DELIVERABLE 2.1

Citrus production conditions (public)

Citrus production conditions:
Report on current requirements, challenges and opportunities for innovation within citrus (by-products) supply chains

October 2022

Work package	**WP 2:** Eliciting requirements, challenges, and opportunities for adoption of innovation through IKH.
Task	**T2.1:** Citrus production conditions in Mediterranean region based on local specificities (North Africa).
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Abstract

A sustainable citrus cropping system requires increasing water use efficiency and enhancing knowledge of crop water use. This prerequisite is more pronounced in the regions qualified as climate change hotspot such as the Mediterranean region. Therefore, this study aimed to investigate citrus climatic conditions in the region of North Africa as well as at finding the water requirement of citrus trees. To reach this goal, a descriptive method which describes the crop water requirement (*CWR*) affecting the citrus productivity using the FAO software CROPWAT 8.0; it requires the implementation of agrometeorological, cultural and soil data. Soil texture, because of its tight relation to the CWR, is the most investigated in this study.

The results show a disparate *CWR* of citrus according to climate differences between North African regions and the values go from 297 mm/year in Algiers to 1739 mm/year in Cairo. The *CWR* projection to 2050 shows an increment of 6 to 22%. Additionally, Agricultural Stress Index has been used and has shown that the flowering, which is most sensitive phonological stage, is particularly threatened by drought during the first decade of March 2022.

A predictive study has been carried out as well by using climatic models concerning Mediterranean region. The data, mainly temperature and rainfall has been modified consequently and reintroduced in CROPWAT. The results foresee 6 to 22% of irrigation requirement increment in the study region and Egypt is the most affected.

1 Introduction

Citrus is a genus of flowering trees and shrubs, which belongs to the family of Rutaceae. Plants in the genus produce citrus fruits, including the most important crops such as: Oranges, Tangerines, Lemons, Limes and Grapefruits. The genus *Citrus* is native to the Southeast of Asia, Melanesia and Australia characterized by fairly hot and wet climates. Despite the dry season of Mediterranean climate, it offers ideal conditions for citrus crops.

From an economic point of view, citrus rank first in terms of world fruit production and international trade value. Citrus fruits are cultivated in many countries around the world (140 countries), although production shows geographical concentration in certain regions such as the Mediterranean region leading by Spain then Egypt and Turkey (**Figure 1.**).

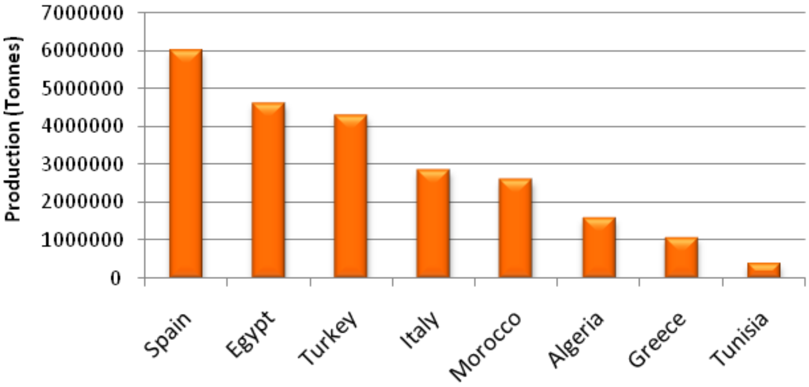


Figure 1. Ranking citrus production in few Mediterranean countries in 2019 (data source: FAO, 2021).

Mediterranean citrus production represents about 20% of the world total production. This production is mainly composed of sweet oranges and mandarins-like fruits mainly for fresh consumption and secondarily for agro-industry (Wilson, 2018). However, farmers struggle against environmental conditions in particular drought, pests and diseases. A better knowledge of the ecology of citrus trees and citrus fruit production may improve agronomic efficiency in the framework of sustainability.

2 General Growth Conditions of Citrus Production

2.1 General considerations

Citrus and its related genera, i.e., *Poncirus*, *Eremocitrus*, *Fortunella*, and *Microcitrus* belong to the same family of Rutaceae (Ghada *et al*. 2019). Due to its tropical and sub-tropical origins, citrus requires a suitable climate for quality production (Khan and Khan, 2021) which extends from the equator to above 40° latitude both North and South, where the risk of prolonged freezing temperatures is low. Countries located in latitude of 20° and higher supply the bulk of the world production (Davenport, 1990; Albigo *et al.,* 2019; Khan and Khan, 2021). According to the FAO statistics (FAO, 2021), Mediterranean citrus production represents about 20% of the world total production. This production is mainly composed of sweet oranges and mandarins-like fruits mostly for fresh consumption and secondarily for agro-industry (Wilson, 2018). Hence, citrus agriculture represents in the Mediterranean countries a major source of revenue to a large number of people. It is a source of employment at various levels from production till the supply chain of agro-industry. In addition, traditional cultivation system of citrus is labour intensive and plays a role as a driving force to the economy of the Mediterranean region (Duarte *et al.*, 2016), especially in North Africa.

It is in Mediterranean and semi-tropical climates that citrus fruits acquire the brightest colours, smoothest peel, and optimum balance of sugars and acidity, perfect for the fresh fruit market. Navel and blood oranges, as well as lemons, are mainly confined to Mediterranean climates. Citrus production in quantity and in quality is tightly linked with climatic factors particularly low temperature and drought (Albigo *et al.,* 2019; Ghada *et al*. 2019; Khan and Khan, 2021). Low temperature restricts geographical citrus cultivation to coastal regions with elevation lower than 400m above sea level. The Mediterranean region suffers from recurrent drought episodes, resulting in highly variable rainfed production and in conflicts over water for irrigation.

According to ECOCROP database (https://gaez.fao.org/pages/ecocrop) the ecological requirements of citrus are shown in **Table 1**.

Table 1. ECOCROP data sheet for *Citrus aurantium* (https://gaez.fao.org/pages/ecocrop-find-plant)

Ecology							
	Optimal		**Absolute**			**Optimal**	**Absolute**
	Min	Max	Min	Max	**Soil depth**	deep (>>150 cm)	medium (50-150 cm)
Temperat. requir. (°C)	25	30	12	42	**Soil texture**	medium, light	heavy, medium, light
Annual rainfall (mm)	1200	1400	350	2000	**Soil fertility**	moderate	low
Latitude(°)	-	-	30	40	**Soil Al. tox**		
Altitude(m)	---	---	-	1000	**Soil salinity**	low (<4 dS/m)	low (<4 dS/m)
Soil pH	6	7	5.5	8.3	**Soil drainage**	well (dry spells)	poorly (saturated >50% of year), well (dry spells), excessive (dry/moderately dry)
Light intensity	very bright	very bright	very bright	clear skies			

2.2 Cultivation conditions in North Africa

2.2.1 Climatic conditions

According to Koeppen-Geiger climate classification (KG level-2) North African region is under *Cs* climate type coined as *Warm temperate, dry summer* (FAO and IIASA, 2021). A shortage of water may have the following effects (Rosenzweig *et al*. 1996):

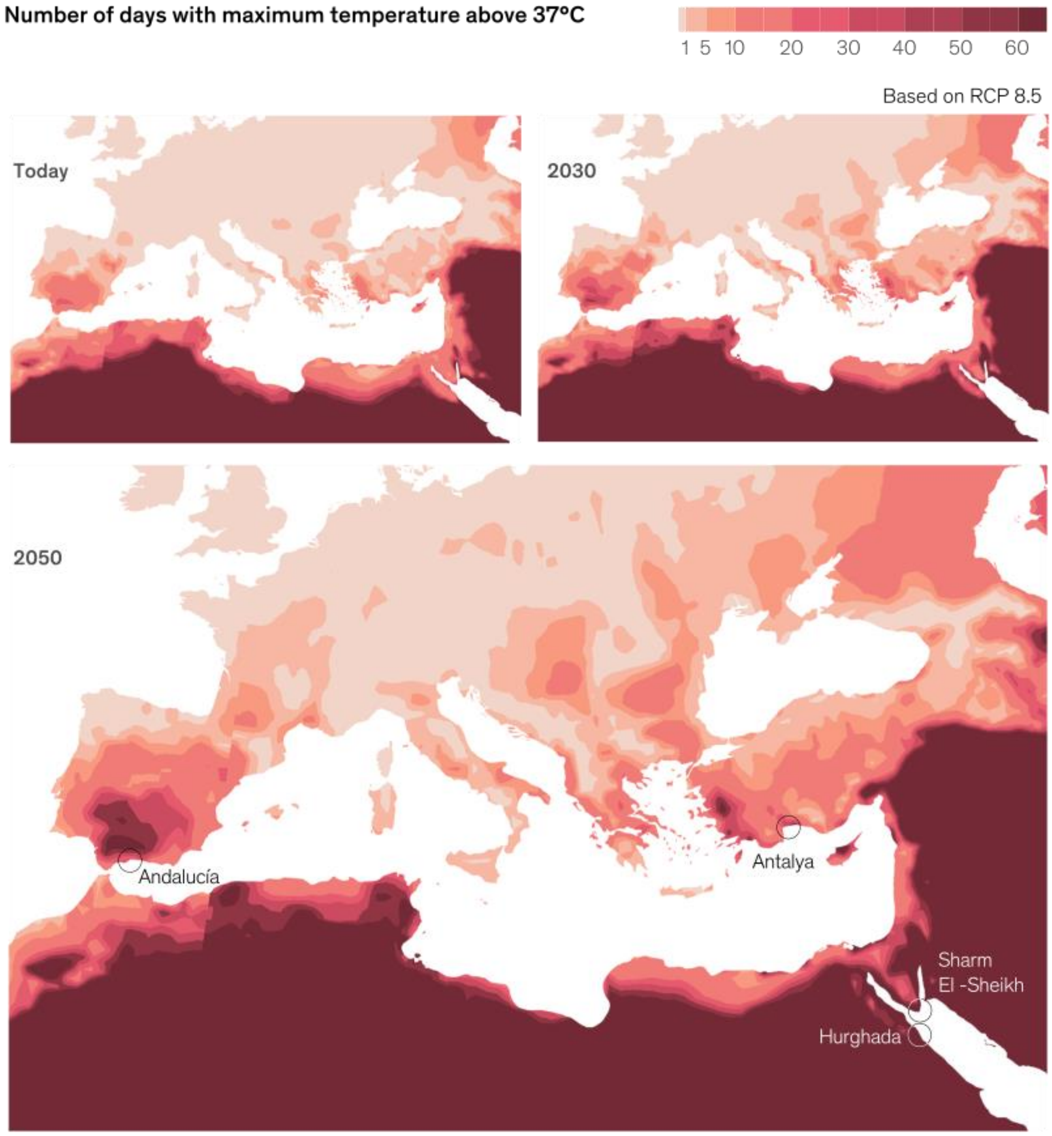
- ✓ Water stress during spring while the tree is flowering could result in excessive drop of flowers and fruitlets, and the crop will be unsatisfactory. A serious drought followed by good rains could produce out-of-season flowering and fruit setting.
- ✓ Citrus is also vulnerable to high temperatures. Excessively warm temperatures during the bloom or early fruit set period are known to induce fruit abscission.
- ✓ A lack of moisture during October to January could result in acid fruit.
- ✓ Fruit quality, with respect to both development of sugars and colour, is also greatly influenced by temperature, with tree-storage time decreased and rind re-greening increased as temperatures rise.

Hence, irrigation of citrus in the North West African countries (Morocco, Algeria, Tunisia and Egypt) is not a choice since citrus water demand is around 1200mm/year and citrus cultivation regions receive rainfall on the average between 300 to 600mm/year occurring from October to April. Therefore, North African region presents 900 to 600mm/year of water deficit that must be overcome between May to September, a period where reference evapotranspiration (ET_0) demand is very high.

- **Climate change 'hotspot'**

The global climate change is already a reality that must be taken into account. But some regions are particularly affected. These so-called "hotspots" are areas where strong physical and ecological effects of climate change come together impacting notably agriculture (Cos *et al*., 2022). Although global climate models vary in many ways, they agree on this: The western Mediterranean region will be significantly drier in coming decades, potentially seeing 40% less precipitation during the winter rainy season December – January – February (DJF) and 20 to 30% in the eastern Mediterranean region. Winter precipitation is key to the region's agriculture and economy, with its future of paramount importance for the Mediterranean's countries (Tuel and Eltahir, 2020; Cos *et al*., 2022).

Models show also significant warming in summer June – July – August (JJA) by 3 to 4°C for the upcoming century (Tuel and Eltahir, 2020; Cos *et al*., 2022). **Figure 2** shows temporal evolution of the number of days with maximum temperature above 37°C.



Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multimodel ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.
Source: EURO-CORDEX RCM ensemble; Woods Hole Research Center

McKinsey & Company

Figure 2. Number of days with maximum temperature above 37°C in the Mediterranean Region (source: www.mckinsey.com)

Citrus, being a perennial woody plant, offers little possibility for short-term adaptation to climate change through management and farming techniques because timing of phenological stages is not under the control of the farmer.

2.2.2 Soil conditions

According to the FAO/UNESCO soil map of the world, chromic cambisols, calcic cambisols, calcaricfluvisols, and eutricfluvisols are the main bearing soils of the North West African citrus orchards. FAO soil class can be used as good indicators in agronomic point of view, but they are not enough. Physical and chemical soil characteristics are considered for the top-soil (0 – 30cm), include: soil textural class, pH, cation exchange capacity of soil, calcium carbonate content.

- **Soil Texture**

Soil capacity to support life and to produce economic goods and services is strongly linked to the maintenance of good soil physical quality (Di Prima et al., 2018). The physical quality of a soil is strongly linked to its texture which is determined by the relative proportions of sand, silt, and clay. Texture determines soil structure which has a major influence on the ability of soil to receive, store and transmit water, the dispersal of chemicals fertilizers, and soil aeration. This is especially important for citrus species, their roots are hungry for oxygen, and hence pushes the feeder roots close to the soil surface. Thus, shallow tillage with disc harrows (**Figure 3**) must be practiced with great care particularly on heavy soils. However, a recent study (Di Prima *et al.*, 2018) has shown that the best practice to improve soil physical quality under citrus crop is manure from sheep and goat.

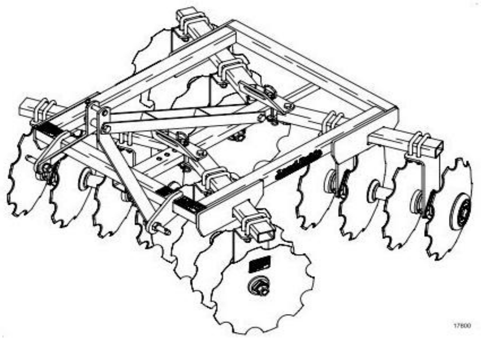


Figure 3. Representative scheme of a disc harrows.

- **Soil moisture balance**

The volume of water available for plant uptake is calculated by means of a daily soil water balance (*Wb*). The *Wb* accounts for accumulated daily water inflow from precipitation (*P*) or snowmelt (*Sm*) and outflow from actual evapotranspiration (*ETa*), and excess water lost due to runoff and deep percolation (*We*) (FAO and IIASA, 2021). Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. In the **Figure 4**, the root zone is presented by means of a container in which the water content may fluctuate.

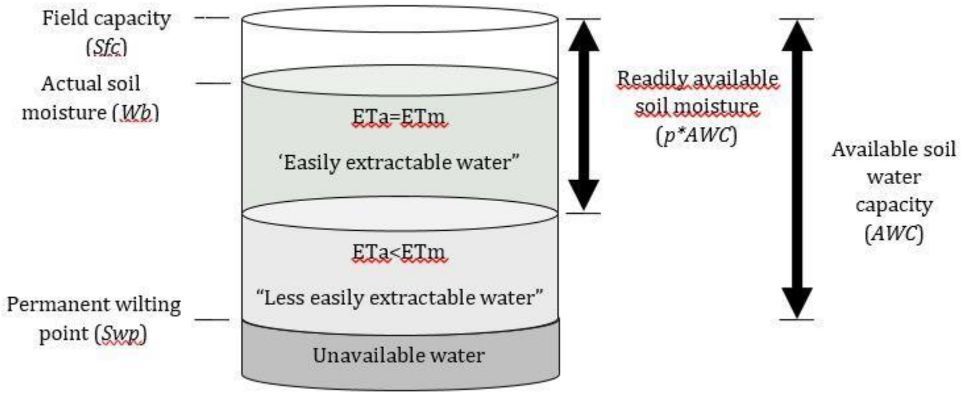


Figure 4. Schematic representation of water balance calculations (source: FAO and IIASA, 2021).

3 Methodology

The study is carried out by using the FAO software CROPWAT which calculates the crop water requirement (*CWR*) and irrigation scheduling for citrus crop based on agrometeorological data. The result of the study will be useful in calculation of agricultural water demand of the study area as the first part of the study. In the second part, we will try to make *CWR* projection in 2050 by using results from global climate change models concerning the Mediterranean area.

3.1 Computerized crop water use simulations (CROPWAT)

Computer programs have been developed for the estimation of reference crop evapotranspiration from agrometeorological data and allow the development of standardized information and criteria for planning and management of rainfed and irrigated agriculture. The FAO CROPWAT program (Smith, 1992) incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate, crop, and soil conditions.

CROPWAT integrates several agrometeorological parameters, such as geographic coordinates of the area, surface temperature (max. and min.), Relative Humidity (RH - max. and min.), wind speed, and solar radiation/sunshine hours, and calculates the ET_0 and crop evapotranspiration (ETc) by considering different climates, crops, and soil structure types. If the data is not available, the model has the provision of calculating the unknown parameters of the RH and wind speed based on the available known parameters.

CROPWAT 8.0 for Windows has been used for the calculation of citrus water requirements (*CWR*) and irrigation requirements from existing climatic data retrieved from CLIMWAT 2.0[1] for CROPWAT, and citrus crop data e.g. *Kc* (for definition see below). Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

Additionally to CLIMWAT data, we have used an adjusted data following climatic models in order to forecast *CWR* till 2050.

- **Climatic models data:** As aforementioned, significant warming is expected in summer (JJA) by 3 to 4°C for the upcoming century (Tuel and Eltahir, 2020; Cos *et al*., 2022). The same models show a decreased frequency of winter (DJF) precipitation of 30 to 40% in North Africa. Due to the high number of scenarios and models, we have chosen in this study to use the worst scenario with 4°C increment in the total year and 40% decrease of rainfall in order to estimate future *CWR* and citrus production. The input climate data are modified according to these previsions. By assuming that both temperature increment and precipitation decrease follow a linear progression all along the century; so in 2050 we will reach +2°C and -20% of precipitations. These two values have been applied for Algeria, Tunisia and Egypt, in the case of Morocco and because of the influence of the Atlantic the drought is less severe for Rabat-Salé and Casablanca so we suggest +1.6°C and -15%, for Marrakech +2°C and -15% and finally we suggest for Oujda +2°C and -20% the same as in Algeria and Tunisia.

- **Crop water requirements (*CWR*):** The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration under standard conditions (*ETc*) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

- **Crop evapotranspiration under standard conditions (*ETc*):** represents the evapotranspiration from disease-free, well-fertilised crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. *ETc* is calculated in proportion to reference potential evapotranspiration (ET_0),

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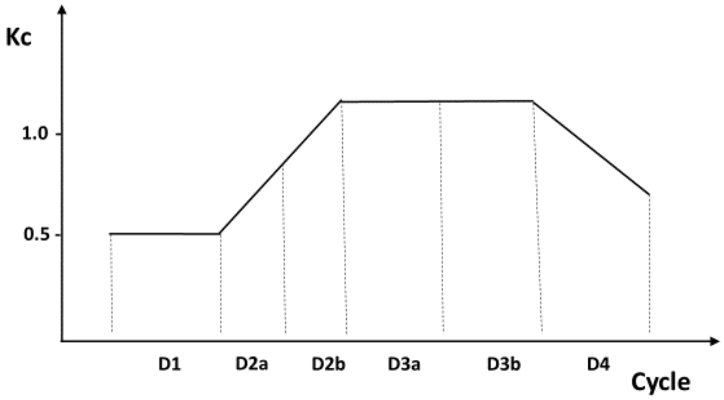
[1] CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT and allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. CLIMWAT is developed by FAO.

multiplied by crop and crop-stage specific parameters '*Kc*'. The values of *Kc* for different stages of crop development (**Figure 5**) are given as input parameters (Allen *et al.*, 1998).

$$ETc = Kc \times ET_0$$

➢ **Crop coefficient (*Kc*):** The Crop coefficient (*Kc*) integrates the effect of characteristics that distinguish a specific crop from the Reference crop. According to the Crop coefficient approach, Crop evapotranspiration under standard conditions (*ETc*) is calculated by multiplying the Reference evapotranspiration (ET_0) by the suitable *Kc*.

Figure 5. Schematic representation of *Kc* values for different crop development stages.



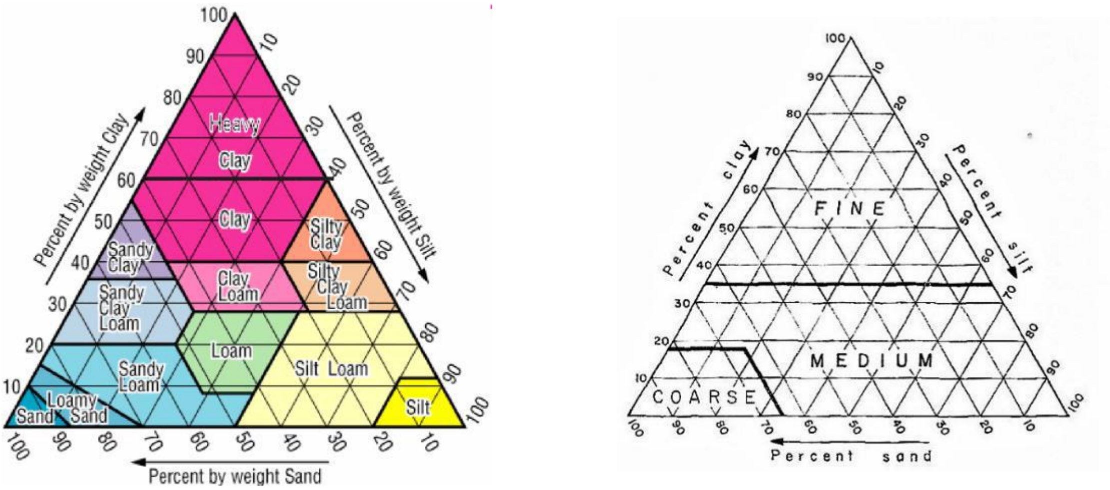
- **D1:** Initial phase: from planting to 10% ground cover (from planting/germination/emergence to establishment);
- **D2a:** early crop development stage;
- **D2b:** late crop development stage;
- **D3a:** early mid-season stage (flowering);
- **D3b**: late mid-season stage (reproductive stage), and
- **D4:** late season stage (start maturation to full maturity).

Kc is influenced mostly by crop type and to a minor extent by climate and soil evaporation. Moreover, the *Kc* for a given crop varies over the crop growing stages, since ground cover, crop height and leaf area change as the crop develops.

➢ **Reference evapotranspiration (ET_0):** The reference evapotranspiration (ET_0) represents evapotranspiration of well-watered grass of uniform height (12cm), actively growing and completely shading the ground. The ET_0 is calculated with the Penmann-Monteith equation. The purpose of calculating ET_0 is to assess irrigation needs and determine irrigation schedule (FAO and IIASA, 2021).

➢

- **Soil texture:** It indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. Texture influences the ease with which soil can be worked, the amount of water and air it holds and the rate of which water can enter and move through soil as such it influences the following soil qualities: nutrient availability, nutrient retention, rooting conditions and soil workability. Soil texture is also an important factor for determining soil drainage (FAO and IIASA, 2021). Usually, soil classes are determined by using soil triangle texture. The most used is the USDA (United States Department of Agriculture) soil triangle texture (**Figure 6 (a)**), it shows 13 textural classes, these classes are grouped into 3 main soil textural groupings (Fisher *et al.*, 2021) (**Figure 6 (b)**):



(a) **(b)**

Figure 6. The USDA Soil textural triangle **(a)** and Soil textural groupings **(b)** (Fisher *et al.*, 2021).

CROPWAT requires introducing soil textures:

- Heavy: for fine texture
- Medium: for medium texture
- Light: for coarse texture

3.2 An agriculture drought monitoring system (ASIS)

During the last four decades, drought has affected the most human activities especially agriculture than any other natural hazard. Recent prediction models show an exacerbation of the drought phenomenon with an increased frequency and intensity due to the global climate change. According to the Food and Agriculture Organization of the United Nations (FAO), 83% of all damages and losses caused globally by drought between 2006 and 2016 have been absorbed by agriculture, putting a large part of the world's population at risk of food insecurity and hunger (Rojas, 2021).The FAO has developed an agricultural drought monitoring and early warning system, called agriculture stress index system (ASIS), to support individual countries to monitor and manage agricultural drought and the risks it entails. ASIS uses satellite data to detect agricultural areas in which drought poses a severe threat to crops and livestock (Van Hoolst *et la.*, 2016; Rojas, 2021).

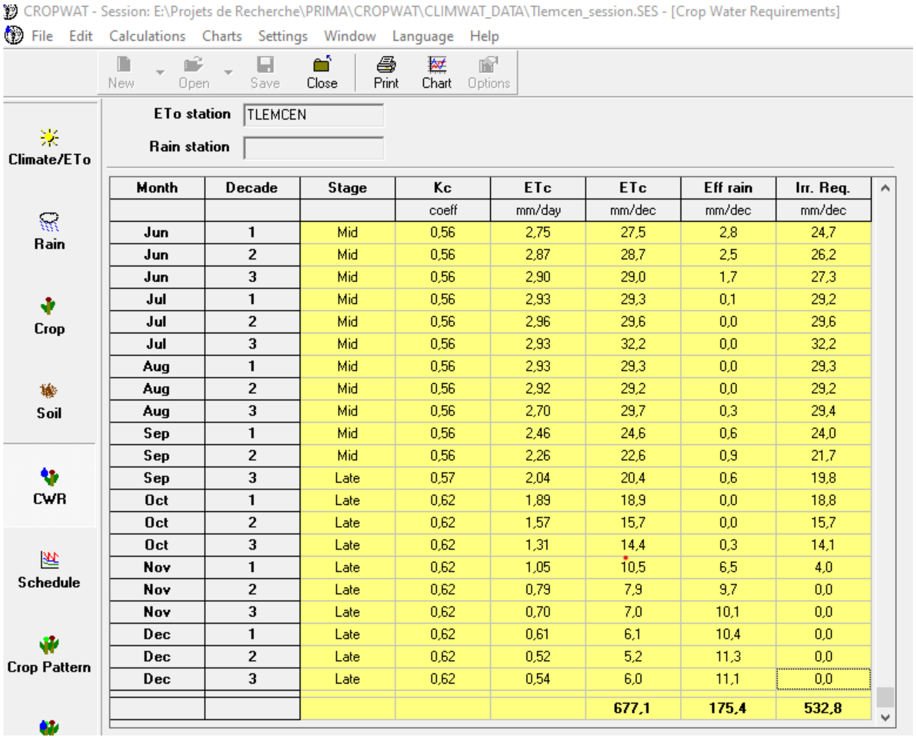
4 Results and Analysis

4.1 Soil Texture:

The bulk of North West African citrus orchard soils show a medium to fine texture while the optimum should be coarse to medium. However, an exception is noted concerning the Nile delta in Egypt where fluvisols show coarse texture which is in optimal requirements of citrus.

4.2 Crop Water Requirement results from CROPWAT 8.0

Irrigation is applied at critical depletion and it refills soil to field capacity (*sfc* in **Figure 4**). **Figure 7** shows computation of crop water requirement of Citrus in the particular case of Tlemcen (NW of Algeria).



CROPWAT - Session: E:\Projets de Recherche\PRIMA\CROPWAT\CLIMWAT_DATA\Tlemcen_session.SES - [Crop Water Requirements]

ETo station: TLEMCEN

Rain station:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Mid	0,56	2,75	27,5	2,8	24,7
Jun	2	Mid	0,56	2,87	28,7	2,5	26,2
Jun	3	Mid	0,56	2,90	29,0	1,7	27,3
Jul	1	Mid	0,56	2,93	29,3	0,1	29,2
Jul	2	Mid	0,56	2,96	29,6	0,0	29,6
Jul	3	Mid	0,56	2,93	32,2	0,0	32,2
Aug	1	Mid	0,56	2,93	29,3	0,0	29,3
Aug	2	Mid	0,56	2,92	29,2	0,0	29,2
Aug	3	Mid	0,56	2,70	29,7	0,3	29,4
Sep	1	Mid	0,56	2,46	24,6	0,6	24,0
Sep	2	Mid	0,56	2,26	22,6	0,9	21,7
Sep	3	Late	0,57	2,04	20,4	0,6	19,8
Oct	1	Late	0,62	1,89	18,9	0,0	18,8
Oct	2	Late	0,62	1,57	15,7	0,0	15,7
Oct	3	Late	0,62	1,31	14,4	0,3	14,1
Nov	1	Late	0,62	1,05	10,5	6,5	4,0
Nov	2	Late	0,62	0,79	7,9	9,7	0,0
Nov	3	Late	0,62	0,70	7,0	10,1	0,0
Dec	1	Late	0,62	0,61	6,1	10,4	0,0
Dec	2	Late	0,62	0,52	5,2	11,3	0,0
Dec	3	Late	0,62	0,54	6,0	11,1	0,0
					677,1	**175,4**	**532,8**

Figure 7. Computation of *CWR* for citrus in Tlemcen (NW of Algeria), retrieved from CROPWAT 8.0.

The results show that a total irrigation requirement of citrus is 532.8mm and the total *Etc* is 677.1mm/year and can be scheduled from the second decade[2] of February to the first decade of November with a peak of irrigation in the second decade of July with 33.7mm; that means a volume of 33.7litres/m². With flood irrigation system that is commonly used in North African countries it is quite difficult to monitor the quantity of water.

Table 2. Results table for the actual requirement and the 2050 projection for citrus crop in some North West African stations. **Eff. rain**: Effective rain is the part of rain water stored in the root zone and can be used by the citrus. **Irr. Req**.: Irrigation requirement

		Actual			**Projection 2050**		
	Stations	**ETc (mm/year)**	**Eff. rain (mm/year)**	**Irr. Req. (mm/year)**	**ETc (mm/year)**	**Eff. rain (mm/year)**	**Irr. Req. (mm/year)**
Morocco	Casablanca	570.3	391.7	311.5	595.6	337.8	351.6
	Rabat-Salé	850.7	485.3	507	890.7	421.1	563.3
	Marrakech	1074.9	226	854.1	1126.9	193.2	939.1
	Oujda	1039.7	317.7	722.3	1095.4	257.5	837.9
Algeria	Tlemcen	729.1	246	556.8	763	199.3	613.8
	Mohammadia	701.4	269.1	474.2	742.1	219.1	535.5
	Algiers	673.2	598.3	297.1	716.6	492.5	363
	Annaba	692.7	545	362.9	733.6	447.4	420.3
Tunisia	Kélibia (Cap Bon)	916.6	186.5	765.6	969.2	151.7	828.3
Egypt	Cairo	1734.9	26.1	1739	1834.5	21	1834.7
	Mansoura	965	53.4	923.2	1011.5	42.8	980.7
	Tahrir	1171.3	34	1150.7	1238.5	27.2	1225.4
	Sakha	877.2	64	813.2	921.4	51.4	870
	Ismailia	1369.8	36.9	1350	1438.7	29.6	1427

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[2] Decade: successive 10 days of a given month, so a month contains 3 decades.

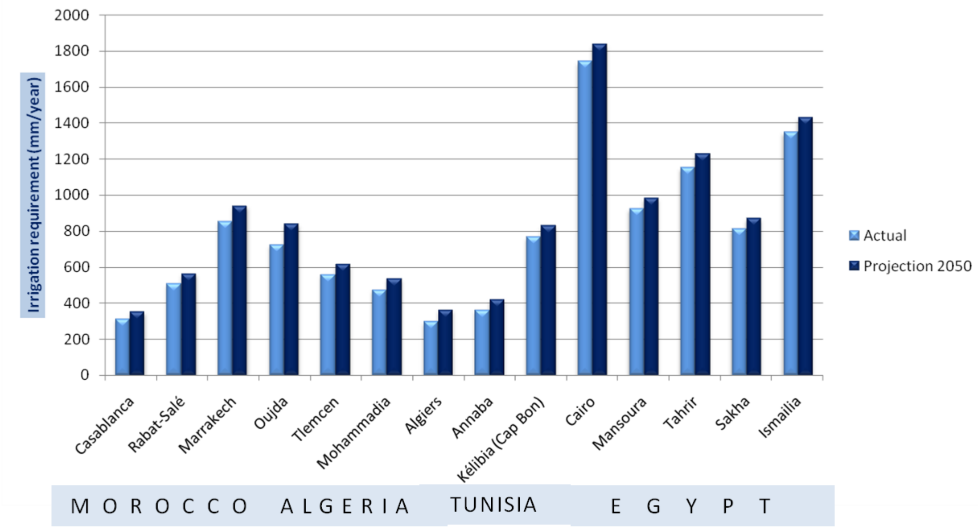

Figure 8. Irrigation requirement results for citrus crop of the different stations in North Africa and the projection in 2050.

Figure 8 represents the irrigation requirement for citrus crop in North West Africa carried out with CROPWAT 8.0. The global warming projection to 2050 is responsible for 6 to 22% of irrigation requirement increment; Egypt is the most affected.

4.3 Agricultural Stress Index (ASI)

For drought monitoring, it is important to focus on the periods most sensitive to water stress, such as the flowering and fruit set phases. Citrus has a phenological life cycle of the whole year, starting from February to next year January. Flowering starts during March-April and is generally considered a critical period for citrus.

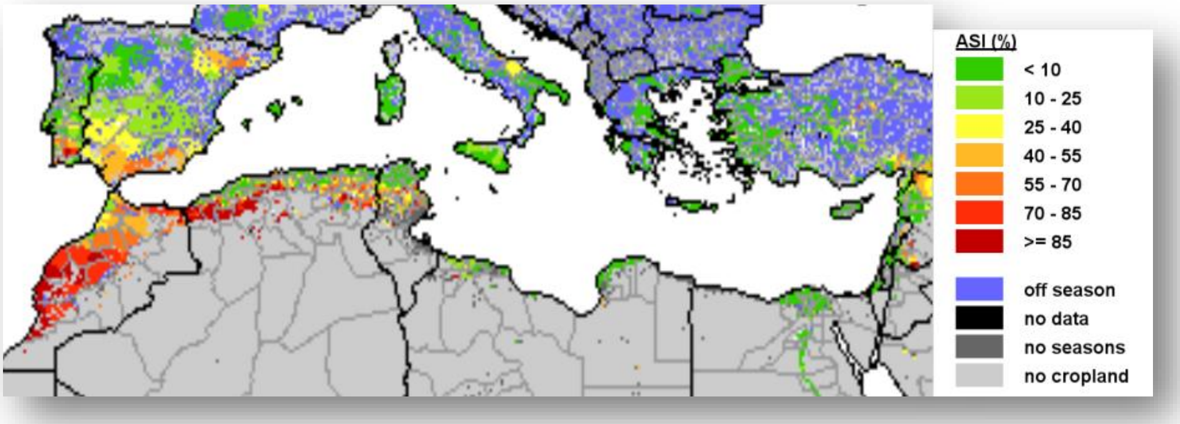

Figure 9. Agricultural Stress Index (ASI) representing the percentage of cropland area affected by severe drought from the beginning of season 1 to decade 1 of March 2022.

The **Figure 9** shows the Agricultural Stress Index (ASI) of the Mediterranean region. In the beginning of March 2022, a severe drought has been affected almost the whole of Morocco and a big part of Algeria, particularly in the western regions, posing a severe threat of citrus production. The main citrus areas of Tunisia (Cap Bon) and of Egypt present an ASI < 10%, hence Tunisian and Egyptian citrus orchards are much less affected by severe drought during this period.

5 Conclusion

There is no doubt that global climate change in the Mediterranean region is evolving toward drought which threatens agricultural systems, particularly citrus crop production. Mediterranean climatic conditions host two main crop production systems, rain-fed and irrigated; citrus belongs to the latter making irrigation one of the key issue of quantitative and qualitative citrus crop production. Hence additional challenges to farmers include the responsibility for maintaining natural resources especially water resources.

The present study focused attention on a possible use of the FAO CROPWAT 8.0 software to monitor citrus crop irrigation in North African countries (Morocco, Algeria, Tunisia and Egypt) both for present and future climate changes. The results show that all the studied countries are closely dependent on irrigation at different levels. Egypt is the most dependent followed by Tunisia, Morocco and finally Algeria. Regarding the working scale (regional scale) the results are presented solely for information purposes.

Regarding ASI the presented map shows a clear water shortage in the western Mediterranean including Morocco and Algeria. This might have an impact on the future production costs corresponding to water irrigation surplus and installation of water-saving techniques.

A great deal more work is yet be done to improve the methods and techniques to be applied on a field scale for more accurate data and greater irrigation efficiency.

Document metadata

Title of Deliverable	Citrus production conditions: Report on current requirements, challenges and opportunities for innovation within citrus (by-products) supply chains
Deliverable No.	D2.1
Work Package	WP2
Dissemination level	Public
Type	Report
Keywords	Citrus production, citrus harvesting, climate change, crop water requirements, citrus supply chain, sustainability
Target Group	Academia, Industry, Policymakers, Public
Contractual Delivery Date	30.11.2021
Actual Delivery Date	31.10.2022
Version	1.0
Persistent Identifier (DOI)	10.17185/duepublico/77097
Project title	Innovation in the By-ProdUct Supply chain of citrus in Mediterranean area (ImPUISe)
Grant Program	Partnership for Research and Innovation in the Mediterranean Area (PRIMA)
Corresponding authors	Lotfi Mustapha KAZI TANI (BAUT) Fatima YOUCEFI (BAUT) Ahmed TAÏBI (BAUT)
Internal Reviewer	Nermine Harraz and Diaa El-Ansary (Alexandria University)
Approved by	Denis Daus, UDE ZLV GF ImPulSe coordinator

Version history

Version	Date	Description
0.1	31.07.2022	First version sent by Lotfi Kazi Tani
0.2	16.09.2022	Revision by Nermine Harraz and Diaa El-Ansary
0.3	19.10.2022	Edited version sent by Lotfi Kazi Tani
1.0	31.10.2022	Final revision by Denis Daus and submission to PRIMA

Funding acknowledgements

ImPUISe is implemented under the umbrella of the Partnership for Research and Innovation in the Mediterranean Area (PRIMA). The PRIMA programme is an Art. 185 initiative supported and funded under Horizon 2020, the European Union's Framework Programme for Research and Innovation.

The PRIMA programme is supported and funded under Horizon 2020, the Framework European Union's Programme for Research and Innovation

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The various project partners are each funded by their national funding institution:

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DOI: 10.17185/duepublico/77097
URN: urn:nbn:de:hbz:465-20221103-111518-7