Enhancing Mediterranean Agriculture: Towards a Sensor Based Decision Support Tool for Efficient Irrigation Management in Smallholder Orchards

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Abstract

The Mediterranean agriculture is currently facing various challenges resulting from population growth, need for nature conservation, efficient usage of resource and necessary resilience regarding climate change. The fact that smallholders play an important role in the agricultural community raises the question how they could adopt new efficient irrigations strategies and technologies. We present the concept of a decision support tool for irrigation management that aims to overcome obstacles in adapting new technologies for smallholders and provides irrigation recommendations for orange and olive orchards. The derived irrigation recommendations are either based on the FAO-56 approach, or on a soil water balance model relying on soil moisture data. The second is based on soil moisture sensors and here, we are addressing two crucial factors: (i) the assurance of good data quality, and (ii) the site-specific threshold identification for soil moisture measurements, showing possible methods and occurring challenges.

Keywords— irrigation management, sensor data, quality control

I. Introduction

Mediterranean agriculture needs to face a transition in food production in the interplay of population growth, protecting the environment, resource efficiency and ensuring resilience to future climatic change. Smallholders act as crucial part of Mediterranean agricultural community and Mediterranean region could save 35% of water by implementing more efficient irrigation and conveyance systems [1]. To achieve a water-efficient agricultural sector, new irrigation technologies and best practices need to be adopted. In this sense, the PRIMA project HANDYWATER is focused on gaining new knowledge and offering low-cost and lean solutions for enhancing the adoption of efficient irrigation innovations by small farmers. We target to increase the environmental and economic sustainability of two different crop productions models, both highly water demanding and widely cultivated in the Mediterranean area: citrus and olive. The application of decisions support systems in agriculture has recently rapidly increased, especially with focus on irrigation practices [2].

In the project we work on aspects that address to overcome the barriers in the adoption of innovative irrigation technologies by the small farmers. This includes our concept towards a simple decision support system taking agronomic and socio-economic considerations into account and resulting in an App implemented for mobile phones. Existing decision support systems to optimize irrigation are often based on combining climate and soil variables in order to properly manage irrigation in a more efficient way. However, this also increases the amount of data flow, its analysis and its use to create effective models [3]. In order to face this, we aim to provide irrigation recommendations in dependence from the data availability.

Above all, agronomic decisions depend on either (I) a simple approach based on FAO-56 [4] or (II) on soil moisture and/or plant status where ideally both variables rely on inexpensive but reliable sensors. The presented work will focus on the application of soil moisture sensors and climate data for soil water balance modelling, especially on

- automated sensor quality control
- site specific threshold identification for soil moisture sensors

II. Methods of Implementing the Decision Support Tool

A. General Workflow

The overall flow from data acquisition in the field towards the irrigation recommendation is shown in Figure 1.

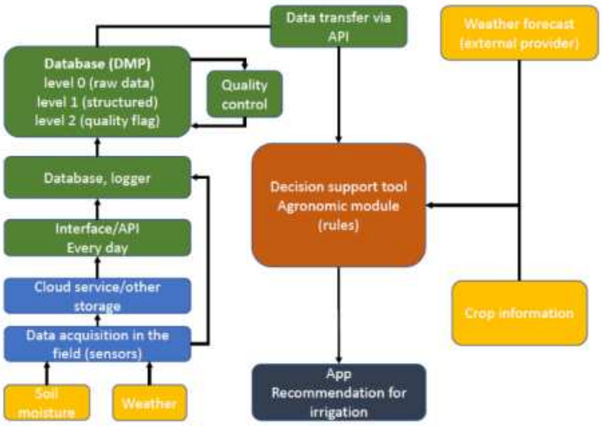

Figure 1: Description of data flow from sensors to irrigation recommendation

Relevant information about current soil water content and climate data is collected by sensors installed on the fields. The data is transferred to the database directly or via cloud services using interfaces and saved as level 1 data. Once the data is stored, a standardized automatic quality control system [5] is used to ensure no erroneous data is used in the following processes. The data is then ready to be sent to the decision support tool (DST) and to the App to provide information about the current status at the field site. Data transfer and calculation of irrigation recommendation is carried out using scripts written in python programming language (Python Software Foundation, https://www.python.org/) and application programming interfaces (APIs). The DST uses the collected information and additional weather forecast data to calculate the current need for irrigation. The process therefore reduces the amount of needed human expertise. Climate data can be collected using weather stations, e.g Vantage Pro 2 by Davis Instruments (Hayward, CA, USA) or iMetos D3 by Pessl Instruments (Weiz, Austria). Collected parameters include temperature, wind speed, humidity and solar radiation.

B. Sensor Quality Control

All recorded data used as basis for the calculation of irrigation needs is automatically checked for integrity. The data control includes the following approaches:

- Check for valid data range
- Check for constant values over defined time period
- Control battery level of the sensor

In general, the developed SaQC procedure aims to identify possible errors and irregularities without being too strict and falsely flagging correct data.

Regarding the data range, minimum and maximum value were defined for all parameters that are being recorded. The thresholds are oriented on possible data ranges in the Mediterranean area with the aim of easily identifying possible errors during data acquisition. The specific values are shown in Table 1. In addition, the time series are checked for constants over a defined period. A maximal time span is defined that allows for constant values, before the recordings are being flagged. The duration of the time span is as well shown in Table 1.

Table 1: Minima, maxima and constant value maximum for quality control of selected parameters for 15 min averages; h = hours, D = days

Parameter	Min	Max	Constant max
Soil moisture θ (m^3/m^3)	0	1	-
Temperature (°C)	-30	60	4h
Wind speed (m/s)	0	53	1D
Solar radiation (W/m^2)	0	2000	1D
Humidity (%)	0	100	1D
Precipitation (mm)	0	30	-

The selected time range of the investigated time series data holds some limitations to the quality control. As the data is transferred and checked once per day, the maximum time range available to check for constants is one day as well. For soil moisture and precipitation, in some cases this time frame is too small for changes in measured values. It is therefore not possible to check for constants, as there would be high risk of accidently flagging valid data as erroneous. Due to this limitation, the quality control procedure for soil moisture values relies on minimum and maximum values and battery voltage. A small example of flagged soil moisture data is shown in Figure 2.

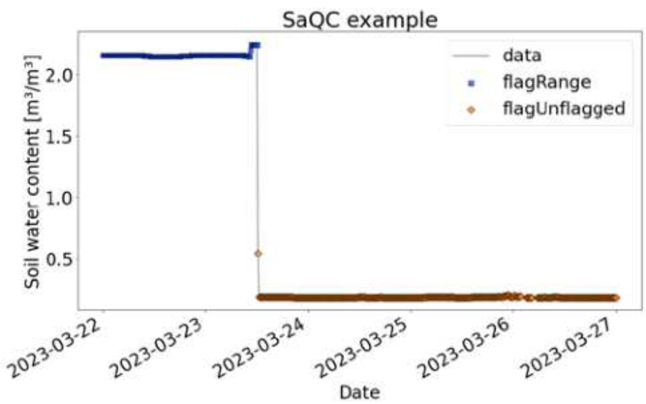

Figure 2: Example of SaQC data flagging of soil moisture data

Further, all values recorded with a battery level below 20% are flagged as data collection can be error prone under these circumstances. If the recorded data passes all described tests, it is flagged as “OK” and can then be used in the DST.

III. Results: Site specific soil moisture

In order to be able to use the collected soil moisture data to derive irrigation recommendations, a proper sensor set-up should be implemented. Previous studies recommend to install soil sensors adjacent to the drip irrigation line and at about 5-20 cm from the emitter [6]. The vertical distance depends on the root depth. For monitoring the most tree crops, about 30 cm from the soil surface is adequate [7]. Larger depths and distances can be found in literature for trees as well [8]. In addition, local expert-based knowledge about tree species, soil texture and type of irrigation should be considered. Figure 3 shows a possible installation in for an orange orchard with a drip irrigation system and plastic mulching. It aims to record changes in the irrigation bulb as well as soil water content in deeper depths. Therefore, the sensors are placed between two drippers of the irrigation system. Soil moisture is measured by sensors “SMT100” from Truebner GmbH (Neustadt, Germany) with a measuring accuracy of ± 1% vol% using a soil specific calibration and ± 3% using the standard calibration. It is however possible to use different sensors for the DST as well, e.g “TEROS 10”, from METER Group (Pullman WA, USA).

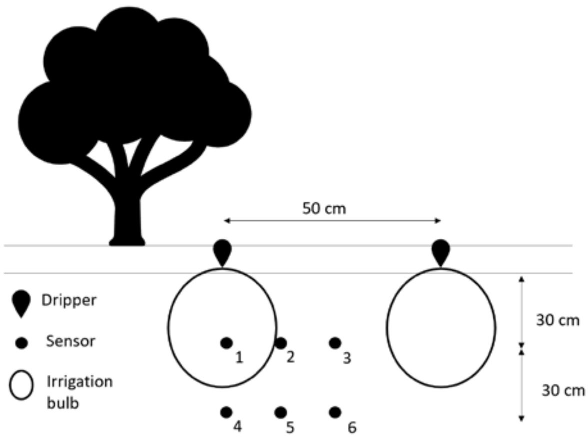

Figure 3: Schematic representation of soil moisture sensor arrangement

For further usage the values also have to be transformed to relative soil water status (RWS):

$$\mathrm{RWS} = \frac{\theta}{\theta_{FC}} \qquad (1)$$

For this, a site-specific soil moisture value (θ) at field capacity (FC) value is needed. However, it can be challenging to find a point that represents a suitable θ_{FC} value [7]. After rainfall events, the soil is saturated with water above the FC. Therefore, the selection must be done at a certain point after the precipitation event where the water runoff already took place, and only the water that is stored by the soil is left. As this process is highly soil specific we decided for a manual selection at the sensors below the dripper. In any case selection has to be done after a major rain event (a) during early morning before water uptake by roots is starting and (b) ruling out disturbances by follow up peaks. At our site a period of 3-5 days after a rain event is reasonable. In Figure 4, the selection of possible fc θ_{FC} values is shown to illustrate the challenges in identifying a suitable θ_{FC} value.

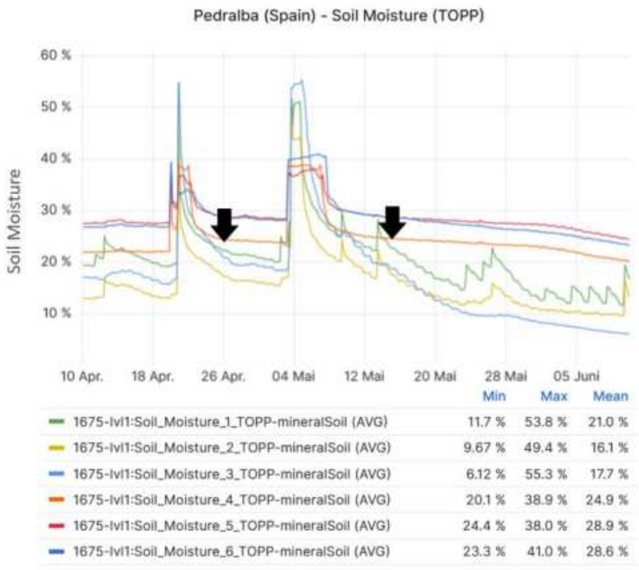

Figure 4: Possible selection of θ_{FC} values on test a test site in spring 2022 based on sensor 1; sensors 1-3 are installed at 30 cm, 4-6 at 60 cm depth

Two precipitation events are used to define the θ_{FC} value based on sensor 1, which is located right below the dripper. However, it can be seen that sensor 2 and 3 would results in a different value, despite the fact that they are installed at the same depth. Table 2 presents the date and time of the highest measured soil moisture value at sensor 1, together with possible selections for θ_{FC} and the timespan between the maximum and the selected measurement for two different rainfall events.

It shows the differences of the possible θ_{FC} values in dependency of the duration after the precipitation event. The different time span highlights the challenges resulting from the specific intensity and duration of each rainfall event, which can influence the θ_{FC} determination procedure.

Table 2: θ_{FC} values and time span of selection after two rainfall events in April (upper part) and May (lower part) 2022

Max value [vol%]	Max date	Selected value of θ_{FC} [vol%]	Selected date	Time span
53.9	2022-04-20 18:43:00	22.9	2022-04-25 01:43:00	4 days 7 h
		22.3	2022-04-26 01:43:00	5 days 7 h
		21.6	2022-04-26 01:43:00	6 days 7 h
51.2	2022-05-04 13:42:00	22.2	2022-05-14 03:41:00	8 days 14 h
		24.4	2022-05-14 03:41:00	9 days 14 h
		22.7	2022-05-14 03:41:00	10 days 14 h

In Table 3, the impact of the θ_{FC} selection on the calculation of RWS is shown for soil moisture values between 10 and 25 vol%. For citrus orchards, the threshold to start the irrigation could be 0.9. In this case, e.g. for a soil moisture value of 20 vol%, the differences in RWS resulting from the θ_{FC} value would result in an irrigation recommendation for $\theta_{FC}2$ and $\theta_{FC}3$, but not for $\theta_{FC}1$.

Table 3: Impact of fc value on the calculation of RWS

θ [vol%]	θ_{FC} 1 [vol%]	θ_{FC} 2 [vol%]	θ_{FC} 3 [vol%]	RWS1	RWS2	RWS3
10.0	23.0	22.3	21.6	0.43	0.45	0.46
15.0	23.0	22.3	21.6	0.65	0.67	0.69
20.0	23.0	22.3	21.6	0.87	0.90	0.93
25.0	23.0	22.3	21.6	1.09	1.12	1.16

IV. Model Application

A. Irrigation models

For the application of sensor data in the irrigation models, two different approaches are possible, depending on the available input data. We are aiming to calculate the irrigation needs on a weekly basis. The FAO-56 approach uses the evapotranspiration of a given time span and plant specific coefficients to determine the amount of water needed to ensure proper irrigation of the fields. It is a simple and easy to use approach that does not require the installation of soil sensors. The irrigation need is calculated as:

$$ETc = ETo \times Kc \qquad (2)$$

The evapotranspiration can be derived from climate data (temperature, humidity, wind speed, solar radiation). The coefficient is dependent on the crop and region of the irrigated site.

Another approach to derive information about irrigation needs is the application of a soil water balance model [9]. In contrast to the FAO-56 approach, in this case a correction factor is calculated to adapt the previously applied amount of water. This correction factor is based on the current RWS that was recorded on the site in the previous week. It is further combined with weather forecast or historical climate data of the coming week that is to be irrigated.

B. Final product

In order to ensure that smallholders are getting access to sustainable irrigation management procedures, the final product is derived in form an application for mobile devices. It aims to be intuitive and simple to use. The main advantage of the proposed DST is the possibility of data integration from a variety of sensors and platforms and provision of its results to smallholders via mobile phones. This way, the currently measured data on the agricultural fields and up-to-date irrigation needs are easily accessible.

An example of the prototype application layout can be seen in Figure 5. On the left side, the different available fields can be selected. The right side shows the user interface for one specific field or irrigation zone, with current soil water content data and a traffic light system for the irrigation recommendation.

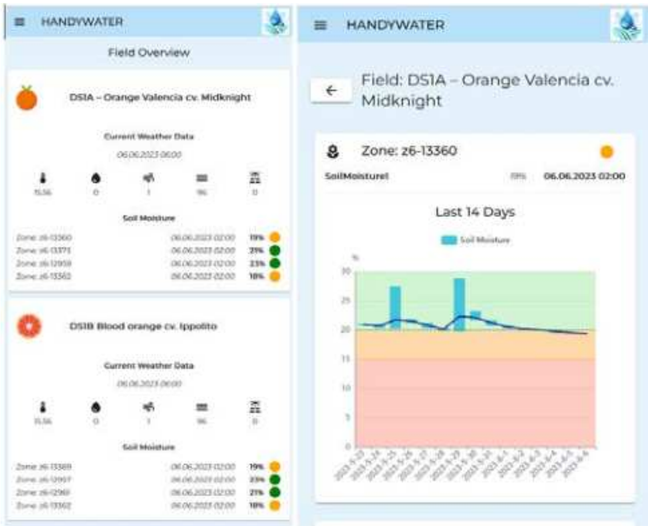

Figure 5:Screenshot of the application as final product

V. Conclusion

In general, the installation and usage of soil moisture sensors offers the possibility of applying alternative solutions for irrigation modelling. In order to make use of the collected data, we conclude that processing procedures like automatic quality control is essential in order to ensure that only reliable data is integrated in further modelling approaches. This makes the derived irrigation recommendations more reliable and trustworthy for approaches based on evapotranspiration as well as soil water balance models.
The meaningful usage of collected soil moisture data is depending on site specific θ_{FC} values. The presented challenges in θ_{FC} value determination showed that in drip irrigation systems, the positioning of the sensors is crucial and requires well-founded decisions based on the local conditions.

Acknowledgment

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