve %20 kısıntılı sulama oranları arasındaki ilişki

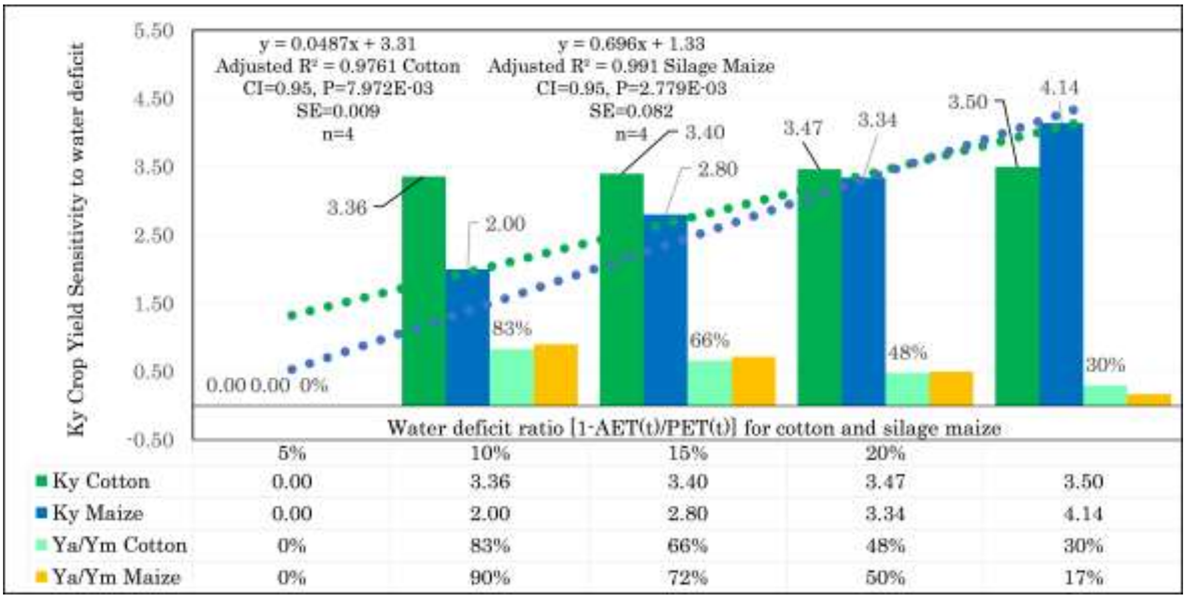


Figure 9 The relationship with water deficit [1-AET(t)/PET(t)] in per cent 5 %, 10%, 15% and 20%. and crop yield ratio Ya/Ym with respect to Ky crop yield factor

Şekil 9 Verim tepki faktörü Ky ve bitki verim katsayısı Ya/Ym ile %5, %10, %15 ve kısıntılı sulama oranları [1-AET(t)/PET(t)] arasındaki ilişki

The x-axis of Figure 9 represents the water deficit ratio ranging from 0% to 20%, indicating increasing water stress. The y-axis represents two independent variables Ky for cotton and silage maize. Their trendlines are $y= 0.0487x + 3.31$ with an Adjusted $R^2 = 0.9761$ for cotton and $y = 0.696x + 1.33$ with an Adjusted $R^2 = 0.991$ for silage maize. It can be deduced that there is a strong positive linear relationship between the water deficit ratio and Ky for both.

Confidence Interval (CI) in the results is 0.95 for both crops. The P value is = 7.972 E-03 for cotton and 2.779 E-03 for silage maize. Statistically, both values are significant since they are highly bigger than 0.05. Then the null hypothesis H0 are rejected for both cotton and silage maize. The Standard Error (SE) is 0.009, which indicates high precision for cotton, while 0.082 for silage maize designates a slight increase over 0.05 but still represents a high level of precision. The two crops have a total of 4 data points, which has a small sample size (n=4), but is sufficient for the analysis of the trends.

Silage Maize has a steeper slope (0.696)) compared to cotton (0.0487)), meaning silage maize is more sensitive to water deficit. Its performance declines more rapidly as water stress increases. At 0% water deficit (no stress), both crops perform well, but as the deficit increases, their performance declines. Silage Maize shows a sharper decline, which makes it more vulnerable to water stress compared to cotton. Maize is significantly affected by water stress, which impacts various yield components such as plant height, dry weight, and grain yield. The correlation between these traits and yield is notably altered under stress conditions, emphasizing the crop's sensitivity to water deficit. (Khatibi, et al. 2023). Drought stress affects maize forage yield and quality, with significant reductions in wet and dry forage yields under reduced irrigation (Lobell, Deines and Tommaso 2020).

While cotton yield drops from 100% to 30% as water deficit increases, silage maize yield drops from 100% to 17%, showing greater yield sensitivity. The larger slope for silage maize shows it suffers a greater yield loss per unit of water deficit than cotton. Cotton is more resistant to water deficit, but both crops experience severe yield loss beyond a 15-20% deficit.

If they compete for the same water resources which are limited or unreliable and the only factor is the yield to take a decision, choose cotton. Cotton's yield remains stable even under water stress, making it a more resilient choice. Choose silage maize only if water resources are abundant and consistent. Its yield may be higher under optimal conditions since it is more vulnerable to water stress.

While silage maize is more sensitive to water stress, it may offer higher yields under optimal conditions. The choice between silage maize and cotton should consider not only water availability but also economic and agronomic factors such as market value, soil suitability, and pest resistance (Wei, et al. 2019). These considerations are crucial for making informed decisions. There is no doubt that not only economic but social factors such as agricultural practices also affect the decision. We should consider all the factors have an impact on the decision.

CONCLUSION

The main data source used in this study is the Turkiye Plant Water Consumption Guide, published by TAGEM and DSI in 2016. This guide was prepared using the FAO Penman-Monteith method and this makes it a unique and valuable source for irrigation studies of Turkiye. This study takes related data, including PETc of crops, growing periods, vegetation time, and rainfall values from this source. Studies related to crop yield sensitivity factors are mainly supported by practical field studies, considerably contribute to the country's economy and the sustainable use of natural resources, usually conducted by agricultural scientists in Turkiye. Our model and solution of the problem using the optimization algorithms make our study one step ahead.

In this article, we present the findings of our unbiased investigation into the impact of water scarcity on the yield of cotton and silage maize. Our research, conducted using the data of Gaziantep's Islahiye district, reveals an interesting observation. Despite both crops competing for water during the same period, the difference in their water-yield sensitivity relationship is moderate.

This study reveals that the yields of both crops are highly affected by water deficit. Their sensitivities change depending on the percentage of water deficit. Until a 15 per cent deficit, cotton is more sensitive, and beyond this value, silage maize has higher sensitivity.

Our model was developed under the assumption that water deficit remains consistent across all time periods (t). The crop response factor to water deficit, Ky^t, varies for each plant depending on its growth stage. Typically, the flowering and fruiting stages are the most vulnerable to drought. For instance, the highest Ky^t for cotton occurs during the flowering and boll formation period, which corresponds to time periods t9 to t14. In contrast, for maize, the peak Ky^t is observed during the grain development period, which spans from t6 to t9. Incorporating these considerations into future model studies will yield more meaningful results for practical applications.

To make a decision, choose cotton over silage maize if there are limited or unreliable water resources and only the yield matters. The yield of cotton remains stable under water stress, which makes it more resilient. If water resources are abundant and consistent, silage maize is a good choice. As it is more sensitive to water stress, its yield may be higher under ideal conditions.

This article points out a critical knowledge gap regarding water stress forecasting in the Eastern Mediterranean region. Since linear models are inherently limited in capturing non-linear dynamics of climate data, advanced forecast models and artificial intelligence (AI) algorithms are recommended. These innovative approaches, with their continually evolving capabilities, are crucial in addressing the water stress in the region and improving agricultural water management.

Summary of Researchers' Contribution Declaration

The authors declare that they have contributed equally to the article.

Conflict of Interest Statement

The authors of the articles declare that they have no conflict of interest.

REFERENCES

Akcay, S., and N. Dagdelen. 2016. "Water Use Efficiency, Yield and Yield Components of Second Crop Sunflower Under Deficit Irrigation." *Turkish Journal of Field Crops 21(2), 190-199*. doi:10.17557/tjfc.05690.

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. 1998. "FAO Irrigation and Drainage Paper No. 56 Crop Evapotranspiration." (Food and Agriculture Organization of the United Nations).

Asil,, H. 2018. "Irrigation from Tahtakopru Dam Change of Plant Pattern in the Dry Years of Irrigation." *International Eurasian Conference on Science, Engineering and Technology November 22-23, 2018.* Ankara: (EurasianSciEnTech 2018). Accessed October 30, 2024. https://www.researchgate.net/publication/329972930_Tahtakopru_barajindan_sulama_yapan_sulama_birliklerinin_kurak_yillarda_bitki_deseni_degisikligi. ,

Doorenbos, J., and A. H. Kassam. 1979. "Yield Response to Water FAO-33". Rome, The Food and Agriculture Organization of the United Nations.

Droogers, P., and R. G. Allen . 2002. "Estimating Reference Evapotranspiration Under Inaccurate Data Conditions." *Irrigation and Drainage Systems (Food and Agriculture Organization of the United Nations) 16*, 33–45. doi:doi.org/10.1023/A:1015508322413.

FAO,. 2017. "*The Future of Food and Agriculture Trends and Challenges"*. Rome: FAO.

Ghahraman, B., and A. R. Sepaskhah. 2004. "Linear and non-linear optimization models for allocation of a limited water supply." *Irrigation and Drainage 1,* 39-54. doi:doi.org/10.1002/ird.108.

Ghahraman, B., and A. R. Sepaskhah. 2002. "Optimal allocation of water from a single purpose reservoir to an irrigation project with pre-determined multiple cropping patterns." *Irrig Sci 21*, 127-137. doi:doi.org/10.1007/s002710100040.

Gonen, E., and C. Tanriverdi. 2021. "The Effects of Different Nitrogen Levels and Irrigation Intervals on Yield and Water Productivity of Cotton Grown in the Eastern Mediterranean Region." *Turkish Journal of Agricultural and Natural Sciences (TURKJANS) 1,* 898 - 904. doi:doi.org/10.30910/turkjans.789963.

IPCC,. 2021. *Climate Change (IPCC).* Cambridge University Press, 2023. Accessed February 5, 2025. doi:https://doi.org/10.1017/9781009157896.

Irmak,, S. 2008. "Evapotranspiration." In Encyclopedia of Ecology, by Fath B. D. Jørgensen S.E., 1432-1438. Academic Press 1. doi:doi.org/10.1016/B978-008045405-4.00270-6.

Jia, L., L. Xuecan, S. Yuanyuan, and Y. Haiye. 2024. "Different Irrigation Rates Effect on the Yield and Quality of Greenhouse Cultivated Platycodon Grandiflorum Crops Considering Transpiration." *Turkish Journal of Agriculture and Forestry (Tubitak) 48*, 1-14. doi:10.55730/1300-011X.3158.

Khatibi, A., S. Omrani, A. Omrani, S. H. Shojaei, A. Illés, C. Bojtor, S. Mousavi, and J. Nagy. 2023. "Study of drought stress correlation on yield and yield components of maize cultivars (Zea mays L.)*". Acta Agraria Debreceniensis*. doi:https://doi.org/10.34101/actaagrar/1/11495.

Kizilsimsek, M., T. Gunaydin, and F. Akbay. 2024. "Determination of Feed Quality Chracteristics of Soma Silage Maize (Zea Mays L.) Hybrids Cultivated in Eastern Mediterranean Conditions." *Turkish Journal of Field Crops 29 (1)*, 46-53. doi:1017557/tjfc1458251.

Koc, D. L., M. Unlu, A. Nur, and R. Kanber. 2022. "Determination of Crop Evapotranspiration and Single Crop Coefficients of Maize Using by a Using by a Weighing Lysimeter in Mediterranean Region in Turkey." *KSU J. Agric Nat 25 (4)*, 890-900. doi:10.18016/ksutarimdoga.vi.802192.

Lobell, D. B., J. M. Deines, and S. Tommaso. 2020. "Changes in the drought sensitivity of US maize yields." *Nature Food,* 729-735. doi:https://doi.org/10.1038/s43016-020-00165-w.

Loucks, D., and Beek E. Van. 2017. *Water Resource Systems Planning and Management An Introduction to Methods, Models, and Applications.*

Ozturk, Yasin, and Adnan Orak. 2020. "Determination of the Yield and Yield Components of Some Corn Varieties as a Second Crop in Tekirdag." *KSU J. Agric Nat 23 (6)*, 1634-1646. doi:10.18016/ksutarimdoga.vi.727880.

Ozudogru, T., and TEPGE. 2024. *Agricultural Products Market Cotton.* Monthly, Ankara: TEPGE-Agricultural Economics and Policy Development Institute. Accessed February 12, 2025. https://arastirma.tarimorman.gov.tr/tepge.

Rao, N. H., P.B. S. Sarma, and S. Chander. 1988. "A Simple Dated Water-Production Function for Use in Irrigated Agriculture." *Agricultural Water Management 13*, 25-32. doi:doi.org/10.1016/0378-3774(88)90130-8.

Steduto, P., T. C. Hsiao, E. Fereres, and D. Raes. 2012. "Crop yield." *FAO Irrigation and Drainage Paper (FAO) 66*. Accessed October 30, 2024. https://www.fao.org/4/i2800e/i2800e00.pdf.

TAGEM, and DSI. 2016. *Plant-Water Use Guide of irrigated crops in Turkey.* Ankara.

Tasdan, K., and TEPGE. 2024. *Agricultural Products Markets Misir.* Ankara: TEPGE. Accessed February 12, 2025. https://arastirma.tarimorman.gov.tr/tepge.

UN-Water,. 2023. *Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2023.* Newyork: United Nations Publications.

Vedula, S., and P. P. Mujumdar. 2016. "Applications of Linear Programming." Chap. 7 in *Water Resources Systems - Modelling Techniques and Analysis*, 207-214. Bangalore: Indian Institute of Science.

Wei, Y., J. Jin, S. Jiang, S. Ning, Y. Cui, and Y. Zhou. 2019. "Simulated Assessment of Summer Maize Drought Loss Sensitivity in Huaibei Plain, China." *Agronomy 9(2), 78* . doi:https://doi.org/10.3390/agronomy9020078.

Worldbank,. 2021. Accessed October 2, 2024. https://www.worldbank.org/en/topic/water/publication/ebb-and-flow-water-migration-and-development.

Xing, L., Y. Feng, N. Cui, L. Guo, T. Du, Z. Wu, Y. Zhang, S. Wen, D. Gong, and L. Zhao. 2023. "Estimating Reference Evapotranspiration Using Penman-Monteith Equation." *Journal of Hydrology Volume 620 (Part A)*, doi:doi.org/10.1016/j.jhydrol.2023.129407.