Deliverable 2.2

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[Report on the agronomical and environmental characteristics of the main agricultural crops of the Mediterranean Basin]

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Summary

Deliverable **D2.2 – "***Report on the agronomical and environmental characteristics of the main agricultural crops of the Mediterranean Basin*" focuses on the main challenges of agriculture in the Mediterranean basin in the context of climate change. The main objective of this deliverable is to integrate and organise previous scientific results and describe the potential benefits that could arise from the application of innovative irrigation and fertilisation (fertigation) technologies in relation to water and nutrient conservation in arid and semi-arid regions such as the Mediterranean basin.

The deliverable is divided into two parts, the first part mainly referring to the agronomical and environmental characteristics of two main greenhouse crops of the Mediterranean Basin and the second one to the agronomical and environmental characteristics of the main open field crops.

1. Greenhouse crops

Regarding the integration and organisation of previous research work, several scientific reviews were published in scientific journals and book chapters concerning irrigation and fertigation practices in greenhouse soilless culture systems. Advances in irrigation/fertigation techniques in greenhouse soilless culture systems (SCS) were published as a chapter in a scientific book, namely "Advances in horticultural soilless culture". Moreover, a review entitled "Implementing sustainable irrigation in water-scarce regions under the impact of climate change" was published in a peer-reviewed journal. Furthermore, a review divided into two parts namely, "Energy and water-related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part I: Energy and microclimatic parameters" and "Energy and water-related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part II: Irrigation and fertigation" has been also presented.

1.1. Advances in irrigation/fertigation techniques in greenhouse soilless culture systems (SCS)

This review focuses on the irrigation and fertigation practices applied in soilless culture systems (SCS) in the past, following traditional techniques, while emphasising the modern fertigation practices applied in computer-generated high-tech greenhouses combined with precision agriculture practices to improve water and nutrient use efficiency whilst minimising costs and manual work (see **Annex I**). In brief, the notion of open, closed and semi-closed hydroponic systems is presented, indicating some of the main means of fertigation, such as drip irrigation. In addition, this chapter reviews a series of factors affecting irrigation frequency and duration, accentuating the importance of irrigation scheduling based on the local internal and external growing conditions, the type of SCS, the plant species and cultivar, as well as the crop's developmental stage. Moreover, the quality of water used in soilless systems is highlighted as the electrical conductivity (EC) of the water used in closed hydroponic systems should not exceed 0.5 dS m^{-1}.

In addition, several irrigation supply methods are proposed to be used separately or in combination. These common irrigation management systems refer to irrigation practices based on crop transpiration, crop nutrient and water needs, substrate and/or drainage nutrient content, and water content of the plant tissue. To avoid water supply deficiency in SCS, scientists suggest following an irrigation management based on solar radiation and time clock scheduling rather than irrigation based on plant growth as this method does not comply with the plant's transpiration fluctuations.

In addition, plant-based sensing and monitoring systems have been reported in this review as an alternative to irrigation scheduling in greenhouses. However, the difficulties of applying such irrigation methods are highlighted, as parameters, such as the reference and/or threshold stress values, and a variety of sensors, such as stem micro-variation, leaf temperature, sap-flow, radiometric, and leaf thickness sensors are required for the method to run properly. In this review, a case study scenario is presented aiming to assess the irrigation scheduling, dose and frequency, as affected by different cooling greenhouse systems in the Mediterranean region as well as to determine the efficiency of wireless plant-sensing technology in SCS. Finally, an extensive discussion regarding the Internet of Things (IoT) technologies and their benefits in precision agriculture, as well as future trends in smart farming, are being reported in this chapter of the book "***Advances in horticultural soilless culture***".

1.2. Implementing sustainable irrigation in water-scarce regions under the impact of climate change

In this review, water scarcity is highlighted as one of the main problems already affecting the population as a result of climate change while emphasising the importance of irrigation management that would help to improve water use efficiency in water-scarce regions. A literature review dealing with the benefits of modern irrigation techniques such as pressurised irrigation and irrigation scheduling, as well as sustainable irrigation for open-field, and greenhouse or screenhouse cultivations in water-scarce regions including the Mediterranean area, is presented in this article (see **Annex II**). Over the longer term, intensive drought events, water scarcity, overexploitation of groundwater resources and water quality issues remains much-less the same between regions in arid and semi-arid climate. Several countries have already developed extensive legislation, institutional capabilities actions and practices that are required for the effective climate change adaptation. Moreover, the importance of selecting the most appropriate irrigation method based on the region and the type of cultivation (open-field, protected cultivation) is projected.

1.3. Energy and water related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part I: Energy and microclimatic parameters.

The current review article highlights the importance of the utilisation of renewable energy potential systems (i.e., geothermal, solar and wind) to the greenhouse energy profile modifying the microclimatic conditions for optimisation yield per unit of energy. Energy and water efficiency are of high importance especially nowadays as modern agriculture is affected strongly by water scarcity, energy use, and climate change (see **Annex III**). In this review, it is highlighted that greenhouses are considered intensively energy-consuming constructions compared to other buildings such as animal and grain production facilities as a large energy amount is required in order to achieve the most appropriate climatic conditions for the proper plant growth. For this reason, this paper was written to assess the renewable and green energy-efficient control systems that are applied in arid and semi-arid areas such as the Mediterranean region, where tomato and cucumber are some of the main crops cultivated in this area. Some examples of energy loss reduction are stated in this work and are related to the replacement of heating oil with gas or aerothermal, solar, biomass and shallow geothermal energy, which could lead to up to 60% of energy savings. Moreover, recommendations regarding the increase in energy efficiency and decrease in energy consumption are analyzed in-depth in this article. The current review article highlights the importance of the utilisation of renewable energy potential systems (i.e., geothermal, solar and wind) to the greenhouse energy profile modifying the microclimatic conditions for optimisation yield per unit of energy.

1.4. Energy and water related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part II: Irrigation and fertigation

Following the previous review: "Part I: Energy and microclimatic parameters", a second review was released aiming to evaluate the irrigation and fertigation practices in the Mediterranean region to improve water and nutrient sustainability in regard to some of the most popular and consumable vegetables, such as tomato and cucumber crops grown in both open fields and in greenhouses (see **Annex IV**). After emphasising global warming and the overexploitation of groundwater resources over the years, the authors review the challenges that the Mediterranean growers face in terms of water and fertiliser application to fertigated tomato and cucumber crops showing the low number of growers adopting precise sustainable fertigation practices. Firstly, the authors start analysing some of the irrigation methods used in agriculture, emphasising the importance of precision agriculture in terms of productivity, sustainability and increase in water and nutrient use efficiency. In addition, web-based algorithms correlated with plant evapotranspiration are reported herein. Moreover, an in-depth discussion in regard to the fertigation management followed in the open field and protected crops is taking place addressing the significance of plant nutrient uptake and a series of models developed to estimate the appropriate amount of fertilisers required for each specific crop. This paper summarises the highest level of knowledge on fertigation management in relation to variations in environmental conditions and the challenges that growers have to overcome to achieve a sustainable way of food production.

2. Open field crops

In the context of climate change, the problem of water scarcity in regard to agriculture has been accentuated during recent years for open field crops. In this sense, Mediterranean countries are looking for more innovative irrigation approaches, not only to cope with water scarcity and policies involving better use of water, but also to meet the needs of the farmers and the demands of the consumers. Many open field crops can be strongly affected by water scarcity, especially when unsustainable irrigation management practices are followed. In this sense, the advances in the digital transformation of the European agri-food sector, based on the rapid adoption of advanced technologies of the Internet of Things (IoT), data science and smart irrigation should be highlighted. These will ensure the long-term viability and sustainability of the sector in the agroecosystems of the Mediterranean region.

2.1. Digital transformation in the open field crops of the Mediterranean Region

Some problems such as climate change, demographic imbalances between rural and urban areas or the degradation of water quality, among others, are especially relevant in the Mediterranean Region; where agriculture is one of the most productive and profitable sectors, but also one of the most vulnerable regions to water scarcity. In this sense, the Mediterranean countries have made a significant effort to modernise irrigation systems with the aim of improving the efficiency and uniformity of irrigation, reducing costs and energy consumption, increasing the profitability of the crop, and improving water and nutrient use efficiency.

In relation to this, much research is being done on new deficit irrigation strategies, achieving significant water savings while maintaining productivity, agronomic quality and crop health. On the other hand, alternative sources of water such as reclaimed water (RW) are required to meet the needs of crops and its use is gradually becoming a common practice worldwide. With appropriate management, RW has great potential to become a valuable irrigation water source and the interest in its utilisation is increasing.

Thanks to advances in electronics, computational and material science technology, recent attempts have been made to optimise the sustainability of agriculture through the use of precision irrigation techniques with the adoption and implementation of new water and nutrients management practices. In this sense, sensor measurements based on physiological aspects of plants, such as dendrometers, sap flow sensors and foliar temperature have regained a prominent role as indicators of the water status of plants with the possibility of being used in automatic irrigation scheduling. However, little has been studied so far about some factors that affect sensors that measure soil moisture and soil salinity. In this sense, dielectric sensors are capable of estimating the soil volumetric water content by measuring its dielectric permittivity, a property that has been used to set irrigation systems that address the actual water demand of plants. However, temperature may affect dielectric sensors by directly affecting sensor circuitry, by modifying the dielectric properties of the soil, or by modifying water–soil interactions. This means that it would not be possible to accurately estimate the Volumetric Water Content (VWC). For that, studies on how variations in substrate temperature and salinity affect measurements of voltage, permittivity and bulk electrical conductivity (EC) of two soil sensors were carried out (see **Annex V**).

On the other hand, nowadays the IoT has acquired special relevance. IoT is a very promising family of technologies capable of providing many solutions for the modernisation of agriculture. This refers to systems of physical devices that receive and transfer data over wireless networks without human intervention. Advances in IoT will enable the launch of a data-driven irrigation management tool that integrates knowledge about fertilisers and irrigation water management with Information and Communication Technologies (ICT). All this is reflected in the dissemination article, exposing the most pressing problems of the Mediterranean region in relation to irrigation, some of the solutions adopted so far and the solution proposed by this project (see **Annex VI**).

2.2. Agronomical and environmental characteristics of the main crops under study

2.2.1. Pomegranate trees

Pomegranate (*Punica granatum* L.) is one of the main crops grown in the Region of Murcia that are considered susceptible to water scarcity when unsustainable irrigation strategies are applied. Pomegranate trees cope with water stress by developing stress avoidance, and stress tolerance mechanisms and they are considered as drought-resistant crops (Galindo et al., 2014). However, when produced for commercial purposes, they require regular irrigation during the season, especially in arid or semi-arid areas, in order to achieve optimal yields with high-quality fruits and to reduce fruit physiopathies, such as fruit cracking and splitting (Griñán et al., 2019).

In this regard, deficit irrigation strategies may play an important role in pomegranate production in the Mediterranean countries, improving water use efficiency at farm level and additionally reducing nutrient loss from the root zone. However, some situations such as a rapid increase in temperature when a low amount of irrigation events are applied can difficult the task of maintaining the water status of plants, resulting in a loss of yield or a reduction in fruit quality. Therefore, it is of great importance to determine the appropriate deficit irrigation strategy to be applied to this crop. In this way, the use of plant-based water status indicators could predict crop performance under a given irrigation scheduling regime, since plant water status controls several physiological processes and crop productivity.

Conventional irrigation scheduling based on soil water measurements is characterised by certain disadvantages while increasing global water scarcity and irrigation costs necessitate the development of new precise irrigation scheduling and control methods that promote increases in water and nutrient use efficiency. In recent years, there has been a wide range of proposed new approaches to irrigation scheduling that have not yet been widely adopted. Many of them are based on modern and precise soil-plant sensors (Ortuño et al. 2010).

In this sense, the use of sensors that measure soil water status is a key complement modulating crop water requirements. Taking into account the advances of digital transformation of the agriculture sector in the Mediterranean region, we set out to study the development of a decision support system (DSS) for irrigation management in a pomegranate field, based on the interpretation of the soil water content in different depths provided by soil sensors (see **Annex VII**). So far, different irrigation strategies are performed by the user through the PRECIMED platform, but it is expected that at the end of the project, the DSS will execute the irrigation programs according to the user's convenience, triggering or stopping the electrovalves, and scheduling the irrigation in a more efficient way, either based on the reference evapotranspiration (ET_0) criteria, capacitance probes or deficit irrigation strategies. Some preliminary results show how some strategies developed on the frame of project (PRECIMED protocol, **Annex VII**) could be in line with traditional irrigation approaches regarding water use efficiency.

2.2.2. Pear trees

As with other fruit trees, in pear plantations, the main objectives of deficit irrigation strategies are based on irrigation water savings and control of plant vigor.

Regulated deficit irrigation (RDI) is known to reduce the amount of water applied, but it is possible to maintain good yield without adversely affecting fruit quality, which, in some cases, improves. However, for a good application of this strategy, the frequency and dose of water application must be well defined. In this sense, water deficits during fruit development significantly reduce vegetative growth without affecting production. In fact, the RDI strategy was successfully applied to field-grown plants of the cultivar 'Barlett' when water deficits were imposed during stage I of fruit development when cell division occurs (Mitchell et al., 1989). The RDI strategy resulted in water saving, and lower vegetative growth without affecting fruit yield. RDI was also tested on plants of the same pear cultivar grown in containers resulting in decreased shoot growth and to a lesser extent fruit growth (Marsal et al., 2000). The authors of the aforementioned work suggested that the effect of RDI on canopy growth may be more positive when vigorous rootstocks are used, when soils are fertile or plantation density is very high. López et al. (2011) found that a moderate water deficit resulted in greater firmness, acidity and concentration of soluble solids at the fruit ripening stage of the reference pear cultivar than in treatments with no deficits. Under tropical conditions, moderate deficit irrigation during filling and ripening in pear fruits may be convenient for internal changes in fruit quality, mainly increasing the content of soluble solids and acids but can also affect volatile compounds. Moreno-Hernández et al. (2017) found that pear trees showed mechanisms of osmotic adjustment, allowing those experiencing water stress to cope with irrigation restrictions during the rapid growth stage of the fruit without affecting yield. According to Vélez-Sánchez, et al., 2021, the RDI did not affect fruit firmness, pigments (chlorophyll and carotenoids), color index, content of phenols, sugars or acids at harvest, but resulted in significant water savings. Therefore, RDI is an efficient irrigation technique recommended for pear production under tropical conditions.

Another deficient irrigation strategy, partial root-zone drying (PRD) can save 23 to 52% of irrigation water as compared to fully irrigated trees, with no or only marginal reduction in fruit yield or size (Kang et al. 2002). In contrast, O'Connell and Goodwin (2004) found that PRD strategies (at 50% of ETc) resulted in water-stressed plants for the cultivar 'Williams Bon Chretein'.

In general, the success of incorporating RDI strategies into the set of agronomic practices in fruit trees, is conditioned both by the plant's ability to respond to a stress situation, which will be different depending on the phenological moment that this stress occurs, and by the environmental and edaphic conditions in which it is found. This is why, the integration of these factors together with the possibilities that offer the new technologies derived from the IoT in a DSS capable to give recommendations about the optimal schedule and volume of irrigation, will play a decisive role on the sustainability of the agroecological sector of the coming years.

2.2.3. Potato and Cereal crops

Low agricultural crop productivity is a major challenge that needs to be addressed in most countries. The main factors affecting crop production can be associated to the susceptibility to biotic and abiotic stresses such as drought and salinity, which currently is considered as a formidable challenge in the Mediterranean region. Salinity interferes with crop response to nutrient and water uptake and may cause Cl, B and Na toxicity. Two other major factors affecting crop productivity are water scarcity and low soil fertility. In addition, a poor soil management and an inadequate use of fertigation affects also crop productivity.

The challenge lies in increasing yields and quality of agricultural production while conserving water and preventing the degradation of lands. Since land resources are limited and non-expandable in Algeria, intensification of agricultural production appears as a strategic option. To this end, irrigating more land associated to the good agricultural practices appears as the main solution to improve food security. Indeed, Algeria is facing severe environmental stresses due, in particular to drought, water scarcity and salinity aggravated by climatic changes. It is necessary to improve; among others, water and nutrient use efficiency through the adoption of new agricultural practices to save water/fertilisers in irrigated agriculture (use of treated wastewater for irrigation, use of the improved irrigation systems, development of water harvesting techniques, reuse of saline water and development of rainfed agriculture). The technique of supplementary irrigation was introduced under rainfed cereal crops to reduce the effects of water stress caused by insufficient precipitations.

Herein, the characteristics of the different agro-ecological zones will be examined to identify the different constraints that agriculture is facing. Five agro-ecological zones have been defined in Algeria: Sahara, arid, semi-arid, sub-humid and humid areas. In particular,

- The humid, sub-humid and semi-arid zones of North Algeria: The humid zones are characterised by rainfall of more than 600 mm/year oriented toward diversified agricultural products such as cereals, vegetable crops and fruit trees. The sub-humid zones receive more than 400 and less than 600mm of precipitations (P) per year oriented towards diversified agricultural products, and intensive cereals, and finally the semi-arid zones are receiving a precipitation of more than 300 and less than 400mm per year oriented towards extensive livestock.
- The intermediate zone (steppe) (arid zone) that receives more than 200 mm and less than 350 mm/year of precipitation.
- The fifth non-productive agro-ecological zone with a hyper-aridity tendency (P<200mm/year) represents the Saharan desert where the only agricultural activities are based on irrigated agriculture and the exploitation of the palm trees (oasis production system).

2.2.3.1. Agricultural practices

2.2.3.1.1. Fertilisation

Regarding the fertilisation, some experiments on potato were carried out at the National Institute of Agronomic Research (INRAA) within the framework of technical cooperation project with International Agency of Atomic Energy in semi-arid and sub-humid areas to assess the nutrient use efficiency using isotopic techniques. These experiments were based on the fertiliser rates applied on potato crops by farmers and the rates recommended by National Technical Institute. Moreover, this work was also based on increasing nitrogen rates for all crops tested. In regard to the different fertilisation management followed by farmers on potatoes, the comparative N-P-K fertiliser (kg ha^{-1}) was 120-80-200, 170- 120- 340, 250-150-300 and 292-180-180; whilst in the case of the increasing nitrogen rates, four nitrogen fertiliser treatments were compared, namely: 60, 120, 180 and 240 kg N ha^{-1}

The results obtained from the experiments conducted with potato crops showed that fresh yield differences between the different rates used in four regions are not significant ($p>0.05$) in semi-arid areas. The average yield obtained was 36.63 tn ha^{-1}. However, although weakly significant, % fertiliser N utilisation decreased with increasing N fertiliser rates. The % of fertiliser N utilisation was 33.7, 17.4, 25.22 and 20.4%, respectively for the N fertiliser rates of 120, 170; 250 and 292 kg N ha^{-1}. Thus, the rate of 120 kg N ha^{-1} seems to be the best nitrogen level for potato fertilisation under the conditions of semi-arid areas (Tiaret region).

Similar results were found in sub-humid regions (Mitidja region). The yield increased significantly ($p<0.05$) with increasing N rate up to 180 kg N ha^{-1}, 1 and decreased for higher N rate values. Although weakly significant, the % fertiliser N utilisation decreased with the increase of the applied nitrogen fertiliser rate. In both regions, the most efficient nitrogen rate with the best fresh yield is that of 120 kg N per ha^{-1}. These results suggest that the additional nitrogen beyond the rate of 120 kg N ha^{-1} did not affect yields.

2.2.3.1.2. Irrigation

A study was carried out to characterise rainfed cereal production in semi-arid regions. The results showed that the cereal crop is under the permanent influence of rainfall fluctuations and drought events. In this context, the study attempts to analyze over a period of 80 years (1940 to 2020), the temporal and spatial analysis of monthly rainfall and the occurrence of drought events based on the determination of monthly rainfall deficits or excesses and its severity. These characteristics can contribute quantify the vulnerability of the crop evolution under the climatic hazards, which affect yields (Annex VIII).

Accurate estimation of reference evapotranspiration (ET_o) is important in studies concerning the management of water resources. In this context, a study was implemented aiming to define the simple and reliable ET_o model that can be used in the sub-humid conditions of Mitidja region instead of Penman-Monteith FAO 56 standard model (PMF-56 ET_o) requiring many climatic parameters. Meteorological dataset recorded at the National Institute of Agronomic Research of Algeria (INRAA) Centre of Baraki, Algiers between 2014 and 2019 were used for estimating daily evapotranspiration. Eighteen alternative models of ET_o were evaluated and compared to the PMF-56 ET_o model, classified into three methods based on: a) mass transfer, b) solar radiation and c) air temperature. Simple linear regression as well as statistical criteria (RMSE, MBE, MAE, RE, Willmott d index) were used to evaluate the performance of the eighteen models for estimating ET_o **(see Annex IX)**. The obtained results showed that the four «mass transfer» models performed the weakest performance by underestimating evapotranspiration in Mitidja conditions. The eight «solar radiation» models are clearly the best compared to the previous ones but slightly less efficient than the six «temperature» models. Finally, by showing the lowest errors in estimating evapotranspiration among the 18 evaluated models, the Trakjovic (2007) temperature-based model was chosen for its use in Mitidja region instead of the standard PMF-56 model (Table 1).

The ET_o temperature-based methods are among the oldest ET estimation methods used (Xu and Singh, 2002). The most famous of all is the Hargreaves and Samani (ETo_{HS}) method (1985) which was recommended by Allen et al. (1998) in situations where only the air temperature is available.

The alternative equations of temperature-based ET_o are all inspired by the ETo_{HS} equation but many authors have suggested the calibration of the terms of the equation before its use locally (Jabloun and Sahli, 2008; Todorovic et al., 2013; Ren et al., 2016).

Trajkovic (2007) fitted the equation of Hargreaves-Samani for the region Western Balkan characterised by humid climate as follows:

$$ETo_{HS-Trajk} = 0.0023\, x\, 0.408\, R_a\, x\, (T_{mean} + 17.8)\, x\, (Tmax - Tmin)^{0,424}$$

where:

$ETo_{HS-Trajk}$ is the temperature-based method for estimating Reference Evapotranspiration of Hargreaves-Samani calibrated by Trajkovic (mm/day), R_a is the extraterrestrial solar radiation (MJ m^{-2} day^{-1}), T_{mean}, T_{max} and T_{min} are the mean, maximum and minimum daily air temperatures respectively (° C).

Table 1. Evaluation of the performance of the 18 evapotranspiration models compared to the standard FAO 56 Penman-Monteith model. Daily climatic variables recorded between 2014 and 2019 at the INRAA Mehdi Boualem Center, Baraki (Algiers).

ET_o models	R^2	RMSE	RANK	MBE	RANK	MAE	RANK	d	RE	RANK	Average RANKS
	-	mm/day		mm/day		mm/day		-	-		
Dalton	0.52	1.27	15	-0.60	13	0.99	15	0.82	0.45	15	14.5
Penman1948	0.53	1.28	16	-0.62	14	1.00	16	0.82	0.45	16	15.5
Schendel	0.60	1.68	17	1.28	17	1.34	17	0.75	0.59	17	17.0
Mahringer	0.53	1.80	18	-1.47	18	1.52	18	0.67	0.63	18	18.0
Makkink	0.93	0.52	6	-0.25	8	0.41	6	0.96	0.18	6	6.5
Turc	0.94	0.54	7	0.39	10	0.45	8	0.97	0.19	7	8.0
Priestley-Taylor	0.95	0.47	4	0.23	7	0.37	4	0.98	0.17	4	4.8
Caprio	0.93	1.11	14	0.79	16	0.88	14	0.91	0.39	14	14.5
Hargreaves original	0.94	0.65	12	0.51	12	0.58	12	0.96	0.23	12	12.0
Irmak	0.94	0.59	10	0.41	11	0.49	11	0.96	0.21	10	10.5
Tabari 1	0.91	0.50	5	-0.04	1	0.41	5	0.97	0.18	5	4.0
Tabari 2	0.95	0.46	2	-0.15	5	0.36	3	0.97	0.16	2	3.0
Hargreaves-Samani	0.91	0.90	13	0.75	15	0.80	13	0.92	0.32	13	13.5
Trajkovic	0.92	0.45	1	0.14	3	0.34	1	0.98	0.16	1	1.5
Ravazzani	0.91	0.46	3	0.11	2	0.35	2	0.97	0.16	3	2.5
Bogawski	0.86	0.59	11	-0.17	6	0.46	10	0.96	0.21	11	9.5
Berti	0.91	0.54	8	0.30	9	0.43	7	0.97	0.19	8	8.0
Dorji	0.93	0.57	9	-0.15	4	0.45	9	0.95	0.20	9	7.8

R^2: coefficient of determination of the linear regression, RMSE: Root Mean Square Error, MBE: Mean Bias Error, MAE: Mean Absolute Error; d: Willmott index, RE: Relative Error.

2.2.3.1.3. Irrigation water management

The agricultural sector is of vital importance in the Mediterranean basin (Harmanny and Malek, 2019). In this region, irrigation is considered as a strategic key to improve food security. Due to the prevailing semi-arid climatic conditions and the increasing needs, in terms of water demand, as a result of urbanisation, and demographic and economic growth (García-Ruiz et al., 2011), the Mediterranean region is characterized by water scarcity that is exacerbated by climate change that pose serious constraints for irrigation and its sustainability (Mekonnen and Hoekstra, 2016). This situation requires, among other things, the efficient management of water to avoid its waste. It is estimated that gross irrigation requirements will face an increase between 4 and 18% if irrigated agriculture does not adapt to these changing climate conditions (Fader et al. 2016).

Different adaptation strategies have been reported in the Mediterranean region, including more efficient irrigation systems in response to water scarcity, such as drip and sprinkler irrigation systems, selection of cultivars more resistant to abiotic stress, and appropriate irrigation scheduling.

In the framework of the PRECIMED project, a review of some water management tools to improve irrigation scheduling is achieved. The water management tools considered are the Diviner 2000, the Drill and Drop probes and the water balance model that take into account climatic conditions, soil and plant characteristics and irrigation. In this context, some soil water measurements have been performed in the field allowing the characterisation of irrigation as applied by farmers in irrigated and rainfed agriculture. For rainfed agriculture, in the case of wheat, the climatic conditions recorded during the growing season 2018-2019 are presented in Fig. 1.

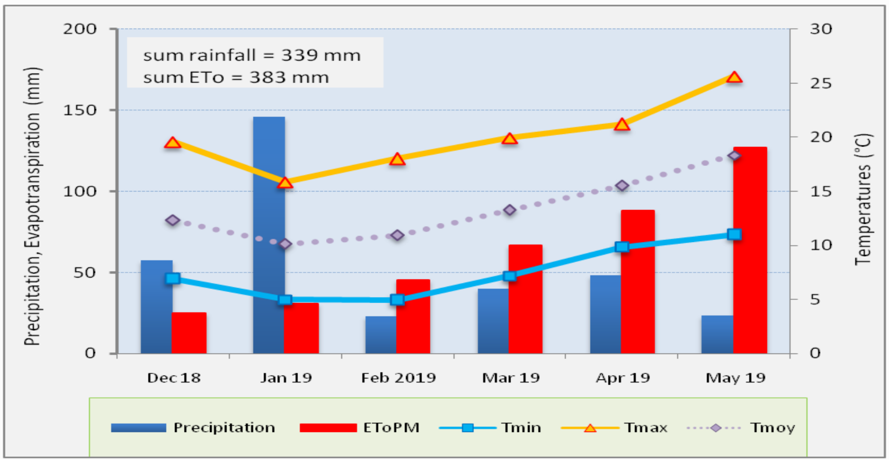

Figure 1. Evolution of climatic parameters in Mitidja region, Baraki, Algiers during year 2019.

After a very wet month of January (146 mm), the four successive months were relatively dry (average rainfall/month was 34 mm vs. 82 mm/month for evapotranspiration).

Under these climatic conditions, the evolution of water content per 10 cm of soil layer and the accumulated soil water storage from 0 – 60 cm are reported respectively in Figures 2 and 3, respectively.

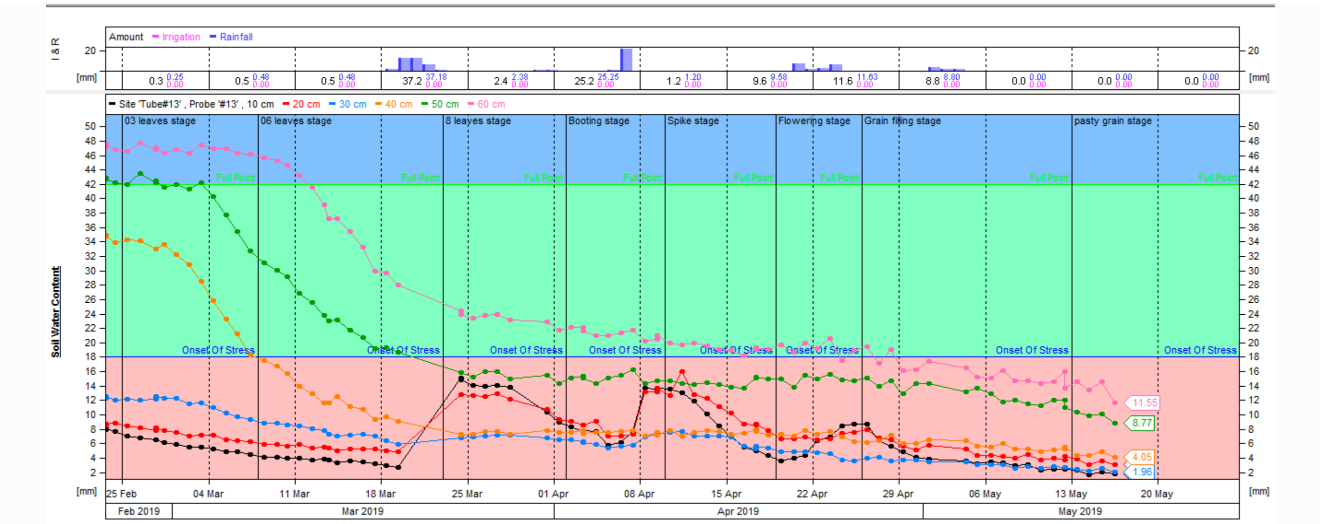

Figure 2. Evolution of water soil content in each soil layer during the growth cycle of wheat (year 2019) (mm)

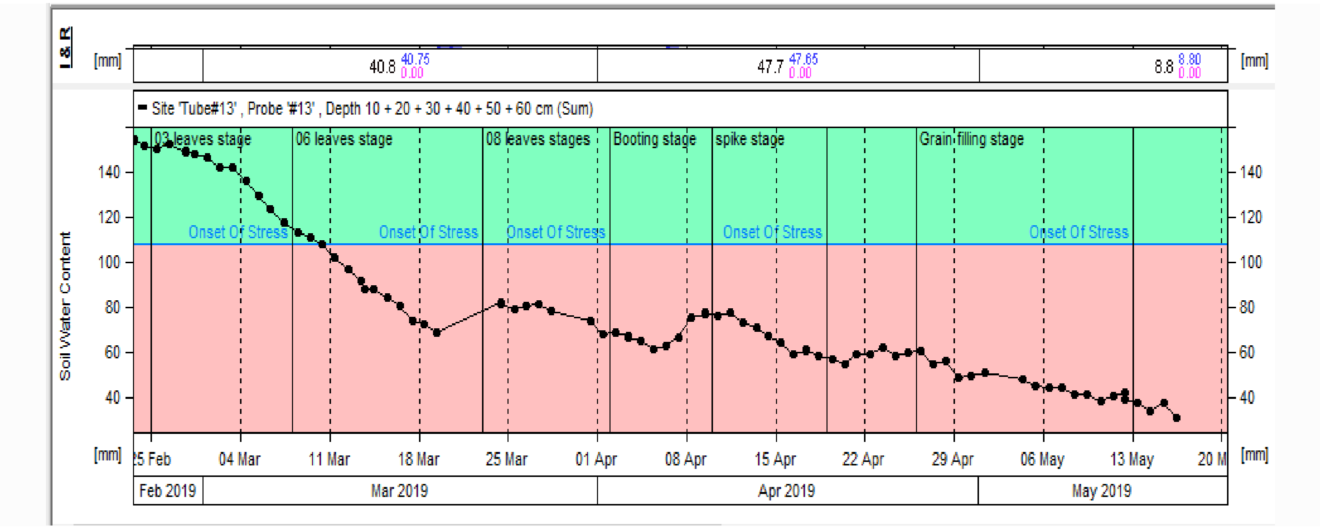

Figure 3. Evolution of soil water storage under wheat crop at the depth of 0 – 60 cm (mm)

Globally, at the beginning of the wheat cropping cycle, soil water content to a depth of 30 cm was below the wilting point but was at field capacity for the deep layers of wheat from 30 – 60 cm up to the growing stage of the wheat of the 08 leaves (Fig. 2). These conditions may affect crop establishment. From the flowering stage to harvest, the crop faced severe water stress. In these conditions, supplemental irrigation will be required.

Simulation of soil water content using the FAO AquaCrop model confirms the evolution of soil water content (Fig. 4). The results showed a period of water stress due to excess water during the month of January followed by a second period affecting leaf expansion and finally, the crop experienced severe water stress affecting stomatal closure.

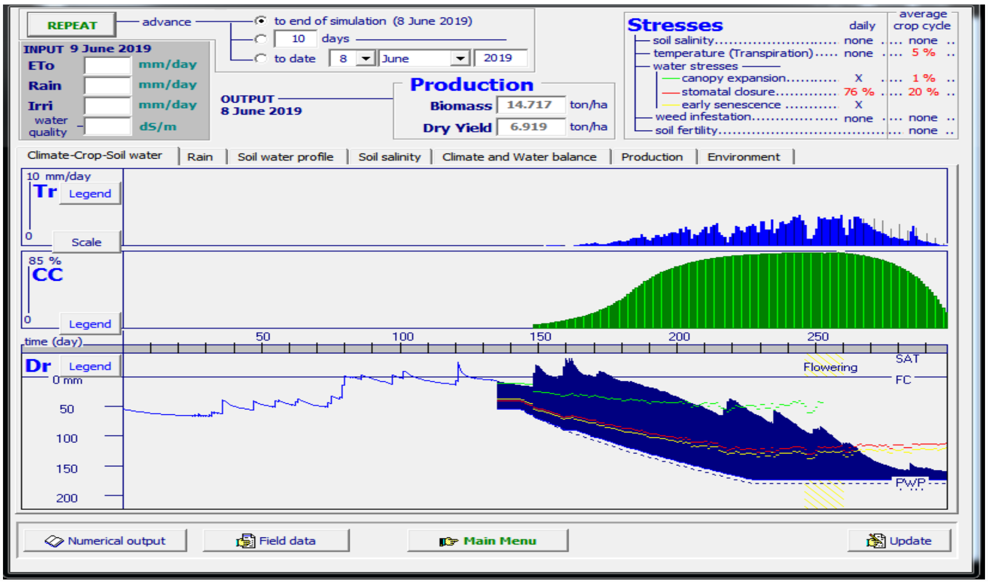

Figure 4. Simulation of soil water content using FAO AquaCrop model.

For irrigated agriculture, in the case of citrus, the soil water content of different soil layers measured with the Diviner 2000 is presented in Fig 5. Figures 5 and 6 show that, at the farm level, irrigation varied from year to year. This situation indicated the necessity of the adoption/dissemination of irrigation water management tools to save water.

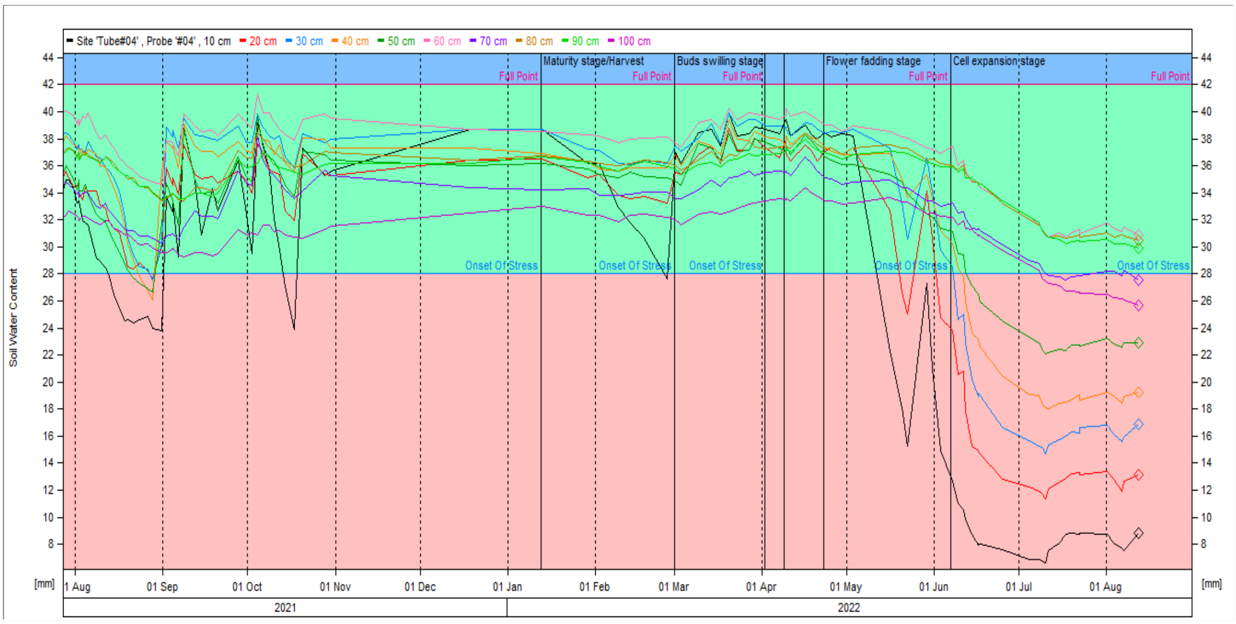

Figure 5. Evolution of soil water content of different soil layers from 10 to 120 cm during the period from July 2021 to August 2022, Mitidja region, Algiers

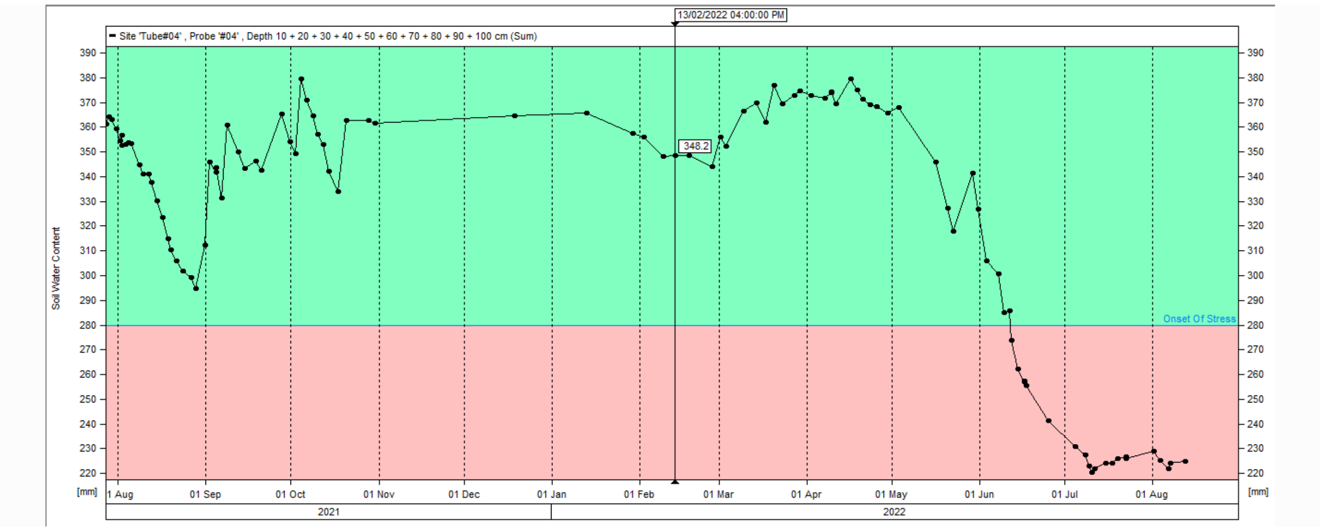

Figure 6. Evolution of soil water storage at depth 0-100m of citrus crop during the period from July 2021 to August 2022, Mitidja region, Algiers

2.3.Conclusion

As it has been mentioned in this document, one of the main challenges in the agricultural sector in the Mediterranean basin is water scarcity. This is the reason why the trend of today's irrigation systems is towards precision irrigation based on specific crop-soil indicators, being necessary to improve the interpretation of the data obtained and thus transfer this knowledge to farmers, in order to control their fertigation equipment and strategies efficiently.

Therefore, to deal with these issues and optimise risks and yields, tools such as the DSS which is being developed under the frame of this project, might play an important role in the sector. However, given the heterogeneity of the Mediterranean agrarian system, not only due to crops but also due to the different characteristics of the farms, we face a challenge in being able to carry out these highly competitive technologies to the end-users. So far, we are validating this technology in our pilot farms and it is expected that PRECIMED DSS will be able to run not only on the crops or scenarios cited in this document, but also in other types of greenhouse and open field crops.

Annex I

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Annex IV

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