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Linking participatory approach and rapid appraisal methods to select potential innovations in collective irrigation systems

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ABSTRACT

This paper presents a novel approach that integrates participatory methods and a rapid appraisal process to identify constraints and select potentially innovative solutions aimed at improving water and energy use efficiency at different levels in collective irrigation systems. First, a set of quantitative performance indicators is calculated, allowing the identification of the main problems. The study then adopts a bottom-up approach and emphasizes the need for active involvement of stakeholders from different backgrounds to identify potential opportunities to improve the sustainability of the collective irrigation system. From this collaborative and integrative approach, an innovation basket is developed, that includes a variety of techniques, technologies and management practices tailored to the specific challenges of the Lucefecit Collective Irrigation System. The results show that high-energy consumption is the main problem, with high values for energy consumption per hectare (2919.9 kWh) and per m^3 of water delivered at the hydrants (0.43 kWh). Another problem is the lack of support for farmers in irrigation scheduling, which leads to large variations in irrigation water productivity across farms. The results of this study provide valuable insights into the effectiveness of the participatory approach and the feasibility of implementing innovative solutions in collective irrigation systems.

1. Introduction

1.1. The problem

Restrictions on access to freshwater affect human activities in many regions of the world. This situation will tend to worsen given the growing demand for this limited resource and worsening climate variability (Saadi et al., 2015; Fader et al., 2016; Ellison et al., 2017). The Mediterranean countries in southern Europe are among the regions where increasing climate variability and its impacts on the reduction of available water resources are already clearly felt. Portugal's vulnerability to the impacts of climate change and climate variability is obvious (Paulo et al., 2012; Rolim et al., 2017; Gomes et al., 2018; Fonseca et al., 2022). In recent decades, Portugal has experienced an increase in average and extreme air temperatures, which are expected to continue to rise (Ramos et al., 2011; Carvalho et al., 2014; Andrade et al., 2014; Cardoso et al., 2019). The Mediterranean region, and Portugal in particular, is considered a climate change hotspot, which, among other impacts, should register the greatest drought among 26 other regions in the world (Giorgi, 2006; Carvalho et al., 2014; Lima et al., 2023). According to the climate change model predictions, the new climate pattern in Portugal will be characterized by longer summers, a fewer rainy months and a higher frequency of droughts (Dias et al., 2018; Nunes et al., 2017). Since the agricultural sector is the largest consumer of fresh water, the described changes in climatic conditions will tend to have a negative impact on the agricultural sector and, due to increased demand for irrigation water, the pressure on water resources will tend to increase. The effects of climate change will also contribute to this intensification of water competition, particularly in water scarce regions such as those around the Mediterranean (Saadi et al., 2015; Lionello and Scarascia, 2018).

There are several studies on the effects of climate change in

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agriculture, for example the one by Rolim et al. (2017) who studied two crop rotations in Alentejo, Portugal. These authors concluded that increasing irrigation demand could lead to a reduction in irrigated area, changes in cropping pattern (to match water demands with water available for irrigation), and/or reduced crop yields (due to water deficit). Other studies suggest that projected climate change will also have negative impacts on wheat (Carvalho et al., 2014; Bento et al., 2021) and maize yields (Valverde et al., 2015; Yang et al., 2017, 2019, 2020) and economic returns (Fragoso and Noéme, 2018). Olive trees and vineyards are other crops that are also at great risk from temperature increase due to climate change (EEA, 2019, Fraga et al., 2018, 2020a,b), particularly because these crops present chilling requirements (De Melo-Abreu et al., 2004).

Therefore, the adoption of agricultural practices and technologies by farmers and water users' associations is crucial to increase the efficiency of irrigation water use. As an extensive literature shows, the adoption of such practices and technologies not only brings environmental and economic benefits to farmers, but is also a key component of agricultural adaptation to climate change (Cameira and Pereira, 2019; Ferreira et al., 2023).

1.2. Agricultural innovations

In this context, the PRIMA HubIS project consortium (PRIMA/0006/2019) was established in 2020, which includes seven countries around the Mediterranean Sea. Its global objective was to contribute to reducing the performance gap in irrigation systems in the Mediterranean region by encouraging the emergence, evaluation and promotion of innovations that include new tools and services for farmers and water users' associations, using bottom-up processes based on a participatory approach. This approach is used to select innovations and thus involve stakeholders in the decision.

There is no uniform understanding of the term innovation (OECD and Eurostat, 2005), as it depends on the scientific field (management, economics, marketing, sociology, political science, history, etc.), each with their own theoretical framework. Consequently, there are a variety of definitions, core components that make up innovations, models, theories, and frameworks for understanding innovations, and analyses of the development and life cycle of innovations (Singh and Aggarwal, 2022; Lee and Trimi, 2018; Taylor, 2017; Fagerberg and Mowery, 2006; Seaden and Manseau, 2001).

In the broadest sense, innovation is synonymous with change (Tushman and O'Reilly, 1997), therefore, technology is used concurrently with innovation in most relevant literature (Alston and Pardey, 2016). An innovation can consist of the implementation of a single significant change or a series of smaller incremental changes that together constitute a significant change (OECD and Eurostat, 2005; Taylor, 2017).

Agricultural innovation in the broadest sense is defined as a process by which individuals or organisations use new or existing products, processes or forms of organisation for the first time in a specific context to increase effectiveness, competitiveness, and resilience to shocks or environmental stresses (FAO, 2018). A similar definition has been used by several researchers (Hall et al., 2003; Klerkx et al., 2010; Schut et al., 2013; Guimarães et al., 2019; Oliveira et al., 2019). Agricultural innovation focuses not only on technology but also, and perhaps most importantly, on social, economic, institutional/organizational and political processes. Farmers play a central role in innovation processes, as the adoption of innovations is believed to not only reflect, but also depends on the socio-economic and cultural lives of end-users (FAO, 2018; Chavas and Nauges, 2020; Norton and Alwang, 2020).

1.3. Participatory approach and rapid appraisal

Stakeholder involvement is the key factor in the participatory approach (PA) throughout the innovation selection process. Their involvement ensures that innovations are contextually appropriate and meet the specific needs and goals of the collective. Dialogue with local stakeholders is an essential part of the innovation process, from the initial performance assessment to co-creation of innovations and their dissemination. The PA strategy enables an open innovation environment and facilitates technology transfer. In addition, it promotes personal responsibility and promotes the adoption and scaling up of the selected innovations. In this context, learning- and action-based participatory approaches have become central in Farming Systems Research (Blackmore et al., 2012) aiming to enable knowledge and understanding of problems and possible solutions arising from the interaction between all stakeholders: farmers, practitioners and researchers (Darnhofer et al., 2012). Chevalier and Buckles (2019) argue that PA is the best strategy to bridge the current performance gap in irrigation systems. It privileges real-world situations, the specificities of contexts and the participation of individuals as social actors (Reason and Bradbury, 2008; Jones et al., 2011; Apgar and Douthwaite, 2013).

On the one hand, this perspective of conceiving research enables the identification of specific problems, their causes and the procedures to be used to better solve them to a relevant degree of realism and practicality. On the other hand, it also enables joint participation and co-learning (between and among researcher and other types of participants) of different types of knowledge systems, skills and viewpoints. These dimensions make research an iterative and interactive process (Reason and Bradbury, 2008). In addition, it not only promotes the training and leadership of those who take charge of the change process, but also contributes to this process gaining stability in order to continue it and gain a future.

In parallel with the development of participatory research methods, a method of gathering information known as the Rapid Appraisal Process (RAP) has gained importance (Chambers, 1981, 1992). This tool, intended to be used in the diagnostic phase of research, aims to identify the main problems in a less costly and time-consuming way compared to traditional assessments.

The RAP first searches and classifies relevant documents, databases and web sources for each study case. Secondly, key actors, stakeholders and institutions are identified. The RAP itself will consist of interviews with experts, focus groups discussions and in-depth participatory analyses with key actors. The interviews and discussions are followed by semi-structured questionnaires. Participatory analysis includes a quantitative aspect that focuses on determining performance indicators, based on available data. The diagnosis covers a wide range of technical, social, environmental and scale factors (Wongtragoon et al., 2017).

The RAP uses specific indicators to evaluate performance and compare irrigation systems. These indicators include ratios relating variables such as irrigated area to applied volume of irrigation and irrigated area to crop productivity (Rodríguez-Díaz et al., 2008, 2011). Each indicator has a reference value that allows the necessary interventions to be evaluated (El-Gamal, 2018).

Participatory approaches and rapid appraisal procedures can be viewed as complementary methods. Participatory approaches emphasize the active involvement and engagement of stakeholders throughout the decision-making process, ensuring that their perspectives, knowledge and experience are incorporated into the selection of innovations. On the other hand, rapid appraisal enables rapid data collection, analysis and feedback loops to accelerate decision-making. Together they create a synergistic approach that increases the effectiveness and efficiency of the decision-making process when selecting innovations to improve water and energy use efficiency in collective irrigation systems.

1.4. Objectives

The overall aim of the current work is to select potential innovations to improve water and energy use efficiency in a collective irrigation system in southern Portugal, the Lucefecit Collective Irrigation System, through a bottom-up process that integrates a participatory approach

and rapid assessment processes. In particular, it is intended to: i) calculate performance assessment indicators; ii) conduct semi-directive face-to-face interviews with the manager and technicians of the water users´association; iii) conduct structural questionnaires with farmers; iv) develop an innovation basket that includes a range of different techniques, technologies and management practices tailored to the specific challenges faced by the Lucefecit Collective Irrigation System. The methods that form the core of the methodology used include analysis of relevant documents, databases and web sources, key informant interviews, focus group discussions, community/group interviews, structured direct observation and informal surveys.

2. Materials and methods

The aim of the fieldwork was to gather qualitative and quantitative information to support the development of a basket of technological innovations tailored to the Lucefecit collective irrigation system (LCIS). These innovations aim to increase the water and energy use efficiency of the LCIS. The methodology used integrates a RAP and a PA, as shown in Fig. 1.

2.1. General description of the study area

The Lucefecit Collective Irrigation System (LCIS) is located in the Alentejo, south of Portugal, in the Guadiana hydrographic region (Fig. 2). According to the Köppen classification (Kottek et al., 2006), the climate in the study region is a Csa - temperate Mediterranean climate with hot and dry summers. The long-term average (2002–2022) rainfall is 491.7 ± 125.9 mm and the average temperature is 16.9 ºC. About 80% of precipitation falls between October and April (COTR, 2023).

The LCIS is of great interest in promoting agricultural development in the region (DGADR, 2022). Construction took place in two phases, the first between 1977 and 1988, in which a canal was built to distribute water by gravity serving an area of 211 ha. In the second phase, from 1990 to 1995, the pipe network and the associated infrastructures to supply pressurized water to an area of 950 ha were installed. The system operates on-demand, meaning farmers have access to the hydrants and can use water without time restrictions. The irrigation water comes from the Lucefecit reservoir, which was created by a dam built in the Lucefecit river. Part of the water coming from the reservoir is pumped directly to the distribution pipeline and another part flows to the distribution canal (DGADR, 2022).

Currently, the LCIS is managed by a water users association (WUA), which has 99 registered beneficiaries who pay a conservation rate and a water fee. The updated data for 2022 show that the conservation rate per hectare of crop and per year is 65 € for gravity distribution and 80 € for pressurized distribution. The water fees are 0.020 € m^{-3} y^{-1} and 0.080 € m^{-3} y^{-1} for the first and second phase, respectively and for the command area, depending on the volume of water consumed (WUA, 2022). Most farmers use sprinkler irrigation systems (solid set-SS and centre pivot-CP) and some drip systems (DS). The irrigation season begins around April 1st and ends around September 30th. However, in autumn and winter there is supplemental irrigation for annual crops such as wheat and permanent crops such as olive groves.

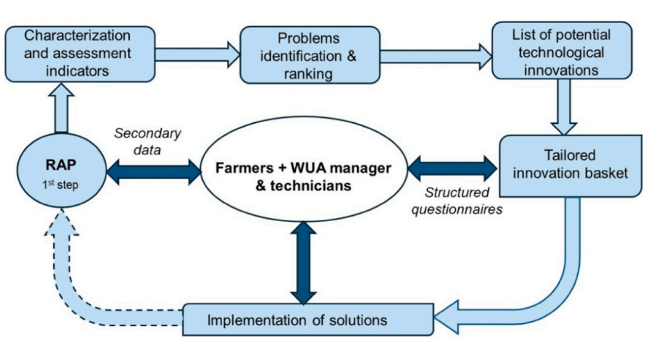

Fig. 1. Overview of the research approach for the participatory development of tailored solutions for the Lucefecit collective irrigation system (RAP- rapid appraisal process, WUA-water users' association). The dotted line indicates that the evaluation of the implemented innovations using a new RAP will extend for several years beyond the project.

2.2. Methodological framework

2.2.1. Rapid appraisal procedure

Secondary data for the period 2016–2021 were collected using RAP (Table 1) and a set of selected water and energy use efficiency indicators (Tables 2 and 3) were calculated at both the plot level and the collective irrigation system level. Key stakeholders have been identified to provide information, including water users' association manager and technicians, farmers, service providers and irrigation equipment dealers. A randomly selected group of beneficiary farmers played an active role in data collection, providing information about their plots, and participated in face-to-face, telephone and email interviews. In this way, 34 plots were characterized in the period 2016–2022. The WUA was the other main source of information, providing various characterization data including crop occupancy and identification of irrigation systems and their management. Information was also collected from other sources (Table 1). Irrigation requirements were calculated for the irrigated plots of the LCIS and for the period 2016–2022 by Rodrigues (2022), based on the actual evapotranspiration determined using the FAO56 approach (Allen et al., 1998), and therefore estimating the FAO-PM reference crop evapotranspiration (ET_o) coupled with the actual crop coefficients retrieved from Sentinel-2 imagery. Throughout the data collection phase, careful work was carried out to verify and select the information, in particular by comparing information from different sources, analysing satellite imagery and calculating areas in the GIS to ensure its reliability.

A set of indicators were selected from the literature, focusing on both the plot and on the collective irrigation system level, showing various agronomic, technical, socio-economic and environmental aspects. Table 2 and Table 3 show the selected indicators for assessing the water use efficiency at the plot level and the water and energy use efficiency in the collective irrigation system level, i.e. including the transport and distribution network. The determined values of the indicators made it possible to identify weak points in water and energy use.

2.2.2. The participatory action research

As a result of the RAP and with the aim of improving irrigation water and energy use efficiency, the HubIS Project team created a list of potential technological innovations (physical tools or equipment and their associated procedures and processes). The innovations were then evaluated by the different stakeholders as part of the participatory approach research carried out in 2020, and some of them were selected to form an innovation basket tailored to the LCIS. Two levels of application were considered, one was the transport and distribution network and the other was the individual farmers' plots. Both levels contribute, in a coordinated way, to improve the water and energy use efficiency in the LCIS. The common features of the proposed technological innovations are: (i) low cost; (ii) easy to implement, i.e. no special technical knowledge is required; (iii) not very time consuming; (iv) do not involve significant changes in daily activities; (v) specifically tailored to end-users (mainly small farmers, older people with low education and low yields, and technicians); (vi) achieving water and energy efficiency gains. Ultimately, the innovations introduced by the project are intended to be adapted to climate change and contribute to the competitiveness of small farmers.

In line with the conceptual understanding of innovation and the farmer-driven-innovation-Participatory Approaches, the research methodology used in this study required the involvement of all

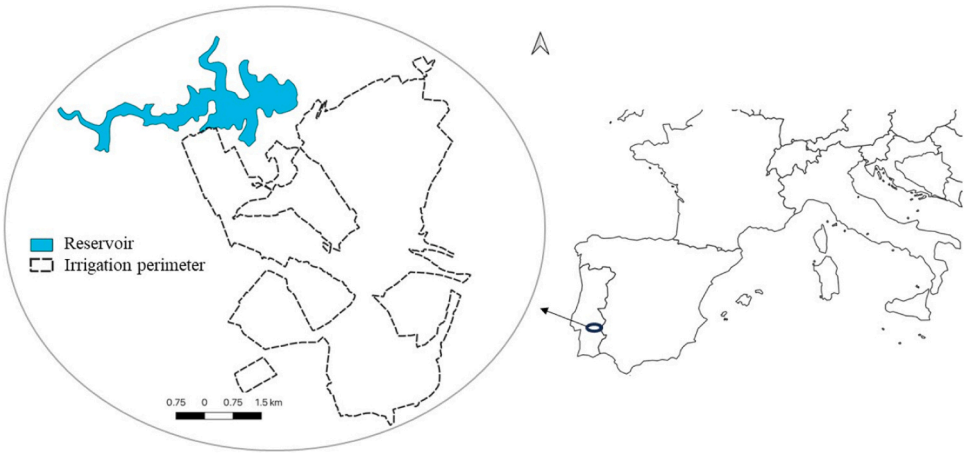

Fig. 2. Location of the Lucefecit Collective Irrigation System in Portugal and Europe.

Table 1
Secondary data for the rapid appraisal and relevant sources of information.

Data	Source
Soil map 1:25 000 (1982), ESRI:102164	Ministry of the Environment, SNIAmb (2022)
Lucefecit collective irrigation system limits	Collective Irrigation Systems Map – Ministry of Agriculture DGADR (2022)
Farm/plot identification	IFAP (2022)
Cropping patterns	Sentinel-2 images (Level-2A), Google Earth Satellite Images (QMS) GEE (2022)
Irrigation requirements	Rodrigues (2022)
Irrigation calendars, irrigation systems, water and energy consumptions and costs, on-farm irrigation systems efficiency	Lucefecit Water Users Association and selected farmers

stakeholders. These include the WUA manager and the two technicians (office technician and field technician), the farmers, a company that offers paid advice to some farmers who irrigate the largest areas and the research team of the HubIS project.

2.2.2.1. Study design and sampling procedure. The research phases and techniques for collecting primary data in the PA implementation process are presented below.

First, the focus group methodology was used with the involvement of all stakeholders. The research team explained the project goal, reduced communication barriers through face-to-face dialogues, facilitated processes for building trust and commitment to collaboration, and exchanging viewpoints about what should be achieved together (Morgan, 1996). Given the dual consultative and collaborative role of the focus groups, the following aspects were analysed in detail: i) selection of innovations to be implemented in the LICS; ii) the potential benefits and difficulties of application; and iii) how and when the project team intended to monitor the implementation of innovations in the area.

The other research phases, which took place sequentially for operational reasons, aimed to determine in detail the willingness of the participants to accept the innovation proposals and the possible types of knowledge, skills and tools that should be made available to enable the adoption of innovation. To this end, the project team used both qualitative and quantitative research techniques to collect empirical data at both the collective irrigation system level (CIS) and the farmers' field level.

With a focus on innovation at the CIS level and with the aim of improving the organizational structure of the WUA, semi-directive face-to-face interviews were conducted with the manager and each of the two technicians.

Regarding the WUA manager, the questions aimed to find out his opinion on the following topics: i) the main weaknesses and limitations of the LCIS functioning, ii) the interest in potential innovations to be implemented in the organizational design of the collective irrigation system, iii) the skills and abilities of the two technicians to implement these innovations, iv) his perspective on the procedures and timelines that the project team wanted to implement.

The use of semi-directive interviews with the office technician and the field technician focused on specific aspects of the daily activities that each individual performs and their assessment of the changes resulting from the adoption of the innovations proposed by the HubIS Project. The interview included questions that allowed the technicians' to express themselves on the feasibility and interest of the innovations proposed by HubIS, their willingness to adopt them given possible constraints they impose in terms of available time, identify changes in routines and determine the need to acquire appropriate technical and organizational knowledge, skills and tools. Since these two technicians have also been in regular contact with farmers for decades, it seemed important to us to get their opinions on the innovations that should also take place at the

Table 2
Indicators used in rapid appraisal at the irrigated plot level.

Indicator	Equation		Reference
Crop yield (Y, ton ha^{-1})	$Y = \frac{P}{A}$	[1]	Córcoles et al. (2012) Fernandéz *et al.* (2020)
Irrigation water productivity (WP$_I$, kg m^{-3})	$WP_I = \frac{Y}{V_H}$	[2]	Pereira et al. (2012); (2021); Ferreira et al.(2023)
Relative irrigation supply (RIS)	$RIS = \frac{V_H/A}{IR}$	[3]	Córcoles et al., 2012; Rodríguez-Díaz et al. (2008)
Economic irrigation water productivity (EWP, € m^{-3})	$EWP = \frac{Value(Y)}{V_H/A}$	[4]	Pereira et al. (2012); Ferreira et al. (2023)

P (ton) is the crop production; A is the irrigated area (ha); V_H (m^3) is the volume of water supplied at the plot hydrant; IR (m^3 ha^{-1}) are the irrigation requirements; Value(Y) (€ ha^{-1}) is the monetary value of the achieved yield.

Table 3
Indicators used in rapid appraisal at the collective irrigation system level.

Indicator	Equation		Reference
Irrigated area/ command area ratio (ICR, %)	$ICR = \frac{A_{IR}}{A_C}$	[5]	Zema et al. (2018)
Volume diverted per unit of irrigated area (VIR, m^3 ha^{-1})	$VIR = \frac{V_O}{A_{IR}}$	[6]	Moreno et al. (2010); Rodríguez-Díaz et al. (2008)
Water delivery efficiency (WDE, %)	$WDE = \frac{V_H}{V_O} 100$	[7]	Rodríguez-Díaz et al. (2008); Zema et al., (2015)
Relative irrigation supply at the CIS level (RIS_{CIS}, %)	$RIS_{CIS} = \frac{V_O}{IR_{CIS}} 100$	[8]	IDEA (2008); Zema et al. (2018)
Consumed energy per unit of irrigated area (CE/ A_{IR}, kWh ha^{-1})	$CE/A_{IR} = \frac{CE}{A_{IR}}$	[9]	Córcoles et al. (2012); Rodríguez-Díaz et al. (2008)
Consumed energy per unit of irrigation supply (CE/V_H, kW h m^{-3})	$CE/VH = \frac{CE}{V_H}$	[10]	Córcoles et al. (2012); Rodríguez-Díaz et al. (2008)
Consumed energy per unit of volume diverted (CE/Vo, kWh m^{-3})	$CE/V_O = \frac{CE}{V_O}$	[11]	Rodríguez-Díaz et al. (2011)
Energy cost per unit of irrigated area ($Cost_E/A_{IR}$, € ha^{-1})	$Cost_{E/A_{IR}} = \frac{Cost_E}{A_{IR}}$	[12]	Córcoles et al. (2012)
Energy cost per unit of volume diverted ($Cost_E$/Vo, € m^{-3})	$Cost_{E/Vo} = \frac{Cost_E}{Vo}$	[13]	Rodríguez-Díaz et al. (2011)
Energy cost relative to total MOM $Cost_E$/MOM (%)	$Cost_E/MOM = \frac{Cost_E}{MOM}$ 100	[14]	Córcoles et al. (2012); Rodríguez-Díaz et al. (2008)

A_{IR} (ha) is the irrigated area; A_C (ha) is the area considered in the project (command area); Vo (m^3) is the volume of water diverted and sent to the transport and distribution network; V_H (m^3) is the volume supplied to the plots and accounted at the hydrants; IR_{CIS} (m^3) are the irrigation requirements of the collective irrigation system; CE (kWh) is the annual consumed energy; CostE (€) is the annual energy cost in the pumping stations; MOM (€) is the annual maintenance, operation and management cost.

farmers' plot level.

Finally, at farm/field level, the possibilities for implementing the innovations were evaluated using empirical data provided by the water users. For this purpose, a structured questionnaire was applied face-to-face. The questionnaire consisted of nine sections aimed at obtaining target information (Table 4).

The questionnaire was applied to a statistically representative sample of the current population of all (47) water users. To proceed with the selection of the representative sample of farmers to be questioned face-to-face, we first characterized the 47 water users whose plots were irrigated in 2020. The two technicians played the role of privileged informants. Their expertise and close individual relationships maintained with water users for decades have proven relevant to this purpose. For each of the 47 farmers, their name and age (according to age groups: <44; ≥45 to <64 and ≥65) were identified. In addition, information about the crops grown, the area and the irrigation system used in each plot (solid set sprinkler-SS, drip-D, centre pivot-CP) was also collected. A significant part of the LCIS irrigable area (referred to as command area) was not used in 2020. Thus, information on the percentage of total irrigated area relative to the command area (in 2020), with three ranges: < 25%, ≥ 25 to < 50% and ≥ 50%, was also collected. Finally, empirical information on the suitability of soils for irrigation was obtained from the two local informants, based on a 4-point Likert scale (Croasmun, and Ostrom, 2011; Joshi et al., 2015) considering the categories "Good", "Fair", "Inadequate" and "Poor".

Table 4
Sections of structured questionnaires applied to the farmers during 2020 and related information.

Section	Information about
1	socio-economic profile of respondents
2	structural features of farms
3	agricultural systems
4	climate change (with the aim of assess the state of knowledge regarding the actual impacts of climate change on the agricultural activity)
5	irrigation systems used and procedures for installation, maintenance, and performance assessment
6	irrigation scheduling (when and how much to irrigate)
7	methods for measuring soil water (e.g. knowledge of the existence of soil water sensors, readiness and type of conditions that must be met for the adoption of the sensors)
8	deficit irrigation and effects on crop yield
9	miscellaneous

2.2.2.2. Sample size estimation. Given the small size of the WUA staff, consisting of a manager and two technicians with different roles, we decided to conduct the semi-directive interviews to the entire population. Regarding farmers, the information obtained in accordance with 2.2.2.1 was taken into account when determining the sample for the face-to-face structured questionnaires, as described below. Since the irrigated area of three of the largest landholders was managed by another farmer along with his own irrigated area, these three beneficiaries were excluded from the population for which the sample was selected. The representative sample was then drawn from a population of 43 farmers.

In order for the sample to be statistically representative of the population, it was extracted using well-defined probabilistic methods so that its characteristics are distributed similarly to those of population under study (Ritchie and Lewis, 2003). Determining the size of the sample to collect in order to obtain valid estimates of the parameters of interest is a difficult matter and depends on several factors: the parameter being studied, the variability of the population members, the size of the population, etc. Given the size of the population being studied and the diversity of characteristics, a sample size equivalent to 20% of the size of the population was considered. Due to the diversity of population characteristics, a stratified sample was used to conduct the present study. Adequate stratification of the population makes it possible to increase the precision of the results, while maintaining the degree of confidence. The population was divided into subgroups (strata) that were as homogeneous as possible, and the proportion of the total irrigated area in the command (in 2020) was chosen as the stratification variable. Three ranges were considered to define the strata: <25%, ≥25% to <50% and ≥ 50%. A simple random sample was selected in each stratum (Fink, 2003). The number of individuals to be selected in each stratum was determined by proportional allocation (Cochran, 1977), i.e. in each stratum i (i=1,2,3), the sample size, n_i, is calculated as

$$n_i = \left(\frac{n}{N}\right) N_i \tag{15}$$

Were N is the population size, N_i is the size of each stratum and n in the total sample size.

3. Results and discussion

3.1. Rapid appraisal results

3.1.1. Crops, soils and irrigation systems

The collected data on crops and land suitability for irrigation in the Lucefecit Collective Irrigation System were spatialized (Fig. 3). The results show that the main irrigated crops are maize (*Zea mays* L.), winter cereals (e.g. *Avena sativa* L. and *Triticum aestivum* L.), olive groves (*Olea europaea* L.) and fodder crops (*Medicago sativa* L., *Sorghum bicolor* (L.),

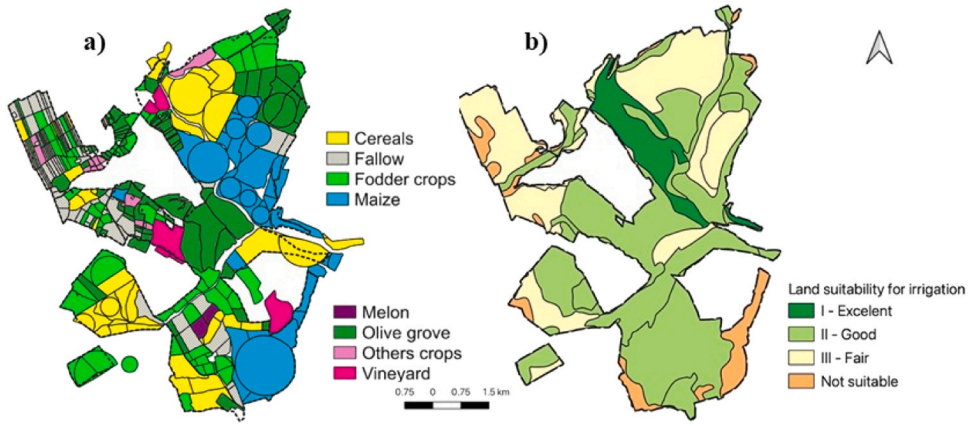

Fig. 3. Spatial distribution of a) crops and b) land suitability for irrigation in the Lucefecit Collective Irrigation System.

Moench and *Sorghum* × *drummondii* (Nees ex. Steud.) Millsp. & Chase) (Fig. 3a). Various crops are grown on the remaining irrigated area, including melons (*Cucumis melo* L.) and vineyards (*Vitis vinifera* L.).

The classes of land suitability for irrigation shown in Fig. 3b result from the integration of three characteristics (Ferreira et al., 2022): soil texture, slope and permeability. Class I includes soils with excellent suitability for irrigation, sandy loam or clay texture, good structure and permeability and a maximum slope of 2%. Class II soils present good suitability for irrigation, and are generally deep and moderately drained. Class III present a fair suitability for irrigation because they are shallow soils with a heavy texture, with slopes between 4% and 6%. The soil textures were extracted from the Portuguese Soil Map (CSP). The slopes were obtained from the digital terrain model (MDT), which was created using information on contour lines, elevation points and the hydrographic network, supported by QGIS. The permeability classes according to ARS/USDA (Renard et al., 1997) were used. Most of the area is well suited for irrigation, but a considerable portion is only fairly adapted to irrigation.

Fig. 4 shows both the spatial distribution of irrigation systems in the LCIS (Fig. 4a) and the areas irrigated by the different systems (Fig. 4b). On the medium and small plots, the solid set sprinklers (SS) and drip systems (DS) predominate, the latter particularly in orchards and vineyards (Fig. 3b). There are small and large irrigated plots, with plots smaller than 5 ha predominating. The larger ones are irrigated by centre pivots (CP), typically with daily irrigations of 20 hours or more.

3.1.2. Performance indicators

The analysis of plot-level performance indicators focused mainly on maize and olive orchards, as these are the main crops in the LCIS. Fig. 5a shows that the average maize yield (Y) for the period 2016–2021 is higher for the plots irrigated by CP (12.5 ± 3.3 ton ha^{-1}) than for the plots with SS systems (9.7 ± 2.6 t ha^{-1}). This difference is likely related to the potentially higher efficiency and distribution uniformity associated with the centre pivots. The statistical data for Alentejo (INE, 2024) shows maize yield between 12.73 ton ha^{-1} and 13.84 ton ha^{-1} for the period 2016–2021. As reported by Paredes et al. (2014), a low yield at the plot-level is often associated with low irrigation uniformity due to inadequate system maintenance or system design. In both plot types, yield can be above 15 ton ha^{-1}, and bellow 5 ton ha^{-1}. This large variability among plots irrigated with the same irrigation system can be explained by farmers' different approaches to irrigation scheduling, especially under conditions of high climatic demands (e.g. Dechmi et al., 2003a,b; Grassini et al., 2011; Domínguez et al., 2022; Zapata et al., 2023). Another reason for this variability could be fertilization management.

Irrigation water productivity, WP_I, at the plot level, assesses how much irrigation water is used to achieve a given production (Ferreira et al., 2023; Pereira et al., 2012). For the study area, WP_I values for maize, ranged from 0.23 kg m^{-3} to 2.69 kg m^{-3} during the six years in which data were collected for the 34 characterized irrigated plots (Fig. 5b).

Lower WP_I values may indicate low yield, or that irrigation water supplied at the hydrant (V_H) is higher than expected. Additionally, it was

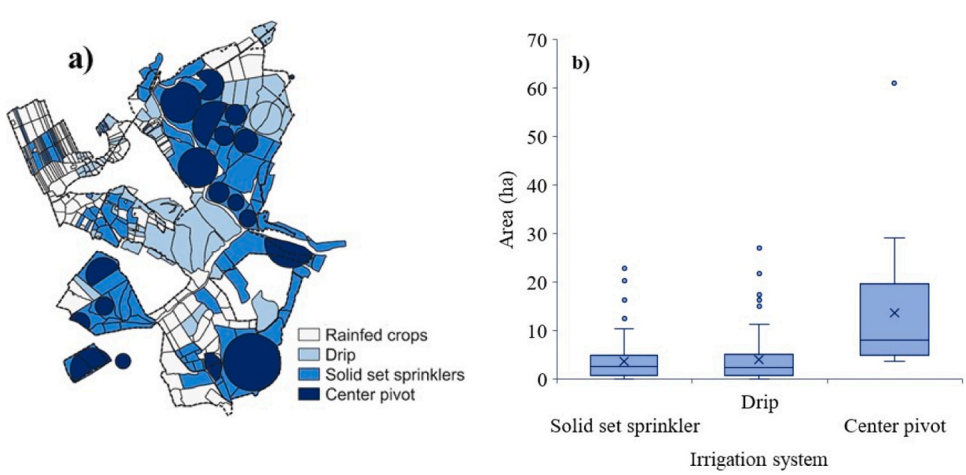

Fig. 4. a) Spatial distribution of irrigation systems and b) box-and-whiskers plot relative to the areas of plots per irrigation system in the Lucefecit Collective Irrigation System.

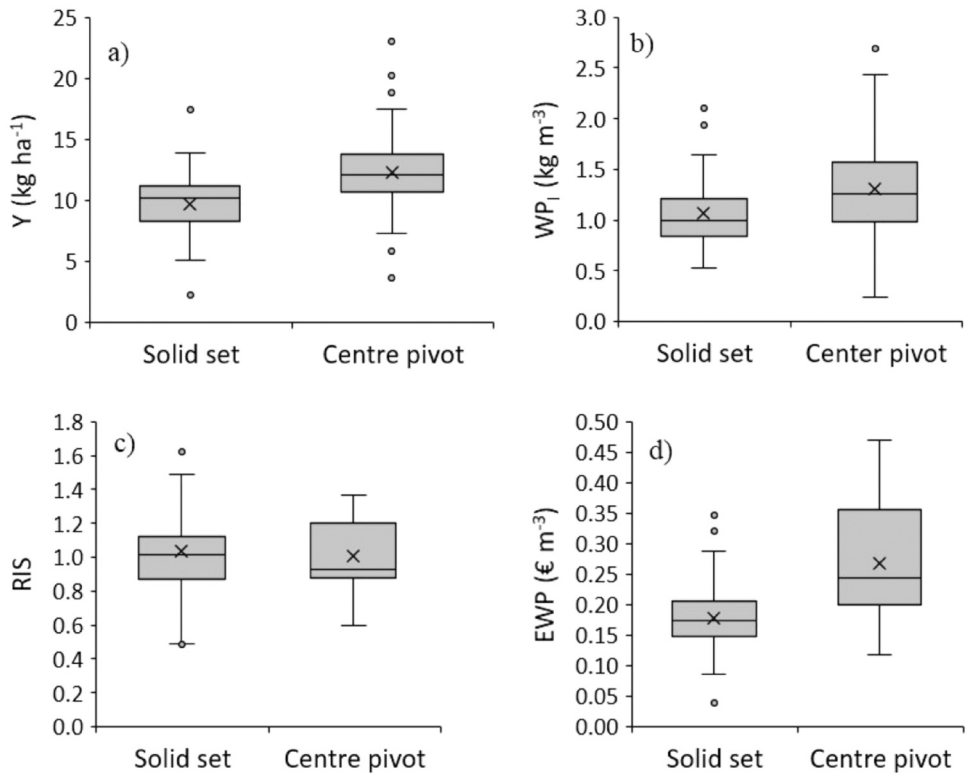

Fig. 5. Water and energy performance indicators for maize for the period 2016–2021: a) crop yield (Y); b) irrigation water productivity (WP_I); c) relative irrigation supply (RIS); d) economic productivity of irrigation water (EWP).

found that farmers with greater risk aversion to water stress tended to over irrigate, resulting in lower WP_I. The results show that the plots with centre pivot have an average WP_I that is 45% higher than that achieved with the SS systems. The fact that irrigation systems have lower application efficiency leads to higher consumption of irrigation water and therefore lower water productivity. The WP_I results in the present study are comparable to those of several authors. Rodrigues et al. (2010) estimated WP_I values between 1.21 kg m^{-3} and 1.82 kg m^{-3} for several irrigation systems and with different performances. A study by Paredes et al. (2014), reported WP_I values between 1.48 kg m^{-3} and 3.15 kg m^{-3}, with the lowest values obtained in the plot with poor distribution uniformity. In the study by Greaves and Wang (2017) the WP_I was between 1.64 and 2.95 kg m^{-3} for the non-stress irrigation treatments. Similar WP_I values were reported by Araya et al. (2019) with values from 1.60 to 2.80 kg m^{-3}, depending on the amount of irrigation applied. Mohammed and Irmak (2022) reported much higher WP_I values in CP irrigated maize (3.61–7.04 kg m^{-3}).

The relative irrigation supply (RIS) results are shown in Fig. 5c. A RIS value of one means that the water supplied at the hydrant meets the crop irrigation requirements. However, irrigation can be considered well managed with RIS values in the range of 0.9–1.2 (Segovia-Cardozo etal., 2019). The results of the current study show that in some of the plots studied, seasonal irrigation supply was much higher than the IR of maize, and RIS reached values of 1.6 and 1.3 for the solid set systems and centre pivot, respectively. On the other hand, in some plots, farmers were not provided with enough irrigation water, with relative irrigation supplies for the SS and CP, being 0.5 and 0.6, respectively. This likely had an impact on crop yield and consequently on WP_I. Salvador et al. (2011) reported maize RIS values of 1.20 ± 0.30 for SS and 1.40 ± 0.38 for surface irrigation in the Ebro basin. Borsato et al. (2019) presented a value of 0.79 for CP irrigation in north-eastern Italy. Lorite et al. (2012) reported RIS values between from 0.7 and 1.32 for maize irrigated with SS. However, there was high variability in irrigation applied by farmers in each of the three periods of the crop cycle analysed for each irrigation season in Genil-Cabra. Expósito and Berbel (2017) reported an average RIS for maize plots of 0.75 and 0.70 respectively for the Guadalquivir river basin in Spain in 2005 and 2012, respectively.

The EWP results (Fig. 5d) also show high degree of variability, especially in the CP (0.10–0.48 € m^{-3}). However, the average EWP value is the highest for this type of system. Average values of 0.18 and 0.27 € m^{-3} were determined for SS and CP respectively. These results follow the same trend and values as those of Rodrigues et al. (2010) with higher EWP values in plots with CP (0.30 € m^{-3}). Paredes et al. (2014) present EWP values between 0.29 € m^{-3} and 0.51 € m^{-3} in maize plots also irrigated with CP. Salvador et al. (2011) reported an average EWP value for maize of 0.16 € m^{-3} under solid set sprinkler irrigation for the Ebro basin in Spain. Amarasinghe et al. (2021) reported an average EWP value for maize of about 0.40 € m^{-3} for the Sina irrigation system in India.

Fig. 6 shows the same results as Fig. 5, but for olive groves. Regarding the yield of the olive groves (Fig. 6a), our results (6.5 ± 3.3 ton ha^{-1}) are consistent with those in the literature. The statistical data for Alentejo (INE, 2024) shows a yield of 1.93 ton ha^{-1} to 5.35 ton ha^{-1} for olives for oil production for the period 2016–2021. Santos (2018) reported average values of 6.0 ± 1.8 ton ha^{-1} for full irrigation and 7.8 ± 2.1 and 5.0 ± 2.5 ton ha^{-1} for different levels of regulated deficit irrigation-RDI (70 and 50% of full irrigation, respectively) from 2011 to 2014 in the Alentejo region (Portugal).

Table 5 shows the reported average yield (Y) and irrigation water productivity (WP_I) values for olives in different Mediterranean countries. The high variability of the results presented in Table 5 is likely due to farmers´different approaches to irrigation scheduling and the different annual rainfall amounts. Other sources of variability relate to the biennial bearing of olives, olive cultivar and plant density (Marra et al., 2016).

Table 5 shows that in terms of irrigation water productivity WP_I (Fig. 5b), our results (3.88 ± 2.5 kg m^{-3}) are consistent with other studies, but again show high variability with a minimum of 1.22 and a maximum of 9.84 kg m^{-3}.

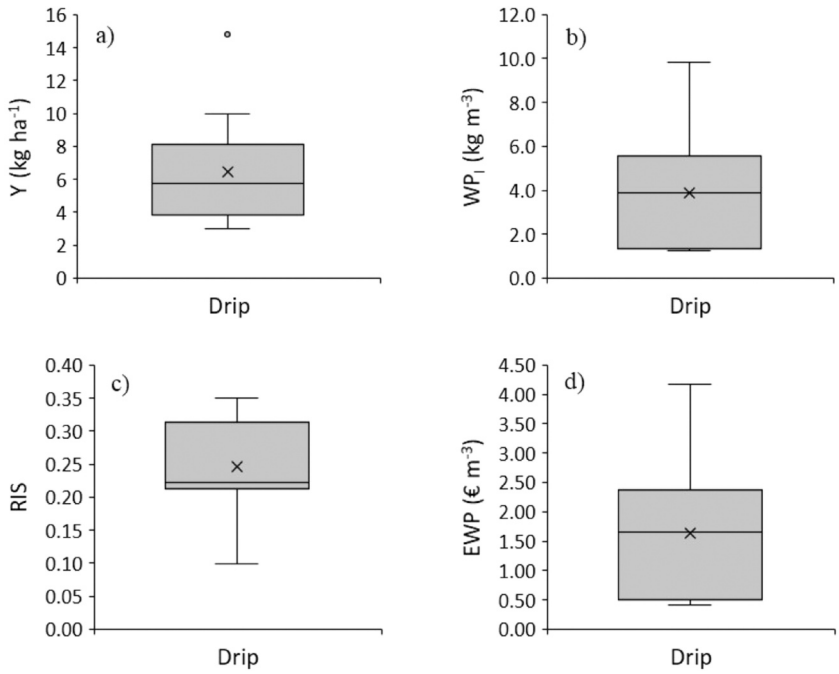

Fig. 6. Water and energy performance indicators for olive groves for the period 2016–2021: a) yield (Y); b) irrigation water productivity (WP_I); c) relative irrigation supply (RIS); d) economic productivity of irrigation water (EWP).

Table 5
Values reported in the literature for average yield and irrigation water productivity for Mediterranean olive groves.

Reference	Location	Years of the study	Yield (ton ha^{-1})	WP_I (kg m^{-3})	Description
	Portugal				
Our study	Lucefecit CIS	2016–2021	6.5± 3.3	3.88 ± 2.5	
Fernandes-Silva et al., (2010)	Trás-os-Montes	2004–2006	3.9±1.9–5.8±3.1	n/r	FI, DI
Santos (2018)	Ferreira Alentejo	2011–2014	2.1±0.7–14.4±2.5	0.51–1.18	Intensive orchard FI
			2.7±1.5–16.6±2.6	1.08–6.37	RDI = 70% FI
			1.6±1.1–12.2±3.9	0.81–6.73	RDI =50% FI
INE, 2024	Alentejo	2016–2021	1.9–5.4	n/r	Regional average
Expósito and Berbel (2016), (2017)	Guadalquivir Basin, **Spain**	2010–2013	3.9±1.6–9.1±2.8	3.40–7.32	
				1.11–1.67	
Marra et al. (2016)	Sicily, **Italy**	2008–2010	5.7±0.7	n/r	
Kourgialas et al. (2022)	Crete, **Greece**	2017–2019	2.5–10.0	2.02–5.59	LD
Abboud et al. (2019)	Sidi Bouzid	2015–2016	3.8–17.2	0.65–3.24	Diverse IT & cultivars
Souissi et al. (2019)	**Tunisia**	n/r	n/r	1.41–2.5	Country average
Elfkih et al. (2023)	Sfax, **Tunisia**	2012–2013	1.1–5.7	0.69–2.86	Diverse IT
Tadayon and Hosseini (2023)	Fasa region, **Iran**	2016–2019	4.0±0.3–7.2±0.3	n/r	
Ibba et al. (2024)	Marrakech	2021–2022	8.71–17.8	4.26–7.82	Diverse IT

DI - deficit irrigation; FI - full irrigation, IT – irrigation treatment; RDI – regulated deficit irrigation; LD – low-density orchard

Regarding the relative irrigation supply, RIS, (Fig. 6c), Salvador et al. (2011) presented values of 0.64 ± 0.11 for the Ebro basin, while Moreno-Pérez and Roldán-Cañas (2013) presented an average value of 0.59 for eight irrigation seasons in the Genil-Cabra collective irrigation system. Expósito and Berbel (2017) reported an average RIS for traditional olive orchards of 0.41 and 0.62 for the years 2005 and 2012 respectively, and 0.60 for intensive olive groves in the Guadalquivir river basin in Spain. Our values are below these values, indicating the water supplied at the hydrants accounts for, on average, 25% of the full irrigation requirements. A large part of the crop needs is likely to be met by direct spring precipitation or the storage of winter precipitation in the soil.

In the present study (Fig. 6d), the average EWP value is 1.64 ± 1.09 € m^{-3}. Salvador et al. (2011) reported an average EWP value for olive groves of 0.52 € m^{-3} for the Ebro basin in Spain. For Tunisia, Souissi et al. (2019) reported an average EWP of about 0.11–0.20 € m^{-3} and 0.18–0.60 € m^{-3} for rainfed and irrigated olive groves, respectively. Kourgialas et al. (2022) recorded values between 2.03 € m^{-3} and 4.48 € m^{-3} from 2017 to 2019 in Crete (Greece). Fernández et al. (2020) report EWP values of 0.44 ± 0.1 7 € m^{-3} for a very high-density olive grove in Spain, for the period 2010–2012, which increased to 0.65 ± 0.26 € m^{-3} in the period 2013–2015 for full irrigation. For regulated deficit irrigation (RDI) the values were 0.44 ± 0.24 € m^{-3} for 60RDI, 0.72 ± 0.31 € m^{-3} for 45RDI and 1.18 ± 0.38 € m^{-3} for 30RDI. This shows that the lower the amount of water supplied at the hydrant, the higher the economic productivity. However, when the water deficit is very high the crop is affected resulting in lower yield. These results are not directly comparable with those in the present study, since Fernández et al. (2020) used the profit to calculate the EWP and we used the crop value.

Fig. 7 shows the results for the indicators selected in the assessment at the level of the collective irrigation system, described in Table 2. Fig. 7a shows the evolution of relative water supply at the collective irrigation system level, RIS_{CSI}. In all years except 2018, the seasonal water supply of all plot hydrants was higher than the sum of the irrigation requirements for all the plots. This means that the entire irrigated

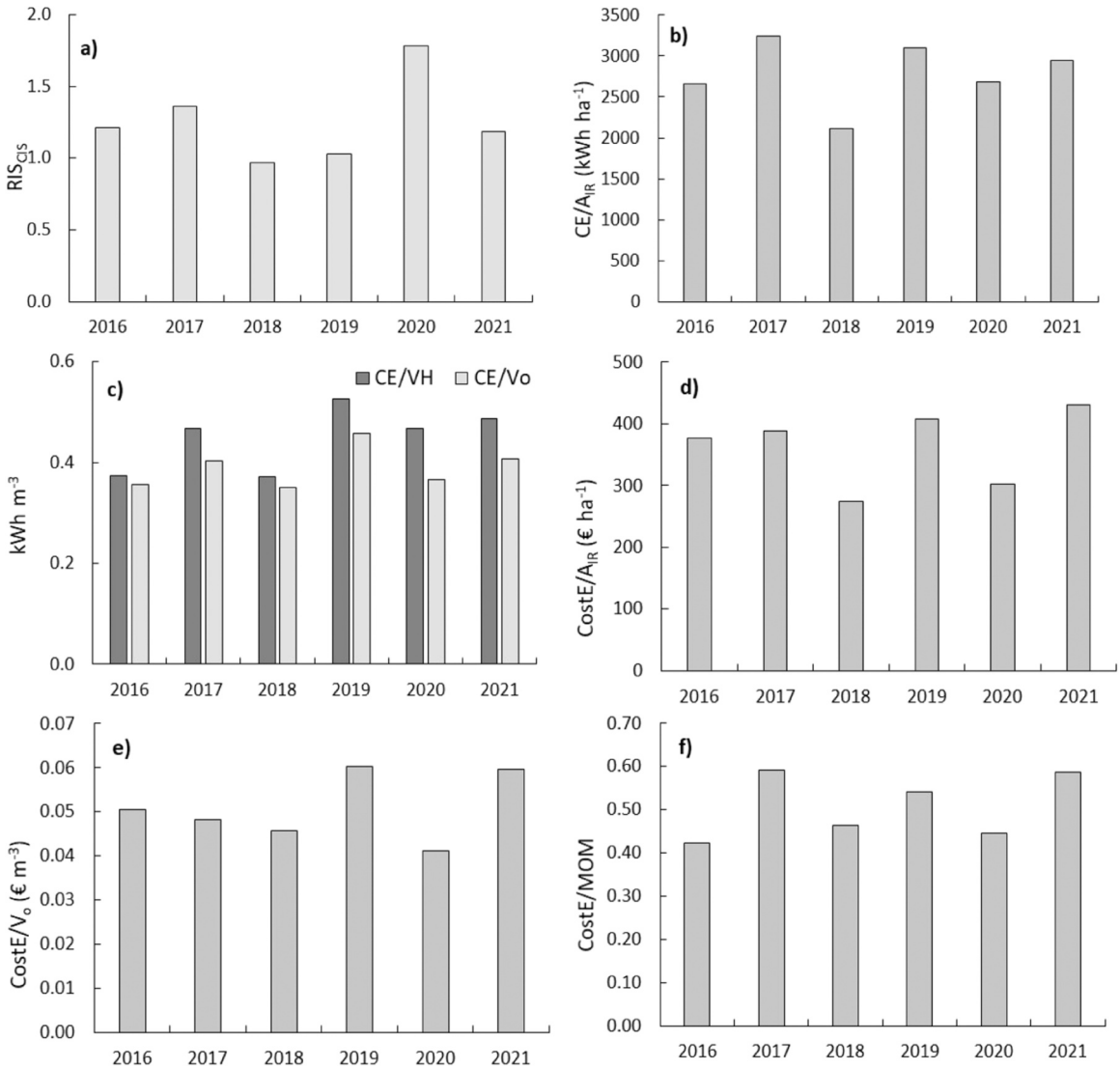

Fig. 7. Indicators at the collective irrigation system level: a) relative irrigation supply (RIS_{CIS}); b) energy consumption per unit of irrigated area (CE/A_{IR}); c) energy consumption per unit of volume diverted to the network (CE/V_o) and supplied to the plots (CE/V_H); d) cost of pumping energy per unit of irrigated area ($CostE/A_{IR}$); e) cost of pumping energy per unit of water supplied to the network ($CostE/V_o$); f) ratio of energy costs to total MOM costs (CostE/MOM).

area received an excessive volume of water, but some plots did not receive enough water to meet crop requirements (plots with a RIS less than one). Much higher RIS_{CIS} were reported by Zema et al. (2020), with values of 3.68, with a peak value as much as 9.2, for 10 CIS in Calabria (Italy) (9 with water distribution by rotation and one by on-demand). Lozano and Mateos (2008) presented RIS_{CIS} values between 2.67 and 1.61 for CIS with the fixed rotation delivery method in Seville (southern Spain). Benavides et al. (2021) reported for Guanacaste irrigation scheme, Costa Rica RIS_{CIS} ranging 2.48–3.78 during 2014–2018.

In contrast, Lorite et al. (2004) reported much lower RIS_{CIS} for the Genil–Cabra CIS in Andalusia in Spain, with values between 0.45 and 0.64 during the period 1996–2000. Similar RIS_{CIS} values were reported by Soto-García et al. (2013) for the CIS of Cartagena (rotation delivery method), ranging from 0.61 to 0.80 in normal years and decreasing values with increasing water scarcity, reaching values of about 0.45 in dry years. Salgado et al. (2021) reported RIS_{CIS} values between 0.40 and 0.80 for two subsystems of the Río Dulce Irrigation Scheme in Argentina, for the period 2012–2015. Kibret et al. (2021) reported an average RIS_{CIS} value of 0.95 for the Dirma small scale CIS in Ethiopia. Mateos et al. (2010) reported that the relative irrigation supply increases with the number of irrigation hours per day.

Fig. 7b) shows the yearly values of energy consumption per unit of irrigated area, CE/A_{IR}. The inter annual variation of this indicator can be due to a number of variables, namely the overall irrigation needs which affects the volume pumped into the network and the efficiency curve of the pumping station. The CE/A_{IR} values are higher in all years than in the study cases reported in the literature, and are, on average 2919.9 ± 502.3 kWh ha^{-1}. Rodríguez-Díaz et al. (2011) present values for this indicator ranging from 455 kWh ha^{-1} to 2000 kWh ha^{-1} for 10 CISs in Spain with pressurized water distribution. Córcoles et al. (2012) indicate an energy consumption per unit of irrigated area of 1722 kWh ha^{-1} with pressurized water distribution and the prevalence of sprinkler irrigation systems.

The IDAE (2008) classifies collective irrigation systems with energy consumption of more than 2000 kWh ha^{-1} as large energy consumers. Accordingly, the Lucefecit collective irrigation system can be considered a large energy consumer, since in all years of the study the energy consumption per unit of irrigated area was higher than 2000 kWh ha^{-1}.

The time evolution of the energy consumption per unit volume pumped into the network (CE/V_o) and per volume distributed in the hydrant (CE/V_H) from 2016 to 2021 is shown in Fig. 7c. Regarding CE/V_o, Rodríguez-Díaz et al. (2011) propose the following classification:

CISs with a value greater than 0.4 kWh m^{-3} are considered large consumers, CISs with values between 0.4 and 0.3 kWh m^{-3} are considered average consumers and CISs with values below 0.3 kWh m^{-3} are small consumers. Thus, accordingly, LCSI lies on the border between large and average energy consumers, with an average value of 0.43 ± 0.13 kWh m^{-3}. Rodríguez-Díaz et al. (2011) reported an average of 0.41 kWh m^{-3} for the 10 Spanish CISs, while Córcoles et al. (2012) reported average values of 0.31 kWh m^{-3}. Lima et al. (2019) reported CE/V_o values between 0.3286 and 0.3485 kWh m^{-3} for the actual conditions of the "SORETA" irrigation network, Albacete, Spain. Chibeles (2007) reports an average CE/V_o value of 0.336 kWh m^{-3} for four collective irrigation blocks (EFMA) in the Alentejo (Portugal).

For the Lucefecit Collective Irrigation System, the average value of energy costs per unit area irrigated ($CostE/A_{IR}$) for the studied period was 386.0 ± 81 € ha^{-1}. Córcoles et al. (2012) present energy costs per unit irrigated area of 118.5 € ha^{-1} for CISs with predominantly sprinkler irrigation systems. Lima et al. (2019) reported values between 56.3 and 59.0 € ha^{-1} for the actual conditions of the "SORETA" irrigation network.

The energy costs per unit volume of water pumped ($CostE/V_o$) are 0.052 ± 0.008 € m^{-3} (Fig. 6e). Rodríguez-Díaz et al. (2011), report values between 0.01 and 0.08 € m^{-3} for 10 Spanish CISs, with an average value of 0.04 € m^{-3}. In six other Spanish CSIs, reported by Córcoles et al. (2012), the energy cost per unit volume of water supplied to the plots was 0.025 € m^{-3}. Lima et al. (2019) reported $ECost_{Vo}$ ranging from 0.0175 to 0.0185 € m^{-3} for the actual conditions of the "SORETA" irrigation network in Spain. For Portugal, Chibeles (2007) gives the average value of 0.034 € ha^{-1} for four AFMA irrigation blocks.

The average value for the ratio between energy costs and total costs associated with MOM for the study period was 0.52, meaning that 52% of the costs spent on MOM are energy costs (Fig. 7f). Rodríguez-Díaz et al. (2011) present results for this ratio, for 10 CSIs in Spain with pressurized water distribution, with a mean of 0.36 and a maximum of 0.65. In the LCIS, 30% of irrigation systems are solid set, followed by drip system (23.7%) and centre pivots (20.2%) (Fig. 4). Córcoles et al. (2012) report an average value of 45% for this ratio for six case studies, two with drip irrigation systems, for which the energy cost represents 20% of MOM costs, and the remaining 4 with solid set and centre pivot, for which the ratio is 60%.

Another interesting result concerns the distribution of energy consumption by billing periods during the 24 hours of the day (Fig. 8).

Energy costs vary from 0.05844 € kWh^{-1} in the minimum off-peak season to 0.11047 € kWh^{-1} in the maximum peak period. Less than 40% of consumption occurs during off-peak periods when energy is cheaper (from 10 p.m. to 8 a.m.). However, 10% of consumption occurs during peak periods when energy costs are highest (10 a.m. to 1 p.m. and 7–9 p.m.). Around 50% of the energy is consumed during the period with intermediate costs. The large proportion of solid set irrigation systems not susceptible to automation, may justify the small percentage of farmers who irrigate during off-peak periods.

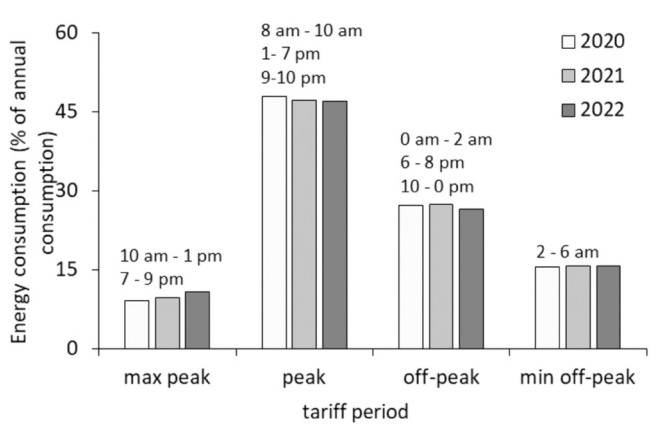

Fig. 8. Energy consumption in the main pumping station of the Lucefecit Collective irrigation system distributed over tariff periods.

Overall, these results underscore the multifaceted nature of agricultural water management within the Lucefecit collective irrigation system, highlighting several opportunities to improve water use efficiency, crop yield, and economic sustainability through targeted interventions in irrigation practices, infrastructure, and energy management. These opportunities are summarized in Section 3.3.

3.2. Participatory approach results

3.2.1. Characterization of farm households, farmers, crops and irrigation systems

The ratio of irrigated area to command area was 0.54 in 2020, meaning that 628.1 ha were irrigated. About one third of this area corresponds to the first implementation phase. The remaining two thirds (410 ha) are included in the second phase and are supplied with pressurized water at the farm hydrants. For this part of the LCIS, the ratio is 0.43, meaning that 540 ha of the command area was not irrigated.

The huge structural inequality in access to land among the 47 water users registered in 2020 is a characteristic aspect of LCIS that is highlighted and reflected in the procedures used to select the sample to be interviewed through face-to-face questionnaires. About 57% of the total irrigated area (532.12 ha) was managed by only four of the 47 beneficiaries. Of these, 53% were located in the 2nd phase area (pressurized water distribution), and 68.4% in the area of the 1st phase (water distribution by gravity). In fact, this entire area was managed by one person. Applying the concept of an agricultural holding (one unit, as long as it remains a single unit both technically and economically -shared use of the means of production- and under a single management) to the 47 water users in total, we conclude that four of these correspond to a single agricultural holding.

The economic and social asymmetry in access to the irrigated areas is also evident among the remaining 43 water users who managed the rest of the registered area (227.85 ha) in 2020, 44.71 ha were in the 1st phase, and 183.14 ha in the 2nd phase. The area managed by the six water users with plots located in the 1st phase varied between 35.5 ha (maximum value) and 0.5 ha (minimum). This asymmetry becomes even clearer for the 37 irrigators whose plots are in the 2nd phase of implementation with a minimum of 0.02 ha and a maximum of 25.5 ha. Of the total 37 irrigators, 28 managed plots with an area less than 1 ha.

In 2020, maize and winter cereals accounted for 63% of the total irrigated area (628.07 ha), almost entirely (91%) cultivated by the four beneficiaries mentioned above. A wide variety of crops were grown on the remaining irrigated area, from permanent crops such as olive groves and vineyards to annual crops such as melon.

The majority of farmers (60%) are over 65 years old which is consistent with the results for the municipality where the LCIS is located and also for mainland Portugal (INE, 2021).

The primary data collected confirms that most water users do not use the entire irrigable area available to them. More specifically, 38% of farmers use less than 25% of the available irrigable area, 15% of farmers use 25–50% and 47% use more than 50% of the available irrigable area. As a result of this analysis, and in accordance to the methodology described in 2.2.2.2., 11 landholders were selected from the population (43), including 4 in the first stratum (<25% of the irrigable area), 2 in the second stratum (≥25% to <50%) and 5 in the third (≥50% of the irrigable area).

3.2.2. Results from the semi-directive face to face interviews and the structured questionnaire

3.2.2.1. Water users' association manager and technicians. According to the WUA manager, the main difficulties are financial and are caused by the high electricity costs of the two pumping stations. The pumps

operate with low efficiency, especially at low demand flow, which is likely to result in high-energy consumption.

There has been no continuous decline in irrigation water availability over the last five years. The catchment area that supplies the dam is quite large and, in recent years, the WUA has managed to carry normal irrigation campaigns without having to impose strict water restrictions. However, concerns about the potential impacts of climate change have influenced management decisions on the efficient use of water and energy in the LCIS.

The manager points out the usefulness of a simple spreadsheet programmed to calculate water and energy balances and estimate use efficiencies. He believes that although the technicians have the basic skills to access and use the spreadsheet, specific training would ultimately be required. However, in order to feed the spreadsheet it is important to continuously monitor the flows and pressures at various points in the system, preferably using remote management, which is not available at LCIS. According to the WUA manager, in addition to remote management, another investment is crucial, namely the installation of a photovoltaic park capable of powering the two pumping stations, in order to reduce the main cost of operating the LCIS.

Regarding his opinion on farmers' willingness to adopt innovations, he believes that the problem lies not in the cost, but in the availability of certain farmers to adopt certain types of tools. Below a certain school level and especially in the older age groups, the farmer is not available for training and is not willing to acquire new knowledge.

The office technician has been working at the WUA since 1995. He is responsible for registering the volumes of water delivered at the hydrants to each irrigator, as well as settling water bills and other fees, among many other technical tasks related to the organic operation of the WUA. He was aware of the existence of water and energy losses at the CIS level, and highlighted the negative financial impacts for the WUA and the farmers, as well as the environmental impact on society. He was willing to adopt procedures to reduce or overcome those losses. He added that, he believes, farmers should also be made aware of such situations. He was willing to receive the necessary training on the innovations to be adopted and the skills required to operationalize them.

The field service technician has been working at the WUA since 1988. He is responsible for overseeing the entire infrastructure of the LCIS, managing the irrigation network, pumping stations and water distribution to the farmer. He describes the LCIS as a nearly 40-years-old system whose equipment is already heavily worn and requires increasing maintenance. The technical constraints resulting from the poor condition of the equipment (pumping stations, pipes and hydrants) and having a negative impact on the financial situation of the management justify the need for a rehabilitation project with very high investments.

According to the field technician, the cropping pattern has changed in the last five years. The predominant crop is still maize, but other crops such as hedgerow olive groves, vineyards, and tomatoes for processing are also emerging. While the dominance of maize cultivation and farmers' interest in this crop cannot be separated from the subsidies of the Common Agricultural Policy, the emerging trend towards super-intensive olive groves and almond orchards can be explained by the prices of these products on international markets. Some farmers are also interested in growing high-density almond tree orchards.

When asked what kind of improvements in data collection and logging he would like to see implemented, the answer demonstrated expertise. According to the respondent, these improvements could be achieved through remote management. This would require a large investment, namely between 100,000 and 200,000 euros, but would be more effective and the monitoring would be rigorous, for example in the event of malfunctions, since in addition to sending out warnings, the system also switches off the pumping station and thus avoids water losses. In the current system, with just a monthly reading and recording of the water delivered in each hydrant, it's only possible to detect the existence of a malfunction if there is a complaint from the farmer. In extreme cases, it may happen that the malfunction is detected only on days when the hydrant is physically visited for readings. This means that the correct amount of water supplied to the farmer cannot be recorded.

3.2.2.2. Farmers

3.2.2.2.1. Socio-economic profile. For 73% of the respondents, most or all of their household income comes from agriculture. Wages and pensions, which predominate among older farmers managing the smallest areas of land, are the main sources of household income for the rest of the respondents. The vast majority of LCIS beneficiaries practice family farming (> 50% or all work on the farm is done by the head of the family and/or family members).

Most respondents (73%) have benefited from LCIS since they started farming. The rest began with the development of the infrastructure. About 27% of farmers have agricultural training: a university degree or a more technical course for farmers. The rest learned the craft based on know-how and knowledge passed down from generation to generation. Although a large body of scientific literature shows associations between the socioeconomic variable of farmers' age and their willingness to adopt innovations (Knowler and Bradshaw, 2007, Prokopy et al., 2008), this study does not confirm this type of association.

3.2.2.2.2. Structural characteristics of the farms. About half of respondents (46%) irrigate a single plot, which represents the farm's total irrigated agricultural area (UAA). In two other cases, this area is divided into 2 plots and 3 plots. The irrigated area managed by the largest farmer is spread over 15 plots. In the 2020 irrigation season, drip irrigation was the most widely used irrigation system (60%) in the benefited area receiving pressurized water (2nd phase), followed by solid set systems and centre pivots. In situations where the UAA is spread over more than one irrigated plot, crops and irrigation system tend to vary. This variation is related to the practice of crop rotation among medium-sized and small-sized farmers.

When asked about the three production factors that have the greatest impact on farm operating costs, water was the first factor mentioned in order of increasing importance (82% of responses). In contrast to this are the two farms in which the agricultural work is performed exclusively through wage labour. For these farmers, wages represent the production factor with the greatest relative weight in farm operating costs. It should be noted that the price of irrigation water per volume delivered is the same for all irrigators in the same phase, regardless of the area. Although this price is subsidized, it still represents a fee that is considered high by the vast majority of irrigators. The economic profitability of the farming systems practiced can help to explain the importance of water price for the overall economic burden. This is consistent with the idea that the cost and availability of water can strongly influence agricultural practices and their economic viability (Molle and Berkoff, 2007; Aidam, 2015; Pronti and Berbel, 2023).

3.2.2.2.3. Climate change. All respondents said they had heard about climate change. However, only four replied that they had never been affected. Most of those who responded that they had already been affected pointed to the irrigation restrictions imposed by the WUA in years of extreme meteorological drought. According to them, droughts are becoming more frequent (1 drought year every 4–5 years). Switching crops has been the strategy of those who are already feeling the effects of climate change. The rest began to control better irrigation amounts and opportunity.

The largest farmer combines productions well-paid by the market (intensive and semi intensive olive orchards, vineyards and cereals) with others subsidized by the Common Agricultural Policy-CAP (maize and tomatoes). This farmer installed sensors such as flow meters to know the amount of water applied by the centre pivots and soil moisture probes to determine when and how much to irrigate, allowing to optimize water use by precisely controlling the amount of water applied to crops. The farmer also uses cameras installed in centre pivot and drone videos to help identifying system repair needs. These results are consistent with

other studies showing that innovation efforts vary across farm systems and that more profitable agricultural systems are generally more innovative (Läpple et al., 2015; Vollaro et al., 2019).

The small farmer adopted crops better adapted to the changing climate, and the medium-sized farmer began to be more careful about irrigation duration using less water in each irrigation. These strategies illustrate that farmers have historically adopted appropriate behaviours to adapt to climate variability and changes (e.g. Bryan et al., 2009; Deressa et al., 2009; Smit and Skinner, 2002, Bartels et al., 2013, Lasage et al., 2015).

3.2.2.2.4. Cropping systems. The above results show that the nature of efficient water use strategies is not independent of the economic profitability of the production systems. Typically, the higher the profitability, the more sophisticated the water efficiency practices. Except for these farmers, most others produce low-paying crops in the market, regardless of the area under cultivation. The farmers who produce melons (except one) manage small areas. Those who cultivate vineyards or olive groves do so in the traditional way (low plant density) and the areas vary between 2 ha and 10 ha. The remaining medium-sized and small size (areas < 1 ha) farmers irrigated the following crops: wheat, oats, Sudanese sorghum, pasture, and small vegetables under vineyard or olive grove cover.

3.2.2.2.5. Installation, assessment and maintenance of irrigation systems. The technical and agricultural support (information, training and advice) that the public extension services provide to the farmers in the LCIS is nil. The lack of this type of service manifests itself in several dimensions, which will be analysed below. Of the eight respondents without specific agricultural training, six chose to install the irrigation system on the advice of commercial companies that sell and install this type of equipment. The remaining farmers looked from neighbours or chose the equipment taking their financial circumstances into account. When asked to what extent the irrigation systems best suited their needs, all responded that they did not know, because they had set the lowest cost as a constraint. The influence of farm financial resources on farmer's ability to purchase appropriate equipment has also been noted in other studies (e.g. Reimer et al., 2012; Koech et al., 2021).

In order to assess the extent and how water losses are addressed by irrigators, questions were designed to assess the correct installation and maintenance of the irrigation system, as these procedures are crucial to ensure the distribution of water uniformly throughout the plot, reducing water losses. Based on the responses collected, it is concluded that all respondents perform some type of inspection (i.e. checking for clogged emitters, burst pipes) and maintenance (i.e. unclogging emitters, replacing pipes and emitters) of the irrigation systems. However, if on the one hand only 6 out of 11 farmers confirmed that they evaluate the irrigation system and, thus, check that the entire plot is uniformly irrigated, on the other hand, only one answered that this evaluation is carried out every 3 years, depending on the needs of the irrigation system. For the rest, this evaluation is carried out sporadically.

3.2.2.2.6. Irrigation scheduling. Knowing the amount of water supplied to crops and improving irrigation practices are two relevant techniques to reduce water losses and thus improve the efficiency of irrigation water use. It was found that all respondents monitor the amount of water delivered to their plots, using a meter at the entrance of their plot or irrigation system. The WUA provides information about the amounts of water delivered to the farms. The majority of farmers (73%) say they know the pressure at which the irrigation is delivered to their plot. On the other hand, procedures related to irrigation scheduling (i.e. when and how much water to apply) show significant deficiencies. Only 4 out of 11 farmers receive information about the days when they should irrigate from private companies providing services in the irrigation sector. Of the 7 who do not receive information, only 2 are aware of the importance of this type of information. When asked if they receive information about the amounts of water to be applied during the irrigation campaign, only 2 farmers answered affirmatively and only 1 of those who did not receive information expressed interest in receiving it.

The behaviours described above show that, in addition to information and training, farmers in the LCIS primarily need technical support. Therefore, the implementation of the irrigation advisory service should be considered by the WUA after assessing farmers' willingness to pay (Allani et al., 2022; Martey et al., 2023).

3.2.2.2.7. Methods for measuring soil water. The consequences of the lack of technical support are also reflected in the answers to the questions designed to determine the readiness for adopting soil water sensors. These questions were preceded by a brief introduction of the topic. From the responses received, it can be concluded that although all respondents answered that they were aware of the existence of soil water sensors, only one uses them. Seven out of 11 said they knew someone who uses these sensors. However, when asked if they would be willing to install these sensors, only two respondents replied affirmatively when they were told that some of these sensors are easy to implement and use and have a low cost. One farmer said he had already adopted this type of sensors but gave up due to technical difficulties in maintaining sensor operation and interpreting measurements. This type of difficulty was also noted by three other farmers to justify their lack of interest in using sensors. Of the remaining 5, 3 identified financial reasons. Out of a total of 11 farmers cultivating an irrigated area of less than 1 ha, only 2 said they were not interested.

3.2.2.2.8. Deficit irrigation. The questions about deficit irrigation were preceded by a short introduction. The concept of deficit irrigation was explained to the farmers in a simple way using the example of the olive grove. The responses received suggest that the majority of farmers (60%), regardless of the irrigated area they manage, indicated that they were aware of the existence of this practice, although only two thirds of them believed they had already applied it. On the other hand, those who did not know were available to apply it if they could count on the appropriate technical support.

3.2.2.2.9. Miscellaneous. When asked if they knew of other types of adaptations/innovations that could be used to minimize water and energy losses, 5 out of 11 said they did not know. One referred to soil moisture sensors, three to solar panels to generate energy for the pumping systems. One suggested better management of irrigation duration and one pointed to precision irrigation technologies and crop varieties that use water more efficiently. The latter is the farmer with a specific academic education in agricultural engineering, who also relies on technical information and advice from a private company. With the exception of this farmer, the remaining four who reported on technologies identified the lack of technical support as a limiting factor for possible adoption.

3.3. Innovation basket

While the indicators used in the RAP quantitatively identified the key issues to be addressed, the bottom-up participatory approach enabled the identification of potential innovations tailored to the LCIS (Fig. 1). By involving key stakeholders, farmers and WUA manager and technicians, the PA ensured that the selected innovations were contextually appropriate and met the specific needs of the collective, which is an added value of this integrated methodology. This basket of innovations at different Technology Readiness Levels (TRL) (EARTO, 2014) promotes flexibility and adaptability and recognizes that there is no one-size-fits-all solution.

The key outcomes from the methodology applied that led to the innovation basket were:

- High energy consumption per hectare of irrigated area and m^3 of irrigation water supplied;
- Low efficiency of pumping stations;
- Inefficient method of recording the amount of water delivered at the farm gate hydrants;
- High variability among plots in terms of irrigation water productivity;

- The cropping pattern in the LCIS is changing towards permanent crops, which use water over longer periods, and annual crops with higher water requirements such as tomatoes for processing;
- Lack of technical support hampers farmers' ability to appropriately select and maintain irrigation systems;
- Awareness of soil water sensors existence, but adoption by farmers is limited due to technical difficulties and financial constraints, highlighting the need for low-cost and user-friendly technologies;
- Farmers are aware of deficit irrigation practices, but implementation is limited, highlighting the importance of technical support and guidance;

The resulting innovation baskets are presented in Table 6 and Table 7 for the collective irrigation system level and the plot level, respectively.

During the 2022 irrigation season, some of the innovations from the basket (Tables 6 and 7) were implement through a joint effort and commitment from all stakeholders. The WUA technicians immediately adopted innovation I_1 (Table 6) from the CIS level basket, developed in response to a direct request to simplify and speed up the reading and recording of water consumption at the hydrants on a monthly basis. The knowledge and experience of using the Excel program made it easier for the office technician to adhere to the new information collection methodology introduced by HubIS.

The positive attitude and commitment of the two technicians as well as their awareness of the need for efficient use of water and energy, contributed also to the adoption of innovations at farm level. All small-scale farmers identified the lack of technical support as a barrier to innovation adoption. The role of disseminating and providing technical information to farmers is all the more important given that in Portugal state-funded advisory services (the so-called agricultural extension services) have been in decline since the 1990s. Similar trend has occurred globally (Norton and Alwang, 2020). Nowadays, activities such as technical training, information provision and advice mainly rely on the private sector and are provided by agricultural business organizations (García-Mollá et al., 2020; Sutherland et al., 2017). This trend towards the generalised privatisation of agricultural advisory services, which is not specific to Portugal but is present throughout Europe, has harmed small-scale agriculture in particular, since it cannot afford them (Labarthe and Laurent, 2013; Kidd et al., 2000; Sutherland et al., 2017; García-Mollá et al., 2020; Sutherland and Labarthe, 2022).

At the farm level, three out of eleven farmers who formed the statistically representative sample of the population adopted Innovation I_4 "Irrigation scheduling using low cost soil moisture sensors". The soil water sensors were installed on plots located in the 2nd phase of the project, cultivated with aromatic herbs (4.65 ha) and managed by a private company; melon (21.88 ha) and a hedgerow olive grove (87.42 ha) managed by the largest-holder farmer. This olive grove, which was abandoned at the time the empirical information was collected was leased and managed by a farmer in 2022. With the exception of the latter, the other two farmers own the irrigated area under cultivation. The Innovations I_5 "Guidelines for irrigation systems operation, maintenance and evaluation" and I_6 "Guidelines for deficit irrigation in olives and vineyards" are completed and will be implemented during the 2024 irrigation season, after the HubIS project is finished.

Different types of barriers or factors limited individual responses to new suggestions or innovations. As this case study shows, individuals (e.g. the WUA technicians) are more willing to innovate when they are aware of the benefits, are familiar with technologies whose use is somewhat related to the innovations to be adopted, and when these can be adapted to the daily time management of the tasks performed. The economic characteristics of innovation are variables that differentially influence the adoption of agricultural innovations by small-scale and large-scale farmers. Initial investment costs and time of return on investment, as well as access to credit, are examples of economic barriers that tend to discourage small-scale farmers from adopting innovations

Table 6
Innovation (I) basket to be tested at transport and distribution levels in the Lucefecit Collective Irrigation System.

	I_1: recording method and database for hydrant water accounting	**I_2**: irrigation and energy auditing tool at the water distribution network	**I_3**: Smart pump chart for pumping station management
Origin	Developed within the HubIS project	Developed within the HubIS project	Developed within the HubIS project based on existing software
Type	Excel App	Spread sheet	Model-driven solution
Objective	Assist the WUA technician to record the hydrant data	Monitor the efficiency of water and energy transport in the pressurized pipe from the water source (reservoir) to the hydrants	Optimum functioning of main pump station for different scenarios to reduce energy use and maintain hydrant's reliability
Description	An app opened on a tablet or smartphone enables consumption values to be recorded on site at the farm gate. The data is stored in a spreadsheet that can be accessed on the WUA computer	An Excel tool for calculating water and energy balances that enables rapid assessment of overall water and energy efficiency in the transport and distribution network	An informatics tool based upon an hydraulic software that runs in a GIS environment will determine the most appropriate pump system regulation for different demand scenarios
Justify why this is an innovation for this site	Currently, the technician records the readings on paper and the data have to be entered into a spreadsheet in the office	Currently, technicians do not have a tool to perform calculations and are unaware of the water and energy balances	Currently, the pumping efficiency is low due to low irrigation intensity of the LCIS, particularly for periods of low demand
Expected impacts and Improved Indicators	This innovation shortens the time required to complete the task and also minimizes data loss. Improves operational management	Estimating water and energy losses allows the definition of an intervention strategy to improve water and energy use efficiency, favouring operational management	The adequate programing of the pumping stations allows the efficient use of water and energy. Improves energy related indicators.
Readiness level	TRL7	TRL4	TRL4
End user	WUA managers and technicians	WUA manager and technicians	WUA engineer
Cost level	The costs for a tablet or smartphone, which are considered residual costs in the WUA budget	None	None
Operational difficulty*	1	2–3	3–4
Expected setbacks	None	If there is little or no data on water and energy consumption, balancing cannot be carried out.	Water and energy consumption profiles are required to feed the spreadsheet.

* 0-No particular skills required, 1-Deal with a smart phone, 2-Deal with an excel spreadsheet, 3-Deal with multiple data sources and environments, 4-Capable of data analysis, 5-Capable of data calibration and validation for action

Table 7
Innovation (I) basket to be tested at farm level in Lucefecit Collective Irrigation System.

	I_4: Irrigation scheduling using low-cost soil water sensors	**I_5**: Guidelines for irrigation systems operation, maintenance and evaluation	**I_6**: Guidelines for deficit irrigation in olives and vineyards
Origin	Adapted from existing	Adapted from existing	Adapted from existing
Type	Equipment and procedure	Guidelines	Guidelines
Objective	Help farmers decide when to start and end each irrigation event	Describe and establish a set of tasks/practices to be performed to improve system performance	Provide farmers with knowledge to support their day-to-day irrigation scheduling decision
Description	Low-cost sensors installed in the centre and bottom of the rootzone. Based on readings from the sensors and provided thresholds, farmers control the system	These guidelines will be implemented at plot level with the support of the HubIS team. Farmers will be trained to perform the related tasks	The information provided along with I4 will support farmers making irrigation scheduling decisions throughout the season
Why this is an innovation for this site	Small scale farmers do not have soil moisture sensors installed, so over- or under irrigation can occur, leading to poor irrigation performances	Very few farmers consider the need to maintain their irrigation systems. Therefore, poor irrigation is practiced which has a major impact on yields and water losses	Most farmers in the region lack knowledge about crop behaviour under water stress conditions. They rely on the traditional knowledge and not on scientific knowledge
Impacts Indicators	P_A, WP_I, EWP	P_A,WP_I, EWP	WP_I, EWP
Read level	TRL 9	TRL 6	TRL 6
End user	Farmers	Farmers	Farmers
Cost level	2 sensors ha^{-1} (in and below root zone) = 140 € ha^{-1}. Portable meter = 440 €; Total investment = 580 € ha^{-1}. For a 10 ha farm with a gross margin of 6000 € y^{-1}, this investment is<10%	Technical assessment report with improvement recommendations = 5 € ha^{-1} for centre pivot and 12.6 € ha^{-1} for drip and solid set systems. These costs are marginal	None
Operational Difficulty*	0–1. Innovation provides information of thresholds for start and end irrigation	0–1. It can be higher if the farmer wants to be involved in the task.	2. It can be higher if the farmer wants to be involved in the task.
Expected setbacks	Financial investment by the farmers	Skills required to perform the maintenance tasks and interpret assessment results, labour	Implementation is limited, highlighting the importance of technical support and guidance

* 0-No particular skills required, 1-Deal with a smart phone, 2-Deal with an excel spreadsheet, 3-Deal with multiple data sources and environments, 4-Capable of data analysis, 5-Capable of data calibration and validation for action

compared to larger-scale farmers. Similar results were reported by Koech et al. (2021). Further obstacles to the acceptance of innovation identified in the current study were structural factors, age, level of education, and the accumulated experience in the agricultural sector. These results are consistent with others in the literature (e.g. Vollaro et al., 2019; Berthold et al., 2021).

4. Conclusions

A synergistic method combining a participatory approach and rapid appraisal was successfully used for the selection of a series of innovations aimed at improving the efficient use of water and energy in the Lucefecit collective irrigation system.

The RAP performance indicators used to assess the LCIS showed high energy consumption per hectare of irrigated area and per m^3 of irrigation water supplied, with more than 50% of MOM costs associated with energy. Therefore, the LCIS is a high energy consumer, requiring tailored innovations. Furthermore, the LCIS showed a high variability in WPI among plots that had different equipment levels and irrigation scheduling practices. The application of the bottom-up participatory approach allowed the selection of an innovation basket tailored to the specific challenges previously identified. The active engagement of stakeholders instilled a sense of ownership and responsibility, which led to increased acceptance and adoption of the selected innovations. Furthermore, the results shed light on the challenges and opportunities associated with incorporating bottom-up approaches, basket of innovations, and stakeholder engagement in decision-making processes (co-decision and co-learning). The main limitation of the presented methodology is its dependence on the willingness of farmers and technicians to provide data from their fields and the irrigation network. Taking into account that one of the main challenges for the sustainability of the agricultural sector in the current context is the efficient use of natural resources such as water and energy, this research study provides useful information for policy makers and its results and innovations can be extended to farms in other public collective irrigation systems. The successful transferability of the proposed methodology relies, on the one hand, on the adequate design of the RAP and, on the other hand, on the identification of the stakeholders who co-select the innovations according to the specifics of the contexts. The HubIS PRIMA project provided an insightful case study in Portugal, about the diverse ways in which agricultural innovation transfer projects can contribute to pathways to smallholder resilience and climate change mitigation.

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CRediT authorship contribution statement

Antónia Ferreira: Software. **Paula Paredes:** Writing – review & editing. **Andreia Garção:** Investigation. **Manuela Neves:** Methodology. **Maria Rosário Cameira:** Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Isabel Rodrigo:** Methodology, Data Curation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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References

Abboud, S., Dbara, S., Abidi, W., Braham, M., 2019. Differential agro-physiological responses induced by partial root-zone drying irrigation in olive cultivars grown in semi-arid conditions. Environ. Exp. Bot. 167 https://doi.org/10.1016/j.envexpbot.2019.103863.

Aidam, P.W., 2015. The impact of water-pricing policy on the demand for water resources by farmers in Ghana. Agric. Water Manag. 158, 10–16. https://doi.org/10.1016/J.AGWAT.2015.04.007.

Allani, M., Frija, A., Nemer, R., Ribbe, L., Sahli, A., 2022. Farmers' Perceptions on an Irrigation Advisory Service: Evidence from Tunisia. Water (Switz.) 14. https://doi.org/10.3390/w14223638.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration. guidelines for computing crop water requirements. In: Irrig, Drain. Paper No.56, 300. FAO, Rome, p. D05109.

Alston, J.M., Pardey, P.G., 2016. Antipodean agricultural and resource economics at 60: agricultural innovation. Aust. J. Agric. Resour. Econ. 60, 554–568. https://doi.org/10.1111/1467-8489.12162.

Amarasinghe, U.A., Sikka, A., Mandave, V., Panda, R.K., Gorantiwar, S., Ambast, S.K., 2021. Improving economic water productivity to enhance resilience in canal irrigation systems: A pilot study of the Sina irrigation system in Maharashtra, India. Water Policy 23, 447–465. https://doi.org/10.2166/wp.2021.231.

Andrade, C., Fraga, H., Santos, J.A., 2014. Climate change multi-model projections for temperature extremes in Portugal. Atmos. Sci. Lett. 15, 149–156. https://doi.org/10.1002/asl2.485.

Apgar, M., Douthwaite, B., 2013. Particip. Action Res. CGIAR Res. Program Aquat. Agric. Syst. 2013–2040. ⟨https://hdl.handle.net/20.500.12348/796⟩.

Araya, A., Prasad, P.V.V., Gowda, P.H., Kisekka, I., Foster, A.J., 2019. Yield and water productivity of winter wheat under various irrigation capacities. J. Am. Water Resour. Assoc. 55, 24–37. https://doi.org/10.1111/1752-1688.12721.

Bartels, W.L., Furman, C.A., Diehl, D.C., Royce, F.S., Dourte, D.R., Ortiz, B.V., Zierden, D. F., Irani, T.A., Fraisse, C.W., Jones, J.W., 2013. Warming up to climate change: A participatory approach to engaging with agricultural stakeholders in the Southeast US. Reg. Environ. Change 13, 45–55. https://doi.org/10.1007/S10113-012-0371-9/FIGURES/3.

Benavides, J., Mateos, L., García-Vila, M., Fereres, E., 2021. Evaluating irrigation scheme performance in a tropical environment: The Guanacaste scheme, Costa Rica*. Irrig., Drain. 70, 1331–1346. https://doi.org/10.1002/IRD.2621.

Bento, V.A., Ribeiro, A.F.S., Russo, A., Gouveia, C.M., Cardoso, R.M., Soares, P.M.M., 2021. The impact of climate change in wheat and barley yields in the Iberian Peninsula, 2021 11:1 Sci. Rep. 11, 1–12. https://doi.org/10.1038/s41598-021-95014-6.

Berthold, T.A., Ajaz, A., Olsovsky, T., Kathuria, D., 2021. Identifying barriers to adoption of irrigation scheduling tools in Rio Grande Basin. Smart Agric. Technol. 1, 100016 https://doi.org/10.1016/J.ATECH.2021.100016.

Blackmore, C., Cerf, M., Ison, R., Paine, M., 2012. The role of action-oriented learning theories for change in agriculture and rural networks. In: Darnhofer, I., Gibbon, D., Dedieu, B. (eds) Farming Systems Research into the 21st Century: The New Dynamic159–177. https://doi.org/10.1007/978-94-007-4503-2_8/COVER.

Borsato, E., Martello, M., Marinello, F., Bortolini, L., 2019. Environmental and economic sustainability assessment for two different sprinkler and a drip irrigation systems: a case study on maize cropping. Agriculture 2019 9, 187. https://doi.org/10.3390/AGRICULTURE9090187.

Bryan, E., Deressa, T.T., Gbetibouo, G.A., Ringler, C., 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environ. Sci. Policy 12, 413–426. https://doi.org/10.1016/j.envsci.2008.11.002.

Cameira, M. do R., Pereira, L.S., 2019. Innovation issues in water, agriculture and food. Water (Switz.) 11, 1230. https://doi.org/10.3390/w11061230.

Cardoso, R.M., Soares, P.M.M., Lima, D.C.A., Miranda, P.M.A., 2019. Mean and extreme temperatures in a warming climate: EURO CORDEX and WRF regional climate high-resolution projections for Portugal. Clim. Dyn. 52, 129–157. https://doi.org/10.1007/S00382-018-4124-4/TABLES/3.

Carvalho, A., Schmidt, L., Santos, F.D., Delicado, A., 2014. Climate change research and policy in Portugal. Wiley Interdisciplinary Reviews: Climate Change. https://doi.org/10.1002/wcc.258.

Chambers, R., 1981. Rapid rural appraisal: rationale and repertoire. Public Adm. Dev. 1, 95–106. https://doi.org/10.1002/PAD.4230010202.

Chavas, J.P., Nauges, C., 2020. Uncertainty, Learning, and technology adoption in agriculture. Appl. Econ. Perspect. Policy 42, 42–53. https://doi.org/10.1002/AEPP.13003.

Chevalier, J.M., Buckles, D.J., 2019. Participatory action research: theory and methods for engaged inquiry. Particip. Action Res.Theory Methods Engaged Inq. 1–434. https://doi.org/10.4324/9781351033268/participatory-action-research-jacques-chevalier-daniel-buckles.

Cochran, W.G., 1977. Sampling Techniques. Wiley, New York.

Córcoles, J.I., Juan, J.A., de, Ortega, J.F., Tarjuelo, J.M., Moreno, M.A., 2012. Evaluation of Irrigation Systems by Using Benchmarking Techniques. J. Irrig. Drain. Eng. 138, 225–234. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000386.

COTR, 2023. Meteorological data. National Irrigation Centre ⟨https://www.cotr.pt/⟩ (accessed 15 May.23).

Croasmun, J.T., Ostrom, L., 2011. Using likert-type scales in the social sciences. J. Adult Educ. 40, 19–22.

Darnhofer, I., Gibbon, D., Dedieu, B., 2012. Farming Systems Research: an approach to inquiry. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, Dordrecht, pp. 3–30. DOI: 10.1007/978-94-007-4503-2_1 https://doi.org/10.1007/978-94-007-4503-2_1/COVER.

De Melo-Abreu, J.P., Barranco, D., Cordeiro, A.M., Tous, J., Rogado, B.M., Villalobos, F. J., 2004. Modelling olive flowering date using chilling for dormancy release and thermal time. Agric. Meteor. 125, 117–127. https://doi.org/10.1016/J.AGRFORMET.2004.02.009.

Dechmi, F., Playán, E., Faci, J.M., Tejero, M., 2003a. Analysis of an irrigation district in northeastern Spain: I. Characterisation and water use assessment. Agric. Water Manag. 61, 75–92. https://doi.org/10.1016/S0378-3774(03)00020-9.

Dechmi, F., Playán, E., Faci, J.M., Tejero, M., Bercero, A., 2003b. Analysis of an irrigation district in northeastern Spain: II. Irrigation evaluation, simulation and scheduling. Agric. Water Manag. 61, 93–109. https://doi.org/10.1016/S0378-3774(03)00021-0.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Change 19 (2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002.

Dias, S., Acácio, V., Bifulco, C., Rego, F., 2018. Improving Drought Preparedness in Portugal, in, Iglesias, Ana; Assimacopoulos, Dionysis and Van Lanen, Henny A.J. (eds.), Drought: Science And Policy,183-199. DOI:10.1002/9781119017073.

Domínguez, A., Schwartz, R.C., Pardo, J.J., Guerrero, B., Bell, J.M., Colaizzi, P.D., Louis Baumhardt, R., 2022. Center pivot irrigation capacity effects on maize yield and profitability in the Texas High Plains. Agric. Water Manag. 261, 107335 https://doi.org/10.1016/J.AGWAT.2021.107335.

EARTO, 2014. TRL Scale as a Research & Innovation Policy Tool, European Association of Research and Technology Organizations Recommendations. ⟨https://docplayer.net/21819778-The-trl-scale-as-a-research-innovation-policy-tool-earto-recommendations.html⟩ (accessed 12 March 2022).

EEA, 2019, Climate change adaptation in the agriculture sector in Europe, EEA Report, N.°04/2019, Luxembourg, 112p. European Environment Agency ⟨https://euroseeds.eu/app/uploads/2019/09/Climate-change-adaptation-in-the-agriculture-sector-in-Europe.pdf⟩ (Accessed 12 March 2022).

Elfkih, S., Hadiji, O., Ben Abdallah, S., Boussadia, O., 2023. Water accounting for food security: virtual water and water productivity in the case of Tunisian Olive Oil Value Chain. Agriculture 13, 1205. https://doi.org/10.3390/AGRICULTURE13061205.

El-Gamal, T., 2018. Examining an Egyptian Irrigation Network Using MASSCOTE Approach. J. Soil Sci. Agric. Eng. 9, 103–110. https://doi.org/10.21608/JSSAE.2018.35577.

Ellison, C.E., Morris, B., Locatelli, D., Sheil, J., Cohen, D., Murdiyarso, V., Gutierrez, M., van Noordwijk, I.F., Creed, J., Pokorny, D., Gaveau, D.V., Spracklen, A.B., Tobella, U., Ilstedt, A.J., Teuling, S.G., Gebrehiwot, D.C., Sands, B., Muys, B., Verbist, E., Springgay, Y., Sugandi, C.A., Sullivan, 2017. "Trees, forests and water: cool insights for a hot world. Glob. Environ. Change 43, 51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.

Expósito, A., Berbel, J., 2016. Microeconomics of deficit irrigation and subjective water response function for intensive olive groves. Water 8 (6), 2548. https://doi.org/10.3390/W8060254.

Expósito, A., Berbel, J., 2017. Agricultural irrigation water use in a closed basin and the impacts on water productivity: The case of the Guadalquivir River Basin (Southern Spain). Water (Switz.) 9. https://doi.org/10.3390/w9020136.

Fader, M., Shi, S., von Bloh, W., Bondeau, A., Cramer, W, W., 2016. Mediterranean irrigation under climate change: More efficient irrigation needed to compensate for increases in irrigation water requirements. Hydrol. Earth Syst. Sci. 20, 953–973. ⟨www.hydrol-earth-syst-sci.net/20/953/2016/doi:10.5194/hess-20-953-2016⟩.

Fagerberg, J., Mowery, D.C. (Eds.), 2006. The Oxford Handbook of Innovation. Oxford University Press, Oxford. https://doi.org/10.1093/oxfordhb/9780199286805.001.0001.

FAO, 2018. Concept note", International Symposium on Agricultural Innovation for Family Farmers: Unlocking the potential of agricultural innovation to achieve the Sustainable Development Goals, Rome, 21-23 November. ⟨https://www.fao.org/3/BU658en/bu658en.pdf⟩.

Fernandes-Silva, A.A., Ferreira, T.C., Correia, C.M., Malheiro, A.C., Villalobos, F.J., 2010. Influence of different irrigation regimes on crop yield and water use efficiency of olive. Plant and soil 333, 35–47. https://doi.org/10.1007/s11104-010-0294-5.

Fernández, J.E., Alcon, F., Diaz-Espejo, A., Hernandez-Santana, V., Cuevas, M.V., 2020. Water use indicators and economic analysis for on-farm irrigation decision: a case study of a super high density olive tree orchard. Agric. Water Manag. 237, 106074 https://doi.org/10.1016/J.AGWAT.2020.106074.

Ferreira, A., Rolim, J., Paredes, P., Cameira, M. do R., Cameira, M.R., 2022. Assessing Spatio-Temporal Dynamics of Deep Percolation Using Crop Evapotranspiration Derived from Earth Observations through Google Earth Engine. Water 14, 2324. https://doi.org/10.3390/W14152324.

Ferreira, A., Rolim, J., Paredes, P., Cameira, M.R., 2023. Methodologies for water accounting at the collective irrigation system scale aiming at optimizing water productivity. Agronomy 13, 1938. https://doi.org/10.3390/AGRONOMY13071938.
Fink, A., 2003. How to Sample in Surveys. SAGE Publications.
Fonseca, A., Andrade, C., Santos, J.A., 2022. Agricultural Water Security under Climate Change in the Iberian Peninsula. Water (Switz.) 14 (5), 768. https://doi.org/10.3390/w14050768.
Fraga, H., de Cortázar Atauri, I.G., Santos, J.A., 2018. Viticultural irrigation demands under climate change scenarios in Portugal. Agric. Water Manag. 196, 66–74. https://doi.org/10.1016/j.agwat.2017.10.023.
Fraga, H., Pinto, J.G., Santos, J.A., 2020a. Olive tree irrigation as a climate change adaptation measure in Alentejo, Portugal. Agric. Water Manag. 237, 106193 https://doi.org/10.1016/J.AGWAT.2020.106193.
Fraga, H., Pinto, J.G., Viola, F., Santos, J.A., 2020b. Climate change projections for olive yields in the Mediterranean Basin. Int. J. Climatol. 40 769–781. https://doi.org/10.1002/JOC.6237.
Fragoso, R., Noéme, C., 2018. Economic effects of climate change on the Mediterranean's irrigated agriculture. Sustain. Account. Manag. Policy J. 9 (2), 118–138. ⟨http://hdl.handle.net/10174/24551⟩.
García-Mollá, M., Ortega-Reig, M., Boelens, R., Sanchis-Ibor, C., 2020. Hybridizing the commons. Privatizing and outsourcing collective irrigation management after technological change in Spain. World Dev. 132, 104983 https://doi.org/10.1016/J.WORLDDEV.2020.104983.
GEE. (2022). Platform Google Earth engine. Retrieved May 15, 2022, from ⟨https://code.earthengine.google.com/⟩(Accessed May 15, 2023).
Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett. 33, L08707. https://doi.org/10.1029/2006GL025734.
Gomes, M.P., Santos, L., Pinho, J.L., Do Carmo, J.S.A., 2018. Hazard assessment of storm events for the portuguese northern coast. Geosciences 8 (5), 178. https://doi.org/10.3390/geosciences8050178.
Grassini, P., Yang, H., Irmak, S., Thorburn, J., Burr, C., Cassman, K.G., 2011. High-yield irrigated maize in the Western US Corn Belt: II. Irrigation management and crop water productivity. Field Crops Res. 120 (1), 133–141. https://doi.org/10.1016/j.fcr.2010.09.013.
Greaves, G.E., Wang, Y.M., 2017. Yield response, water productivity, and seasonal water production functions for maize under deficit irrigation water management in southern Taiwan. Plant Production Science 20 (4), 353–365.
Guimarães, H., Esgalhado, C., Ferraz-de-Oliveira, I., Pinto-Correia, T., 2019. When does innovation become custom? A case study of the montado, Southern Portugal. Open Agric. 4 (1), 144–158. https://doi.org/10.1515/opag-2019-0014.
Hall, A., Rasheed, S., V, Clark, N., Yoganand, B., 2003. From measuring impact to learning institutional lessons: An innovation systems perspective on improving the management of international agricultural research. Agric. Syst. 78 (2), 213–241. https://doi.org/10.1016/S0308-521X(03)00127-6.
Ibba, K., Er-Raki, S., Kassout, J., Bouizgaren, A., Hadria, R., 2024. Optimizing water productivity for Menara olive cultivar: Exploring the impact of regulated and sustained deficit irrigation strategies in Morocco. E3S Web Conf. 489, 08002. https://doi.org/10.1051/e3sconf/202448908002.
IDAE, 2008. Protocolo de Auditoria Energética en Comunidades de Regantes. Ministerio de Industria. Turismo y Comercio, Madrid, Spain (in Spanish).
IFAP, 2022. Instituto de Financiamento Agricola ⟨http://www.ifap.pt/isip/ows/⟩ (assessed on April 2022).
INE, 2024. Agricultural dabatase. Instituto Nacional de Estatística (In Portuguese) (assessed on March 2024).
Jones, N.A., Ross, H., Lynam, T., Perez, Pascal, Leitch, A., 2011. Mental models: An interdisciplinary synthesis of theory and methods. Ecol. Soc. 16 (1), 46. ⟨http://www.ecologyandsociety.org/vol16/iss1/art46/⟩.
Joshi, A., Kale, S., Chandel, S., Pal, D., 2015. Likert Scale: Explored and Explained. Br. J. Appl. Sci. Technol. 7, 396–403. https://doi.org/10.9734/BJAST/2015/14975.
Kibret, E.A., Abera, A., Ayele, W.T., Alemie, N.A., 2021. Performance evaluation of surface irrigation system in the case of Dirma small-scale irrigation scheme at Kalu Woreda, Northern Ethiopia. Water Conserv Sci. Eng. 6, 263–274. https://doi.org/10.1007/s41101-021-00119-8.
Kidd, A.D., Lamers, J.P.A., Ficarelli, P.P., Hoffmann, V., 2000. Privatising agricultural extension: caveat emptor. J. Rural Stud. 16 (1), 95–102. https://doi.org/10.1016/S0743-0167(99)00040-6.
Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agric. Syst. 103 (6), 390–400. https://doi.org/10.1016/j.agsy.2010.03.012.
Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32 (1), 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003.
Koech, R., Haase, M., Grima, B., Taylor, B., 2021. Barriers and measures to improve adoption of irrigation technologies: A case study from the Bundaberg region in Queensland, Australia. Irrig., Drain. 70 (4), 909–923. https://doi.org/10.1002/ird.2583.
Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World Map of the Köppen-Geiger climate classification updated. Meteorol. Z. 15, 259–263.
Kourgialas, N.N., Psarras, G., Morianou, G., Pisinaras, V., Koubouris, G., Digalaki, N., Malliaraki, S., Aggelaki, K., Motakis, G., Arampatzis, G., 2022. Good Agricultural Practices Related to Water and Soil as a Means of Adaptation of Mediterranean Olive Growing to Extreme Climate-Water Conditions. Sustain. (Switz.) *14* (20). https://doi.org/10.3390/su142013673.
Labarthe, P., Laurent, C., 2013. Privatization of agricultural extension services inthe EU: Towards a lack of adequate knowledge for small-scale farms? Food Policy 38 (1)), 240–252. https://doi.org/10.1016/j.foodpol.2012.10.005.
Läpple, D., Renwick, A., Thorne, F., 2015. Measuring and understanding the drivers of agricultural innovation: Evidence from Ireland. Food Policy 51, 1–8. https://doi.org/10.1016/j.foodpol.2014.11.003.
Lasage, R., Muis, S., Sardella, C.S., Van Drunen, M.A., Verburg, P.H., Aerts, J.C., 2015. A Stepwise, participatory approach to design and implement community based adaptation to drought in the Peruvian Andes. Sustainability 7 (2), 1742–1773. https://doi.org/10.3390/su7021742.
Lee, S.M., Trimi, S., 2018. Innovation for creating a smart future. J. Innov. Knowl. 3, 1–8. https://doi.org/10.1016/j.jik.2016.11.001.
Lima, D.C., Bento, V.A., Lemos, G., Nogueira, M., Soares, P.M., 2023. A multi-variable constrained ensemble of regional climate projections under multi-scenarios for Portugal–Part II: Sectoral climate indices. Clim. Serv. 30, 100377 https://doi.org/10.1016/j.cliser.2023.100351.
Lima, F.A., Córcoles, J.I., Tarjuelo, J.M., Martínez-Romero, A., 2019. Model for management of an on-demand irrigation network based on irrigation scheduling of crops to minimize energy use (Part II): Financial impact of regulated deficit irrigation. Agric. Water Manag. 215, 44–54. https://doi.org/10.1016/j.agwat.2019.01.006.
Lionello, P., Scarascia, L., 2018. The relation between climate change in the Mediterranean region and global warming. Reg. Environ. Change 18, 1481–1493. https://doi.org/10.1007/s10113-018-1290-1.
Lorite, I.J., García-Vila, M., Carmona, M.A., Santos, C., Soriano, M.A., 2012. Assessment of the irrigation advisory services' recommendations and farmers' irrigation management: a Case Study in Southern Spain. Water Resour. Manag. 26 (8), 2397–2419. https://doi.org/10.1007/s11269-012-0023-3.
Lorite, I.J., Mateos, L., Fereres, E., 2004. Evaluating irrigation performance in a Mediterranean environment: II. Variability among crops and farmers. Irrig. Sci. 23, 85–92. https://doi.org/10.1007/s00271-004-0096-8.
Lozano, D., Mateos, L., 2008. Usefulness and limitations of decision support systems for improving irrigation scheme management. Agric. Water Manag.. *95* (4), 409–418. https://doi.org/10.1016/j.agwat.2007.11.003.
Marra, F.P., Marino, G., Marchese, A., Caruso, T., 2016. Effects of different irrigation regimes on a super-high-density olive grove cv. "Arbequina": vegetative growth, productivity and polyphenol content of the oil. Irrig. Sci.. 34 (4), 313–325. https://doi.org/10.1007/s00271-016-0505-9.
Martey, E., Etwire, P.M., Adombilla, R., Abebrese, S.O., 2023. Information constraint and farmers' willingness to pay for an irrigation scheduling tool. Agricultural Water Management 276, 108043. https://doi.org/10.1016/j.agwat.2022.108043.
Mateos, L., Lozano, D., Baghil, A.B.O., Diallo, O.A., Gómez-Macpherson, H., Comas, J., Connor, D., 2010. Irrigation performance before and after rehabilitation of a representative, small irrigation scheme besides the Senegal River, Mauritania. Agric. Water Manag.. *97* (6), 901–909. https://doi.org/10.1016/j.agwat.2010.01.021.
Mohammed, A.T., Irmak, S., 2022. Maize response to coupled irrigation and nitrogen fertilization under center pivot, subsurface drip and surface (furrow) irrigation: soil-water dynamics and crop evapotranspiration. Agric. Water Manag 267, 107634. https://doi.org/10.1016/J.AGWAT.2022.107634.
Molle, F., Berkoff, J., 2007. Water pricing in irrigation: mapping the debate in the light of experience. In: Molle, F., Berkoff, J. (Eds.), Irrigation Water Pricing: The Gap between Theory and Practice. Comprehensive Assessment of Water Management in Agriculture. CABI, Wallingford, CT, pp. 21–93. ⟨https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-09/010045237.pdf⟩. Chapter 2.
Moreno, M.A., Ortega, J.F., Córcoles, J.I., Martínez, A., Tarjuelo, J.M., 2010. Energy analysis of irrigation delivery systems: monitoring and evaluation of proposed measures for improving energy efficiency. Irrig. Sci.. *28* (5), 445–460. https://doi.org/10.1007/s00271-010-0206-8.
Moreno-Pérez, M.F., Roldán-Cañas, J., 2013. Assessment of irrigation water management in the Genil-Cabra (Córdoba, Spain) irrigation district using irrigation indicators. Agric. Water Manag. 120 (1)), 98–106. https://doi.org/10.1016/j.agwat.2012.06.020.
Morgan, David L., 1996. Focus Groups. Annu. Rev. Sociol. 22, 129–152. https://doi.org/10.1146/annurev.soc.22.1.129.
Norton, G.W., Alwang, J., 2020. Changes in agricultural extension and implications for farmer adoption of new practices. Appl. Econ. Perspect. Policy 42 (1), 8–20. https://doi.org/10.1002/aepp.13008.
Nunes, J.P., Jacinto, R., Keizer, J.J., 2017. Combined impacts of climate and socio-economic scenarios on irrigation water availability for a dry Mediterranean reservoir. Sci. Total Environ. 584-585, 219–233. https://doi.org/10.1016/j.scitotenv.2017.01.131.
OECD/Eurostat, 2005. Oslo Manual, Guidelines for Collecting and Interpreting Innovation Data, Third edition, OECD, 164 p. ⟨https://doi.org/10.1787/9789264013100-en⟩.
Oliveira, M.D.F., Gomes da Silva, F., Ferreira, S., Teixeira, M., Damásio, H., Dinis Ferreira, A., Gonçalves, J.M., 2019. Innovations in sustainable agriculture: case study of Lis Valley irrigation district, Portugal. Sustainability 11 (2), 331.
Paredes, P., Rodrigues, G.C., Alves, I., Pereira, L.S., 2014. Partitioning evapotranspiration, yield prediction and economic returns of maize under various irrigation management strategies. Agric. Water Manag. *135*, 27–39. https://doi.org/10.1016/j.agwat.2013.12.010.
Paulo, A.A., Rosa, R.D., Pereira, L.S., 2012. Climate trends and behaviour of drought indices based on precipitation and evapotranspiration in Portugal. Nat. Hazards Earth Syst. Sci. 12, 1481–1491. https://doi.org/10.5194/nhess-12-1481-2012.
Pereira, L.S., Cordery, I., Iacovides, I., 2012. Improved indicators of water use performance and productivity for sustainable water conservation and saving. Agric. Water Manag. 108, 39–51. https://doi.org/10.1016/j.agwat.2011.08.022.
Pereira, L.S., Paredes, P., Hunsaker, D.J., López-Urrea, R., Shad, Z.M., 2021. Standard single and basal crop coefficients for field crops. Updates and advances to the FAO56

crop water requirements method. Agric. Water Manag. 243, 106466 https://doi.org/10.1016/j.agwat.2020.106466.
Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D., Baumgart-Getz, A., 2008. Determinants of agricultural BMP adoption: evidence from the literature. J. Soil Water Conserv. 63 (5), 300–311. DOI:10.2489/jswc.63.5.300.
Pronti, A., Berbel, J., 2023. The impact of volumetric water tariffs in irrigated agriculture in Northern Italy. Environ. Impact Assess. Rev. 98, 106922 https://doi.org/10.1016/j.eiar.2022.106922.
Ramos, A.M., Trigo, R.M., Santo, F.E., 2011. Evolution of extreme temperatures over Portugal: recent changes and future scenarios. Clim. Res. 48 (2-3), 177–192. DOI: https://doi.org/10.3354/cr00934.
Reason, P., Bradbury, H. (Eds.), 2008. Handbook of Action Research: Participative Inquiry and Practice, 2nd edition. Sage, London, p. 720. ⟨https://ikhsanaira.files.wordpress.com/2016/09/action-research-participative-inquiry-and-practice-reasonbradburry.pdf⟩.
Reimer, A.P., Weinkauf, D.K., Prokopy, L.S., 2012. The influence of perceptions of practice characteristics: an examination of agricultural best management practice adoption in two Indiana watersheds. J. Rural Stud. 28 (1), 118–128. https://doi.org/10.1016/j.jrurstud.2011.09.005.
Renard, K.G., Foster, G.A., Weesies, D.K., McCool, Yoder, D.C., 1997. Predicting Soil Erosion by Water: A Guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Research Service, United States Government Printing, Washington, DC, USA, p. 384. ⟨https://www.ars.usda.gov/arsuserfiles/64080530/rusle/ah_703.pdf⟩.
Ritchie, J., Lewis, J., 2003. Qualitative Research Practice - A Guide for Social Science Students and Researchers. SAGE Publications, London.
Rodrigues, G.C., 2022. Irrigated agricultural systems in the Lucefecit collective irrigation system. Energy and water uses efficiencies. Master's dissertations, Instituto Superior de Agronomia, University of Lisbon (in Portuguese).
Rodrigues, G.C., Carvalho, S., Paredes, P., Silva, F.G., Pereira, L.S., 2010. Relating energy performance and water productivity of sprinkler irrigated maize, wheat and sunflower under limited water availability. Biosyst. Eng. *106* (2), 195–204. https://doi.org/10.1016/j.biosystemseng.2010.03.011.
Rodríguez Díaz, J.A., Camacho Poyato, E., Blanco Pérez, M., 2011. Evaluation of water and energy use in pressurized irrigation networks in Southern Spain. J. Irrig. Drain. Eng. *137* (10), 644–650. https://doi.org/10.1061/(asce)ir.1943-4774.0000338.
Rodríguez Díaz, J.A., Camacho Poyato, E., López Luque, R., Pérez Urrestarazu, L., 2008. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: An application in spain. Agric. Syst. *96* (1–3), 250–259. https://doi.org/10.1016/j.agsy.2007.07.010.
Rolim, J., Teixeira, J.L., Catalão, J., Shahidian, S., 2017. The impacts of climate change on irrigated agriculture in Southern Portugal. Irrig. Drain. 66 (1), 3–18. https://doi.org/10.1002/ird.1996.
Saadi, S., Todorovic, M., Tanasijevic, L., Pereira, L.S., Pizzigalli, C., Lionello, P., 2015. Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. Agric. Water Manag. 147, 103–115.
Salgado, R., Salvatierra, J.I., Mitre, C., Prieto Garra, D., Angella, G.A., Arriaza, M., Mateos, L., 2021. Irrigation management transfer: The experience of the Río Dulce Irrigation Scheme, Argentina. Irrig. Drain. 70 (4), 845–860. DOI: 10.1002/ird.2572.
Salvador, R., Martínez-Cob, A., Cavero, J., Playán, E., 2011. Seasonal on-farm irrigation performance in the Ebro basin (Spain): Crops and irrigation systems. Agric. Water Manag.. *98* (4), 577–587. https://doi.org/10.1016/j.agwat.2010.10.003.
Santos, F.L., 2018. Olive water use, crop coefficient, yield, and water productivity under two deficit irrigation strategies. Agronomy 8 (6), 1–17. https://doi.org/10.3390/agronomy8060089.
Schut, M., van Paassen, A., Leeuwis, C., Klerkx, L., 2013. Towards dynamic research configurations. A framework for reflection on the contribution of research to policy and innovation processes. Sci. Public Policy 41 (2), 207–218. https://doi.org/10.1093/scipol/sct048.
Seaden, G., Manseau, A., 2001. Public policy and construction innovation. Build. Res. Inf. 29 (3), 182–196. DOI: 10.1080/09613210010027701.
Segovia-Cardozo, D.A., Rodríguez-Sinobas, L., Zubelzu, 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. Agric. Water Manag.. *212* (August 2018)), 241–251. https://doi.org/10.1016/j.agwat.2018.08.042.
Singh, S., Aggarwal, Y., 2022. In search of a consensus definition of innovation: a qualitative synthesis of 208 definitions using grounded theory approach. Innov. Eur. J. Soc. Sci. Res. 35 (2), 177–195. https://doi.org/10.1080/13511610.2021.192552.
Smit, B., Skinner, M.W., 2002. Adaptation options in agriculture to climate change: a typology. Mitig. Adapt. Strateg. Glob. Chang. 7, 85–114. https://doi.org/10.1023/A:1015862228270.
Direção-Geral. De. Agric. e Desenvolv. Rural DGADR, 2022. ⟨https://www.dgadr.gov.pt/⟩ (accessed 11 March 24).
SNIAmb, 2022. Sistema Nacional de Informação de Ambiente, https://sniamb.apambiente.pt/ (accessed 12 May 2022).
Soto-García, M., Martínez-Alvarez, V., García-Bastida, P.A., Alcon, F., Martin-Gorriz, B., 2013. Effect of water scarcity and modernisation on the performance of irrigation districts in south-eastern Spain. Agric. Water Manag *124*, 11–19. https://doi.org/10.1016/j.agwat.2013.03.019.
Souissi, A., Chebil, A., Mtimet, N., Thabet, C., 2019. Virtual water flows and water value in Tunisia: the case of wheat and olive. Arab J. Geosci. 12, 1–10. https://doi.org/10.1007/s12517-019-4589-4.
Sutherland, L.A., Madureira, L., Dirimanova, V., Bogusz, M., Kania, J., Vinohradnik, K., Creaney, R., Duckett, T.K., Knierim, A., 2017. New knowledge networks of small-scale farmers in Europe's periphery. Land Use Policy 63, 428–439. https://doi.org/10.1016/j.landusepol.2017.01.028.
Tadayon, M.S., Hosseini, S.M., 2023. Effect of irrigation regimes and foliar nutrition on flower development and water productivity of olive (Olea europaea L. cv.'Shengeh'). J. Plant Growth Regul. 42 (2), 735–747. https://doi.org/10.1007/s00344-022-10580.
Taylor, S.P., 2017. What Is Innovation? A study of the definitions, academic models and applicability of innovation to an example of social housing in England. Open J. Soc. Sci. 5, 128–146. ⟨http://www.scirp.org/journal/jss⟩.
Tushman, M.L., O'Reilly, C.A., 1997. Winning through Innovation: A Practical Guide to Leading Organizational Change and Renewal. Harvard Business School Press, Boston, MA.
Valverde, P., Serralheiro, R., de Carvalho, M., Maia, R., Oliveira, B., Ramos, V., 2015. Climate change impacts on irrigated agriculture in the Guadiana river basin (Portugal). Agric. Water Manag. 152, 17–30. https://doi.org/10.1016/j.agwat.2014.12.012.
Vollaro, M., Raggi, M., Viaggi, D., 2019. Innovation adoption and farm profitability: what role for research and information sources? Bio-Based Appl. Econ. 8 (2), 179–210. https://doi.org/10.13128/bae-8930.
Wongtragoon, U., Trisup, K., Suwanmaneepong, S., 2017. Evaluating the irrigation efficiency using Rapid Appraisal Process Technique (RAP) in a large-scale irrigation, case study: Mae Lao operation and maintenance project and Chiang Rai irrigation project. Thail. Int. J. Agric. Technol. 13 (7.2), 1821–1834. ⟨https://www.cabdirect.org/cabdirect/abstract/20183304177⟩.
WUA, 2022. Lucefecit Water users Assoc. Pers. Commun.
Yang, C., Fraga, H., van Ieperen, W., Santos, J.A., 2017. Assessment of irrigated maize yield response to climate change scenarios in Portugal". Agric. Water Manag. 184, 178–190. https://doi.org/10.1016/j.agwat.2017.02.004.
Yang, C., Fraga, H., van Ieperen, W., Trindade, H., Santos, J.A., 2019. Effects of climate change and adaptation options on winter wheat yield under rainfed Mediterranean conditions in southern Portugal. Clim. Change 154, 159–178. https://doi.org/10.1007/s10584-019-02419-4.
Yang, C., Fraga, H., van Ieperen, W., Santos, J.A., 2020. Assessing the impacts of recent-past climatic constraints on potential wheat yield and adaptation options under Mediterranean climate in southern Portugal. Agric. Syst. 182, 102844 https://doi.org/10.1016/j.agsy.2020.102844.
Zapata, N., Bahddou, S., Latorre, B., Playán, E., 2023. A simulation tool to optimize the management of modernized infrastructures in collective and on-farm irrigation systems. Agric. Water Manag. 284, 108337 https://doi.org/10.1016/j.agwat.2023.108337.
Zema, D.A., Filianoti, P., D'Agostino, D., Labate, A., Lucas-Borja, M.E., Nicotra, A., Zimbone, S.M., 2020. Analyzing the performances of water user associations to increase the irrigation sustainability: An application of multivariate statistics to a case study in Italy. Sustainability 12 (16). https://doi.org/10.3390/SU12166327.
Zema, D.A., Nicotra, A., Zimbone, S.M., 2018. Diagnosis and improvement of the collective Irrig, Drain. Services in water users' associations of Calabria (Southern Italy). Irrig., Drain. 67 (5), 629–644. https://doi.org/10.1002/ird.2276.
Zema, D.A., Nicotra, A., Tamburino, V., Zimbone, S.M., 2015. Performance Assessment of Collective Irrigation In Water Users' Associations of Calabria (Southern Italy). Irrig. Drain. 64 (3), 314–325. https://doi.org/10.1002/ird.1902.