The MEDWATERICE project: objectives and expected impacts

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Abstract

The MEDWATERICE project (https://www.medwaterice.org/), started in April 2019, explores the sustainability of innovative water-saving irrigation strategies to reduce rice water consumption and environmental impacts, and to extend rice cultivation outside of traditional paddy areas to satisfy the increasing rice demand in Mediterranean countries. Innovative irrigation methods and technologies were implemented in experimental pilot farms of each country involved in the project (EG, IT, TR, ES, PT; Work Package 2). Tested water-saving irrigation methods were tailored to local conditions using a participatory action research approach through the establishment of Stake-Holder Panels (SHPs). For each irrigation solution, innovative technologies and the most appropriate rice varieties and agronomic practices were implemented to minimize impacts on yield quantity and quality. Experimental activities were conducted in the pilot farms for at least two agricultural seasons in the period 2019-2021. A dataset including agro-climatic data, soil physic-chemical properties, groundwater depth and salinity, irrigation water inflow and outflow, irrigation water salinity, grain yield and quality was produced in all Case Studies (CSs) and stored in a common FAIR and OpenAIRE compliant repository (https://dataverse.UMIL.it/). For some CSs, also GHGs emissions and nutrient and pesticides losses in surface waters and groundwater were measured. Datasets were used to assess water saving, yield and product safety and other environmental impacts for the wet seeding and continuous flooding (WFL, considered as the 'reference' irrigation in all CSs) and for the alternative irrigation solutions implemented, which are: alternate wetting and drying (AWD); dry seeding and delayed flooding (DFL), reduction in irrigation inflow/outflow (WIR), hybrid irrigation (HYBRID), multi-nozzle sprinkler irrigation (SPRINKLER), surface drip irrigation (DRIP), and subsurface drip irrigation (SDI). Moreover, the reuse of agricultural water drainage and waste water civil effluents, as well as the implementation of automated gates for optimising irrigation management in case of continuous flooding, were tested in specific experiments. A set of indicators for the quantitative assessment of the environmental and economic sustainability of the irrigation options were defined and applied to the datasets collected in the agricultural seasons 2019-2021. In addition, the social acceptability of the proposed water saving techniques was investigated through the Technology Acceptance Model (TAM) through questionnaires compiled by rice growers of the pilot areas, to explore barriers to the adoption and identify solutions to overcome them (Work Package 5). A particular focus is dedicated to the Egyptian situation, where rice is the second staple food after wheat (Work Package 4). Results achieved at the pilot farm scale are being extrapolated to the irrigation district level through agro-hydrological models of different complexity (heuristic, conceptual, physically-based), to support water management decisions and policies (Work Package 3). Results of the project are being disseminated through different channels (Work Package 6).

Keywords: Water-saving, Irrigation, Sustainability, Rice, Production, Mediterranean basin

1. Introduction

Rice is the world's most important food crop, since it is a staple food for more than half of the world's population and the world demand for rice is expected to increase by approximately 24-28% over the next 20-30 years (Nguyen and Ferrero, 2012; Alexandratos and Bruinsma, 2012). Rice is cultivated over about 1,300,000 ha in Mediterranean countries (FAOSTAT, 2019). Although in the Mediterranean region it is concentrated in specific areas, rice production has a great socio-economic and environmental importance due to the fact that rice is often a crucial product for internal consumption and export, and its cultivation uses important water volumes and has a strong link with biodiversity maintenance (many important rice areas are in river deltas, estuaries or coastal wetlands or, however, part of protected ecosystems such as the EU Natura-2000 network).

The most important rice-producing countries are Italy and Spain in Europe (72% of the EU production; 345,000 ha), and Egypt and Turkey among the non-EU countries (789,000 ha). Average crop yields range from 10 t ha^{-1} in Egypt (highest yield of rice worldwide, together with Australia and USA) to 6-7 t ha^{-1} in the European countries. Per-capita annual rice consumption ranges from 6–18 kg $person^{-1}$ $year^{-1}$ in southern Europe to 50 kg $person^{-1}$ $year^{-1}$ in Egypt. EU, Turkey and Egypt self-sufficiency rates are, respectively, 70%, 80% and almost 100%, but in all the countries human consumption is steadily increasing (World Atlas, 2016). In Egypt, rice is the most important staple food after wheat, and it is the second major foreign exchange-earning agricultural commodity.

Traditionally, rice is grown in paddies flooded from before sowing to before harvest, thus it requires much more irrigation water than non-ponded crops (Cesari et al., 2016). Under flooded conditions, significant amounts of nutrients may be lost by leaching and runoff, with important implications on water quality (Katoh et al., 2004). Like other important cereals, rice requires a great amount of chemicals, particularly fertilizers and pesticides, which may cause water pollution in a peculiar environment like paddy. Water management has been recognized as one of the most important factors that affect greenhouse gas emissions from paddy fields; in particular, rice paddies are one of the most important sources of atmospheric methane (CH_4), producing about 5-20% of the total emission from anthropogenic sources (USEPA, 2006) and approximately 30% of the global agriculture CH_4 emissions. Moreover, many important rice growing areas in the Mediterranean region are in environments where soil salinity is an important factor constraining production.

Mediterranean rice agro-ecosystems are nowadays facing numerous problems, such as the need to harmonize irrigation demand with the availability of the resource, the protection of the environment, the need to ensure an adequate income for rice producers, the impossibility of being introduced in agricultural areas characterized by a limited water availability despite the increase of rice consumption in the Mediterranean basin, and the lack of specific studies conducted in Mediterranean countries addressing environmental and socio-economic peculiarities of these areas. Due to these issues, the introduction of water management practices alternative to the continuous flooding is imperative to enhance water use efficiency and safeguard environmental quality in Mediterranean rice agro-ecosystems. However, these practices must be tested and adapted to country-specific conditions.

In the context of the MEDWATERICE project (https://www.medwaterice.org), seven case studies (CSs) were implemented in experimental pilot farms of the countries involved (EG, IT, TR, ES, PT). Tested water-saving irrigation strategies were tailored to local conditions using a participatory action research approach through the establishment of Stake-Holder Panels (SHPs). Data collected at the farm scale were up-scaled at the irrigation district level to support management and policy-making decisions. Indicators for the quantitative assessment of environmental, economic, and social sustainability of the irrigation options were defined and computed for each rice irrigation strategy for at least two agricultural seasons in the period 2019-2021.

2. Materials and methods

The general structure of the MEDWATERICE project is illustrated in Figure 1.

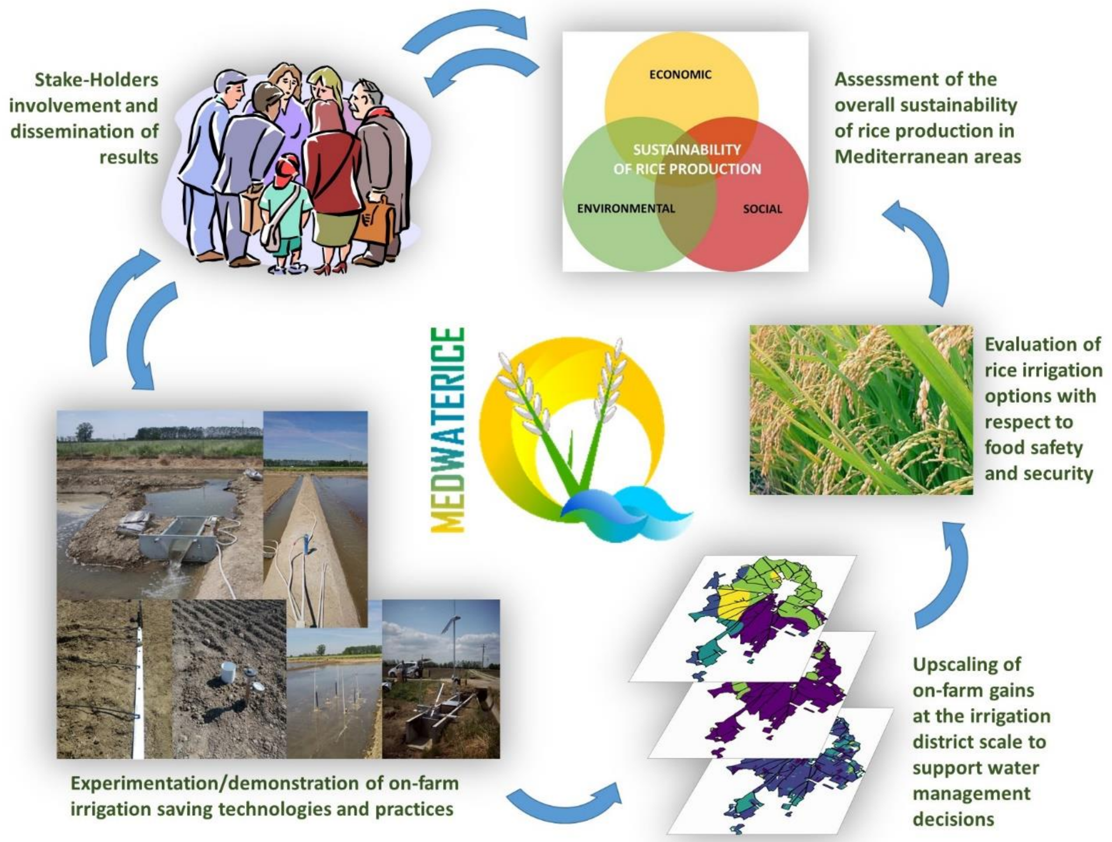

Figure 1: General structure of the project and main activities

Innovative irrigation methods and technologies were implemented in experimental pilot farms of each country involved in the project (EG, IT, TR, ES, PT; Work Package 2). For each irrigation solution, innovative technologies and the most appropriate rice varieties and agronomic practices were implemented to minimize impacts on yield quantity and quality.

The irrigation strategies experimented in the MEDWATERICE Case Studies (CSs) during the agricultural seasons 2019, 2020, and 2021, are illustrated in detail in Table 1.

Table 1: Irrigation strategies experimented in the MEDWATERICE Case Studies (CSs) during the agricultural seasons 2019, 2020 and 2021

Country and location	CS No	2019	2020	2021
Italy (Lomellina area, Pavia)	**1**	- Wet seeding and traditional flooding (pilot farm 1; subplots with 3 nitrogen treatments, and subplots untreated respectively with fungicides and herbicides are moreover included in the experiment) - Dry seeding and delayed flooding (pilot farm 1; subplots with 3	SAME AS IN 2019	- Dry seeding and traditional flooding implementing automated gates (pilot farm 2)

		nitrogen treatments, and subplots untreated respectively with fungicides and herbicides are moreover included in the experiment) - Wet seeding and alternate wetting and drying (pilot farm 1; subplots with 3 nitrogen treatments, and subplots untreated respectively with fungicides and herbicides are moreover included in the experiment)		
Spain (Baix Ter area, Pals, Girona)	**2**	- Wet seeding and traditional flooding (pilot farm 1) - Subsurface drip irrigation (pilot farm 2)	SAME AS IN 2019 + - Dry seeding and delayed flooding (pilot farm 1)	SAME AS IN 2019 + - Dry seeding and delayed flooding (pilot farm 1)
Spain (Guadalquivir marches, Seville)	**3**	- Wet seeding and traditional flooding (pilot farm 1) - Wet seeding and traditional flooding with a 15%-30% reduction of input water along the whole cycle with longer dry periods (considering the salinity level) (pilot farm 1) - Wet seeding and traditional flooding with a 15%-30% reduction of input water (considering the salinity level) along the whole cycle (pilot farm 1) - Wet seeding and traditional flooding with a 15%-30% reduction of input water (considering the salinity level) from day 100 after sowing (pilot farm 1) - Surface drip irrigation (pilot farm 2)	SAME AS IN 2019 (except for: Wet seeding and traditional flooding with a 15%-30% reduction of input water (considering the salinity level) along the whole cycle (pilot farm 1)	Two water saving options approved by the SHP were continued during the 2021 season: - Wet seeding and traditional flooding with a 15%-30% reduction of input water along the whole cycle with longer dry periods (considering the salinity level) (pilot farm 1) - Wet seeding and traditional flooding with a 15%-30% reduction of input water (considering the salinity level) from day 100 after sowing (pilot farm 1)
Portugal, (Lower Mondego Valley, Coimbra)	**4**	- Wet seeding and traditional flooding (pilot farm 1) - Wet seeding and alternate wetting and drying (pilot farm 1). *The test was abandoned due to weeds and pests affecting yield.* - Wet seeding and traditional flooding (pilot farm 2) - Wet seeding and alternate wetting and drying (pilot farm 2) *Both tests were invalidated by the low representativeness of the soil type.*	SAME AS IN 2019 (but changing location of pilot farm 2).	SAME AS IN 2020
Portugal (Lis Valley, Leiria)	**5**	- Wet seeding and traditional flooding (pilot farm 1) - Wet seeding and alternate wetting and drying (pilot farm 1): *Test was not carried out.* - Surface Drip Irrigation (pilot farm1): *Test was not completed.* - Subsurface drip irrigation with conventional water (in pots) - Subsurface drip irrigation with civil wastewater (in pots)	SAME AS IN 2019 (but the Surface drip irrigation plot was moved from pilot farm1 to a pilot farm 2.	SAME AS IN 2020

Egypt (Nile Delta: East, North, West)	**6**	North Delta site: - Traditional flooding with high (fresh)and low (agricultural drainage) quality water (pilot farm 1; 2 cultivation methods and 6 varieties are moreover experimented in different plots) - Traditional flooding (pilot farm 2; 4 cultivation methods and 8 varieties are moreover experimented in different plots) East Delta site: - Traditional flooding (pilot farm 1; 3 cultivation methods and 5 varieties are moreover experimented in different plots) West Delta site: - Traditional flooding (pilot farm 1; 3 cultivation methods and 8 varieties are moreover experimented in different plots)	North Delta site: - Traditional flooding compared with hybrid irrigation method (pilot farm 1; 2 water qualities, 3 cultivation methods and 5 varieties are moreover experimented in different plots) East Delta site: - Traditional flooding (pilot farm 1; 3 cultivation methods and 5 varieties are moreover experimented in different plots) - Surface drip irrigation (pilot farm 1; 3 cultivation methods and 5 varieties are moreover experimented in different plots) - Hybrid irrigation (pilot farm 1; 3 cultivation methods and 5 varieties are moreover experimented in different plots) - Multi-nozzle irrigation (pilot farm 1; 3 cultivation methods and 5 varieties are moreover experimented in different plots) West Delta site: - Traditional flooding compared with hybrid irrigation method (pilot farm 1; 2 water qualities, 3 cultivation methods and 5 varieties are moreover experimented in different plots)	SAME AS IN 2020
Turkey (Bafra Valley)	**7**	- Wet transplanting and traditional flooding (pilot farm 1; 2 rice varieties experimented) - Wet transplanting and alternate wetting and drying – considering a 1st soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Wet transplanting and alternate wetting and drying – considering a 2nd soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Wet transplanting and alternate wetting and drying – considering a 3rd soil water content depletion	- Dry seeding and traditional flooding (pilot farm 1; 2 rice varieties experimented) - Dry seeding and alternate wetting and drying – considering a 1st soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Dry seeding and alternate wetting and drying – considering a 2nd soil water content depletion rate (pilot farm	Only two irrigation techniques were implemented to determine Green-House Gas emissions (CH4 and N2O) under two irrigation practices at the Bari farm: - Traditional flooding (pilot farm 1) - Alternate wetting and drying – considering the 3rd soil water content depletion rate (pilot farm 1)

		rate (pilot farm 1; 2 rice varieties experimented) - Wet transplanting and surface drip irrigation, considering a 1st soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Wet transplanting and surface drip irrigation, considering a 2nd soil water content depletion rate (pilot farm 1; 2 rice varieties experimented)	1; 2 rice varieties experimented) - Dry seeding and alternate wetting and drying – considering a 3rd soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Dry seeding and surface drip irrigation, considering a 1st soil water content depletion rate (pilot farm 1; 2 rice varieties experimented) - Dry seeding and surface drip irrigation, considering a 2nd soil water content depletion rate (pilot farm 1; 2 rice varieties experimented)	

In the pilot farms, many data were measured directly in the field, while others were the result of estimations carried out using simple models. With the objective to allow a comparison among results obtained in the different pilot farms, the MEDWATERICE participants collected a minimum common set of data (called 'minimum dataset') for each farm. The 'minimum dataset' was collected both for the traditional flooding irrigation ('reference' irrigation management) and for the experimented water-saving irrigation strategies. The 'minimum dataset' includes: agro-climatic data, soil physico-chemical properties, soil water status data, groundwater level and quality data, irrigation volumes and quality data, water balance components, crop development, yield and product quality. Datasets were collected in each CS for at least two agricultural seasons in the period 2019-2021. In some pilot farms, additional data were measured, such as those needed to compute the soil nutrient balance, the soil salt balance and other environmental impacts (e.g. water pollution due to the use of pesticides, greenhouse gas emissions); these results will allow a better investigation of specific environmental aspects involved in rice cropping.

Data collected during the lifetime of the project are being stored in a FAIR and OpenAIRE compliant repository called DATAVERSE (https://dataverse.unimi.it/) offered by UMIL (Università degli Studi di Milano - University of Milan), following the best practices and standards available. DATAVERSE is a repository software platform created by Harvard University to support universities and research institutions to facilitate the management and archiving of research data according to FAIR principles. After an embargo period of 2 years, data access will be 'opened' under a Creative Common (CC) licence.

A set of indicators for the quantitative assessment of the environmental and economic sustainability of the irrigation options were defined and applied to the datasets collected in the agricultural seasons 2019-2021. The social acceptability of the proposed water saving techniques was investigated through the Technology Acceptance Model (TAM) through questionnaires compiled by rice growers of the pilot areas, to explore barriers to the adoption and identify solutions to overcome them. A particular focus is dedicated to the Egyptian situation, where rice is the second staple food after wheat.

Results achieved at the pilot farm scale are being extrapolated to the irrigation district level through agro-hydrological models of different complexity (heuristic, conceptual, physically-based), to support water management decisions and policies.

3. Results

The main results obtained so far are listed below and will be illustrated during the MEDWATERICE workshop and in specific papers published in the workshop e-book.

- Identification, with the support of SHPs set up in each project rice area, of the most suitable irrigation solutions which were implemented in pilot farms alongside the traditional irrigation technique (continuous flooding). Experimental activities in the pilot farms were carried out at least for two years in the period between 2019-2021.
- Definition and collection of a 'common set of experimental data' both for the traditional flooding ('reference') and for the innovative irrigation management options in all the pilot farms for at least for two experimental years in the period between 2019-2021.
- Definition of a database structure to store data collected in the pilot farms, creation of a FAIR and OpenAIRE compliant repository (https://dataverse.UMIL.it/) where data collected from the experimental pilot farms during the agricultural seasons 2019-2021 were uploaded. This common repository, at the end of the project, will allow to benchmark data from different countries and different technologies and practices.
- Conduction of a literature review on the current irrigation technologies and practices in Egypt, and design and distribution of 300 questionnaires to rice farmers to investigate their practices.
- Conduction of a literature review on the existing methodologies to assess techno-economic, environmental and social sustainability of agricultural production, with a focus on rice systems (Gharsallah et al., 2021).
- Development of a novel indicator-based methodology to assess the overall sustainability of rice systems at the on-farm scale, and design of a questionnaire to collect data for the assessment. Application of the methodology to the MEDWATERICE pilot farms for at least two experimental years in the period between 2019- 2021. Data obtained at farm scale are being used for the district scale.
- Development of guidelines (in local languages) for the irrigation solutions tested in MEDWATERICE characterized by the higher technical/technological degree of readiness, and therefore judged to be suitable to be disseminated among farmers. For the same solutions, development of fact-sheet (in English) to support their international dissemination.
- Definition of a novel conceptual framework to upscale water use efficiencies and environmental impacts of traditional and innovative irrigation strategies at the irrigation basin scale. The framework is adaptable to the complexity, information availability and expertise of each area and is under implementation for each project CS.
- Organization of numerous SHs meetings and farm field days, more than 40 contributions to national and international seminars and congresses, 4 papers in scientific journals, and 4 articles in trade journals were produced so far. The final meeting will be held in Albacete, Spain on 5-7 September 2022 (https://crea.uclm.es/crea/SUPWASConference)
- Development of MEDWATERICE website (www.medwaterice.org) and update of its contents every 6 months. All the results and material produced are constantly uploaded to the website. The website will be maintained for a minimum of 3 years after the closure of the project, in order to guarantee a long-term impact of project results.

4. Conclusions

MEDWATERICE is successfully investigating the introduction of innovative water-saving irrigation techniques/technologies tailored to local conditions in the rice sector of the Mediterranean basin, assessing their overall sustainability (economic, environmental, and social) at the on-farm and irrigation district scales.

The most innovative achievements of the project, are: (1) introduction of participatory action research as an innovation strategy in the Mediterranean rice sector to explore the applicability of non-conventional irrigation-efficient methods tailored to local conditions; (2) production of a field-proved, ready-to-be-adopted set of water-saving techniques unique in the Mediterranean basin: first, because of the ground-breaking nature of some of them, and second, because the transnational research approach used confers them strength and robustness; preparation of fact-sheets for their dissemination and guidelines for their implementation; (3) use of state-of-the-art hydraulics, low cost sensors, and ICTs to set-up integrated multi-sensor system for the continuous monitoring of water dynamics in rice fields under different irrigation regimes; (4) development of a comprehensive multidisciplinary indicator-based tool to assess the overall sustainability (economic, environmental, and social) of rice systems at the on-farm and irrigation district scales; (5) building of a novel framework for computing effective water efficiency and productivity by up-scaling farm efficiency data to the irrigation district scale, in order to prevent fake or rebound effects of water saving measures; few studies in the literature deal with these complex phenomena in rice areas.

The project implemented several dissemination actions, including the preparation of fact-sheets and guidelines, and the involvement of the Stake-Holder Panels in each project step. The indicator system developed for the sustainability assessment, and the modelling framework to upscale water savings at the irrigation district scale, are novel tools that will be appropriately described in technical and scientific publications since they are expected to survive to the project and be available to the technical and scientific communities working in rice areas.

More in general, outcomes produced by MEDWATERICE are expected to inject tailored and updated knowledge to improve the sustainability of rice production in the Mediterranean countries, with a particular attention to the adoption of water-saving techniques.

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