


AUTOMATED EVAPOTRANSPIRATION: a systematic review and meta-analysis

EVAPOTRANSPIRAÇÃO AUTOMATIZADA: uma revisão sistemática e meta-análise
 EVAPOTRANSPIRACIÓN AUTOMATIZADA: una revisión sistemática y metanálisis

Luís Roberto Almeida Gabriel Filho

Degree in Mathematics from FCT/UNESP (2000), and Free Teaching in Applied and Computational Mathematics from UNESP (2015).
gabriel.filho@unesp.br

 0000-0002-7269-2806


Camila Pires Cremasco

Degree in Mathematics from FCT/UNESP (2000), and Free Teaching in Applied Mathematics from UNESP (2018).
camila.cremasco@unesp.br

 0000-0003-2465-1361


Paulo Sérgio Barbosa dos Santos

Graduated in Mechatronics Engineering from UniSALESIANO of Araçatuba-SP (2010), and PhD in Mechanical Engineering from São Paulo State University (UNESP) (2017).
paulo.sb.santos@unesp.br

 0000-0001-8211-3882

Jucilene de Medeiros Siqueira

PhD in Biosystems Engineering from the University of Lisbon.
jucilene.siqueira@unesp.br

 0000-0002-0687-6631

Alisson Rodolfo Leite

Master in Electrical Engineering at Escola Politécnica - USP (2016), Doctoral Student in Agribusiness and Development at São Paulo State University (UNESP).
alisson.rodolfo@unesp.br

 0000-0003-0838-4566


Renata Nagima Imada

Degree in Mathematics from FCT/UNESP (2011), and Master's in Applied and Computational Mathematics from UNESP (2014).
renata.imada@unesp.br

 0000-0002-7355-822X

Fabiano Pinto Neves

Business Administration from the Faculty of Accounting Sciences and Administration of Tupã - FACCAT (2005) Master's student in Agribusiness Development at São Paulo State University (UNESP).
fabiano.neves@unesp.br

 0000-0002-2228-8426

João Paulo Mantovani


Master's Degree in Agronomy in Plant Production from Universidade do Oeste Paulista. Doctoral in Agribusiness and Development at São Paulo State University (UNESP).
joao.matovani@unesp.br

 0000-0003-3083-8237

Leandro Paloma Mantovani


Graduated in Agronomy from Faculdades Adamantinenses Integradas (2016). Master's in

Agribusiness Development at São Paulo State University (UNESP).
lmatovani@unesp.br

 0000-0001-7050-1351

Celso da Silva

Bachelor in Business Administration from São Paulo State University (Unesp). Postgraduate student in People, Business and Performance Analytics Development at University Center Maurício de Nassau (UNINASSAU).
celso.silva@unesp.br

 0000-0002-2049-0858

Mailing address: Universidade Estadual Paulista Júlio de Mesquita Filho, Câmpus de Tupã. Rua Domingos da Costa Lopes, 780 – Jardim Itaipu, CEP: 17602-496, Tupã, SP – Brasil.

Received: 04.16.2023.
 Accepted: 06.19.2023.
 Published: 08.02.2023.

ABSTRACT:

Given the scarcity of water resources that has been worsening over time and the high consumption of these resources by agribusiness, there is a need for studies that can manage such action in a sustainable way, providing food security for the present and future world population. **Background:** with the topic: What is the systemic view of automated models and techniques for determining or estimating transpiration, evaporation or evapotranspiration for plantations? **Objectives:** to identify in recent literature what researchers and scientists have disclosed about automation methods for supervision, with a focus on estimating evapotranspiration. identify methods, models and techniques for inferring evapotranspiration. **Methods:** A methodology based on exploratory theoretical testing with qualitative and quantitative characteristics through Systematic Review and Meta-Analysis of data. Results: Using specific software and methods, simulation studies with experimental data make it possible to calibrate efficient models to estimate evapotranspiration, but low-cost methods still have little adherence.

KEYWORDS: Efficiency in water use; Irrigation; Automation; Evapotranspiration; Systematic review.

Introduction

Since water is one of the most precious goods existing in nature and in most of the surface of Planet Earth, present in three forms of state of matter such as: gaseous, solid and liquid, and essential for the survival of all living organisms, even in abundance, not all water is suitable for consumption, yet, of what is suitable for consumption, a large part is not accessible (Nagel et al., 2020), there is thus a need and care regarding the use of this natural resource (V. D. C. Pereira et al., 2018).

It is estimated that most of the consumption of water resources is associated with agribusiness and industrial production sectors. In Brazil, it is estimated that *"of the 30,554 hm³ of water consumed in the country, 90% or 27,498 hm³ are concentrated in agribusiness"* (Montoya & Finamore, 2020, p. 456). It has a peculiar characteristic in relation to most other natural resources, water circulates naturally and, when it evaporates, changes from liquid to gas and, eventually, condenses and returns to the ground. Assimilated during plant photosynthesis, it becomes part of the carbohydrates stored in plants, but ultimately returned to water by decomposition (Kang et al., 2021; Oki & Kanae, 2006).

It should be noted that in nature, water can change its physical state through several different processes, such as evaporation, which corresponds to the physical process of phase change, passing from a liquid to a gaseous state and which occurs in oceans, lakes, rivers, on the soil and in damp vegetation from dew or leftover rainwater (Allen et al., 2006; Zhang et al., 2022).

There is also the biophysical process of transpiration, from which the water that passes through a plant, being a temporary constituent of its metabolism, is later transferred to the atmosphere by its stomata, following a series of resistances from the soil, passing through the xylems, mesophyll and stomata until reaching the atmosphere. Distinguishing the water vapor released into the atmosphere from the two phenomena (evaporation and transpiration from the plant) is very costly and, for many methods, the term known as evapotranspiration is used, defined as the simultaneous process of water transfer to the atmosphere through the evaporation of water from the soil, from the humid vegetation and through transpiration of plants, and can be considered as one of the most important variables of the hydrological cycle when equating energy, climate and water availability (Barbieri et al., 2020; Lei et al., 2018; J. Liu et al., 2020; Narciso, 2016).

The evapotranspiration process displaces water resources into the atmosphere and this moisture is directed to regions other than the planting site due to the movement of air masses, contributing to the water deficit of crops, this process is one of the main

causes of lost productivity, directly impacting the regional economy (Barbieri et al., 2020; Kamarudin et al., 2021).

The possibility of total reuse on site of the amount that is transferred to the atmosphere, arises the need to carry out the recomposition of water resources to the soil by manual or automated irrigation systems (Jo & Shin, 2021a). Consequently, it is evident the lack of estimating with acceptable accuracy the amount of water necessary for the recomposition of soil moisture for the healthy growth of local crops, since the excessive use of irrigation can be harmful to the soil, causing leaching or local flooding (Jo & Shin, 2021a; Kamarudin et al., 2021). In addition, irrigation systems have an indexed cost, due to the labor operating in manual systems and in systems that involve pumping costs from the consumption of electricity (V. D. C. Pereira et al., 2018).

Analyzing the process in order to optimize irrigation systems, especially for people in need of financial resources, is directly aligned with the United Nations (UN) Sustainable Development Goals (SDGs), as it helps the eradication of poverty (SDG-1) by increasing the efficiency of organic production. In sustainable agriculture systems (SDG-2), such action reduces the amount of water resources for the production of cultivars, in health (SDG-3), given that most rural areas do not have water treatment for the consumption of residents and workers, preserves the best quality of water and sanitation (SDG-6), being a direct action public health by preventing outbreaks of infectious and pathogenic diseases. In addition, with economic growth and decent work (SDG-8). Rational use also cooperates with the preservation of aquatic life (SDG-14), as it prevents the loading of toxic substances, fertilizers and pesticides into groundwater, lakes and rivers located in the regions surrounding the plantations. (Bhattacharyya et al., 2021; GT Agenda 2030, 2022; Moghadam, 2016; Ribeiro et al., 2017).

Due to the importance of water and its use and recovery for reuse aiming at the preservation and maintenance of life, this study was defined with the theme: What is the systemic view of the automated models and techniques for the determination or estimation of transpiration, evaporation or evapotranspiration for plantations?

Based on this theme, the general objective of the research was defined: To identify in the recent literature what researchers and scientists have publicized about the automation methods for irrigation, focused on the estimation of evapotranspiration.

Specific objectives are to answer the following questions:

- a) What automated methods for determining evapotranspiration exist?
- b) Of the existing methods and equipment, are there any that are low cost?

In this sense, the hypotheses established for this study are:

H_0 = There are automated methods and techniques for the determination or estimation of transpiration, evaporation or evapotranspiration for plantations that are low cost. H_1 = There are no automated methods and techniques for the determination or estimation of transpiration, evaporation or evapotranspiration for plantations that are low cost.

H_0 = The models of methods and techniques in the determination or estimation of transpiration, evaporation or low cost evapotranspiration are efficient and easy to use by the small producer. H_1 = The models of methods and techniques in the determination or estimation of transpiration, evaporation or low cost evapotranspiration are not efficient or are difficult to use by the small producer.

Considering the importance of the theme based and grounded in this introduction, and the proposed objectives, it is justified to carry out this research, through a Systematic Review (SR) and Meta-analysis.

Materials and Methods

The relevance of the topic related to the determination of evapotranspiration, shows that a formal survey in the literature on the systems and methods capable of estimating or even predicting the evapotranspiration of vegetative crops is beneficial, both in the academic and technological concept, since it directly impacts the economy and social issues of the population.

Research Strategy

The present study was carried out by the methodology applied in the development of the research as an exploratory theoretical essay with qualitative and quantitative characteristics through Systematic Review (SR), aiming to reach answers to the objectives set by the theme and test the hypotheses in the protocols based on the evidence (Sampaio & Mancini, 2007). The descriptive and analytical method present in the way of reporting the findings and measuring the results (Guyatt et al., 2011; Lakatos & Marconi, 2003), via meta-análise das descobertas nos estudos extraídos para síntese (Kitchenham et al., 2020; Klant & Santos, 2021).

Selection, Inclusion and Exclusion of Studies

All procedures were based on a structured protocol for the identification and verification of evidence in a paired manner by the researchers (Guyatt et al., 2008). The eligibility criteria for the inclusion and exclusion of studies and for the extraction and

other procedures of analysis and reporting of the findings are found in the Research Protocol and Data Management Plan registered in Mendeley® Data (Elsevier Inc., 2021) with the DOI: 10.17632/89wr243dbt.1 (Leite et al., 2022).

The searches and survey strategies for studies in the repositories' databases were carried out in the following databases: IEEE, Scielo, Science Direct, Scopus and Web of Science. The selection, inclusion and exclusion procedures of the studies were carried out through the metadata using the software StArt® - State of the Art Through Systematic Review (LaPES, 2020) for greater assertiveness and recording of actions based on the established protocol (Fabbri et al., 2016; Leite et al., 2022; McGowan et al., 2016).

Data Extraction and Synthesis

The extraction involved a more detailed analysis to identify elements in the studies that made it possible to achieve the research objectives and answer the hypotheses (Santos et al., 2007). Extracting 32 articles that were extensively analyzed for the synthesis, with textual meta-analysis with the software Iramuteq® 0.7 alpha 2 (Klant & Santos, 2021; Mancini et al., 2014; Ratinaud, 2014; M. A. R. de Souza et al., 2018).

Quality Assessment

In all procedures of the selection, extraction and summarization processes with quality assessment filters with the help of the StArt® software to identify key elements and terms of the research in the studies according to the programmed strings, generating for each study a score according to the incidence of the terms, facilitating the identification of studies most correlated to the research scope (Guyatt et al., 2008, 2011). In the summarization, textual meta-analysis was used with the Iramuteq® 0.7 alpha 2 Software (Klant & Santos, 2021; Kunihiro et al., 2022).

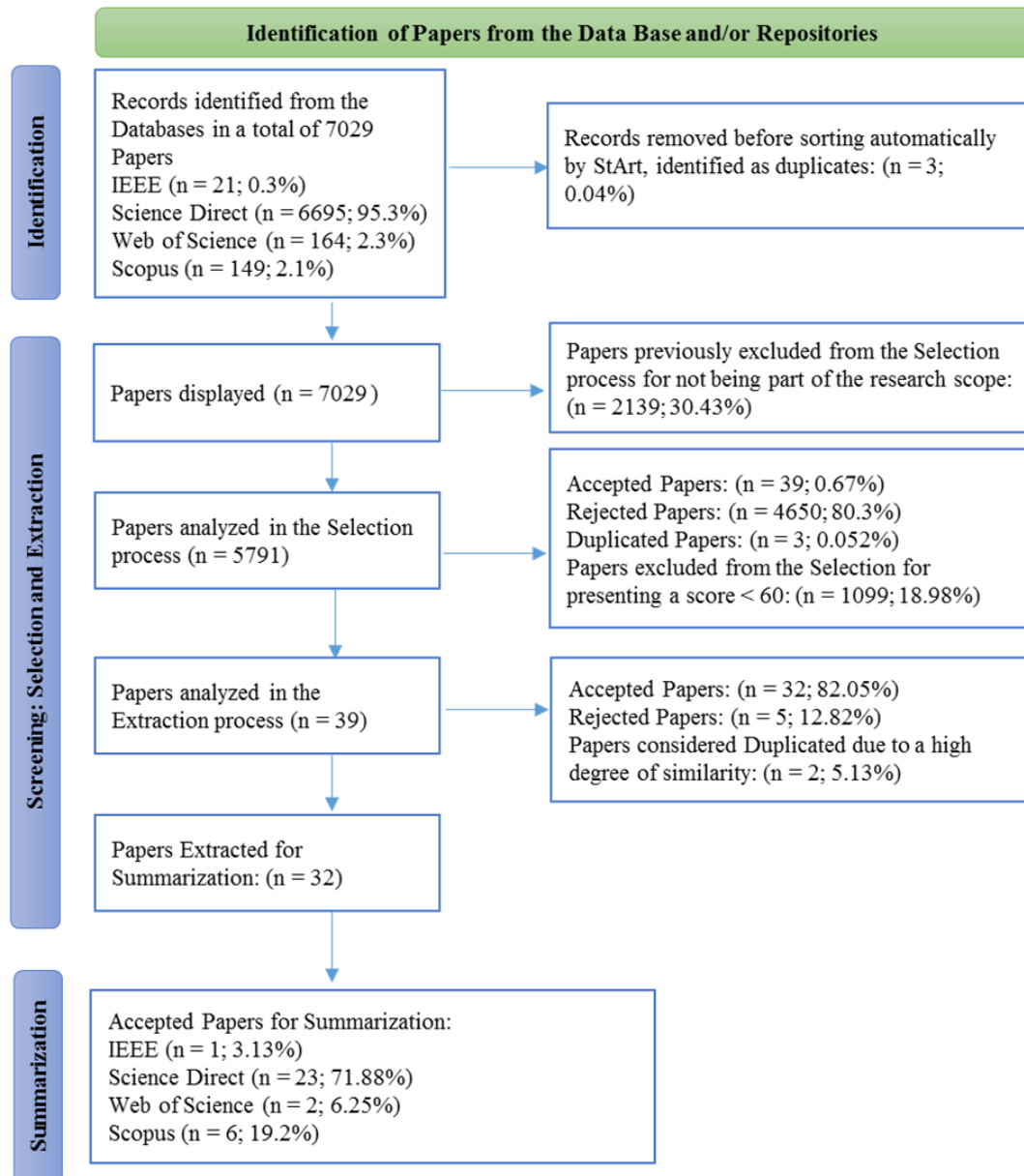
Results

Selection of Studies

In the search for the most current studies in the databases, a time interval was estimated referring to the works published in the period from January 2016 to October 2021, adjusted to the search terms: *“(automation OR automatic OR mechanization OR robotization OR motorization OR self-moving OR self-starting OR self-regulating) AND evapotranspiration”*. A total of 7029 studies were obtained, which were submitted to the systematic review process, with a protocol mentioned in the materials and methods

section, and the development of Selection and Extraction was represented in the flow diagram in **Figure 1**.

Figure 1 Diagram of the Systematic Review



Source: Prepared by the authors according to the PRISMA 2020 model (Page et al., 2021; PRISMA-P Group et al., 2015).

As can be seen in the diagram, of the 7029 studies identified in the searches in the Database of the repositories, after the selection and extraction procedures, resulted in 32 studies qualified for the summarization and meta-analysis of the results.

Characteristics of the Studies and Discussions

For a better explanation of the characteristics of the studies, the discussion follows together according to the developed negotiations. In this sense, in the selected studies, works that estimate evapotranspiration via satellite image analysis were observed to estimate the time and amount of irrigation, correlating optical and thermal data from Landsat-7/8 in four stages: i) partitioning the Landsat land surface temperature (LST) to derive the crop water stress coefficient (Ks), ii) estimating the daily soil moisture in the root zone (RZSM) from the integration of Ks derived from Landsat in a crop water balance model, iii) retrieve irrigation at the Landsat pixel scale and iv) aggregate pixel-scale irrigation estimates at the crop field scale. The method is an innovation tested in an irrigation recovery in three agricultural areas for a period of four seasons and evaluated in five winter wheat fields under different irrigation techniques (drip, flood and no irrigation). Obtaining model accuracy for the seasonal accumulated values ($R \sim 0.95$ and $RMSE \sim 44\text{mm}$) (INPE, 2022; NASA, 2022; Olivera-Guerra et al., 2020).

The studies extracted for the analyzes and the characteristic descriptions are listed in **Table 1**.

Table 1 Studies extracted for the analyzes

Study	Title of the article	Author(s)	Year	Database
1	Evapotranspiration-based Irrigation System for Mustard Green Crop Cultivation using Public Weather Forecast	(Dela Cruz et al., 2020)	2020	IEEE
2	Modeling evapotranspiration changes with managing Japanese cedar and cypress plantations	(Komatsu, 2020)	2020	ScienceDirect
3	Measurement and simulation of the water storage pit irrigation trees evapotranspiration in the Loess Plateau	(Meng et al., 2019)	2019	ScienceDirect
4	Comparing different methods for determining forest evapotranspiration and its components at multiple temporal scales	(Tie et al., 2018)	2018	ScienceDirect
5	Capability of Sentinel-2 data for estimating maximum evapotranspiration and irrigation requirements for tomato crop in Central Italy	(Vanino et al., 2018)	2018	DataScience
6	Modeling deficit irrigation-based evapotranspiration optimizes wheat yield and water productivity in arid regions	(Kheir et al., 2021)	2021	ScienceDirect
7	Simulating on the effects of irrigation on jujube tree growth, evapotranspiration and water use based on crop growth model	(Bai et al., 2021)	2021	ScienceDirect
8	Assessing the performance of a large-scale irrigation system by estimations of actual evapotranspiration obtained by Landsat satellite images resampled with cubic convolution	(Awada et al., 2019)	2019	ScienceDirect
9	Evapotranspiration of a willow cultivar (<i>Salix miyabeana</i> SX67) grown in a full-scale treatment wetland	(Frédette et al., 2019)	2019	ScienceDirect

Study	Title of the article	Author(s)	Year	Database
10	Dynamics of evapotranspiration partitioning for apple trees of different ages in a semiarid region of northwest China	(Wang & Wang, 2017)	2017	ScienceDirect
11	Can the drip irrigation under film mulch reduce crop evapotranspiration and save water under the sufficient irrigation condition?	(Qin et al., 2016)	2016	ScienceDirect
12	Developing irrigation water conservation strategies for hybrid bermudagrass using an evapotranspiration-based smart irrigation controller in inland southern California	(Haghverdi et al., 2021)	2021	ScienceDirect
13	Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept	(Liao et al., 2021)	2021	ScienceDirect
14	Optimization of irrigation scheduling for barley crop, combining AquaCrop and MOPECO models to simulate various water-deficit regimes	(Martínez-Romero et al., 2021)	2021	ScienceDirect
15	Transpiration and evaporation of grapevine, two components related to irrigation strategy	(Montoro et al., 2016)	2016	ScienceDirect
16	Evaluating deficit irrigation scheduling strategies to improve yield and water productivity of maize in arid environment using simulation	(Attia et al., 2021)	2021	ScienceDirect
17	Prediction Model of Transpiration Rate of Strawberry in Closed Cultivation Based on DBN-LSSVM Algorithm	(Shuaishuai et al., 2018)	2018	ScienceDirect
18	Water use efficiency of corn among the irrigation districts across the Duero river basin (Spain): Estimation of local crop coefficients by satellite images	(Segovia-Cardozo et al., 2019)	2019	ScienceDirect
19	Optimizing preplant irrigation for maize under limited water in the High Plains	(Kisekka et al., 2017)	2017	ScienceDirect
20	Irrigation retrieval from Landsat optical/thermal data integrated into a crop water balance model: A case study over winter wheat fields in a semi-arid region	(Olivera-Guerra et al., 2020)	2020	ScienceDirect
21	A reinforcement learning approach to irrigation decision-making for rice using weather forecasts	(Chen et al., 2021)	2021	ScienceDirect
22	A new solution of high-efficiency rainwater irrigation mode for water management in apple plantation: Design and application	(Sun et al., 2022)	2022	ScienceDirect
23	Development of a transpiration model for precise tomato (<i>Solanum lycopersicum</i> L.) irrigation control under various environmental conditions in greenhouse	(Jo & Shin, 2021a)	2021	ScienceDirect
24	Coupling irrigation scheduling with solar energy production in a smart irrigation management system	(Mérida García et al., 2018)	2018	ScienceDirect
25	Determination of the water requirement and crop coefficient values of sugarcane by field water balance method in semiarid region	(Dingre & Gorantiwar, 2020)	2020	ScienceDirect
26	Determination of the water requirement and crop coefficient values of sugarcane by field water balance method in semiarid region	(Dingre & Gorantiwar, 2020)	2019	Web of Science
27	Random forest techniques for spatial interpolation of evapotranspiration data from Brazilian's Northeast	(da Silva Júnior et al., 2019)	2019	Scopus
28	Using soil moisture sensors for automated irrigation scheduling in a plum crop	(Millán et al., 2019)	2019	Scopus

Study	Title of the article	Author(s)	Year	Database
29	An automatic irrigation control system for soilless culture of lettuce	(Z. Liu & Xu, 2018)	2018	Scopus
30	Automated irrigation systems for wheat and tomato crops in arid regions	(Al-Ghobari et al., 2017)	2017	Scopus
31	Ensemble forecasting of short-term system scale irrigation demands using real-time flow data and numerical weather predictions	(Perera et al., 2016)	null	Scopus
32	Water use efficiency in irrigated "Syrah" grape plantation at são francisco river valley	(Segovia-Cardozo et al., 2019)	2016	Scopus

Source: Prepared by the authors using the StAt and Excel (LaPES, 2020; Microsoft Corporation, 2016).

Still using satellites Vanino et al. (2018), carried out the exploration of the potential of the Multispectral Instrument (MSI) sensor aboard the Sentinel-2A to estimate crop parameters, mainly surface albedo (α) and Leaf Area Index (LAI) that influence the dynamics of potential evapotranspiration (ETp) and Irrigation Water (IWR) requirements of tomato crop for processing (*Solanum lycopersicum* L.). The maximum ETp of tomato was calculated according to the FAO Penman-Monteith equation (FAO-56) - (Penman, 1948), with adequacy of Sentinel-2A-derived canopy parameter values in correlation with daily meteorological data. The comparison was of actual crop evapotranspiration (ETa) derived from the soil water balance (SWB) in the Climate Integrated Environmental Policy (EPIC) model and calibrated with in-situ Root Zone Soil Moisture (RZSM). The experiment took place on a farm in Tarquinia, Italy, for a period of 2 years. Results showed canopy growth, maximum evapotranspiration (ETp) and IWR accurately inferred following seasonal patterns of precipitation and air temperature. The estimated net IWR was 272 mm in 2016 and 338 mm in 2017. The estimate was lower than that practiced by the farmer in micro irrigations by sprinkler and drip, which was 364 mm (276 mm micro drip irrigation and 88 mm sprinkler) and 662 mm (574 mm micro drip irrigation and 88 mm irrigation and sprinkler). The findings point to the suitability of Sentinel-2A in forecasting water demand for tomatoes (Vanino et al., 2018).

Awada et al. (2019) created an algorithm for Earth surface energy balance, via satellite images by Landsat 5 Thematic Mapper (TM). The process adopts the 'cubic convolution' method for three seasons. Adoption of areas with automated rotating irrigation with studies of the amount of water consumed throughout the year and a meteorological station to collect data for comparison. The model enabled the quantification of instantaneous, daily, monthly and seasonal ETa, as well as evaluating the performance of the irrigation system, so that it was possible to identify that the system allows savings of 16% to 26% of water consumption (Awada et al., 2019).

In the study by Segovia-Cardozo, there is an evaluation of the efficiency of water use in the maize crop, close to the Duero River, based on the evapotranspiration of the

crop. The analyzes were carried out in 4 locations from 2014 to 2017. The evapotranspiration estimates were generated based on satellite images correlated with data from an advisory service. There were small differences between the kc values of each district, but the gross irrigation needs showed large differences (Segovia-Cardozo et al., 2019).

The study by Dela Cruz et al. (2020), is based on a system that metrified evapotranspiration (ET) in a mustard crop, correlating information on temperature, humidity, solar radiation and wind speed, with data from a Microclimatic Meteorological Station and a Public Meteorology Center of Forecast. The data were used in inference by the Penman-Monteith Method. Applied 3 different irrigation methods: Manual; Irrigation; and ET-based Automatic Irrigation (Penman, 1948). The results showed a conservation of 71.70% of water compared to the manual irrigation system, and in the irrigation with ET using Microclimatic Meteorological Station, it conserved 71.81% of water compared to the manual irrigation system (Dela Cruz et al., 2020).

We see a study that evaluates algorithms for spatial interpolation of evapotranspiration data in terms of accuracy and performance. Compare conventional strategies such as: Inverse Distance Weighting (IDW), Ordinary Kriging (OK), machine learning strategies represented by Random Forest (RF) and a Random Forest variation for spatial predictions (RFsp) (Amorim, 2009; Costa Filho et al., 2019; G. S. de Souza et al., 2010). The analyzes relied on evapotranspiration data from meteorological stations in the Northeast region of Brazil from January 2017. The validation was carried out by leave-one-out crossing in the measurement of precision of the interpolation algorithms, being able to prove that the RF generate results with greater precision in the estimation of the reference evapotranspiration in relation to the conventional methods. Enabling a reduction of approximately 50% of the margin of error. It was found that RFsp did not perform better than RF, generating results very similar to IDW and OK. Also, IDW had the shortest time when running the analyzes to create the interpolation model, it had the shortest forecast times in January 2017 (da Silva Júnior et al., 2019).

In comparing the determination methods, the study by Tie et al. (2018), used different types of sensors and metrics, evaluating: sap flow; meteorological data; soil moisture at levels from 100mm to 800mm spaced 100mm apart; and relative humidity sensors at two heights (2m and 5m), to measure the energy balance by the Bowen ratio and dam systems (Bowen, 1926; Thomas et al., 2019). The results indicate that the sap flow procedure, taking into account diversities in forest types and tree species, produced an estimate of forest evapotranspiration based on components that converged with an estimate based on vortex covariance at the time scales of year, month and day, while the

estimate of forest evapotranspiration based on the soil water balance was also qualitatively consistent with the estimate based on covariance of eddies on the daily scale, considering an annual scale, the estimate of forest evapotranspiration based on the water balance was significantly higher than the estimate based on vortex covariance, which may likely result from non-negligible groundwater runoff caused by widely distributed regolith and rocks with cracks under the ground and at the sub daily scale, the diurnal course of the canopy transpiration estimate based on sap flow lagged significantly behind the forest evapotranspiration estimate, based on vortex covariance, which may be physiologically due to stem water storage and stem hydraulic conductivity. The results in this region can have a lot of referential significance for the estimation of forest evapotranspiration and evaluation of the method in regions with similar environmental conditions (Tie et al., 2018).

Study on the dynamics of evapotranspiration components (canopy intercept, soil evaporation and transpiration) for apple trees of different ages (7 and 17 years) during the experimental cycle within a daily scale, evaluating the components of evapotranspiration, intercepted precipitation (calculated), tree transpiration (thermal dissipation probes) measured at 1 min every 30 min, soil evaporation (microlysimeter) and ET₀ - calculated by the Penman-Monteith formula (Allen & FAO, 1998; Penman, 1948), using maximum and minimum daily temperature at 2m from the ground, maximum and minimum relative humidity, wind speed at a height of 10m and using log to estimate 2m and atmospheric pressure, from May to September 2012, 2013 and 2014, in Changwon County, on the Loess Plateau, focusing on the evapotranspiration response and its partition with tree age. Ages minimally affected soil transpiration, requiring further studies on transpiration, although better calibration is needed, the study was able to determine that ages affect evapotranspiration and suggested that evapotranspiration is higher in older trees (Wang & Wang, 2017).

Jo and Shin, (2021) develop a model of tomato transpiration by correcting the relationship between the transpiration rate and environmental factors, measuring the real transpiration rate. Crop transpiration was estimated based on several models, such as those of Penman-Monteith, Stanghellini, Shuttle-Wallance and Priestley-Taylor. The transpiration rate of the crops was verified by means of several measures, such as soil water balance, stomatal conductivity by means of a porometer, sap flow and change in the weight of the crop using a weight sensor. The actual transpiration rate of the culture, which was measured using a load cell, and weight changes calculated at 10-minute intervals. The experimental results revealed that the transpiration rate did not present a linear relationship with the initial Rad or VPD models, therefore, a transpiration model

was developed compensating the Rad and the VPD based on the existing Penman-Monteith equation. The verification results of the developed models, both Rad and VPD were adjusted and applied to the transpiration model, the transpiration rate of the crop was estimated more accurately compared to the other developed models (Jo & Shin, 2021b; Penman, 1948; Priestley & Taylor, 1972; Stanghellini, 1987).

Agronomic modeling software used by Kheir et al. (2021), on a basis with three wheat varieties (CERES, CROPSIM and N-Wheat), being applied with a software Decision Support System for Agro Technology Transfer (DSSAT) (Sivalakshmi et al., 2021; Thomas et al., 2019), calibrated and evaluated using three growing season datasets and then used for long-term simulation of wheat yield and water use efficiency under irrigation with different crop evapotranspiration (ET_c) fractions. In order to calibrate and evaluate CERES, CROPSIM and N-Wheat models using ET_c datasets based on irrigation, determined by the existing crop (EC) for a new high-yield wheat crop (Giza 171), in this way apply models in the water yield and productivity forecast using ET_c-based irrigation and long-term simulation over a period of 1991-2020, at 10 different locations along the Egyptian Nile River, managing to exploit the recommended irrigation treatment achieved higher yields and water productivity compared to farmer practices. This is the first attempt to assess irrigation-based evapotranspiration (ET) in wheat crops at multiple locations and with long-term meteorological data. It achieved a good fit of data and observed that for some wheat crops irrigation must have a deficit index with respect to ET_c (Kheir et al., 2021).

Another experiment with the same software, presented in the study by Attia et al. (2021), calibrate and evaluate the DSSAT model using detailed experimental datasets on maize (*Zea mays* L.) yield and water productivity in an arid Mediterranean environment and determine the impacts of various irrigation scheduling strategies on corn yield and water productivity in arid sandy soils producing irrigation schedule recommendations that maximize the marginal benefit per unit of water applied. Simulations over a long-term period (1984-2018), using well-calibrated models were performed and included three irrigation scheduling strategies: (i) soil water-based irrigation scheduling, (ii) ET-based threshold irrigation scheduling, and (iii) ET-based irrigation growth-scaling. Four levels of maximum allowable depletion (MAD) of available soil water content (AWC) were tested using the DSSAT self-irrigation option. The results indicated that MAD 50% is recommended for programmed irrigation in arid sandy soils for potential savings in irrigation water without unacceptable yield loss. The ET-based threshold consisted of a combination of four cumulative net ET threshold (ETH) triggers of 14, 21, 28, and 35 mm

and five ET replacement levels of 50%, 70%, 90%, 110%, and 130 % ET using the automatic irrigation option based on DSSAT ET (Attia et al., 2021).

The study by Kisekka et al. (2017), aimed to determine the amount of pre-planting irrigation and irrigation capacity combinations that optimize yield, water productivity, and rainfall use efficiency (PUE) and minimize soil water evaporation losses before planting. of planting (Kisekka et al., 2017). The research involved combining short-term experimental data with long-term historical climate data (1986-2014) and crop simulation modeling to determine optimal pre-planting irrigation water management in the lowlands of the United States. A pre-planting factorial experimental design was carried out with irrigation of 0-76mm and irrigation capacity of 2.5; 3.8; 5 mm/day. The experimental plots were 36 m long by 18 m wide, with irrigation as the main plot factor and seeding rate as subplots (3x36m) with row spacing of 76.2cm. Model RZWQM2 (version 3.0) with embedded DSSAT-CSM CERES-Maize 4.0 culture growth module was used. In RZWQM2, the flow and redistribution of unsaturated soil water were modeled using a one-dimensional Richards's equation. Potential evaporation and transpiration demand from the atmosphere were calculated using Shuttleworth's ET model (Shuttleworth & Wallace, 1985), in RZWQM2 being an extension of the Penman-Monteith ET model (Penman, 1948), but the first takes into account incomplete canopy coverage and plant height in estimates of potential evaporation and transpiration. The actual root water uptake described by the term sink in the Richards equation was calculated numerically using the Nimah procedure (Nimah & Hanks, 1973). Actual root water uptake, potential evaporation and potential transpiration were used in calculating the water stress factors used in CERES-Milho to modulate the plant growth process, such as leaf growth, as soil water is depleted. The CERES-Maize model built into RZWQM2 is a radiation-based mechanistic crop model that predicted maize growth and development based on climate (rainfall, solar radiation, maximum and minimum temperature, to a lesser extent photoperiod). Through the historical series it was possible to build a model that estimates with the ET and the amount of water in the soil and with that it was possible to estimate which pre-irrigation levels are best suited for corn planting. The study also demonstrated that the type of irrigation can affect evapotranspiration, in which the underground drip has a lower evapotranspiration rate than a sprinkler system (Kisekka et al., 2017).

Modeling was also used by Bai et al. (2021), for the calibration of the crop input parameters of the WOFOST model for simulating the limited growth of jujube in water, evaluate the performance of the model and quantitatively describe the response of yield, real evapotranspiration (TRa) and use efficiency of water (UAE) for different irrigation

treatments. The trees were also conducted until their maturation and production and evapotranspiration were measured, thus introducing these data into the WOFOST model (Diepen et al., 1989; FAO, 2022). The calibration of the phenology data was carried out by accounting for the flowering and maturation period. The fruit mass parameters were collected and randomly selected and dried at 85°C. The model was shown to reflect well the effects of irrigation and meteorological information on evapotranspiration, so irrigation significantly affected productivity, especially at its extremes (Bai et al., 2021).

Martínez-Romero et al. (2021), uses the AquaCrop and MOPECO models to calculate and compare the functions of crop water production and irrigation water productivity generated by various irrigation strategies (Anjos, 2015; Oliveira, 2018). Provided by each model for typically irrigated cultivated barley in the area. In addition, it evaluates the performance of both models with a 3-year field experiment applying the regulated deficit irrigation methodology optimized for limited volumes of irrigation water (ORDIL) in the barley crop. The two models were programmed with the same input parameters considering different irrigation regimes of a three-year experiment, some phenological parameters were obtained from bibliographies. Both models provided had an adequate performance in the simulation of the final productivity of the crop (error margin less than $0.50 \times 10^3 \text{ kg ha}^{-1}$), as well as canopy coverage and aboveground biomass evolution, in the case of AquaCrop, whose quality of fit indicators were close to 0.90 or higher. In terms of crop evapotranspiration, AquaCrop simulated an average value 12% higher than MOPECO. The authors conclude that both are complementary and their use will depend on the needs of the end user. Thus, MOPECO offers a wider range of irrigation strategies, while AquaCrop offers more detailed information about the physiological response of the crop during its development, with the simulation results being sufficiently accurate in both (Martínez-Romero et al., 2021).

Modeling systems involving prediction in the study by Shuaishuai et al. (2018), selects strawberries in a closed-growing solar greenhouse as a research object, with sufficient water supply conditions, the deep belief network and least squares support vector regression (DBN-LSSVM) is used to establish a model for predicting the transpiration rate of strawberry leaves, thus predicting the transpiration rate of the strawberry through greenhouse environmental parameters. First, multi-scale feature vectors of greenhouse meteorological parameters were extracted using the deep belief network (DBN) method to eliminate the correlation of variables, thus improving the predictability and generalizability of the model. The extracted feature vectors were used to train and optimize the LSSVM model, finally obtaining the model for predicting the transpiration rate of strawberry leaves in a closed cultivation solar greenhouse, which

were compared in experiments with the traditional BP neural network and the LSSVM model. Wireless sensor network for real-time measurement has been adopted in the greenhouse environment. The main parameters used include air temperature, air humidity, light and substrate temperature these were sent to the data management center through the smart gateway and the portable photosynthetic LI-6400XT was used to collect the transpiration rate of the strawberry during the fruiting period. The developed model had better results than traditional methods when applied to strawberry cultivation in greenhouses (Shuaishuai et al., 2018).

Modeling based on historical data described in the study by Komatsu (2020), examines a model successfully predicting total evapotranspiration for cedar and cypress and changes in evapotranspiration with thinning and clear cutting, which has field input data the diameter of stem, breast height and density and meteorological data. The model was subdivided into evapotranspiration elements (E_t , E_i and E_f) and a model was compared with bibliographic data from the region. It demonstrates that the coupling of the model and the yield tables allow the prediction of annual evapotranspiration for different management scenarios and, then, the evaluation of public policy recommendations. The model also suggests that the decrease in annual evapotranspiration with aging can more than triple by thinning at a rate of 50%, although this suggestion should be tested by observational studies (Komatsu, 2020).

Chen et al. (2021) uses a deep Q-learning (DQN) irrigation decision-making strategy based on short-term weather forecasts to determine optimal irrigation, the method is demonstrated for rice grown in Nanchang, China. Irrigation was decided by two irrigation decision-making strategies, namely conventional irrigation (i.e. flood irrigation commonly used by local farmers) and deep Q-learning (DQN) based irrigation. The results showed that the performance of the daily rainfall forecast was acceptable, with potential room for learning and exploration. The DQN irrigation strategy had strong generalizability after training and could be used to make irrigation decisions using weather forecasts. In this case, the simulation results indicated that, compared to conventional irrigation decisions, DQN irrigation reduced water consumption, resulting in irrigation water savings of 23 mm and reducing drainage by 21 mm and irrigation time by 1.0 times on average, with no reduction in yield. The DQN irrigation strategy of learning from past irrigation experiences and uncertainties in weather forecasts avoided the risks of an imperfect weather forecast (Chen et al., 2021).

Perera et al. (2016), developed a ensemble forecasting system to generate irrigation demand forecasts (5 days) on a short-term probabilistic scale in real time; a deterministic multivariate time series model. Built a model using historical data from

weather stations collected using the Australian Community Climate and Earth System Simulator (ACCESS). The model successively estimates and compares the predicted data with the collected data, after calibration, the data are sent to the SCADA irrigation control system (Ackerley & Dommenget, 2016; V. da C. Pereira et al., 2016).

Some authors study the interference of each plot on evapotranspiration like Dingre; Gorantiwar (2020), report how to more accurately estimate the sugarcane crop coefficient, field studies were conducted during two seasons of 2015 and 2016 in clayey soils to determine crop evapotranspiration and crop coefficients (K_c) from sugarcane to the semi-arid region of India. In addition to precipitation, irrigation scheduling was based on the field water balance approach. Crop evapotranspiration was determined by field water balance and reference evapotranspiration (ET_0) by the Penman-Monteith approach, while the crop coefficient was calculated using the standard FAO-56 methodology. 1388 millimeters respectively (Allen & FAO, 1998; Penman, 1948). The average evapotranspiration of the two-year sugarcane crop estimated by the field water balance method was 1339 mm/year. Irrigation water requirements and effective rainfall were 991 mm/year and 424 mm/year, respectively. The two-year results showed that there was a remarkable symmetry between the K_c obtained from field water balance measurements and the K_c reported by FAO-56. The K_c values determined for the tillering, high growth and maturation stages of sugarcane were 0.70, 1.20 and 0.78, respectively. K_c values were found to be 25.5%, 4% and 20.4% lower during tillering, high growth and maturity stage, respectively, compared to FAO-56 K_c values. The order 2 polynomial equation was fitted with the crop coefficient as the dependent variable and the ratio of days after transplantation to total culture period as the independent variable (Dingre & Gorantiwar, 2020; Penman, 1948).

Pereira et al. (2016), when estimating the water use efficiency (USA) in the irrigated 'Syrah' vine in the Lower São Francisco Valley, based on yield as a function of crop evapotranspiration and maximum transpiration. For the proposed objective, the crop evapotranspiration was determined by the energy balance based on the Bowen ratio method (ET_{cBERB}), (Bowen, 1926), while the maximum transpiration (TR) was estimated by the modified Penman-Monteith model (Penman, 1948), based on the leaf area index of the crop. The micrometeorological data were monitored during a production cycle through an automatic station located in the vineyard. The reference evapotranspiration (ET_0) was also calculated throughout the experiment by the Penman-Monteith method, parameterized in FAO bulletin 56 (Allen et al., 2006; Penman, 1948). The ET_0 and the ET_{cBERB} corresponded to the total value of 474.0 and 376.4 mm/cycle, with an average daily value of 3.9 and 3.1 mm, respectively (Bowen, 1926). The RT ranged between 3.5

and 0.9 mm/d, with a total volume during the cycle of 284.4 mm. The EUA, based on total water consumed and transpired, was 1.17 kg m⁻³ and 1.55 kg m⁻³, respectively. The BERB method and the modified Penman-Monteith model for isolated plants showed reliable results for estimating the EUA under the climatic conditions of the Sub-medium region of the São Francisco Valley. However, further studies need to be carried out mainly in this semiarid region with the vine culture for wine production, where most of the research focused on vineyard management is still under development (V. da C. Pereira et al., 2016).

Thus, it can be seen that the evapotranspiration estimate can be associated with different types of management, as described by Meng et al. (2019). In the study, a model that estimates the evapotranspiration of apple trees with reservoir wells, aiming to modify the Shuttleworth-Wallace (SW) model to establish a practical model (SWp), which can accurately predict the orchard evapotranspiration (WSPI) analyzing comprehensively the prediction error mechanism of the SWp model (Shuttleworth & Wallace, 1985). Precipitation, air temperature, relative humidity, wind speed and wind direction were checked by an Adcon weather station in the middle of the orchard, with measurements every 15 min. In the regions, a portable station NK-3500 was used with sampling at 8:00, 14:00 and 18:00. Evapotranspiration was measured by microlysimeter and sap flow rate. A thermal diffusion rod from Dynamax, Houston, USA, covered with glue and wrapped with plastic film and aluminum in the trunk was used to avoid interference from solar radiation. Soil moisture was measured with a TRIME-PICO-IPH TDR monitoring tube, thus setting up three models: Penman-Monteith (PM), Shuttleworth-Wallace (SW) and practical Shuttleworth-Wallace (SWp). These were compared with the experimental data. The results show that the evapotranspiration model of irrigation trees from water storage wells is established, and the Nash efficiency coefficient of the model is 0.93, the diurnal variation of evapotranspiration obtained by the three models of PM, SW and SWp are equal to the measured value and that the simulated value of the PM model is 11.45% lower than the measured value, the simulated value of the SWp model is 24.01% greater than the measured value and the simulated value of the SWp model is 5.55% greater than the measured value, and sensitivity analysis is performed on the six resistance variables in SWp, which reveals the SWp simulation error mechanism. Thus, SWp has significantly improved accuracy over PM and SW models and can be used to estimate evapotranspiration under irrigation conditions with water storage wells (Meng et al., 2019; Penman, 1948; Shuttleworth & Wallace, 1985).

Frédette et al. (2019) measures and models the evapotranspiration of a willow cultivar, *Salix miyabeana* (SX67), to provide the ET rates and crop coefficient for this species in temperate wetlands, willows are planted in a wetland that receives effluents

from the treatment of wooden poles, the instantaneous conductance measurement (G_s) represents the rate of exchange of water vapor from the leaf to the boundary layer (boundary layer), measured by a steady-state porometer (Decagon, SC1) or Leaf area index was extrapolated from an individual and considering a factor to differentiate edge and center individuals. To estimate the actual ET of the wetland, the water balance method was used (Kadlec & Wallace, 2009), and for culture ET, thus compared to the modified Penman-Monteith reference ET (Allen et al., 2006). The relationship between meteorological parameters and G_s were tested with regressions and Tukey's test in R software (Ihaka & Gentleman, 2018). Considering the great abundance of water, the study defined that evapotranspiration is highly correlated with stomatal conductance (G_s) and that a model described with mean G_s , leaf area index and water vapor pressure deficit could predict evapotranspiration in wetlands (Frédette et al., 2019).

Mérida García et al. (2018) describes an intelligent irrigation management model based on the use of solar energy to supply irrigation water directly to the grid, without intermediate storage elements (water tanks and dams). A system was developed in MATLAB called Smart Photovoltaic Irrigation Manager (SPIM) (The MathWorks, 2022), that considers the climatic and seasonal variables of the culture. The calculation of Evapotranspiration was data from meteorological stations close to the site (Allen et al., 2006). Therefore, the strategy was based on the water balance, always considering the previous day and recording the sectors that had already been irrigated, with preference for the sectors with lower energy consumption. The results showed that the proper management of the photovoltaic irrigation system provided enough water to satisfy the irrigation needs of the crops throughout the irrigation period and avoided the emission of 1.2tn of CO₂, using only the energy generated by the solar panels (Mérida García et al., 2018).

Sun et al. (2022), combines rainwater harvesting technology with a solar smart irrigation system equipped with soil moisture sensors to form a high-efficiency rainwater irrigation (HRI) mode suitable for orchards and conducts an experiment with 3 treatments and a control: T1 (HRI) – when soil moisture is below a threshold, irrigate; T2 (catchment without irrigation control); T3 (rainwater harvesting); CK (no irrigation), T2 and T3 have intermittent irrigation every 10 days. The precision irrigation control system uses soil moisture sensors to collect information (TDR-315L Acclima, Inc.) and load it into the irrigation monitor (GG-002C-3G). The irrigation monitor passes to the computer to analyze and decide when irrigation will be carried out, in this way, not only the roots of the crops can have a sufficient moisture content in the soil and meet the needs of plant growth, but they can also stabilize the humidity, close to a certain predefined value,

avoiding the waste of water resources caused by excessive irrigation. Compared with using only rainwater harvesting and combined with traditional irrigation methods (SDI), HRI mode can increase apple yield by 56.2% and 22.0%, efficient water use by 40, 4% and 12.6%, respectively, giving a financial payback in 2 years (Sun et al., 2022).

As well as more traditional managements as studied by Qin et al. (2016), on evapotranspiration using two irrigation methods: traditional edge irrigation and drip irrigation. Two areas were divided, one with drip system and the other with traditional edge systems, evapotranspiration were analyzed by edge covariance (EC), Bowen ratio energy balance (BREB) and soil water balance (WB) methods (Bowen, 1926). Compared with traditional edge irrigation, drip irrigation induced higher irrigation frequency, lower irrigation amount and wetting depth, and lower deep percolation. In addition, drip irrigation slightly reduced the average daily evapotranspiration of corn, but it can accelerate crop growth and shorten growth stages. Thus, the technology reduced the total maize evapotranspiration at all growth stages by less than 10% during the two years (Qin et al., 2016).

Montoro, Mañas and López-Urrea (2016) carry out an experiment to quantify the evaporation and transpiration of the Tempranillo vine and the effects of irrigation frequency on evaporation. Transpiration and evapotranspiration measurements of the Tempranillo vine crop without soil water limitation were carried out in a 3x3m lysimeter with a depth of 1.7m with a precision of 250g (0.03mm of water) of weighing covered with waterproof canvas during different periods. Transpiration estimation was done by micro meteorological data and using satellite images to determine the leaf cover and thus the vegetation index, also measuring directly using sap flow sensors. Where it was evidenced that transpiration and evaporation are related to irrigation management, therefore, irrigating with greater intensity with longer spaces of time can contribute to the reduction of evaporation in Tempranillo vines (Montoro et al., 2016).

Haghverdi et al. (2021), implements autonomous water conservation and deficit irrigation strategies in rural Southern California, evaluating lawn irrigation strategies in both quantity and frequency, determines minimum irrigation levels, analyzes soil water dynamics in surface and develops a regression-based turf water response function (TWRF) term for irrigation management. At the beginning of planting, all treatments were irrigated equally and, after rooting, a factorial system was made with 36 plots, 12 irrigation treatments (6 irrigation levels x 2 irrigation frequencies). Irrigation took place at night to avoid evaporation losses. A pressure regulator was placed upstream of the sprinklers, using two sensors to measure soil moisture. A smart irrigation controller (Weathermatic Smartline 4800) was connected to a wireless weather sensor (SLW5) and

used to apply irrigation to all treatments. An SLFSI-T10 flow sensor (Telsco Industries, Inc, Garland, TX, USA) was used to control the water flow. Irrigation levels above 72% were considered acceptable for the crop studied and these irrigation levels make the consequences of severe climates less noticeable to the cultivars. The determination of local ET₀ proved to be promising, although it was overestimated by 5.7% in relation to CIMIS ET₀ and more studies should be carried out using the Hargreaves equation (Haghverdi et al., 2021).

Irrigation methods can be evaluated using evapotranspiration measurements Al-Ghobari et al. (2017), verifies whether electronic irrigation systems are effective in saving water and evaluates the effect of these controllers using both drip and sprinkler irrigation systems. The experiment was divided into two plots, where one was irrigated manually and the other automatically with a system - ET Symtem (Nunter Pro-C) - which was chosen due to cost-effectiveness. The ET data were calculated using the sensing of a meteorological station using the modified Penman equations, FAO-56 version (Allen et al., 2006). The results revealed that efficient water use (WUE) and irrigation water use efficiency (IWUE) were typically higher in automated irrigation systems (AIS) than in conventional irrigation control systems (CIS), providing up to 26 % of water savings (Al-Ghobari et al., 2017).

Liao et al. (2021), develops an intelligent irrigation system based on real-time soil moisture data, in which the dynamic water amount of the crop was estimated using the spatio-temporal characteristics of soil moisture distributions. Crop water uptake depth data were acquired using a central irrigation controller to obtain an accurate irrigation depth at each irrigation event, applied in a drip irrigation experiment for tomato (*Lycopersicon esculentum*), wireless moisture sensors were installed to collect real-time moisture data from a 0 to 100 cm soil profile, for comparison a weather station was added (WS1800, Nertica, China), with that, a regression equation was set up quantifying the depth and dynamics of water absorption of the culture, this equation was used to determine the amount of irrigation and provided an economy in the amount of water used. Tomato evapotranspiration calculated using soil moisture data was consistent with that calculated using internal meteorological data, confirming the reliability of the data (Liao et al., 2021).

Dingre and Gorantiwar (2020) implement an automated irrigation system using a PLC and soil moisture sensors in conjunction with a class A tank comparing different irrigation levels for pear planting, performing a randomized block experiment with different irrigation levels 120, 100, 80, 60 and 40% with 3 replications. An autonomous irrigation system with three phases was also built: electrical panel, software and irrigation

system and class A tank. Next to the tank, a rain gauge was installed and the measurement of the tank was performed by a pressure transducer. Once the amount of irrigation water was controlled, the runoff was assumed to be zero. At a depth of 60-90 cm of soil layer the moisture content of the soil was measured using the sensor calibration equations immediately before irrigation and one day after irrigation. The deep percolation from the effective rooting depth (0-60 cm) was determined by subtracting the last measurements. The study demonstrated that automated irrigation systems by the class A tank can be used to determine soil moisture and that irrigation systems with a percentage of 40-60% can be used for regions with water scarcity and 100-120% for regions with an abundance of water (Dingre & Gorantiwar, 2020).

Millán et al. (2019), evaluate an automated irrigation system, which allows the definition of regulated deficit irrigation (RDI) strategies in an orchard. For the proposed objective, an automated device was used with an algorithm that combines irrigation scheduling based on water balance with a feedback adjustment mechanism using 15 capacitive sensors for continuous measurement of soil moisture. Tests were carried out in 2016 and 2017, in Vegas Bajas del Guadiana (Spain), on an experimental plot of 'Red Beaut', an early maturing Japanese plum cultivar. Three irrigation treatments were established: control, RDI and automatic. The control treatment was programmed to cover the crop's water needs, a post-harvest deficit irrigation (40% crop evapotranspiration). The ET_c strategy was applied in the RDI treatment, while the Automatic treatment simulated the RDI, but without human intervention. After two years of testing, the automated system was able to "simulate" the irrigation schedule programmed by a human expert without the need for human intervention. Despite the good results obtained in this study, some aspects of the system can be improved, including the automatic assessment of the representativeness of soil moisture sensors and the integration of a sensor that automatically characterizes the water stress of the plant (Millán et al., 2019).

Liu e Xu (2018), use a mesh with sensors and actuators that communicate via zigbee to constitute an irrigation system based on climate conditions of the greenhouse, soil moisture sensors and "leaf" temperature sensors. Some parameters were established to carry out irrigation, in order to always allow a minimum level of moisture in the soil (0.14cm³/cm³). Thus, the end of irrigation is calculated considering the overlap, the irrigation volume if it is greater than or equal to the evapotranspiration of the water of the crop and the water content in the root zone is greater than the irrigation limit value sensor of soil moisture used: EC-5 (8.9 cm long, 1.8 cm wide, 0.7 cm deep, METER,

Pullman, WA, USA). The study achieved an optimization when compared to the manual method and a reduction in the amount of water used (Z. Liu & Xu, 2018).

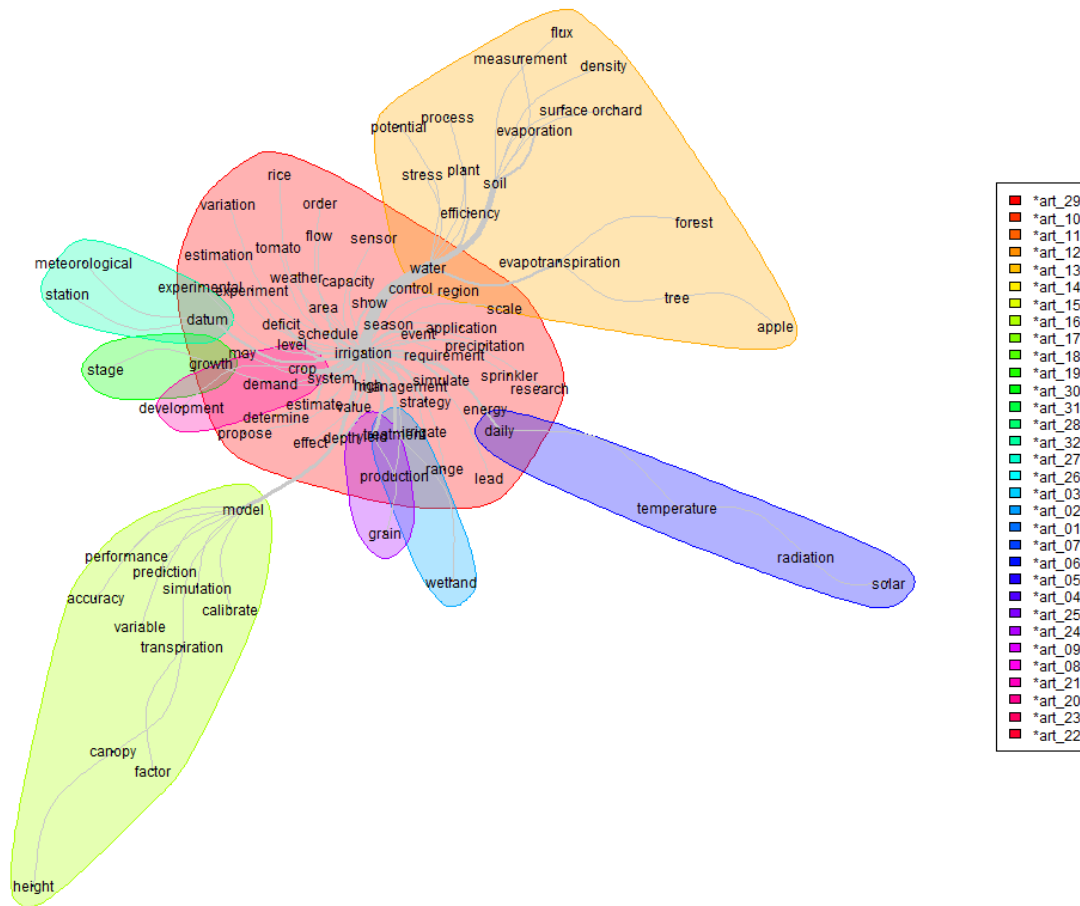
Qualitative Meta-analysis

The meta-analysis was carried out using the Iramuteq® 0.7 alpha 2 software, with a 'textual corpus' composed of texts from the 32 studies in full, treated in a UTF-8 file, structured in 6361 text segments. Lexicography was verified for word frequency, multivariate analysis, descending hierarchical classification and similarity analysis. Based on Reinert's method statistics given by the formula: $P(r) \approx 1/r \ln(1.78R)$ where "r" is the number of different words in a linguistic corpus for analysis of word classes and the χ^2 distribution (Klant & Santos, 2021; Ratinaud, 2014; M. A. R. de Souza et al., 2018).

Identifying 11235 forms, with 221731 occurrences, 9560 lemmas that are the lemmatized forms of words in logical construction for interpretation, 7882 active forms of expressions and 1678 complementary forms of expressions, and 3918 hapax (words that appear only once in the set of 32 studies). It was identified that the active forms had a frequency $\geq 4:2472$, with an average form per text segment of 34.857884, being composed of only two classes with 6116 classified segments of 6361 text segments, obtaining $P(r) \approx 96.15\%$ (Reinert) with significance $p < 0.0001$ (Klant & Santos, 2021; Kunihiro et al., 2022).

In the first class, 5 studies were grouped, the others in the second class. The analyzes also included the generation of visual graphs, for a better understanding of the relationship between the research studies, as can be seen in **Erro! Fonte de referência não encontrada**. (Haghverdi et al., 2021; Komatsu, 2020; Meng et al., 2019; Qin et al., 2016; Tie et al., 2018).

Figure 2 Graphic Analysis of Similitude



Source: Prepared by the authors using the Iramuteq® Software (Klant & Santos, 2021; Ratinaud, 2014).

In the analysis of similarity, shown in Figure 2, the relationship between the studies, their connections and correlation can be seen. Note that "irrigation" is the central axis word present in the studies, with an incidence of 3185 appearances. The words shown are above 100 occurrences. The rings represent the set of articles that are related through words, demonstrating the convergences between the studies. Branches indicate the strength of connection and how close or distant they are between terms in the form of a tree of words with their branches (Klant & Santos, 2021; M. A. R. de Souza et al., 2018).

Likewise, the representation indicates the low or absence of correlation of the studies by Attia et al. (2021) and Montoro; mornings; López-Urrea (2016) and in relation to other studies. Because these two studies in particular have a greater focus on modeling, dealing especially with issues related to: "performance", "prediction", "simulation", "calibration", "accuracy", "feasibility", "transpiration", "factors" and "tests", with a more academic focus on observation and analytical solution development. As for

the others, focusing on "productivity", "sensitivity" of "sensors", "capacity" and "efficiency" to generate practical results.

Quality of the Study and Certainty of the Evidence

The entire process of identification, selection and extraction of studies, eligibility requirements were observed, ensuring the composition of the best works and in a paired way by the research group to minimize the risks of bias. Only studies with a score rate identified by StArt above 60% are included (LaPES, 2020).

The textual meta-analysis comprised the totality of the "textual corpus" of the 32 studies, with 6361 text segments, obtaining $P(r) \approx 96.15\%$ (Reinert) with significance $p < 0.0001$. Thus ensuring the quality and certainty of the evidence observed in the study.

Final Considerations

Aiming to answer the research theme in light of what was exposed in this study, we sought to answer the research objectives, so that for the question: What automated methods to determine evapotranspiration exist? It was understood that the methodology of the different experimental works made use of different sensors, among which the ones that stand out are the implemented metrological stations of air temperature, air humidity, wind speed and direction, solar radiation and precipitation, lysimeters, porometers, soil moisture meters deployed at different depths or even those used as a single parameter for autonomous irrigation. The sap flow meters also showed good results, although they reported difficulties in their calibration even using techniques such as covering with aluminum to reduce the interference of solar radiation (Meng et al., 2019).

The main software found in the works for the acquisition of satellite images were Landsat and Sentinel-2A, which demonstrated with good results the appropriate treatment methods, but with limitations with the acquisition of images with the cloudy temple. In terms of simulation of production and management of agricultural resources, DASSAT stood out, which allows the inclusion of experimental data. As input parameters for model calibration, those identified were CERES, CROPSIM and N-Wheat. Others that stood out were AquaCrop and MOPECO, where MOPECO offers a wider range of irrigation strategies while AquaCrop offers more detailed information on the physiological response of the crop during its development. In general, all models and software proved to be suitable for irrigation (Anjos, 2015; Oliveira, 2018).

And, the models developed using programming techniques such as RZWQM2, deep belief network, least squares support vector regression (DBN-LSSVM), deep Q-

learning, Random Forest and its derivations, using historical data and experimental plots for calibration and validation, were identified as methods to estimate evapotranspiration and predict irrigation values for specific crops. The recurrent models, always compared with those described in the literature, were the Penman-Monteith, modified Penman-Monteith, Bowen and Shuttleworth-Wallace (SW).

Regarding the question: Of the existing methods and equipment, is there any that is low cost? Yes, it is likely that there is, however, in this study, it was not possible to identify elements that would allow us to infer an assertive answer to this question, for which a study on the dynamics of market competition for equipment and software for evapotranspiration would be appropriate.

As for the hypotheses established for this study, given the fact that it does not respond assertively to the second objective, the analyzes of the hypotheses remain impaired, which can be answered in a future study on market analysis and competitive dynamics.

It should be noted that the selected works demonstrate some trends in research lines that involve the term evapotranspiration, which include modeling using satellite images, modeling by local metrological stations, modeling using soil and sap sensors in conjunction with local metrological stations as well as modeling using data from metrological stations near the site. It was also possible to locate, from the use of these tools, simulation studies where the use of experimental data is made in order to calibrate models capable of estimating evapotranspiration.

Another fact that this study revealed is the dependence of evapotranspiration with the type of crop, planting age and its seasonality, thus opening opportunities for studies for the most diverse existing cultures, especially those with greater commercialization and that directly affect the food organization of the population. world population according to their local customs. In the same way, this work makes it possible to simultaneously identify the possibility of studies with low-cost sensors and different programming logics as a possibility for a line of research, aiming at the feasibility of models for needy populations or with the aim of environmental education for vulnerable groups in the society.

Other Information

Record and Protocol: The systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) guidelines, with Research Protocol and Data Management Plan in Mendeley Database with DOI: 10.17632/89wr243dbt.1.

Author Contributions: Conceptualization A.R.L., R.N.I., J.P.M., L.P.M., C.P.C. and L.R.A.G.F.; methodology P.S.B.d.S and. C.d.S.; software A.R.L., R.N.I., C.d.S., P.S.B.d.S, C.d.S., C.P.C. and

L.R.A.G.F.; validation A.R.L., R.N.I., J.P.M., and L.R.A.G.F.; formal analysis A.R.L., L.P.M., C.P.C. and C.d.S.; investigation A.R.L., L.P.M., C.P.C., P.S.B.d.S, and L.R.A.G.F.; resources A.R.L., R.N.I., and L.R.A.G.F.; data curation A.R.L., C.d.S. and L.R.A.G.F.; writing—review and editing: all authors; supervision and project administration: A.R.L., C.d.S., C.P.C. and L.R.A.G.F., All authors have read and agreed to the published version of the manuscript.

Support: This work was supported by the Dean of Research at Unesp - PROPE: Data acquisition, processing and analysis system with a low-cost sensor network for the efficient use of water in agriculture. CNPq Process: 434987/2018-2 - Universal Notice; and Research Productivity Grant (Process #315228/2020-2 (LRAGF)).

Acknowledgment: Thank you for the contributions given by researchers from the Research Group on Fuzzy Systems Applied in Agricultural Sciences.

References

- Ackerley, D., & Dommenges, D. (2016). Atmosphere-only GCM (ACCESS1.0) simulations with prescribed land surface temperatures. *Geoscientific Model Development*, 9(6), 2077–2098. <https://doi.org/10.5194/gmd-9-2077-2016>
- Al-Ghobari, H. M., Mohammad, F. S., El Marazky, M. S. A., & Dewidar, A. Z. (2017). Automated irrigation systems for wheat and tomato crops in arid regions. *Water SA*, 43(2), 354–364. <https://doi.org/10.4314/wsa.v43i2.18>
- Allen, R. G. & FAO (Orgs.). (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. Food and Agriculture Organization of the United Nations.
- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (2006). *Evapotranspiración del cultivo Guías para la determinación de los requerimientos de agua de los cultivos*. Food & Agriculture Org. <https://www.fao.org/3/x0490s/x0490s00.htm>
- Amorim, R. C. F. de. (2009). *Espacialização de variáveis meteorológicas combinando informações de imagens de satélite com técnicas de interpolação para o estado de Minas Gerais* [Agrometeorologia; Climatologia; Micrometeorologia, Universidade Federal de Viçosa]. <https://locus.ufv.br/handle/123456789/1489>
- Anjos, R. M. dos. (2015). *Irrigação deficitária controlada por etapas na cultura do melão, utilizando o modelo MOPECO*. <http://www.repositorio.ufc.br/handle/riufc/18069>
- Attia, A., El-Hendawy, S., Al-Suhaibani, N., Alotaibi, M., Tahir, M. U., & Kamal, K. Y. (2021). Evaluating deficit irrigation scheduling strategies to improve yield and water productivity of maize in arid environment using simulation. *Agricultural Water Management*, 249, 106812. <https://doi.org/10.1016/j.agwat.2021.106812>
- Awada, H., Ciraolo, G., Maltese, A., Provenzano, G., Moreno Hidalgo, M. A., & Còrcoles, J. I. (2019). Assessing the performance of a large-scale irrigation system by estimations of actual evapotranspiration obtained by Landsat satellite images resampled with cubic convolution. *International Journal of Applied Earth Observation and Geoinformation*, 75, 96–105. <https://doi.org/10.1016/j.jag.2018.10.016>
- Bai, T., Zhang, N., Wang, T., Wang, D., Yu, C., Meng, W., Fei, H., Chen, R., Li, Y., & Zhou, B. (2021). Simulating on the effects of irrigation on jujube tree growth, evapotranspiration and water use based on crop growth model. *Agricultural Water Management*, 243, 106517. <https://doi.org/10.1016/j.agwat.2020.106517>
- Barbieri, J. D., Dallacort, R., Daniel, D. F., Dalchiavon, F. C., & Freitas, P. S. L. de. (2020). Cobertura do solo, evapotranspiração e produtividade do milho safrinha. *Revista Cultura Agronômica*, 29(1), 76–91. <https://doi.org/10.32929/2446-8355.2020v29n1p76-91>
- Bhattacharyya, S. S., Adeyemi, M. A., Onyeneke, R. U., Bhattacharyya, S., Faborode, H. F. B., Melchor-Martínez, E. M., Iqbal, H. M. N., & Parra-Saldívar, R. (2021). Nutrient Budgeting—A Robust Indicator of Soil–Water–Air Contamination Monitoring and

- Prevention. *Environmental Technology & Innovation*, 24, 101944.
<https://doi.org/10.1016/j.eti.2021.101944>
- Bowen, I. S. (1926). The Ratio of Heat Losses by Conduction and by Evaporation from any Water Surface. *Physical Review*, 27(6), 779–787.
<https://doi.org/10.1103/PhysRev.27.779>
- Chen, M., Cui, Y., Wang, X., Xie, H., Liu, F., Luo, T., Zheng, S., & Luo, Y. (2021). A reinforcement learning approach to irrigation decision-making for rice using weather forecasts. *Agricultural Water Management*, 250, 106838.
<https://doi.org/10.1016/j.agwat.2021.106838>
- Costa Filho, S. V. S. da, Arce, J. E., Montañó, R. A. N. R., & Pelissari, A. L. (2019). Configuração de algoritmos de aprendizado de máquina na modelagem florestal: Um estudo de caso na modelagem da relação hipsométrica. *Ciência Florestal*, 29(4), 1501–1515. <https://doi.org/10.5902/1980509828392>
- da Silva Júnior, J. C., Medeiros, V., Garrozi, C., Montenegro, A., & Gonçalves, G. E. (2019). Random forest techniques for spatial interpolation of evapotranspiration data from Brazilian's Northeast. *Computers and Electronics in Agriculture*, 166, 105017.
<https://doi.org/10.1016/J.COMPAG.2019.105017>
- Dela Cruz, J. C., Caya, M. V. C., Ballado, A. H., Aggabao, M. C. R., Bacolor, E. I., Riego, H. A. G. G., & Vergara, M. E. M. (2020). Evapotranspiration-based Irrigation System for Mustard Green Crop Cultivation using Public Weather Forecast. *2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC)*, 203–208.
<https://doi.org/10.1109/ICSGRC49013.2020.9232454>
- Diepen, C. A., Wolf, J., Keulen, H., & Rappoldt, C. (1989). WOFOST: A simulation model of crop production. *Soil Use and Management*, 5(1), 16–24.
<https://doi.org/10.1111/j.1475-2743.1989.tb00755.x>
- Dingre, S. K., & Gorantiwar, S. D. (2020). Determination of the water requirement and crop coefficient values of sugarcane by field water balance method in semiarid region. *Agricultural Water Management*, 232, 106042.
<https://doi.org/10.1016/J.AGWAT.2020.106042>
- Elsevier Inc. (2021). *Mendeley Data [software]* (<https://data.mendeley.com/>; 2019.2.1) [Mendeley]. Mendeley Ltd.; 2022 Elsevier B.V.
- Fabbri, S., Silva, C., Hernandez, E., Octaviano, F., Di Thommazo, A., & Belgamo, A. (2016). Improvements in the StArt tool to better support the systematic review process. *Proceedings of the 20th International Conference on Evaluation and Assessment in Software Engineering*, 1–5. <https://doi.org/10.1145/2915970.2916013>
- FAO. (2022). World Food Studies Simulation Model (WOFOST) | Tierras y Aguas | Organización de las Naciones Unidas para la Alimentación y la Agricultura | Land & Water | Food and Agriculture Organization of the United Nations. *FAO - Food and Agriculture Organization of the United Nations*.
<https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/es/c/1236431/>
- Frédette, C., Grebenshchikova, Z., Comeau, Y., & Brisson, J. (2019). Evapotranspiration of a willow cultivar (*Salix miyabeana* SX67) grown in a full-scale treatment wetland. *Ecological Engineering*, 127, 254–262.
<https://doi.org/10.1016/j.ecoleng.2018.11.027>
- GT Agenda 2030. (2022). *VI Relatório Luz da Sociedade Civil da Agenda 2030 de Desenvolvimento Sustentável Brasil* (Relatório Luz sobre a Agenda 2030 no Brasil 2022 VI). <https://gtagenda2030.org.br/relatorio-luz/relatorio-luz-2022/>
- Guyatt, G. H., Oxman, A. D., Kunz, R., Vist, G. E., Falck-Ytter, Y., & Schünemann, H. J. (2008). What is “quality of evidence” and why is it important to clinicians? *BMJ: British Medical Journal*, 336(7651), 995–998.
<https://doi.org/10.1136/bmj.39490.551019.BE>

- Guyatt, G. H., Oxman, A. D., Montori, V., Vist, G., Kunz, R., Brozek, J., Alonso-Coello, P., Djulbegovic, B., Atkins, D., Falck-Ytter, Y., Williams, J. W., Meerpohl, J., Norris, S. L., Akl, E. A., & Schünemann, H. J. (2011). GRADE guidelines: 5. Rating the quality of evidence—publication bias. *Journal of Clinical Epidemiology*, *64*(12), 1277–1282. <https://doi.org/10.1016/j.jclinepi.2011.01.011>
- Haghverdi, A., Singh, A., Sapkota, A., Reiter, M., & Ghodsi, S. (2021). Developing irrigation water conservation strategies for hybrid bermudagrass using an evapotranspiration-based smart irrigation controller in inland southern California. *Agricultural Water Management*, *245*, 106586. <https://doi.org/10.1016/j.agwat.2020.106586>
- Ihaka, R., & Gentleman, R. (2018). *The R Project for Statistical Computing [software]* (<https://www.r-project.org/>; 3.5.1) [R; R: Software Development Life Cycle]. The R Foundation; the Statistics Department of the University of Auckland.
- INPE. (2022). *LANDSAT* [Instituto Nacional de Pesquisas Espaciais (INPE)]. Divisão de Geração de Imagens Instituto Nacional de Pesquisas Espaciais (INPE). <http://www.dgi.inpe.br/documentacao/satelites/landsat>
- Jo, W. J., & Shin, J. H. (2021a). Development of a transpiration model for precise tomato (*Solanum lycopersicum* L.) irrigation control under various environmental conditions in greenhouse. *Plant Physiology and Biochemistry*, *162*, 388–394. <https://doi.org/10.1016/j.plaphy.2021.03.005>
- Jo, W. J., & Shin, J. H. (2021b). Development of a transpiration model for precise tomato (*Solanum lycopersicum* L.) irrigation control under various environmental conditions in greenhouse. *Plant Physiology and Biochemistry*, *162*, 388–394. <https://doi.org/10.1016/j.plaphy.2021.03.005>
- Kadlec, R. H., & Wallace, S. D. (2009). *Treatment wetlands* (2nd ed). CRC Press.
- Kamarudin, M. H., Ismail, Z. H., & Saidi, N. B. (2021). Deep Learning Sensor Fusion in Plant Water Stress Assessment: A Comprehensive Review. *Applied Sciences*, *11*(4), 1403. <https://doi.org/10.3390/app11041403>
- Kang, J., Hao, X., Zhou, H., & Ding, R. (2021). An integrated strategy for improving water use efficiency by understanding physiological mechanisms of crops responding to water deficit: Present and prospect. *Agricultural Water Management*, *255*, 107008. <https://doi.org/10.1016/j.agwat.2021.107008>
- Kheir, A. M. S., Alrajhi, A. A., Ghoneim, A. M., Ali, E. F., Magrashi, A., Zoghdan, M. G., Abdelkhalik, S. A. M., Fahmy, A. E., & Elnashar, A. (2021). Modeling deficit irrigation-based evapotranspiration optimizes wheat yield and water productivity in arid regions. *Agricultural Water Management*, *256*, 107122. <https://doi.org/10.1016/j.agwat.2021.107122>
- Kisekka, I., Schlegel, A., Ma, L., Gowda, P. H., & Prasad, P. V. V. (2017). Optimizing preplant irrigation for maize under limited water in the High Plains. *Agricultural Water Management*, *187*, 154–163. <https://doi.org/10.1016/j.agwat.2017.03.023>
- Kitchenham, B., Madeyski, L., & Brereton, P. (2020). Meta-analysis for families of experiments in software engineering: A systematic review and reproducibility and validity assessment. *Empirical Software Engineering*, *25*(1), 353–401. <https://doi.org/10.1007/s10664-019-09747-0>
- Klant, L. M., & Santos, V. S. dos. (2021). O uso do software IRAMUTEQ na análise de conteúdo—Estudo comparativo entre os trabalhos de conclusão de curso do ProfEPT e os referenciais do programa. *Research, Society and Development*, *10*(4), e8210413786. <https://doi.org/10.33448/rsd-v10i4.13786>
- Komatsu, H. (2020). Modeling evapotranspiration changes with managing Japanese cedar and cypress plantations. *Forest Ecology and Management*, *475*, 118395. <https://doi.org/10.1016/j.foreco.2020.118395>
- Kunihiro, S., Vernasque, J. R. da S., Silva, C. da, Santos, M. F. dos, Cremasco, C. P., & Gabriel Filho, L. R. A. (2022). Intersectoral Actions for the Promotion and

- Prevention of Obesity, Diabetes and Hypertension in Brazilian Cities: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, 19(20), 13059. <https://doi.org/10.3390/ijerph192013059>
- Lakatos, E. M., & Marconi, M. de A. (2003). *Fundamentos de metodologia científica*. Atlas.
- LaPES. (2020). *StArt (State of the Art through Systematic Review) [software]* (Laboratório de Pesquisa em Engenharia de Software; 3.0.3 Beta) [Portuguese; Laboratório de Pesquisa em Engenharia de Software]. Universidade Federal de São Carlos (DC/UFSCar).
- Lei, H., Gong, T., Zhang, Y., & Yang, D. (2018). Biological factors dominate the interannual variability of evapotranspiration in an irrigated cropland in the North China Plain. *Agricultural and Forest Meteorology*, 250–251, 262–276. <https://doi.org/10.1016/j.agrformet.2018.01.007>
- Leite, A. R., Imada, R. N., Mantovani, J. P., Mantovani, L. P., Neves, F. P., Siqueira, J. D. M., Santos, P. S. B. D., Silva, C. da, Cremasco, C. P., & Gabriel Filho, L. R. A. (2022). *Automated Evapotranspiration Research Dataset used in a Systematic Review and Meta-analysis. 1*. <https://doi.org/10.17632/89wr243dbt.1>
- Liao, R., Zhang, S., Zhang, X., Wang, M., Wu, H., & Zhangzhong, L. (2021). Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept. *Agricultural Water Management*, 245, 106632. <https://doi.org/10.1016/j.agwat.2020.106632>
- Liu, J., Cheng, F., Munger, W., Jiang, P., Whitby, T. G., Chen, S., Ji, W., & Man, X. (2020). Precipitation extremes influence patterns and partitioning of evapotranspiration and transpiration in a deciduous boreal larch forest. *Agricultural and Forest Meteorology*, 287, 107936. <https://doi.org/10.1016/j.agrformet.2020.107936>
- Liu, Z., & Xu, Q. (2018). An Automatic Irrigation Control System for Soilless Culture of Lettuce. *Water*, 10(11), 1692. <https://doi.org/10.3390/W10111692>
- Mancini, M. C., Cardoso, J. R., Sampaio, R. F., Costa, L. C. M., Cabral, C. M. N., & Costa, L. O. P. (2014). Tutorial for writing systematic reviews for the Brazilian Journal of Physical Therapy (BJPT). *Brazilian Journal of Physical Therapy*, 18(6), 471–480. <https://doi.org/10.1590/bjpt-rbf.2014.0077>
- Martínez-Romero, A., López-Urrea, R., Montoya, F., Pardo, J. J., & Domínguez, A. (2021). Optimization of irrigation scheduling for barley crop, combining AquaCrop and MOPECO models to simulate various water-deficit regimes. *Agricultural Water Management*, 258, 107219. <https://doi.org/10.1016/j.agwat.2021.107219>
- McGowan, J., Sampson, M., Salzwedel, D. M., Cogo, E., Foerster, V., & Lefebvre, C. (2016). PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. *Journal of Clinical Epidemiology*, 75, 40–46. <https://doi.org/10.1016/j.jclinepi.2016.01.021>
- Meng, W., Sun, X., Ma, J., Guo, X., Lei, T., & Li, R. (2019). Measurement and simulation of the water storage pit irrigation trees evapotranspiration in the Loess Plateau. *Agricultural Water Management*, 226, 105804. <https://doi.org/10.1016/j.agwat.2019.105804>
- Mérida García, A., Fernández García, I., Camacho Poyato, E., Montesinos Barrios, P., & Rodríguez Díaz, J. A. (2018). Coupling irrigation scheduling with solar energy production in a smart irrigation management system. *Journal of Cleaner Production*, 175, 670–682. <https://doi.org/10.1016/j.jclepro.2017.12.093>
- Microsoft Corporation. (2016). *Microsoft® Excel 2016 [software]* (Versão 2016) [English; Microsoft Office Professional Plus 2016]. Microsoft Corporation.
- Millán, S., Casadesús, J., Campillo, C., Moñino, M. J., & Prieto, M. H. (2019). Using Soil Moisture Sensors for Automated Irrigation Scheduling in a Plum Crop. *Water* 11(10), 2061. <https://doi.org/10.3390/W11102061>

- Moghadam, H. R. T. (2016). Application of super absorbent polymer and ascorbic acid to mitigate deleterious effects of cadmium in wheat. *Pesquisa Agropecuária Tropical*, 46, 09–18. <https://doi.org/10.1590/1983-40632016v4638946>
- Montoro, A., Mañas, F., & López-Urrea, R. (2016). Transpiration and evaporation of grapevine, two components related to irrigation strategy. *Agricultural Water Management*, 177, 193–200. <https://doi.org/10.1016/j.agwat.2016.07.005>
- Montoya, M. A., & Finamore, E. B. (2020). Os recursos hídricos no agronegócio brasileiro: Uma análise insumo-produto do uso, consumo, eficiência e intensidade. *Revista Brasileira de Economia*, 74(4). <https://doi.org/10.5935/0034-7140.20200021>
- Nagel, G. W., Novo, E. M. L. de M., & Kampel, M. (2020). Nanosatellites applied to optical Earth observation: A review. *Rev. Ambient. Água*, 15(3). SciELO Brasil. <https://doi.org/10.4136/ambi-agua.2513>
- Narciso, K. R. (2016). “Rios Voadores” da Amazônia e o Direito Internacional. *UFPR*, 56. <https://acervodigital.ufpr.br/handle/1884/52292>
- NASA. (2022). *Landsat Missions / U.S. Geological Survey* [Gov]. National Aeronautics and Space Administration (NASA). <https://www.usgs.gov/landsat-missions>
- Nimah, M. N., & Hanks, R. J. (1973). Model for Estimating Soil Water, Plant, and Atmospheric Interrelations: I. Description and Sensitivity. *Soil Science Society of America Journal*, 37(4), 522–527. <https://doi.org/10.2136/sssaj1973.03615995003700040018x>
- Oki, T., & Kanae, S. (2006). Global Hydrological Cycles and World Water Resources. *Science*, 313(5790), 1068–1072. <https://doi.org/10.1126/science.1128845>
- Oliveira, C. T. (2018). Modelo Aquacrop: Calibração, validação e uso para soja e milho na região dos campos gerais. <https://acervodigital.ufpr.br/handle/1884/56229>
- Olivera-Guerra, L., Merlin, O., & Er-Raki, S. (2020). Irrigation retrieval from Landsat optical/thermal data integrated into a crop water balance model: A case study over winter wheat fields in a semi-arid region. *Remote Sensing of Environment*, 239, 111627. <https://doi.org/10.1016/j.rse.2019.111627>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, 18(3), e1003583. <https://doi.org/10.1371/journal.pmed.1003583>
- Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 193(1032), 120–145. <https://doi.org/10.1098/rspa.1948.0037>
- Pereira, V. D. C., Sedyama, G. C., De Moura, M. S. B., Da Silva, T. G. F., & De Souza, L. S. B. (2018). Eficiência do uso da água em videira ‘Syrah’ irrigada no submédio do vale São Francisco. *IRRIGA*, 21(2), 269. <https://doi.org/10.15809/irriga.2016v21n2p269-283>
- Pereira, V. da C., Sedyama, G. C., de Moura, M. S. B., da Silva, T. G. F., & de Souza, L. S. B. (2016). Water use efficiency in irrigated “Syrah” grape plantation at são francisco river valley. *IRRIGA*, 21(2), 269–283. <https://doi.org/10.15809/irriga.2016v21n2p269-283>
- Perera, K. C., Western, A. W., Robertson, D. E., George, B., & Nawarathna, B. (2016). Ensemble forecasting of short-term system scale irrigation demands using real-time flow data and numerical weather predictions. *Water Resources Research*, 52(6), 4801–4822. <https://doi.org/10.1002/2015WR018532>
- Priestley, C. H. B., & Taylor, R. J. (1972). On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters. *Monthly Weather Review*, 100(2), 81–92. [https://doi.org/10.1175/1520-0493\(1972\)100<0081:OTAOSH>2.3.CO;2](https://doi.org/10.1175/1520-0493(1972)100<0081:OTAOSH>2.3.CO;2)

- PRISMA-P Group, Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, 4(1), 1. <https://doi.org/10.1186/2046-4053-4-1>
- Qin, S., Li, S., Kang, S., Du, T., Tong, L., & Ding, R. (2016). Can the drip irrigation under film mulch reduce crop evapotranspiration and save water under the sufficient irrigation condition? *Agricultural Water Management*, 177, 128–137. <https://doi.org/10.1016/j.agwat.2016.06.022>
- Ratinaud, P. (2014). *IRaMuTeQ (Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires) [software]* (0.7 alpha 2) [French]. LERASS - Laboratoire d'Études et de Recherches Appliquées en Sciences Sociales.
- Ribeiro, H., Jaime, P. C., & Ventura, D. (2017). Alimentação e sustentabilidade. *Estudos Avançados*, 31(89), 185–198. <https://doi.org/10.1590/s0103-40142017.31890016>
- Sampaio, R. F., & Mancini, M. C. (2007). Estudos de revisão sistemática: Um guia para síntese criteriosa da evidência científica. *Brazilian Journal of Physical Therapy*, 11, 83–89. <https://doi.org/10.1590/S1413-35552007000100013>
- Santos, C. M. da C., Pimenta, C. A. de M., & Nobre, M. R. C. (2007). The PICO strategy for the research question construction and evidence search. *Revista Latino-Americana de Enfermagem*, 15(3), 508–511. <https://doi.org/10.1590/S0104-11692007000300023>
- Segovia-Cardozo, D. A., Rodríguez-Sinobas, L., & Zobelzu, S. (2019). Water use efficiency of corn among the irrigation districts across the Duero river basin (Spain): Estimation of local crop coefficients by satellite images. *Agricultural Water Management*, 212, 241–251. <https://doi.org/10.1016/j.agwat.2018.08.042>
- Shuaishuai, L., Li, L., shiwang, C., Fanjia, M., Haihua, W., Zhazhan, S., & Sigrimis, N. A. (2018). Prediction Model of Transpiration Rate of Strawberry in Closed Cultivation Based on DBN-LSSVM Algorithm. *IFAC-PapersOnLine*, 51(17), 460–465. <https://doi.org/10.1016/j.ifacol.2018.08.171>
- Shuttleworth, W. J., & Wallace, J. S. (1985). Evaporation from sparse crops-an energy combination theory: evaporation from sparse crops. *Quarterly Journal of the Royal Meteorological Society*, 111(469), 839–855. <https://doi.org/10.1002/qj.49711146910>
- Sivalakshmi, P., Shanthi, K. G., Sangeethalakshmi, K., SesaVidhya, S., Sandhiya, G., & Rajkumar, M. (2021). Smart auction system flow model for Agro-Based sector farmers using blockchain technology. *Materials Today: Proceedings*, S2214785321042619. <https://doi.org/10.1016/j.matpr.2021.05.634>
- Souza, G. S. de, Lima, J. S. de S., Xavier, A. C., & Rocha, W. S. D. da. (2010). Krigagem Ordinária e Inverso do Quadrado da Distância Aplicados na Espacialização de Atributos Químicos de um Argissolo. *Scientia Agraria*, 11(1), 073. <https://doi.org/10.5380/rsa.v11i1.15939>
- Souza, M. A. R. de, Wall, M. L., Thuler, A. C. de M. C., Lowen, I. M. V., & Peres, A. M. (2018). O uso do software IRAMUTEQ na análise de dados em pesquisas qualitativas. *Revista da Escola de Enfermagem da USP*, 52(0). <https://doi.org/10.1590/s1980-220x2017015003353>
- Stanghellini, C. (1987). *Transpiration of greenhouse crops: An aid to climate management* [Phd, IMAG]. <https://library.wur.nl/WebQuery/wurpubs/2690>
- Sun, M., Gao, X., Zhang, Y., Song, X., & Zhao, X. (2022). A new solution of high-efficiency rainwater irrigation mode for water management in apple plantation: Design and application. *Agricultural Water Management*, 259, 107243. <https://doi.org/10.1016/j.agwat.2021.107243>
- The MathWorks. (2022). *Matlab R2022a [software]* (R2022a 2 (9.12.0.1956245)) [Start MATLAB - The Language of Technical Computing; MATLAB and Simulink]. The MathWorks, Inc.

- Thomas, S., Rane, A., Abitha V. K, Kanny, K., & Dutta, A. (Orgs.). (2019). *Hydraulic rubber dam: An effective water management technology*. William Andrew is an imprint of Elsevier.
- Tie, Q., Hu, H., Tian, F., & Holbrook, N. M. (2018). Comparing different methods for determining forest evapotranspiration and its components at multiple temporal scales. *Science of The Total Environment*, 633, 12–29. <https://doi.org/10.1016/j.scitotenv.2018.03.082>
- Vanino, S., Nino, P., De Michele, C., Falanga Bolognesi, S., D’Urso, G., Di Bene, C., Pennelli, B., Vuolo, F., Farina, R., Pulighe, G., & Napoli, R. (2018). Capability of Sentinel-2 data for estimating maximum evapotranspiration and irrigation requirements for tomato crop in Central Italy. *Remote Sensing of Environment*, 215, 452–470. <https://doi.org/10.1016/j.rse.2018.06.035>
- Wang, D., & Wang, L. (2017). Dynamics of evapotranspiration partitioning for apple trees of different ages in a semiarid region of northwest China. *Agricultural Water Management*, 191, 1–15. <https://doi.org/10.1016/j.agwat.2017.05.010>
- Zhang, Q., Fan, L., Wang, H., Han, H., Zhu, Z., Zhao, X., & Wang, Y. (2022). A review of physical and chemical methods to improve the performance of water for dust reduction. *Process Safety and Environmental Protection*, 166, 86–98. <https://doi.org/10.1016/j.psep.2022.07.065>

RESUMO:

Tendo em vista a escassez de recursos hídricos que vem se agravando ao longo do tempo e o alto consumo desses recursos pelo agronegócio, há a necessidade de estudos que possam gerir tal ação de forma sustentável, proporcionando segurança alimentar para a população mundial presente e futura. **Background:** com o tema: Qual a visão sistêmica dos modelos e técnicas automatizadas para determinação ou estimativa de transpiração, evaporação ou evapotranspiração para plantações? **Objetivos:** Identificar na literatura recente o que pesquisadores e cientistas têm divulgado sobre métodos de automação para irrigação, com foco na estimativa da evapotranspiração. Identificar métodos, modelos e técnicas de inferência da evapotranspiração. **Métodos:** A metodologia baseou-se no ensaio teórico exploratório com características qualitativas e quantitativas por meio de Revisão Sistemática e Metanálise dos dados. **Resultados:** Com o uso de softwares e métodos específicos, estudos de simulação com dados experimentais permitem calibrar modelos eficientes para estimar a evapotranspiração, mas métodos de baixo custo ainda têm pouca aderência.

PALAVRAS-CHAVE: Eficiência no uso da água; Irrigação; Automação; Evapotranspiração; Revisão sistemática.

RESUMEN:

Dada la escasez de recursos hídricos que se ha ido agravando con el tiempo y el alto consumo de estos recursos por parte de la agroindustria, se necesitan estudios que puedan gestionar dicha acción de manera sostenible, brindando seguridad alimentaria a la población mundial presente y futura. **Antecedentes:** con el tema: ¿Cuál es la visión sistémica de los modelos y técnicas automatizadas para determinar o estimar la transpiración, evaporación o evapotranspiración para plantaciones? **Objetivos:** Identificar en la literatura reciente lo que investigadores y científicos han publicado sobre métodos de automatización para riego, con enfoque en la estimación de la evapotranspiración. Identificar métodos, modelos y técnicas para inferir la evapotranspiración. **Métodos:** La metodología se basó en un ensayo teórico exploratorio con características cualitativas y cuantitativas mediante Revisión Sistemática y Metaanálisis de datos. **Resultados:** Utilizando software y métodos específicos, los estudios de simulación con datos experimentales permiten calibrar modelos eficientes para estimar la evapotranspiración, pero los métodos de bajo costo aún tienen poca adherencia.

PALABRAS CLAVE: Eficiencia en el uso del agua; Irrigación; Automatización; Evapotranspiración; Revisión sistemática.