Operationalizing the increase of water use efficiency and resilience in irrigation (OPERA)

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Acknowledgements

The authors would like to thank the EU and The Ministry of Economic Affairs (The Netherlands), CDTI (Spain), MINECO (Spain), ANR (France), MIUR (Italy), NCBR (Poland) and WRC (South Africa) for funding, in the frame of the collaborative international consortium OPERA financed under the ERA-NET Cofund WaterWorks2015 Call. This ERA-NET is an integral part of the 2016 Joint Activities developed by the Water Challenges for a Changing World Joint Programme Initiative (Water JPI).

April, 2020

Partner organisations

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OPERA

Introduction

Background
Extreme climatic events have negatively affected crop productivity in Europe and this is expected to further increase yield variability under climate change. Information is needed about when and where water shortage is to be expected. Recent decades provided large developments in sensors and models to analyse soil water dynamics. However there is a significant gap in applying the necessary combination of such techniques to predict upcoming water demands within a region over a time span of 10 to 15 days. The *Operationalizing the increase of water use efficiency and resilience in irrigation* (OPERA) project focussed on best possible combinations of information technologies to realize a practical transition towards an increased use of precision irrigation. The project was performed in the period 2017-2019.

Main objectives of the project
The objective of the project is to strengthen farmers' adaptation to climate change. A transdisciplinary approach is applied to identify jointly:
- How farmers and irrigation organizations can react more flexible to predicted variability in water amounts;
- Adequate combinations of soil and crop sensors, remote sensing, weather forecast and simulation models for better consideration of rainfall, evapotranspiration and soil moisture in irrigation scheduling;
- How to integrate experience in operationalizing precision irrigation from various climatic zones in Europe and South Africa to identify applicable service models for more robust decision making. On a larger scale, this information can be used to support water management decisions toward mitigation of drought effects.

Case study approach
A series of six case studies demanding increased water use efficiency and resilience were used to test transversal research lines:
a) The use of remote sensing at high resolution for water demand estimation;
b) The use of sensors & upscaling to improve knowledge on soil water content;
c) The use of (ensemble) weather forecast for decision making.

Stakeholder interactions were a central part of the project to identify current shortcomings, priorities for irrigation improvement, design field studies and share findings of the case study experiments.

Case study areas in France, Italy, Spain, Poland, The Netherlands and South Africa

Impact
The project contributes to optimal watering strategies and water saving. The short term impact will be the possibility to pick up elaborated combinations of ICT products to forecast agricultural water needs. The mid-term and long-term benefits will result from realizing a better advisory service in the agricultural sector under anticipation of climate variability and critical moments of water scarcity.

Readers' guide
This leaflet provides a brief overview of the project case studies, developed approaches and innovation, and a synthesis obtained from the pilot experiments. More detailed information can be found in the project deliverables (reports), available at:
http://opendata.waterjpi.eu/dataset/opera-operationalizing-the-increase-of-water-use-efficiency-and-resilience-in-irrigation

Case study areas

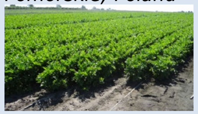
Current practices

In the majority of the case studies there are no decision support services used yet for irrigation scheduling. Farmers irrigate on the basis of experience, and use short term weather forecast achieved from local media.

Needs for improvement

User requirements for irrigation improvement were identified together with farmers, farmer associations, extension services and water management organizations from the pilot areas (interviews, workshops). There was a general interest for tools and advisory services for the prediction of water demand, with the main boundary conditions that tools need to be easy to use and available at low cost. In particular: mapping of actual water needs in irrigation; seasonal forecast to decide on the uptake rate of water reserve in order to secure the end of the crop season; and evaluation of the irrigation volume used to better control water use efficiency. Irrigation infrastructure and high investments costs were reported as current bottlenecks for improvement. Specific interest was shown in more detailed knowledge on the heterogeneity of the farm fields (as e.g. provided by remote sensing), and insight in cost/benefits.

Irrigation practices and current methods for irrigation demand

Volturno River basin in Campania, Italy 	Mostly sprinkler and micro irrigation, marginally furrow and surface irrigation. The most common method used for determining irrigation demand is based on farmers experience. In recent years, the main authority for land reclamation and irrigation of the study area is introducing a system based on the use of remote sensing to determine crops water needs (IRRISAT).
Crau area and Entrechaux (Ouvèze river basin), France 	Crau area: flooding irrigation (grasslands); drip irrigation (orchards); marginally sprinkling techniques; Entrechaux area: drip irrigation, micro sprinkler, marginally flooding or sprinkler. Irrigation needs are determined based on: Crop monitoring from March to September (Entrechaux), Weather services (forecast); Technical advice given by the agricultural chamber; CIRAME agrometeorological service with free advice for farmers and sensors (water mark, plant organ sensors) in a very few cases.
Andalusia, Spain 	Mostly drip irrigation, some surface or gravity irrigation. Farmers use weather forecast to determining irrigation needs and irrigation scheduling (private and/or public).
Kujawsko-Pomorskie, Poland 	Sprinkler and micro irrigation; subsurface irrigation on permanent grasslands. There is no decision support service for irrigation to predict term and doses for irrigation. Currently irrigation by farmers is based on commonly available weather forecast and farmer appreciation. For horticulture, a support system is available (Internet Platform Decision Support Irrigation, InHort).
The Netherlands 	Mainly sprinklers Most farmers take decisions based on the actual precipitation and the precipitation forecast. They don't have specific service providers and contracts, but follow the general media. Also they follow the behaviour of peer farmers. In greenhouse horticulture the use of sensors is widespread. Some frontrunner farmers use sensors and drones in order to measure and determine the moisture in the different parts of their production fields.
Western Cape province, South Africa 	Mostly drip irrigation followed by micro irrigation. Marginally: surface, sprinkler and sub-surface irrigation. Irrigation demand is based on experience (over generations), as well as knowledge of the farm, and particularly soils, are the most important factors behind setting an irrigation schedule for farms. The most common approach to scheduling in the area is checking probes daily, checking plants daily and digging soil profiles every now and then.

Developed approaches and innovation

Bringing advances from remote sensing, soil moisture monitoring, plant responses to water stress and forecasting rapidly towards implementation is key for the OPERA project. The project identified best possible combinations of information technologies to anticipate climate variability, to allow better consideration of rainfall, evapotranspiration and soil moisture in irrigation scheduling. Six methods were developed and implemented in the pilot areas (case studies):

- Agro-climatic and remote sensing-based indices, implemented for olive trees in Spain. The aim is to improve their characterisation and propose combinations of indices to improve irrigation recommendations.

- Plant-based irrigation method, implemented for olive trees in Spain. Irrigation needs are assessed using stomata conductance modelling which considers plant control of the transpiration.
- Soil crop modelling with ensemble weather forecast developed, implemented for field crop (potatoes) in the Netherlands. It is based on the use of a soil-crop model and ensemble weather forecast to provide soil moisture forecast and associated uncertainties.
- Soil water balance modelling combined with meteorological forecast to estimate soil moisture and irrigation needs, implemented for field crops (leaf parsley, celery and sugar beet) in Poland.
- Combining remote sensing and crop modelling implemented for field crops (tomato, corn) in Italy. The method intends to improve the current IRRISAT tool, already operated for commercial application, by adding an assessment of soil moisture using the Aquacrop Model and meteorological forecast to address uncertainties on the forecasts.
- Irrigation requirements at the territory level method based on crop modelling and remote sensing, implemented for a large variety of irrigated crops (grass, orchard, gardening, field crop, vineyard, olive trees) in France. The method aims at mapping actual irrigation water needs at the level of an irrigated sector.

Currently decisions in irrigation are based on experience, current status of the crop and sometimes soil moisture content and perhaps a farmer's interpretation of the weather forecast as presented in the media. Innovations mainly concern combining techniques for the estimation of crop water needs for optimal irrigation and a good distribution of water resources at the scale of a territory (irrigated sector, catchment area) in shortage conditions:

- Use of in situ sensors (soil sensors, plant sensors) to monitor vegetation status and development of upscaling strategies to account for heterogeneities at the field, the farm and the region (county) scale using models, remote sensing and soil texture maps.
- Coupling remote sensing data and models. Use of high-resolution satellite images (Sentinel-2 and Landsat 8) with a crop or soil-crop model (data assimilation, model input, model calibration) to provide spatial soil water content, plant requirements and assess the quality of irrigation implementation.
- Implementation of ensemble weather forecast in soil-crop models and uncertainty assessments.

Both the application of a full transdisciplinary process and the advance processing of high resolution Sentinel information are a breakthrough, which is expected to contribute to innovative services in irrigation. The reduction in sensor costs and the progress made in connecting these sensors to other information (e.g., models) could support new innovations in the future. In addition, the exhaustive spatial coverage and free access to satellite images offer guarantees for the development of operational services.

Synthesis pilot experiments

Use of sensors

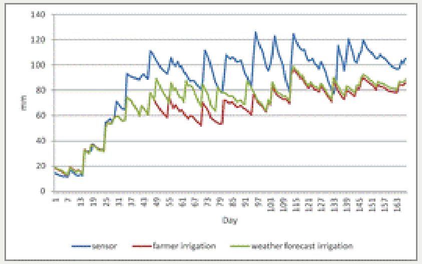
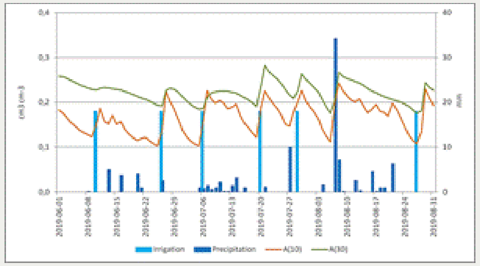
All case studies used local weather stations to estimate reference evapotranspiration, in some cases additional rain gauges were used. Various sites applied soil water content sensors and soil profile probes to monitor soil moisture in the root zone. In Spain specific plant water sensors (sap flow sensors for stomatal conductance estimation and turgor-related probes) were used.

Use of sensors

Andalusia, Spain	Soil water content sensors; Plant water sensors: sap flow sensors, turgor-related probes.
Kujawsko-Pomorskie, Poland	Soil water content sensors and profile probes in 10 cm layer of 50 cm profile; data logger, central database, automatically downloaded to user computer; additional manual measurements: LAI and soil water content.
The Netherlands	Soil water content sensors at 10, 30 cm depth (double sensors for each layer); local rain gauge; data logger, central database, automatically downloaded to user computer.
Western Cape, South Africa	Soil probes for irrigation scheduling.
All sites	Local weather stations.

Soil water content sensors were installed at different depths within the root zone and connected to data loggers with data transmission. Measured time-courses of water content were compared to model predictions. Irrigation demand estimation using soil moisture sensors requires calibration effort and sampling before using first time in the field. To install water content sensors, one needs to select the representative points for the entire field, especially in fields with heterogeneous soils. It is recommended to calibrate sensors when installing them and to recognize indigenous soils hydraulic properties.

Data from Leaf Area Index (LAI) sensors, as reference of actual plant growth and development stage, were used to improve estimation of actual evapotranspiration. These were useful to evaluate crop water requirements. LAI measurements allowed to quantify the thickness and density of the vegetation cover. LAI sensors were helpful in fields with low height arable crops, vegetables and meadows as well as heterogeneous vegetation cover. These also provide data to verify the results from remote sensing images.

Soil water content in root zone (10-50 cm depth) measured by profile sensor, and modelled based on actual farmer irrigation and weather forecast irrigation (1 – April 17th 2019); measured volumetric soil water content (cm3 cm-3), farmer irrigation doses and precipitation (summer 2019), Poland.

For assessing plant water stress conditions, a valuable support are sap flow sensors and turgor-related probes. Such plant-based sensors have been used to estimate stomatal conductance (automated) in a novel approach in the Spanish case study. Plant sensors are useful to estimate stomatal conductance, and to evaluate plant water requirements to decide the optimal desired volumes. These allow to check if actual irrigation doses are correct.


a)

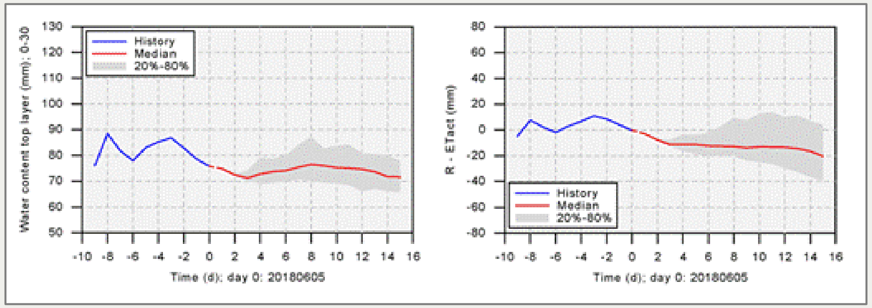
b)

c)

Installed measuring devices: a) water content sensors at two depths (10 and 30 cm below soil surface) – Dutch case study; b) Leaf area index (LAI) sensor – Polish case study; c) Plant sap flow sensor – Spanish case study.

Use of weather forecast and mathematical modelling

Mathematical modelling was used in the case studies to predict water content in the root zone, and/or to estimate crop water needs. In some cases weather forecasts were used as input to the mathematical models. It appeared that precipitation forecast has the lowest predictability among the main weather parameters. Based on the weather forecast, it is possible to predict crop water demands for the next days, shown in the Dutch and Polish case studies. Precipitation amounts have high impact on soil water content and operational assessment of irrigation needs. As indicated by the Spanish case study, predicted duration of heat wave days is also important, especially to avoid under-irrigation. Since weather forecasts are uncertain, ensemble weather forecasts available from ECMWF were used to obtain insight in the uncertainty of the predicted future water contents in the root zone (Dutch case study). The band-width of the 51 ensemble weather forecasts provided information on the uncertainty around the average or median behaviour of the water content in the root zone. In this way decisions to be taken by the farmer or water distributor can be done using insight in uncertainties (e.g. 20-80% range) of expected rainfall and of irrigation demand.



Time courses of historic (9 days; blue line) and future (15 days; red line + grey confidence interval) modelled soil water content and irrigation needs (R-ETact) for date June 5, 2018, the Netherlands

Use of remote sensing (Sentinel 2) and drones

Sentinel 2 satellite images were used to detect irrigated crop in the French case study, starting with existing land use information as a benchmark and then improve irrigated crop detection using the characteristics obtained from the Sentinel images. For Italy and Spain images were used to support and improve mathematical modelling. For Italy and South Africa existing irrigation platforms with processed Sentinel 2 images were used (evapotranspiration, vegetation indices) and their usefulness for estimating crop water needs has been assessed.

The medium and high resolution satellite images can deliver valuable information for irrigation purposes: 1) frequent observations provide time series able to capture dynamic patterns of the vegetation development, 2) spatial resolution able to address small fields, which are frequent in irrigated area, and 3) rich spectral content useful to characterize plant traits (e.g., LAI, Fraction of absorbed photosynthetically active radiation faPAR, vegetation water content, soil moisture). The challenge is still to identify patterns in temporal evolution of satellite vegetation indices that improves the identification of irrigated crop and irrigation water efficiency.

Use of drones for olive tree height, Seville, Spain

The infrared cameras, used with unmanned aerial vehicles (UAV), showed large sensitivity to water stress dynamics. The most promising and innovative results have come from the use of the visible 4K camera - it was possible to reconstruct the canopies in 3-D. This information is highly valuable since it solves one of the main difficulties to estimate the water consumption by trees: the actual leaf area and its seasonal evolution. This information is also important to estimate the heterogeneity of plant sizes in the field. Also, in special cases, like long lasting dry periods, UAV can provide data at strategic dates.

Remote sensing data used for irrigation support purpose

Volturno River basin in Campania, Italy	IrriSAT platform, images at field scale of actual evapotranspiration (ETa) and fractional canopy cover (FCC); Comparing the values of tomato ETa estimated using AquaCrop model and from IrriSat; direct / operational upload FCC values to AquaCrop to improve the model.
Crau area and Entrechaux (Ouvèze river basin), France	Sentinel-2 imagery, at catchment scale in grassland area (CRAU area) and fruit trees domination area (Entrechaux site); Mapping irrigated orchards and vineyards; Testing new methods based on Sentinel-2 data: to map the main irrigated crops and to identify flooding patterns on grassland and their consequences on the irrigation doses.
Andalusia, Spain	Sentinel-2 imagery; drone flights with multispectral and infrared cameras (field scale); Identifying the differences among irrigation water treatments for olive trees in water stress and without water stress conditions.
Kujawsko-Pomorskie, Poland	IrriSAT irrigation platform, at field scale, images of crop coefficients Kc in years 2018 and 2019; one drone flight (2017); Improvement of the values of 10-days Kc in dependence on growth and developments stage of leaf parsley; Useful for crops harvested multiple times during the growing season (grasslands and leaf parsley).
Western Cape province, South Africa	FruitLook irrigation service – weekly totals of ETa and ETdeficit (difference potential and actual evapotranspiration at field scale; Comparison of monthly water requirements for vineyards based on FruitLook data, weather station data and soil water profiles data; This exercise was the first to attempt to make linkages between soil water probes and climate and remote sensing data. This exercise will be useful for FruitLook improvement and for developers of soil water probes.

Combination of technologies for irrigation support

Case studies demonstrated that usage of combination of at least two information technologies result in increased accuracy of irrigation demand forecast. The combination of timely information about the actual development of crops provided by a model with the information retrieved from Sentinel 2, allows more efficient water distribution criteria based on the real irrigation needs of crops. The characteristics of Sentinel-2, with very high revisit frequency and spatial resolutions, make it suitable for mapping crops and irrigated areas also at large scale with good accuracy at low cost.

Combinations of technology for irrigation support

Volturno River basin in Campania, Italy	IRRISAT irrigation service combines high resolution data from satellites with weather data; more recently, combined with numerical weather predictions for forecasting crop water needs up to 5 days in advance. Used for irrigation water requirements estimation; crop water needs forecast up to five days in advance. The combination of timely information about the actual development of crop provided by the model with the information retrieved by the satellite allows more efficient water distribution criteria based on the real irrigation needs of crops. The fractional cover (fc) estimated by Sentinel-2 is sequentially assimilated into AquaCrop in the place of canopy cover (CC) simulated by the model.
Andalusia, Spain	Mechanistic models combined with soil and crop sensor outputs. Improving estimation of stomatal conductance and actual amount of water to be applied
Kujawsko-Pomorskie, Poland	Weather forecast, mathematical modelling and soil maps; supported by remote sensing images and indices. To be used to generate more accurate prediction of water needs taking into account actual crop development and upscaling current and predicted irrigation needs from field to county scale.
Western Cape province, South Africa	Irrigation service FruitLook, open access platform using satellite and weather information. To be used for monitoring of vineyards and orchards in terms of crop growth, crop water-use and leaf nitrogen content.

Conclusions

The project identified adequate combinations of soil sensors, plant-based sensors, remote sensing, weather forecast and simulation models that allow a better consideration of rainfall, evapotranspiration and soil moisture in irrigation scheduling. The OPERA case studies demonstrated that irrigation based on these combinations can actually lead to improve water use efficiency. For example:

- Sentinel 2 in combination with crop models was successfully used to improve estimation of water requirements for irrigation (France, Spain, Italy). For operational irrigation purposes, especially in case of grasslands and frequently harvested crops within the growing season, estimating crop coefficients with the support of remote sensing help in better estimating actual water requirements and consumption. This appeared also the case for other arable crops, orchards, and vineyards.
- A new method was developed and tested in which the stomatal conductance and leaf area is estimated as key factors to determine irrigation needs (Spain). Stomatal conductance is related to photosynthesis and thus with yield and fruit quality. The current widely used method based on the crop coefficient method is unsatisfactory for precision agriculture, and the new approach provides the main unknowns of the Penman-Monteith equation that describe plant transpiration.
- Several case studies have shown that weather forecasts as input for models can be used in irrigation scheduling (Italy, Poland and Netherlands). The precipitation amount has high impact on soil water content and operational assessment of irrigation needs. Accurate forecast of this parameter can result in more precise prediction of crop water demands for next few days. Since weather forecasts are uncertain, it may be of help to consider ensemble weather forecasts. In this way decisions to be taken by the farmer or water distributor can be done with insight in the uncertainties of evapotranspiration demand and of expected rainfall. If only average weather forecasts can be used then from the current study it appears that predictions more than a week ahead may be too uncertain to rely on. Predicted duration of heat wave days is also important, especially to avoid under-irrigation, as shown by the Spanish case study.
- The South African case evaluated an remote sensing based operational irrigation service which provides key insights for European partners in the development of new products to ensure uptake.

These methods are mostly designed for farmers, but can be up-scaled and made of interest to a wider range of users, such as water authorities. Insights from the case studies integrated experience from various climatic zones in Europe and South Africa. While a classical research approach would imply the use of uniform methods in all case studies, a practical approach was chosen because of resource constraints, where each case study was linked to already ongoing research at the sites. Utilizing these experiences allowed a synthesis and sizable progress with limited investment, and co-learning between the partners. A next step is to bring these project advances from remote sensing, soil moisture monitoring, plant responses and forecasting and experiences from users, towards implementation and commercialization in operational advisory services.

Demonstration farm near Bydgoszcz, Poland