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Methods and Software Used in Irrigation Programming Worldwide

Firdevs Bahşi[1]*, M. Cüneyt Bağdatlı[2]

[1] Niğde Ömer Halisdemir University, Graduate School of Natural and Applied Sciences, Department of Interdisciplinary Digital Agriculture, 51240, Niğde, Turkiye.*
[2] Niğde Ömer Halisdemir University, Faculty of Architecture, Department of City and Regional Planning, 51240, Niğde, Turkiye

Abstract

Growing pressure on freshwater supplies worldwide demands that agriculture adopt more efficient irrigation strategies. As conventional scheduling methods increasingly fall short, a diverse ecosystem of software tools—spanning FAO-based calculators, physically based simulation models, and IoT-enabled smart platforms—has emerged to guide water allocation decisions. This study provides a comparative evaluation of eleven such tools used globally, assessing their computational foundations, data requirements, strengths, and limitations. Software tools such as CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO and AGROS are analyzed in terms of their data requirements, advantages, limitations, and application areas. The findings reveal that integrating IoT and machine learning fosters a profound transformation in irrigation management through real-time monitoring and data-driven decision-making. The study also discusses the status and future potential of irrigation software in Türkiye, highlighting the importance of regional and local solutions for sustainable water management.

Keywords: *Irrigation Scheduling, Smart Irrigation, Decision Support Systems*

Introduction

Agriculture accounts for roughly 70 % of global freshwater withdrawals, yet a substantial share of that water is lost to inefficient application practices. Conventional surface irrigation, still dominant in many regions, often delivers water in excess of crop demand, contributing to waterlogging, salinization, and declining soil health. Evidence-based irrigation scheduling addresses these losses by matching water supply to actual crop requirements on a spatially and temporally explicit basis.

The inadequacy of traditional irrigation methods has encouraged the development of irrigation scheduling techniques based on scientific and technological innovations to ensure the sustainability of water resources and to increase agricultural production (Tecim et al., 2016). In this context, modern software grounded in crop water-consumption estimation, soil moisture monitoring, and climate data analysis enables irrigation decisions to be made more accurately and efficiently. Antu et al. (2024) provide a broad overview of these emerging technologies, while Parra-López et al. (2025) focus specifically on digital water-management platforms and Souto et al. (2021) compare the usability of several open-access tools. A recent systematic review further confirms that field-scale irrigation management is being reshaped by these digital advances (Bounajra et al., 2024). The present study systematically addresses the principal software programs used worldwide in irrigation scheduling (CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO, and AGROS) and evaluates their purposes of use, data requirements, strengths and weaknesses, and the potential they offer for Türkiye.

Irrigation automation consists of systems that operate with the support of specific mechanisms and software to use water most efficiently in agricultural areas. Thanks to these systems, irrigation is conducted with even distribution while preventing water waste. Irrigation automation works through systems that continuously monitor parameters such as soil moisture, weather conditions, and plant water demand, and that activate when needed. As exemplified by the Netherlands, it is possible to achieve high export figures and to lead the global agricultural sector through efficient and digitalized farming practices despite a small land area (Ercan et al., 2019). Precision irrigation technologies enhance water-use efficiency, crop yield, and environmental performance under changing climate conditions (Lakhiar et al., 2024), and AI-supported autonomous irrigation systems have been shown to improve both water efficiency and plant quality (Oğuztürk et al., 2025).

Decision support systems ensure that water is delivered to the plant root zone at the most appropriate time and in the most appropriate amount by continuously monitoring soil moisture, plant characteristics, and environmental conditions (Hamidoğlu, 2023; Petraki et al., 2025; Tecim et al., 2016). Farmer-oriented decision support tools have been developed for agronomic decisions in both rainfed and irrigated cropping systems (Phelan et al., 2018), and similar systems have been designed for regional management of agricultural water and salinity issues (Dinar & Quinn, 2022). Effective irrigation practices directly affect plant productivity by supplying the water that is essential for plant growth at the optimal time and in the optimal quantity (Şahin, 2024). These approaches aim not only to reduce water consumption but also to improve product quality, and they offer both economic and ecological benefits by guiding farmers in irrigation planning.

Against this backdrop, the convergence of sensor networks, cloud computing, and predictive analytics has redefined what irrigation scheduling can achieve, shifting the paradigm from static calendars toward adaptive, real-time management (Ali et al., 2025; Shokhujaeva et al., 2023). Within the broader water–food–energy nexus, simulation-based approaches have also been proposed to support sustainable agricultural water management (Variani et al., 2022). Accurately determining the relationships among soil, climate, and crop factors, together with irrigation software based on these relationships, enables irrigation to be conducted at the right time and in the appropriate amount. In this way, more sustainable use of water resources and efficient continuation of agricultural production becomes possible.

The main objective of this study is to comprehensively compare and evaluate irrigation software used worldwide. This evaluation aims to determine which software is the most suitable choice under which conditions by analyzing the different programs in terms of their purposes of use, data requirements, advantages, limitations, and suitability for various application areas. The study covers a broad spectrum, ranging from traditional methods to scientific and data-driven techniques, and further to automatic and smart systems based on IoT, artificial intelligence, and machine learning.

A systematic literature review was conducted to identify and compare the principal software programs used in irrigation scheduling worldwide. The Web of Science, Scopus, and Google Scholar databases were searched using the keywords "irrigation scheduling software," "crop water requirement model," "smart irrigation system," and "evapotranspiration calculator," covering publications from 1979 to 2025. Studies were included if they (i) described a standalone or web-based irrigation scheduling tool, (ii) reported the tool's computational basis and data requirements, and (iii) were published in English or Turkish. Conference abstracts without full text and studies addressing hardware-only prototypes without a software component were excluded. Through this process, eleven programs—CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO, and AGROS—were selected for detailed evaluation. Each program is assessed in terms of its development history, core computational method (e.g., Penman–Monteith, Richards equation), data requirements, user interface, application scope, and limitations. The potential applicability of these tools in Türkiye is discussed under a separate heading.

Results

The eleven software tools reviewed, five remain rooted in classical FAO-based or physically based modelling frameworks, whereas the remaining six incorporate or have been extended with IoT sensors, machine-learning algorithms, or cloud-based data pipelines for real-time scheduling (Abdelmoneim et al., 2025; Bhatti et al., 2023; Dong et al., 2024; Kunt, 2025; Nsoh et al., 2024; Şahin, 2024). AI-based digital systems for intelligent irrigation (Raouhi et al., 2023) and sensor-based micro-irrigation systems powered by solar PV (Manfo & Şahin, 2023; Mohammed et al., 2023) further demonstrate the rapid evolution of this field. These approaches enable irrigation systems to operate autonomously and allow the development of smart irrigation systems that can respond dynamically to environmental and agronomic conditions. The principal irrigation scheduling software programs widely used worldwide are reviewed below.

CROPWAT

CROPWAT, whose name combines the words "Crop" and "Water," is an FAO-developed desktop tool that estimates crop water demand and generates irrigation schedules on the basis of the Penman–Monteith reference ET_0 method, drawing on climate, rainfall, soil, crop, and irrigation-system parameters (Kartal et al., 2019). The programme is organized around seven interlinked modules—Climate, Rain, Crop, Soil, CWR (crop water requirement), Irrigation Scheduling, and Crop Pattern—each accepting a defined set of inputs that collectively drive the scheduling algorithm. Effective rainfall can be estimated through a fixed-percentage approach, empirical formulae, or the dependable-rain method. Soil parameters—water-holding capacity, maximum infiltration rate, root depth, and initial moisture depletion—are coupled with default irrigation-efficiency values that distinguish surface (40–60 %), sprinkler (80–85 %), and drip (90–95 %) systems. On the crop side, Kc coefficients, phenological stages, rooting depth, and yield-response factors are specified per crop, while the Crop Pattern module distributes each crop's sowing ratio, sowing date, and field distribution; based on these inputs, the software derives net and gross irrigation requirements, making it particularly suited to extension-level planning in data-scarce environments.

HYDRUS

HYDRUS is a finite-element simulation platform—originally developed at the University of California, Riverside, under the leadership of Jirka Šimůnek—that solves the Richards equation for variably saturated water flow, coupled with heat and solute transport, across one- (HYDRUS-1D), two-, and three-dimensional (HYDRUS-2D/3D) domains. Soil hydraulic behaviour is parameterized through the van Genuchten–Mualem functions, giving the model flexibility to represent a wide range of soil textures and irrigation configurations (e.g., drip emitters,

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subsurface laterals, ditch drainage). Its modular workflow—domain geometry, mesh generation, hydraulic-property assignment, and boundary/initial-condition specification—facilitates reproducible scenario analyses across scales. For instance, Provenzano (2007) validated subsurface wetting patterns, while Patra et al. (2021) and Siphiwe et al. (2024) applied HYDRUS-2D to drip-irrigated maize under tropical and continental climates, respectively. Because HYDRUS outputs are sensitive to the accuracy of input moisture data, reliable soil-moisture monitoring remains a prerequisite for meaningful simulations (Yetik & Aşık, 2021).

SWAP (Soil Water Atmosphere Plant)

The SWAP model is a physically based model that simulates, over time, the energy and mass transfer processes occurring in the soil–plant–atmosphere system. Developed at Wageningen University (the Netherlands), the model is widely used in analyses of water balance, salt transport, drainage, irrigation applications, and crop yield in agricultural areas. Vertical water movement is computed using the Richards equation, the energy balance using the Penman–Monteith method, and crop growth and evapotranspiration using the FAO-56 crop coefficient (Kc) approach. Water uptake in the root zone is modeled using the Feddes function, and solute transport is modeled using the convection–diffusion equation. The SWAP model is composed of interconnected modules for the atmosphere (ATMOS.INP), soil (SOIL.INP), crop (CROP.INP), and irrigation–drainage. The model is used primarily for agricultural irrigation planning, as well as for assessing groundwater–drainage interactions, salinity and nutrient transport, and the effects of climate change on the agricultural water balance; it also stands out in the analysis of long-term soil and salt accumulation scenarios (Khan et al., 2024; Liu et al., 2020).

DSSAT (Decision Support System for Agrotechnology Transfer)

DSSAT is a software that provides process-oriented crop modeling solutions for various crops under different management and environmental conditions and that incorporates fundamental agronomic components such as soil, weather, and crop management practices (Trenz et al., 2023). Owing to its versatile analytical capacity, it assists farmers in making critical decisions on optimum planting dates, fertilization strategies, and irrigation regimes, while also enabling researchers to evaluate the effects of different management practices on yield (Kephe et al., 2021; Kassie et al., 2016; Jeong & Zhang, 2020). Crop simulation models such as DSSAT have also been applied to identify best management practices for crops under projected climate change scenarios (Mohammed et al., 2017), and recent reviews highlight the potential of coupling such models with weather forecast data for real-time irrigation planning (Mohamed Naziq et al., 2024). While software such as DSSAT contains comprehensive simulation models that assess crop yield responses under varying growing conditions (Pokhariyal et al., 2020), regional solutions developed in Türkiye such as AGROS aim to enhance the efficiency of local agricultural practices by offering the same kind of complex computations through a more user-friendly interface (Köksal, 2018). Systems developed in Türkiye, such as GAPHASSAS, T-Irrigate, and esular, increase the effectiveness of smart irrigation management and provide users with comprehensive data analysis; however, the inadequacy of scientific crop pattern planning limits the potential of these programs (Kılıç & Özçakal, 2024).

REF-ET

The REF-ET software was developed by Allen (1999), with its most recent version released in 2015. When sufficient climate parameters are available, it can estimate ET_0 using 15 different equations. The software is based on the standards of FAO Irrigation Paper No. 56 (Allen et al., 1998) and the ASCE Standardized Penman–Monteith method (ASCE-EWRI, 2005). Recent field studies have validated FAO-56-based ET_0 estimation methods against direct measurements in different agro-ecological zones, including the Andean potato-growing region (Casallas et al., 2024).

DSS_ET

The DSS_ET software (Bandyopadhyay et al., 2012) is a more advanced version of the program developed by George et al. (2002). It can compute daily or monthly ET_0 values using 22 widely used ET_0 equations. It stands out as a user-friendly decision support system that allows ET_0 to be calculated with the desired equation depending on the available climate data.

IAM_ETo

The IAM_ETo software was developed by Steduto and Snyder (1998). It can compute daily or monthly ET_0 values using nine different ET_0 equations.

ETo Calculator

The ETo Calculator was developed by Raes (2012) under the leadership of FAO. When the required climate data are available, the software calculates ET_0 in accordance with FAO standards using the Penman Monteith equation.

DailyET

DailyET is a small, fast, and simple Windows-based program developed by Hess (1996) at Cranfield University, United Kingdom. A single daily or single monthly ET_0 value can be calculated using five different ET_0 equations.

ETO

The ETO software was developed by Gocic and Trajkovic (2010). Daily or monthly ET_0 values can be computed using the Penman–Monteith and modified Hargreaves equations; calculations are performed in accordance with the FAO standards developed by Allen (1999).

AGROS

AGROS distinguishes itself from the ET_0-only calculators reviewed above by coupling reference and actual evapotranspiration with a daily soil water budget and a yield-response module. Reference ET is computed for both short (ETo) and tall (ETr) reference crops following the ASCE Penman–Monteith standard (ASCE-EWRI, 2005), while actual crop water consumption (ETc) is derived through the procedures of Allen et al. (1998). The yield impact of water stress is estimated via the Stewart multiplicative model (Doorenbos & Kassam, 1979), using crop-specific yield-response (Ky) and available-water-ratio (Ry) coefficients alongside phenological-stage definitions and root-depth profiles. Four scheduling strategies are available—automatic optimum irrigation (no yield loss), fixed irrigation interval, fixed application depth, and a fully user-defined regime—giving practitioners flexibility to match local operational constraints (Köksal, 2018).

Discussion

Given the pressure on Türkiye's water resources and the increasing levels of food and water loss reported at the national scale (TÜBA, 2024), the wider adoption of smart irrigation systems and data-driven decision-support tools is of vital importance for the country's agricultural sustainability (Tüzgen et al., 2021). In this context, the dissemination of water-saving irrigation technologies in Türkiye is regarded as a strategic instrument for increasing agricultural productivity and ensuring food security (Ercan et al., 2019). International software programs such as CROPWAT, HYDRUS, SWAP, and DSSAT can produce meaningful results when calibrated to regional climate, soil, and crop data under Turkish conditions, while local solutions such as AGROS, GAPHASSAS, T-Irrigate, and esular offer farmer-level adoption potential thanks to their user-friendly interfaces and parameter sets adapted to local data (Köksal, 2018; Kılıç & Özçakal, 2024). However, the effective use of these programs depends on strengthening meteorological and soil-monitoring infrastructure, improving farmers' digital literacy, and designing training programs integrated with extension services (Tecim et al., 2016). It should also be noted that several sources cited in this review are preprints deposited on platforms such as Research Square and have not yet undergone formal peer review; their findings should therefore be interpreted with appropriate caution until peer-reviewed versions become available.

Conclusion

This review demonstrates that irrigation software has matured along two complementary tracks: standardized, FAO-anchored calculators (CROPWAT, ETo Calculator, REF-ET) that lower the entry barrier for practitioners, and process-oriented simulators (HYDRUS, SWAP, DSSAT) that serve research and scenario-analysis needs. The emerging convergence of these tracks with IoT sensor networks and machine-learning pipelines points toward a third generation of tools capable of autonomous, site-specific scheduling. For Türkiye, four priorities stand out: (i) wider dissemination of locally developed platforms such as AGROS, GAPHASSAS, and T-Irrigate; (ii) systematic calibration of international models against regional soil–climate datasets; (iii) investment in open meteorological and soil-monitoring infrastructure; and (iv) farmer-level digital-literacy programmes embedded in agricultural extension services. Addressing these gaps will be instrumental in reconciling the country's rising food demand with its increasingly constrained water budget.

Declarations

Ethical Approval Certificate

This study is a review article and does not involve any experiments on humans or animals; therefore, ethics committee approval is not required.

Author Contribution Statement

Firdevs Bahşi: Data collection, investigation, formal analysis, and drafting of the initial manuscript.

M. Cüneyt Bağdatlı: Manuscript administration, supervision, conceptualization, methodology, review, and editing.

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Conflict of Interest
The authors declare that there is no conflict of interest regarding this study.

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