

Research Article

Comparison of Three Different Approaches Used for the Determination of Wheat Evapotranspiration in Middle Awash, Werer, Ethiopia

Jemal Mohammed Hassen* , Fikadu Robi Borana 

Werer Agricultural Research Center, Amibara, Ethiopia

Abstract

In the Middle Awash area of Werer, Ethiopia, where efficient water management is paramount for sustainable agriculture, this study critically evaluates three distinct methods AquaCrop, WaPOR, and PySEBAL to estimate evapotranspiration in the context of wheat cultivation. The evaluation includes selected dates, monthly, and the entire growing period of the wheat crop. Comparative analyzes reveal variations in the estimated evapotranspiration values among the three models. Computed results indicate average seasonal actual evapotranspiration (AET) values of 516.12 mm, 537.77 mm and 568.2 mm for pySEBAL, WaPOR, and AquaCrop, respectively. Despite differences in absolute values, all three models produce comparable estimates of water use at both monthly and seasonal time steps. This consistency underscores their reliability in assessing wheat water consumption on varying temporal scales. These findings have significant implications for precision water management and sustainable agricultural practices in the Middle Awash region. The study emphasizes the potential applicability and precision of the assessed models, providing valuable information for field-scale water management strategies. The observed comparability of results improves confidence in the utility of these diverse modeling approaches, strengthening their role in informing water-efficient agricultural practices. Although AquaCrop and SEBAL have demonstrated reliability in estimating evapotranspiration, timely and easily accessible information from WaPOR enhances its practical applicability and underscores its relevance for precision water management and sustainable agricultural practices.

Keywords

AquaCrop, Evapotranspiration, Middle Awash, PySEBAL, WaPOR

1. Introduction

Understanding the water consumption of crops, ecosystems, and landscapes relies on crucial evapotranspiration (ET) estimation methods, which encompass various empirical and model-based approaches [1]. Among the commonly employed methods are the Penman-Monteith equation, a reference-based model that calculates potential evapotranspiration (PET) using

meteorological parameters, particularly solar radiation, temperature, wind speed, and relative humidity [2]. The Crop Coefficient Method adjusts reference evapotranspiration (ET_o) through crop coefficients to estimate actual evapotranspiration (ET_a) for specific crops, using ET_o, crop coefficients, and climate data. Remote sensing-based methods use satellite and

*Corresponding author: jemsmoha@gmail.com (Jemal Mohammed Hassen)

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remote sensing technologies, including land surface temperature and vegetation indices, for large-scale ET monitoring in regions with limited ground-based data.

The Aerodynamic Method estimates ET based on aerodynamic resistance between the land surface and the atmosphere, using wind speed, temperature, and meteorological data [3]. Energy balance models like SEBAL calculate ET as a residual of the energy balance at the land surface, incorporating incoming solar radiation, outgoing long-wave radiation, and sensible and latent heat fluxes, particularly useful for heterogeneous landscapes. AquaCrop, a crop growth model, integrates soil, crop, and management factors to estimate ET and crop water productivity at the field scale [4]. WaPOR, the Open Access Portal to Water Productivity, combines remote sensing and climate data to estimate ET, offering open access information for large-scale water productivity assessments. Thermal-based methods use thermal infrared imagery to estimate ET based on land surface temperature differences, which proves to be effective in regions where temperature variations drive evapotranspiration.

In most cases, in Ethiopia, irrigation fields have not monitored their moisture content before and after irrigation. Although irrigation has been practiced for a long time, farmers' experience in this regard is very limited. Therefore, irrigation water management is not efficient where the irrigation system was developed four decades ago in the middle of the Awash Valley. Recently, with the development and expansion of modern irrigation infrastructure in the country, improving irrigation water management is very important to address water management on farms. The irrigation water will be improved by applying the right crop water at the right time. Therefore, monitoring the water consumption on the farm using efficient technology helps to improve irrigation water management and increase irrigation water use under field conditions.

Evapotranspiration is the movement of water into the atmosphere from sources such as water bodies, soil, plants, and canopy interception. Crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. Crop evapotranspiration can be calculated from climatic data and by directly integrating the crop resistance, albedo, and air resistance factors in the Penman-Monteith approach [5]. To aid agricultural practices and monitor the water consumption of the crop, the FAO has developed a portal to monitor water productivity through open access to remotely detected derived data. Evapotranspiration estimated from remote sensing-derived data provides opportunities for improved agricultural water management at the field, farm, district, basin, state and regional scales [6].

The application of computer-based simulation models as tools for providing support for decision-making in agricultural

research has increased tremendously in the last three decades. Comparing different model results with field observations or inter-comparing models of different natures will provide information on the performance of the models and will reveal strong and weak points [7]. Evapotranspiration (ET) estimation methods are crucial for understanding the water consumption of crops, ecosystems, and landscapes. Various approaches, both empirical and model-based, are employed to estimate ET. This study aims to compare water consumption estimations of growing wheat by applying AquaCrop, WaPOR, and SEBAL on a field scale in the middle Awash, Werer, Ethiopia. We do so for one year during the wheat cropping season.

2. Methods and Data

2.1. Description of the Study Area

The study was carried out at Werer Agricultural Research Center, Middle Awash, Ethiopia, located at 9°16'N latitude and 40°9'E longitude, with a mean altitude of 740 masl. The soil at the experimental site was Vertisol with a bulk density of 1.3 g/cm³. The field capacity and the permanent wilting point of the soil on a volumetric basis were 44.5% and 32.3%, respectively. The climate of the area is characterized as semi-arid with a bimodal low and erratic rainfall pattern, with an annual average of 590 mm. The mean temperature varies from 26.7 °C to 40.8 °C. During this study, the wheat cropping season was from 08 December 2018 to 31 March 2019. Wheat was cultivated on 40 ha of land (Figure 1) and watered with furrow irrigation methods.

2.2. Data Sets and Analysis Procedures

The input data for AquaCrop, SEBAL, and WaPOR were collected from a variety of sources and processed according to the requirements of each model. For AquaCrop, the input data, including daily weather variables (temperature, humidity, wind speed, and solar radiation) and soil characteristics, were obtained from Werer Agricultural Research Center. SEBAL and WaPOR, which rely on remote sensing data, required satellite imagery, Digital Elevation Models (DEM), and meteorological data. For SEBAL, cloud-free Landsat 8 images were acquired from the USGS Earth Explorer website [4]. WaPOR utilized remote sensing-derived data accessible through the FAO's Water Productivity Portal, offering ready-to-use evapotranspiration and water productivity estimates [5].

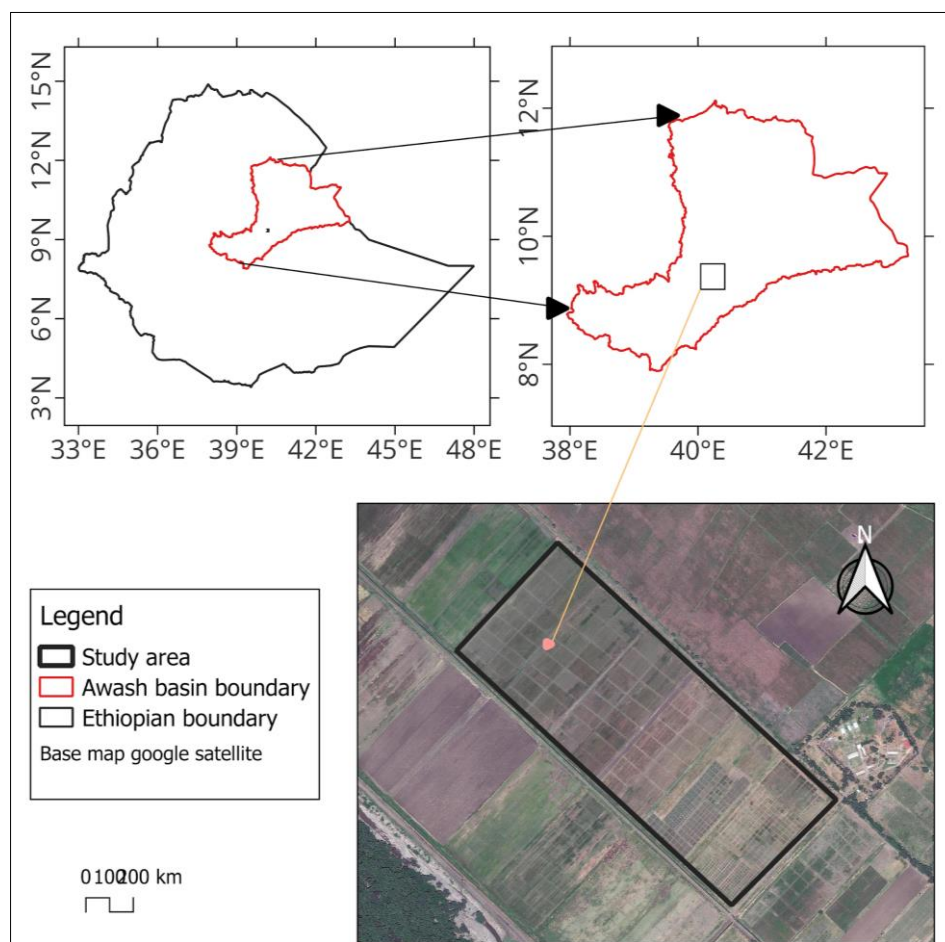


Figure 1. Location of the Study Area.

2.3. Estimation of Water Consumption

2.3.1. AquaCrop Approach

AquaCrop is a crop growth and water productivity model designed to assess the effect of environment and management on crop production [5]. The reference evapotranspiration (ET₀) was derived from weather station data following the FAO Penman-Monteith equation [8], and the ET₀ calculator [9] that is embedded in AquaCrop available for that purpose has been used. For this study, the AquaCrop standard Windows program version 6.1 was used. Input data required for the determination of reference evapotranspiration includes weather datasets such as maximum and minimum air temperature, relative humidity, wind speed, and radiation data. All input weather data, including soil, was obtained from the Werer Agricultural Research Center.

Water consumption estimation in AquaCrop:

AquaCrop advanced by separating crop evapotranspiration (ET) into crop transpiration (T) and soil evaporation (E), obtaining biomass (B) from the cumulative transpiration and water productivity (WP) product, treating the final yield as a product of biomass and harvest index (HI), then normalizing transpiration with reference transpiration (ET₀) and calculat-

ing crop water consumption, growth, and production in daily time steps [9].

2.3.2. WaPOR Approach

WaPOR, which stands for open access portal for water productivity, is a tool developed by the Food and Agriculture Organization of the United Nations (FAO) to provide open access information on water productivity in agriculture (https://wapor.apps.fao.org/home/WAPOR_2/1). Integrates remote sensing data and climate information to estimate and monitor water use in the agricultural sector.

2.3.3. Surface Energy Balance Algorithm for Land Approach (SEBAL)

SEBAL is a satellite-based image processing model used to determine evapotranspiration as a residual of surface energy balance [10]. SEBAL uses spectral radiances recorded by satellite sensors and meteorological data to solve the energy balance on the land surface. The instantaneous latent heat flux (LE) at the time of the satellite overpass can be computed using the following equation.

$$LE = R_n - G - H \quad (1)$$

The instantaneous evaporative fraction was calculated as:

$$\Lambda = \frac{LE}{Rn - G} \quad (2)$$

Then the daily evapotranspiration was calculated as:

$$ET = \Lambda Rn24 \quad (3)$$

LE - is latent heat flux ($W m^{-2}$), Rn - is net radiation ($W m^{-2}$), G - is soil heat flux ($W m^{-2}$), H - is sensible heat flux ($W m^{-2}$), Λ - is evaporative fraction and ET - is evapotranspiration (mm/day).

Net radiation (Rn) is calculated from the land surface radiation balance:

$$Rn = (1 - \alpha)R_{Sin} + R_{Lin} - R_{Lout} - (1 - \varepsilon_0)R_{Lin} \quad (4)$$

R_{Sin} is the incoming short-wave solar radiation, α is the surface short-wave albedo, R_{Lin} and R_{Lout} are the incoming and

outgoing long-wave radiation ($W m^{-2}$), ε_0 is the land surface emissivity.

In this study, the implementation of SEBAL in Python (PySEBAL) version 3.4.0 model for Landsat imagery was used. This model is coded in the Python environment. The input data required for running SEBAL correctly for Landsat images are: location of study area, cloud-free Landsat images, Digital Elevation Model (DEM), weather data, and soil hydraulic properties (saturated soil moisture, residual soil moisture, field capacity, and permanent wilting point). For this study, the sources of the input data are described below.

Satellite images: nearly cloud-free Landsat 8 OLI/TIRS images encompass the period from December 2018 to March 2019 for path 167/row 54 and SRTM DEM of 30 m resolution was obtained from the USGS earth explorer website (<https://earthexplorer.usgs.gov/>). The Landsat images that were used to run the pySEBAL model are presented in (Table 1).

Table 1. Name and acquisition dates of Landsat images used in the study area.

S. N	Name of Landsat Image	Acquisition date
1	LC08_L1TP_167054_20181208_20181211_01_T1	2018-12-08
2	LC08_L1TP_167054_20181224_20190129_01_T1	2018-12-24
3	LC08_L1TP_167054_20190109_20190131_01_T1	2019-01-09
4	LC08_L1TP_167054_20190125_20190205_01_T1	2019-01-25
5	LC08_L1TP_167054_20190210_20190222_01_T1	2019-02-10
6	LC08_L1TP_167054_20190226_20190309_01_T1	2019-02-26
7	LC08_L1TP_167054_20190314_20190325_01_T1	2019-03-14
8	LC08_L1TP_167054_20190330_20190404_01_T1	2019-03-30

Weather data: The incoming short-wave radiation, wind speed, air temperature, and relative humidity data for the Landsat image acquisition time were obtained from the agrometeorological observatory of the Werer Agricultural Research Center.

Soil hydraulic properties: saturated soil moisture, residual soil moisture, field capacity, and permanent wilting point data were obtained from the Werer Agricultural Research Center.

After the PySEBAL model was run for all Landsat images over a season, the daily crop coefficient (kc) and the corresponding daily actual evapotranspiration (ETa) maps were developed by applying linear interpolation. Then, seasonal actual evapotranspiration maps were created.

3. Results and Discussion

3.1. Actual Transpiration

The results of daily actual crop transpiration (Tact) in the wheat field provide information on the water consumption dynamics of the crop under different modeling approaches. In early December, AquaCrop and SEBAL show minimal transpiration, while WaPOR indicates a slightly higher value (Table 2). The observed variations in the results, particularly in the case of WaPOR, could be influenced by the use of decadal average values for the selected dates. As the wheat crop progresses, all three models exhibit an increase in transpiration, reaching peak values in mid-February. In particular, AquaCrop consistently yields higher transpiration estimates compared to WaPOR and SEBAL, especially during the later

stages of crop growth. This suggests that AquaCrop tends to predict more substantial use of crop water. On the contrary, WaPOR and SEBAL exhibit closer values, indicating a degree

of agreement in their estimations. The observed variations could be attributed to differences in the underlying algorithms, input parameters, and model complexities.

Table 2. Daily Actual transpiration (*Tact*) for selected dates.

	08-Dec 2018	24-Dec 2018	09-Jan 2019	25-Jan 2019	10-Feb 2019	26-Feb 2019	14-Mar 2019	30-Mar 2019
Tact_SEBAL [mm]	0.03	0.76	3.22	3.10	4.16	4.00	2.24	2.14
Tact_WaPOR [mm]	1.99	2.57	3.45	5.27	4.99	4.82	3.78	3.08
Tact_AquaCrop [mm]	0.00	1.60	5.30	5.20	6.10	6.70	5.30	1.20

3.2. Actual Soil Evaporation

Daily soil evaporation (*Eact*) results for the wheat field, estimated by the SEBAL, WaPOR and AquaCrop models on selected dates, reveal distinctive patterns in the dynamics of water loss (Table 3). The SEBAL model indicates varying but moderate soil evaporation throughout the monitored period, with notable peaks on 24-December-18 and 14-Mar-19. In contrast, the WaPOR model generally exhibits lower soil

evaporation rates compared to SEBAL, with a continuous decline over the monitoring period. The AquaCrop model consistently demonstrates higher soil evaporation, particularly evident on initial dates. AquaCrop's estimates show a significant decrease in soil evaporation from 8 December-18 to 25 Jan.-19, reaching minimal levels on 10-Feb-19 and 26-Feb-19. These differences underscore the distinct responses of each model to environmental factors, emphasizing the need to carefully consider model selection based on the specific characteristics and objectives of the study.

Table 3. Actual daily soil evaporation (*Eact*) for selected dates.

	08-Dec 2018	24-Dec 2018	09-Jan 2019	25-Jan 2019	10-Feb 2019	26-Feb 2019	14-Mar 2019	30-Mar 2019
Eact_SEBAL [mm]	0.49	3.61	2.14	2.45	2.19	3.05	3.07	2.82
Eact_WaPOR [mm]	0.99	0.80	0.60	0.82	0.74	1.07	1.30	1.16
Eact_AquaCrop [mm]	3.60	1.30	0.60	0.10	0.00	0.00	0.40	0.10

3.3. Water Consumption of Growing Wheat

3.3.1. Actual Evapotranspiration (AET) for Selected Dates

The results of the actual estimates of evapotranspiration (AET) for the wheat crop on selected dates, generated by the SEBAL, WaPOR, and AquaCrop models, offer valuable insights into the dynamics of water consumption in the study area (Table 4). On 8 December 18th, SEBAL estimated a minimal AET of 0.50 mm, while both WaPOR and AquaCrop presented significantly higher values of 3.00 mm and 3.60 mm, respectively. As the monitoring period progressed, SEBAL consistently indicated an increase in AET, reaching its peak at 7.10 mm on 26 February-19. Compared to WaPOR, it

demonstrated fluctuating AET values, with the highest estimate of 6.10 mm on 25-Jan-19. AquaCrop, on the other hand, exhibited varying AET levels, peaking at 6.70 mm on 26 February-19.

In particular, on 30-Mar-19, AquaCrop showed a considerable decrease in AET to 1.30 mm, while SEBAL and WaPOR maintained higher AET values at 5.00 mm and 4.20 mm, respectively. These variations highlight the differences in the models' responses to changing environmental conditions during the wheat cropping season. Despite the disparities in absolute values, all three models consistently demonstrate comparable estimates of water use on different temporal scales. The results emphasize the reliability of SEBAL, WaPOR, and AquaCrop in assessing wheat water consumption, underscoring their potential applicability to inform water-efficient

agricultural practices. Researchers and practitioners should consider these nuanced differences when selecting a model to

estimate evapotranspiration in wheat cultivation, considering the specific objectives and conditions of their study area.

Table 4. Daily Actual Evapotranspiration (AET) for selected dates.

AET estimation approach	08-Dec 2018	24-Dec 2018	09-Jan 2019	25-Jan 2019	10-Feb 2019	26-Feb 2019	14-Mar 2019	30-Mar 2019
AET_SEBAL [mm]	0.52	4.37	5.35	5.55	6.34	7.05	5.31	4.96
AETI_WaPOR [mm]	3.00	3.40	4.00	6.10	5.70	6.00	5.10	4.20
AET_AquaCrop [mm]	3.60	2.80	5.90	5.30	6.10	6.70	5.80	1.30

3.3.2. Actual Monthly and Seasonal Evapotranspiration

The AET estimates for the wheat crop, considering different months and the total growing period, provide a comprehensive view of the water consumption dynamics as assessed by the SEBAL, WaPOR and AquaCrop models. In December 2018, AquaCrop projected an AET of 82.70 mm, while WaPOR and SEBAL estimated slightly lower values at 70.18 mm and 73.36 mm, respectively. As the wheat cropping season progressed, all three models demonstrated an increase in AET, reaching peak values in January 2019. SEBAL estimated 150.13 mm, WaPOR reported 155.15 mm, and AquaCrop indicated 183.1 mm.

In February 2019, SEBAL showed a slight decrease in AET to 157.2 mm, while both WaPOR and AquaCrop exhibited higher values at 166.47 mm and 165.2 mm, respectively. March 2019 witnessed a further decline in AET in all models, with SEBAL estimating 135.44 mm, WaPOR reporting 145.97 mm and AquaCrop showing 137.2 mm. Total AET for the entire growing period indicated that AquaCrop produced the highest cumulative value of 568.20 mm, followed by WaPOR at 537.77 mm and SEBAL at 516.12 mm (Table 5).

These results emphasize the differences in AET estimates

provided by each model and underscore the importance of selecting an appropriate model based on the specific needs of the study. Although AquaCrop consistently presented higher AET values, the general trends across the models were comparable. These findings improve our understanding of the performance and applicability of SEBAL, WaPOR, and AquaCrop in estimating wheat water consumption, contributing valuable information for water management strategies in the Middle Awash region.

The results, particularly the intermediate values and near-real-time data provided by WaPOR, highlight its potential advantages over AquaCrop and SEBAL in certain contexts. The open-access nature of WaPOR and its ability to provide real-time data make it a favorable choice for researchers, practitioners, and decision-makers involved in water management and agricultural planning. This accessibility allows for a more dynamic and up-to-date understanding of water consumption patterns, especially in regions where ground-based data may be limited. Although AquaCrop and SEBAL have demonstrated reliability in estimating evapotranspiration, timely and easily accessible information from WaPOR enhances its practical applicability and underscores its relevance for precision water management and sustainable agricultural practices.

Table 5. Actual monthly and seasonal actual evapotranspiration.

X	'Dec 2018'	'Jan 2019'	'Feb 2019'	'Mar 2019'	'Total'
AET_SEBAL [mm]	73.36	150.13	157.20	135.44	516.12
AETI_WaPOR [mm]	70.18	155.15	166.47	145.97	537.77
AET_AquaCrop [mm]	82.70	183.10	165.20	137.20	568.20

4. Conclusions

Water consumption estimates on the field scale are essential to improve crop water productivity and efficiently manage irrigation resources. In this context, three distinct approaches were implemented to estimate seasonal actual evapotranspiration in the field of seed multiplication of the Werer Agricultural Research Center during the 2019 wheat cropping season (from December 8, 2018, to March 31, 2019). Comparative analysis focuses on the evaluation of the AquaCrop, WaPOR, and PySEBAL models in their calculation of wheat water consumption.

The calculated crop evapotranspiration results for selected dates, monthly intervals, and the total growing period during the wheat cropping season provide valuable information on the dynamics of water use in the study area. The study reveals that all three models provide comparable estimates of water use at both monthly and seasonal time steps. This implies a consistency in their ability to estimate wheat water consumption, emphasizing their reliability in capturing variations over different temporal scales. The findings underscore the potential applicability and precision of these models in estimating evapotranspiration, offering valuable insights for precision water management and sustainable agricultural practices. The comparability of the results across these diverse modeling approaches enhances our confidence in their utility for field-scale water management strategies.

Abbreviations

ETa	Actual Evapotranspiration
Tact	Actual Transpiration
AETI	Actual Evapotranspiration and Interception
DEM	Digital Elevation Model

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Data Availability Statement

The authors confirm that all data underlining the findings

are fully available without restriction. All relevant data are available on the paper itself.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Allen, R., Irmak, A., Trezza, R., Hendrickx, J. M. H., Bastiaanssen, W., Kjaersgaard, J., 2011. Satellite - based ET estimation in agriculture using SEBAL and METRIC. *Hydrol. Process.* 25, 4011-4027.
- [2] Allen, R. G., Pereira, L. S., Raes, D., Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome 300, D05109.
- [3] Bastiaanssen, W. G., Menenti, M., Feddes, R. A., Holtslag, A. A., 1998. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. *Journal of Hydrology*, 212-213, 198-212.
- [4] Earth Explorer. Available from: <https://earthexplorer.usgs.gov/> (accessed 10 November 2022).
- [5] WAPOR (Water Productivity through Open access of Remotely sensed derived data) Portal. Available from: https://wapor.apps.fao.org/home/WAPOR_2/1/ (accessed 10 November 2022).
- [6] Ines, A. V. M., Droogers, P., Makin, I. W., Gupta, A. Das, 2001. Crop Growth and Soil Water Balance Water Modeling to Explore Water Management Water Options. Colombo, Sri Lanka.
- [7] Monteith, J. L., 1965. Evaporation and environment. *Symposia of the Society for Experimental Biology*, 19, 205-234.
- [8] Raes, D., 2017. AquaCrop training handbooks Book I. Understanding AquaCrop. food and agriculture organization of the United Nations, Rome.
- [9] Steduto, P., Hsiao, T. C., Raes, D., Fereres, E., 2009. AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: I. Concepts and Underlying Principles. *Agron. J.* 101. <https://doi.org/10.2134/agronj2008.0139s>
- [10] Thoreson, B., Clark, B., Soppe, R., Keller, A., Bastiaanssen, W., Eckhardt, J., 2009. Comparison of evapotranspiration estimates from remote sensing (SEBAL), water balance, and crop coefficient approaches, in: *World Environmental and Water Resources Congress 2009: Great Rivers*. pp. 1-15.