

Modeling Irrigation Timing and Amounts for Sunflower Under Deficient Water Conditions: A Case Study in Adana

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Abstract

Agriculture has been threatened by insufficient rainfall due to climate change, which makes water-saving measures essential to producing enough food for the world's expanding population. The economic and environmental viability of commercial agriculture depends on the use of water-saving irrigation systems. This study used the CROPWAT Model to estimate the optimal irrigation dates and irrigation amount of Sunflower in the Adana Region for the period of 1991-2020. The CROPWAT software was supplied with climate, precipitation, soil, and crop data to determine the solar radiation, reference evapotranspiration, crop evapotranspiration, effective rainfall, and crop water requirements. The Average reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), and effective rainfall (Reff) were found to be 3.9mm/day, 624 mm, and 108mm, respectively. Irrigation amounts at critical depletion (IR_{cd}) and at user-defined (IR_{ud}) were obtained as 462 mm and 416 mm from the result. The findings also demonstrate that there were five irrigation applications throughout the growing season, which significantly enhanced crop yield and optimized water use efficiency relative to treatments with fewer irrigation events.

Keywords: CROPWAT, Crop Evapotranspiration, Net Irrigation, Effective Rainfall, Crop Water Requirement

Citation: Ibrahim Y.S., Umar U.M., Sen B. Modeling Irrigation Timing and Amounts for Sunflower Under Deficient Water Conditions: A Case Study in Adana. *Impact in Agriculture*. 2025, 1, 4. <https://doi.org/10.65500/agriculture-2025-004>

Received: 19 September 2025 | Revised: 27 October 2025 | Accepted: 21 November 2025 | Published: 03 December 2025

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1. Introduction

The global production of major oil crops has increased steadily in recent decades, driven by rising demand for edible vegetable oils and the expanding use of oil crops in biofuel production [1]. After cereals, oil crops represent one of the most important groups in terms of cultivated area worldwide. However, increasing pressure on freshwater resources, coupled with climate variability, has intensified the need for efficient irrigation planning and sustainable water management in oilseed crop production.

Sunflower (*Helianthus annuus* L.) is a major oilseed crop cultivated widely across temperate and semi-arid regions due to its adaptability to diverse environmental conditions. It is considered a relatively short-duration, day-neutral crop with moderate tolerance to drought and salinity [2]. Globally, sunflower ranks fourth among oilseed crops after soybean, rapeseed, and peanut in terms of production [3]. In Turkey, sunflower plays a crucial role in domestic vegetable oil supply, with significant production concentrated in regions such as Trakya and southern Anatolia. Although sunflower is commonly grown under rainfed conditions, supplemental irrigation is

often required in sub-humid and semi-arid areas with irregular rainfall patterns to achieve stable yields and improve water productivity [4].

Efficient irrigation scheduling requires accurate estimation of reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), and crop water requirements. The FAO CROPWAT model, developed by the Land and Water Development Division of the Food and Agriculture Organization, is widely used for irrigation planning and water management worldwide [5]. The model integrates climatic, crop, and soil data to estimate crop water requirements, design irrigation schedules, and evaluate alternative irrigation strategies under different water availability scenarios [6]. Due to its simplicity, reliability, and broad applicability, CROPWAT has been extensively applied in both research and practical irrigation management.

Previous studies have used CROPWAT and related approaches to estimate evapotranspiration, net irrigation requirements, and irrigation scheduling for various crops under different climatic conditions. Accurate determination of crop water requirements has been highlighted as a key factor for improving irrigation efficiency and sustainable water use [6,7]. Several studies have assessed irrigation strategies for crops such as maize, rice, soybean, oats, and sunflower in different regions, demonstrating the influence of growth stages, soil properties, and climate on water demand and yield response [2,8–10]. However, most existing studies are limited to short-term analyses or specific irrigation treatments and do not sufficiently explore long-term climatic variability or comparative irrigation scenarios.

In particular, comprehensive long-term assessments of sunflower irrigation requirements under Mediterranean climatic conditions remain limited for southern Turkey, including the Adana region. Moreover, few studies have evaluated sunflower irrigation scheduling by systematically comparing rainfed conditions with critical depletion and user-defined irrigation strategies over extended climatic periods.

Therefore, the objective of this study was to estimate reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), and irrigation scheduling for sunflower grown in Adana using the FAO CROPWAT model based on long-term climatic data from 1991 to 2020. The study aims to provide scientifically grounded insights for improving irrigation planning and optimizing water use efficiency in sunflower production under water-limited conditions.

2. Materials and methods

2.1 Study area

Adana Province was selected as the area for this study. Adana, a Mediterranean region situated in the southern part of Turkey, is characterized by moderate and dry summers and hot, humid winters. The station is located within the geographical coordinates of 36.99° N latitude and 35.20° E longitude, at an average altitude of 67 m.

2.2 CROPWAT and Input Data

2.2.1 CROPWAT Model

CROPWAT is a computer program developed by the Food and Agriculture Organization (FAO) under the Land and Water Development Division. It uses the FAO Penman-Monteith procedure for the estimation of reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), and irrigation scheduling [11]. The major input parameters of CROPWAT are climate data, crop data, soil data, and rainfall data, and it contains broad information on a variety of crop structures, soil characteristics, and local climate parameters that help with irrigation schedule optimization and the computation of scheme water supply for various crop patterns under rainfed and irrigated conditions (Figure 1).

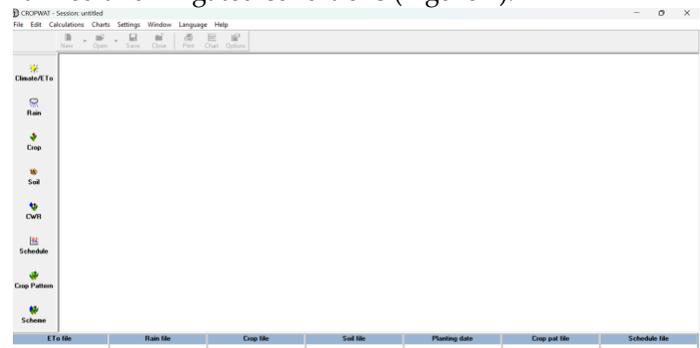


Figure 1. Cropwat inputs
Source. Cropwat 8.0 for Windows

2.2.2 Climate Data

Climatic parameters, including temperature, humidity, wind speed, sunshine duration, and rainfall, were obtained from the Adana Meteorological station as mean values for the 1991–2020 period and integrated into the software. These data were subsequently employed in the Cropwat model to simulate irrigation scheduling and to evaluate crop water requirements under local climatic conditions. Radiation and ET_0 , calculated using the Penman–Monteith method based on temperature, humidity, wind speed, and sunshine duration data, were obtained following the approach described by [12]. Table 1 shows the average climate data for the area of the study.

Rainfall data play a crucial role in assessing agricultural water requirements, and effective rainfall was calculated from the recorded rainfall values (Figure 2).

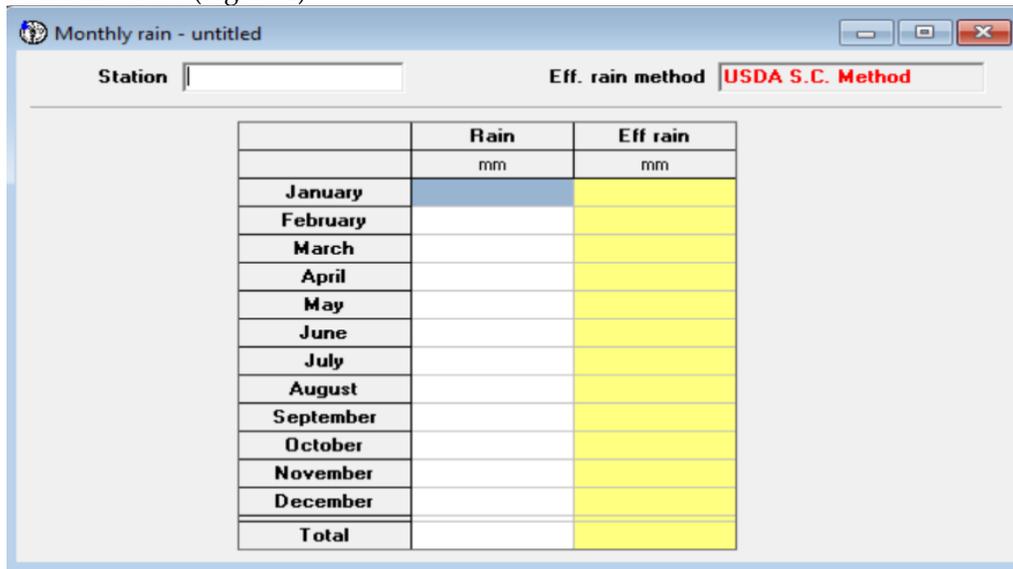


Figure 2. Rainfall input for effective rain calculation
Source: Cropwat 8.0 for Windows

Table 1. Monthly averages of climate data for the period (1991–2020).

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Sunshine (h)	Wind (km/day)	Rainfall (mm)
January	5.6	15	66	4.3	270	111.1
February	6.3	16.6	63.8	5.1	296	81.9
March	8.9	19.9	63.7	5.9	252	59.2
April	12.4	24.1	64.3	6.9	185	51.2
May	16.6	28.4	67.3	8.6	100	48.2
June	20.8	31.7	65.9	9.9	119	20.3
July	24.3	33.9	67.9	10.1	168	12.3
August	24.7	34.9	67.8	9.4	149	10.4
September	21.4	33.2	64.4	8.7	128	25.1
October	16.9	29.5	60.4	7.2	186	39.7
November	11	22.6	64.8	5.7	272	78.4
December	7.3	16.8	69.1	4	292	143
Average	14.7	25.6	65.4	7.1	201	680.8

2.2.3 Soil Data

Clay soil texture was considered in this study, as reported by [13] in Adana. Maximum root depth was obtained from FAO [11], while initial soil moisture depletion was assumed to be 0%. The maximum infiltration rate of rainfall (40mm day⁻¹), maximum root depth (115cm), and the total soil moisture (198mm m⁻¹) are presented in Table 2.

Table 2. Soil data.

Parameters	Values
Total soil moisture (mm m ⁻¹)	198
Maximum rain infiltration rate (mm day ⁻¹)	40
Maximum rooting depth (cm)	115
Initial soil moisture depletion (%)	0

2.2.4 Crop Data

The crop input data included the crop coefficient (K_c), yield response factor (K_y), crop growth period, rooting depth, and critical depletion. Sunflower was selected as the study crop, with a reported planting date of 25th March and a total growth duration of 135 days in the Adana region [14]. Crop height (2 m), crop coefficient (K_c) values of 0.35, 1.07, and 0.40 for the early, middle, and late growth stages, rooting depth, and yield response factor (K_y) were compiled from FAO [11]. The crop parameters employed in the analysis are presented in Figure 3.

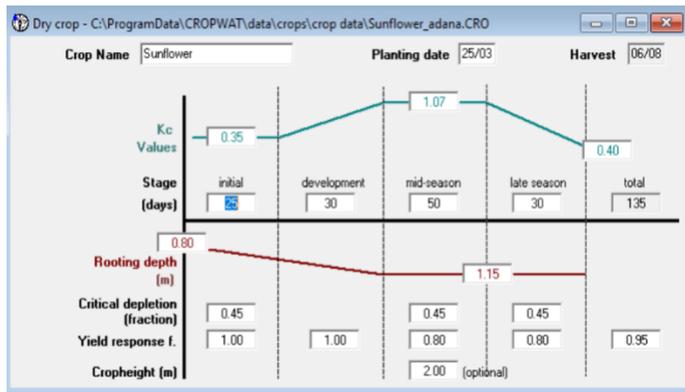


Figure 3. Crop data used in CROPWAT
Source: Cropwat 8.0 for Windows

2.3 CROPWAT Output

2.3.1 Reference Evapotranspiration (ET_o)

Reference evapotranspiration (ET_o) was computed using the FAO Penman–Monteith method incorporated in the CROPWAT model [7]. This method, which integrates climatic parameters such as temperature, humidity, wind speed, and solar radiation, is widely recognized as the standard approach for estimating ET_o. The FAO Penman–Monteith equation applied in the estimation is presented in Equation (1).

$$ET_o = \frac{0,408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0,34u_2)} \quad (1)$$

ET_o denotes the reference evapotranspiration (mm/day)

R_n: crop surface net radiation (MJ/m²-day)

G: density of soil heat flow (MJ/m²-day)

T: the daily average air temperature at a height of two meters (°C)

u₂: wind speed (m/s) at a height of 2 m

e_s: saturated vapor pressure (kPa)

e_a: actual vapor pressure (kPa)

e_s–e_a: Deficit of saturation vapor pressure (kPa)

Δ: vapor pressure curve slope (kPa °C)

Γ: psychrometric standard (kPa °C)

2.3.2 Crop Evapotranspiration (ET_c)

Estimation of crop evapotranspiration (ET_c) is carried out from reference evapotranspiration (ET_o). The calculation of ET_c within the model was based on ET_o and K_c values. Equation (2) presents the calculation of ET_c, derived from the product of reference evapotranspiration (ET_o) and the crop coefficient (K_c).

$$ET_c = K_c \times ET_o \quad (2)$$

2.3.3 Irrigation Water Requirements and Scheduling

The irrigation water requirement (IWR) is the amount of water that must be applied to the crop by irrigation to meet its total water needs. IWR may be lower than ET_c if the plant receives its water from other sources such as runoff, deep seepage, or rainfall [15]. Furthermore, the amount of irrigation water needed will exceed ET_c if irrigation is the only source of water supply. Irrigation schedules establish the ideal watering amount and the precise timing of watering. (Figure 4 shows the output result of irrigation scheduling for the year 2010. To obtain accurate results, two different irrigation scheduling criteria were analyzed: critical depletion and user-defined scheduling. These help in the comparison of the irrigation requirements, scheduling, and efficiency under different strategies. (Figures 5 and 6) shows the user-defined and critical depletion irrigation scheduling settings from the model.

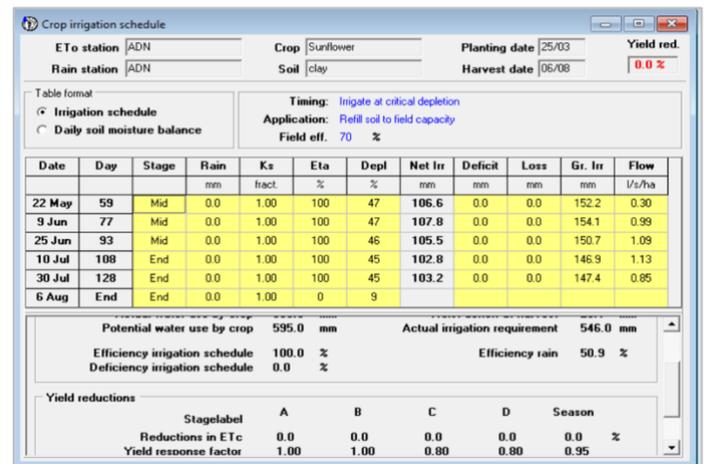


Figure 4. Output of irrigation scheduling and IWR for the year 2010

Source: Croptwat 8.0 for Windows

Application no.	Days after planting	Application depth
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Figure 5. CROPWAT module input of user-defined
Source: Cropwat 8.0 for Windows

Figure 6. Critical depletion set up from the CROPWAT module
Source: Cropwat 8.0 for Windows

3. Result and Discussion

3.1 Effective Rainfall (eff rain) and Reference Evapotranspiration (ETo)

Effective rainfall refers to the portion of total precipitation that is available to meet crop water requirements by either reducing or replacing the need for irrigation. Not all rainfall contributes to plant growth, as part of it may be lost through runoff, deep percolation beyond the root zone, or evaporation from the soil surface. In the study region, the 30-year average effective rainfall was 108 mm. The highest mean effective rainfall was recorded in 2009 at 215 mm, whereas the lowest occurred in 2008 with only 28 mm (Figure 7). Notable peaks occurred in 1993, 2007, 2009, and 2010, suggesting years with

substantial rainfall that likely reduced irrigation demand, while years like 2006, 2008, and 2011 show significant drops, implying increased reliance on supplemental irrigation (Figure 7).

These fluctuations highlight the variability of rainfall distribution and its critical role in irrigation planning. Accurate estimation of effective rainfall is therefore essential for determining net irrigation requirements, optimizing water allocation, and ensuring sustainable agricultural production under variable climatic conditions.

ETo is a fundamental parameter in integrated water resources management, as it represents the atmospheric demand for water from a reference crop under given climatic conditions. Over the 30 years, the average ETo in the study area was calculated as 3.9 mm/day. The maximum value was observed in 1993 (4.3 mm/day), while the minimum was 3.4 mm/day (Figure 8). These fluctuations reflect changes in climatic parameters such as temperature, solar radiation, humidity, and wind speed, which directly influence atmospheric water demand Variations. It is directly influenced by temperature, humidity, wind speed, and solar radiation, making it a key indicator of crop water requirements.

The CROPWAT model was used to compute crop parameters, including ETo, CWR, effective rainfall, and irrigation water requirements. The computed ETo values show an increase within the period of time, and the observed change was ascribed to expected heavy rainfall events in certain years, as predicted by the climate model. Moreover, climate change in the Mediterranean region is expected to lead to fewer but more intense precipitation episodes, particularly in spring [16].

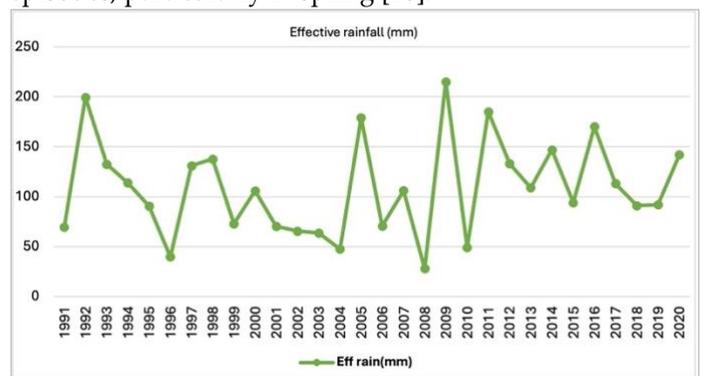


Figure 7. Effective rainfall chart

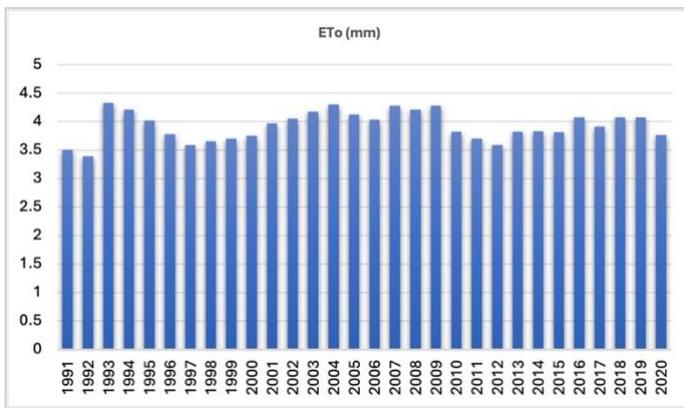


Figure 8. Yearly Average Eto for 30 years (1991-2020)

3.2 Crop Evapotranspiration (ETc)

Figure 9 presents the results of crop evapotranspiration (ETc) for sunflowers over the study period. The total average crop water requirement was 624 mm, with the highest ETc recorded in 2009 (756 mm) and the lowest in 1992 and 1991 (480 mm and 530 mm, respectively). These variations are primarily driven by changes in climatic conditions such as temperature, daylight duration, humidity, and wind speed. ETc tends to increase during dry seasons when high air temperatures, strong winds, and low relative humidity prevail, as these factors intensify atmospheric demand for water and accelerate crop transpiration and soil evaporation [12]. Understanding this variability is crucial for irrigation scheduling and water resource management, as it directly influences the timing and volume of supplemental irrigation required to sustain crop growth under fluctuating climatic conditions.

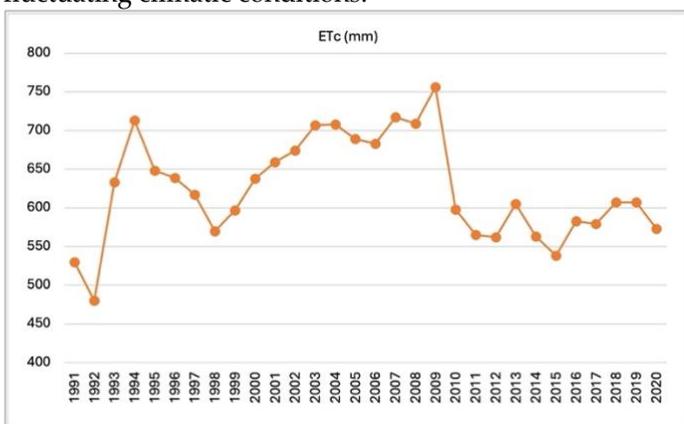


Figure 9. Yearly average Crop Evapotranspiration (ETc)

3.3 Net irrigation at Critical Depletion (cd) and User-Defined (ud)

Net irrigation requirement (NIR) represents the volume of water applied to ensure crops meet their full water demand while minimizing losses during irrigation.

In this study, the average value for irrigation at critical depletion (Irr_cd) was 462 mm, which exceeded the 416 mm recorded for irrigation at user-defined depletion (Irr_ud). This difference highlights the influence of depletion thresholds on irrigation scheduling, where critical depletion prompts earlier water application to prevent crop stress, resulting in higher irrigation volumes. Balancing efficient water use with crop water needs is therefore essential for optimizing both water conservation and agricultural productivity under variable climatic conditions. The comparative trends of Irr_cd and Irr_ud over the 30 years are illustrated in Figure 10. According to the gathered data, crop output is reliant on the rate at which water is consumed, and crop water need was significantly affected by all factors that increase yield while lowering water usage for ETc [18].

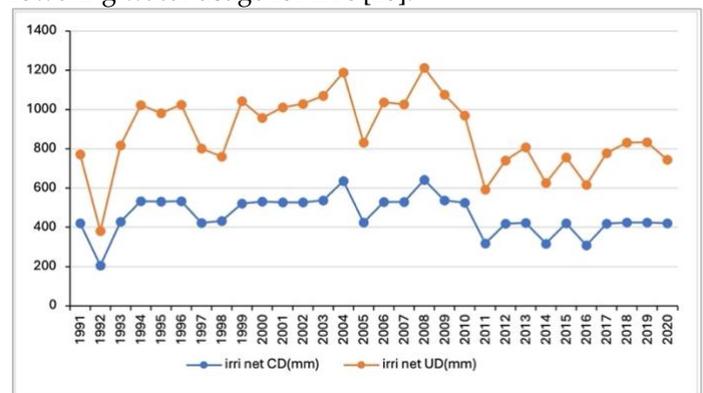


Figure 10. Net Irrigation Requirement

3.4 Irrigation Scheduling and Irrigation Amount

Irrigation scheduling results indicated that five applications of water were required during the sunflower growing season. The first irrigation, amounting to 109 mm, was applied 15 days after planting, while the final irrigation of 106 mm was carried out on 6 August, 131 days after planting. Figure 11 illustrates the irrigation days and amounts for the year 2018.

Comparatively, a study conducted in southern Odisha reported seven irrigation applications for sunflower under sandy loam soils, with irrigation scheduled at 50% of critical depletion. In that study, each application was designed to replenish the soil profile to 100% of field capacity, resulting in a total net irrigation requirement of 193.5mm [8]. These differences highlight the influence of soil texture, climatic conditions, and depletion thresholds on irrigation frequency and water requirement, emphasizing the need for region-specific scheduling strategies to optimize crop yield and water use efficiency.

[17] documented that the total net irrigation water needed for sunflowers between 1971 and 2000 ranged from

261.9 to 546.5 mm in Tekirdağ, 283.5 to 658.3 mm in Edirne, and 279.5 to 642.6 mm in Kırklareli using different soil textures. This corresponds to the result

[19] Conducted a study to determine the crop water requirement and irrigation scheduling for sunflowers. The crop water requirement was found to be 183.2 mm, while the irrigation requirement was 143.0 mm. The irrigation schedule indicated that the total gross irrigation for sunflowers was 233.6 mm, with a total net irrigation of 163.5 mm. A total of five irrigations were required for the sunflower crop

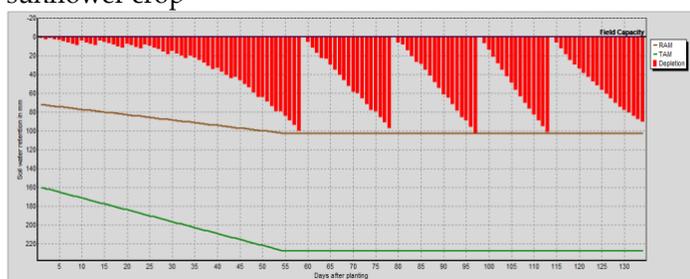


Figure 11. Irrigation scheduling for the year 2018

4. Conclusion

The crop water requirement of sunflower during the growing season was estimated at 624 mm, distributed across five irrigation applications beginning shortly after planting. At critical depletion, the irrigation amount was 462 mm, while at user-defined depletion it was 416 mm, both predicted to support maximum yield. These findings demonstrate the utility of the CROPWAT software in determining irrigation intervals, scheduling, and crop water consumption not only for sunflowers but also for other crops. By applying such modeling tools, irrigation practices can be optimized to achieve efficient water use, reduce wastage, and enhance crop productivity. In the context of the Adana region, where climatic variability strongly influences water demand, these results provide a basis for sustainable irrigation management and improved agricultural output

Informed Consent Statement: Not applicable.

Data Availability Statement: provided upon request.

Acknowledgments: All authors have reviewed and consented to the finalized version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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