

Estimation of water requirements for potato cultivation in arid regions

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Summary : Water scarcity is one of the main challenges facing Algeria. This water stress is expected to increase in the coming years due to the combined effects of climate change and the expansion of socio-economic activities, putting increasing pressure on available water resources. In this context, market gardening, and more specifically potato cultivation, which is the second most important crop in the country after cereals, plays a strategic role in the country's food security. Grown throughout most of the country and throughout the year, this crop is highly dependent on irrigation, particularly in arid areas. The aim of this study is to estimate the irrigation water requirements for seasonal potatoes in the El Oued region, which has a Saharan climate, using the CROPWAT model and a climate series covering the period 2000-2022. The simulations revealed that daily water requirements vary between 3 and 4 mm before tuber formation, then reach 6.5 to 7.5 mm after their development. These results provide valuable benchmarks for rational irrigation management and optimisation of water supply. They serve as a decision-making tool for farmers and water managers working in arid areas, promoting the efficient use of available resources.

Key words : Climate, El Oued, irrigation, water requirements, water productivity.

Résumé : La rareté de l'eau est l'un des principaux défis auxquels l'Algérie est confrontée. Ce stress hydrique devrait s'accroître dans les années à venir sous l'effet combiné du changement climatique et de l'expansion des activités socio-économiques, entraînant une pression croissante sur les ressources hydriques disponibles. Dans ce contexte, le maraîchage, et plus particulièrement la culture de la pomme de terre, qui est la deuxième culture nationale après les céréales, occupe une place stratégique dans la sécurité alimentaire du pays. Cultivée dans la majeure partie du pays et tout au long de l'année, cette culture est fortement dépendante de l'irrigation, en particulier dans les zones arides. Cette étude a pour objectif d'estimer les besoins en eau d'irrigation de la pomme de terre de saison dans la région d'El Oued, caractérisée par un climat saharien, en utilisant le

modèle CROPWAT et une série climatique couvrant la période 2000-2022. Les simulations ont révélé que les besoins journaliers en eau varient entre 3 et 4 mm avant la formation des tubercules, puis atteignent 6,5 à 7,5 mm après leur développement. Le besoin total en eau pour un cycle complet est estimé à 712,5 mm. Ces résultats fournissent des repères précieux pour une gestion rationnelle de l'irrigation et une optimisation des apports hydriques. Ils constituent un outil d'aide à la décision pour les agriculteurs et les gestionnaires de l'eau œuvrant dans les zones arides, en favorisant une utilisation efficace des ressources disponibles.

Mots clés : Climat, El Oued, irrigation, besoins en eau, productivité de l'eau.

INTRODUCTION

Against a backdrop of global population growth, it is essential for countries to boost agricultural productivity in order to guarantee food security and stimulate economic and social development. However, the growing demand for water and the limited availability of water resources may compromise the potential benefits of the agricultural sector for economic growth (FAO, 2021). In Algeria, the agricultural sector is the main user of water, so it is crucial to manage irrigation water rationally in irrigated areas to ensure sustainable agriculture. Stakeholders in the irrigation sector, such as managers and farmers, need indicators on irrigation efficiency and water productivity in order to implement suitable strategies for sustainable water resource management (Kambou *et al.*, 2014). In this context, several scientific researchers have been done worldwide to evaluate and analyse

water productivity on different types of strategic crops, and under various environmental conditions. Delli and Mouhouche (2017) evaluated the water productivity of Algerian phoeniculture for its better use. Greaves and Wang (2017) conducted field trials in southern Taiwan to investigate yield response, water productivity and seasonal water production functions for maize under deficit irrigation water management. In Italy, Ierna and Mauromicale (2018) studied the growth, yield and water productivity of the potato crop, conducted under different irrigation and fertilisation regimes, Foley *et al.*, (2020) conducted a meta-analysis of the global crop water productivity of three major world crops (wheat, maize and rice) in irrigated areas over three decades. Market gardening is booming in the country, with a significant increase in the area cultivated and in production. In 2019, the total area under vegetable crops reached 533,060 ha, compared

with 320,100 ha in 2003. Production also increased, from 49.08 million quintals to 146.70 million quintals (MADR, 2019). Potatoes, the second most important crop in Algeria, occupy around 150,000 hectares each year, or around 30% of the total area under market garden crops (El Moudjahid, 2020). In 2000, the area devoted to potato cultivation was 72,690 ha, but this had increased to 149,465 ha by 2019. Production has also increased considerably, from 12.07 million quintals to 46.95 million quintals (MADR, 2020). Potatoes require a lot of water to grow, as their roots are large but shallow, making them susceptible to drought (Galland, 2023). It is therefore crucial to ensure that potatoes receive sufficient water during the flowering, runner formation and tuberisation periods. The wilaya of El Oued is currently Algeria's main potato producer, accounting for 25.67% of national production (MADR, 2020).

Most farmers in this region use small-scale irrigation systems for their crops. According to a study by the AFC (2022), these systems can provide 22,000 m³/0.8 ha of irrigation water for potatoes during the season for a period of 100 days. However, the FAO indicates that water requirements for potatoes vary from 5,000 to 7,000 m³/ha depending on the climate. The aim of this study is to assess water requirements for potato irrigation in the El Oued region, with a view to promoting more efficient use of water and farming practices associated with this crop.

MATERIALS AND METHODS

Presentation of the study area

The El Oued region is located in south-east Algeria, 650 km from the capital (Figure 1). It lies between 33.35° North latitude and 6.86° East longitude, at an



Figure 1. Location of the study region.

altitude of 84 metres. It occupies an area of 44586 km², representing 1.87% of the national land area (ANDI, 2014). It is bordered to the north by the wilaya of Biskra, to the east by the wilayas of Khenchela and Tebessa and by Tunisia, to the west by the wilayas of El M'Ghair and Touggourt ; and to the south by the wilaya of Ouargla.

The El Oued region has an arid Saharan desert climate, with average annual rainfall of around 62 mm/year and average evapotranspiration of around 6 mm/day. Average monthly minimum and maximum temperatures over the period 2000/2022 range from 8.10°C to 42.90°C, and average monthly relative humidity over the same period from 31.03% to 66.57%. High insolation values are observed during the dry season, with a maximum of (12.27 hours) in June, while during the rainy season, insolation reaches a minimum of 7.10 hours in December.

To define the bioclimatic stage of the study region, we used the Emberger climagram. This is a quotient based on the mean maximum temperature (M) of

the warmest month, the mean minimum (m) of the coldest month in degrees Celsius and the mean annual rainfall (P) in mm. This quotient is higher the more humid the climate of the region (Stewart, 1969). It is calculated using the following formula:

$$Q2 = 3.34 * P/(M-m)$$

Humid for $Q2 > 100$; Temperate for $100 > Q2 > 50$; Semi-arid for $50 > Q2 > 25$; Arid for $25 > Q2 > 10$; Desert for $Q2 < 10$.

Description of the CropWat model

The CropWat model is a decision-support tool developed by the FAO's Land and Water Development Division. The software was designed to calculate evapotranspiration, crop water requirements and, more specifically, the design and management of irrigation systems. Determining the water requirements of a crop requires knowledge of various parameters, including:

Table I. Emberger rainfall-thermal quotient calculated for the study regions and the corresponding bioclimatic stage

Region	Rainfall (mm)	M (C°)	m (C°)	Q2	Bioclimatic floor
El Oued	62.21	42.9	8.1	6.1	Desert

Climatic parameters

To provide an overview of the climate in the area, the climate data used comes from the NMO (National Meteorological Office) and climate sites. Measurements were taken on a monthly basis, covering minimum and maximum temperatures (°C), rainfall (mm), wind speed (m/s) at 2 m above ground level, sunshine (hours) and relative humidity (%). These parameters were used to calculate reference evapotranspiration using the FAO Penman-Monteith method (Allen *et al.*, 1998).

Soil parameters

Soil data are necessary for irrigation management to determine the useful reserve (UR), which is linked to two factors: soil texture and crop root depth (Figure 2). According to Saccon (2014), the dominant soil unit in the El Oued region is classified as "Yy1-1a" (Gypsic

Yermosols of coarse texture class), which is characterised by the following texture : sand : 96%, silt : 2% and clay 2%.

Culture related parameters

To determine a plant's water requirements, Cropwat needs to know a number of parameters specific to that plant. These characteristics (Figure 3) are the duration of each phase, a parameter that varies depending on where the crop is grown and the time of year. The software divides the life of the plant into 4 stages (initial, development, mid-season, and finally afterseason). The crop coefficient, Kc, is the ratio of crop evapotranspiration (ETm) to potential evapotranspiration (ETo). The yield response factor, Ky, which is used to estimate yield reductions due to water stress (Langlois, 2006). All the crop-related data entered into the Cropwat software are summarised in Figure 3.

The screenshot shows a window titled "Sol - C:\ProgramData\CROPWAT\data\soils\FAO\LIGHT.SOI". Inside, there is a section "Données générales sur le sol" with the following fields:

Nom du sol	
Light (sand)	
Données générales sur le sol	
Eau disponible totale (CC - PF)	60.0 mm/mètre
Taux d'infiltration maximum de l'eau de pluie	40 mm/jour
Profondeur maximum d'enracinement	60 centimètres
Épuisement de la teneur en eau initiale (en % TAM)	0 %
Eau disponible initiale	60.0 mm/mètre

Figure 2. Soil data requested by CropWat.

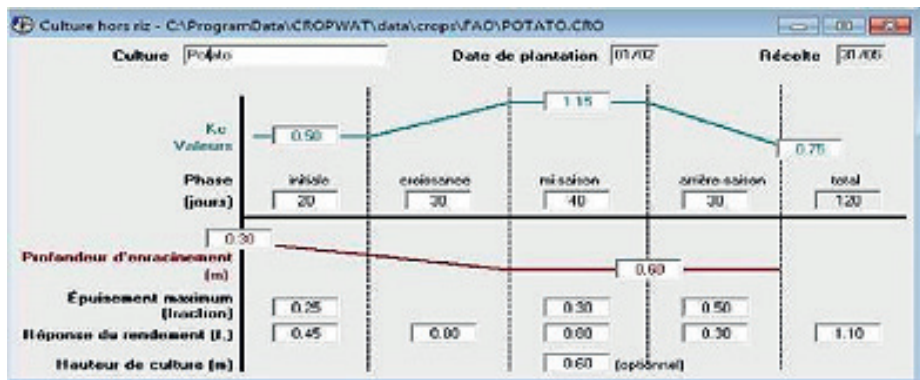


Figure 3. Crop data required by CropWat.

Calculation methodology

The determination of irrigation water requirements (IWR) for field crops is based on a standardised methodology proposed by the FAO. This approach comprises five main steps:

- (1) Calculation of reference evapotranspiration (ET_0) based on climatic parameters (air temperature, solar radiation, relative humidity and wind speed) ;
- (2) Selecting crop coefficients (K_c) corresponding to the different phenological stages of the crop under study ;
- (3) Calculating crop evapotranspiration (ET_c) using the following equation: $ET_c = K_c \times ET_0$;
- (4) Estimating effective rainfall (Pe), defined as the portion of precipitation that can actually be used by the plant ;
- (5) and finally, the calculation of net irrigation water requirements (IN) using the formula: $IWR = ET_c - Pe$.

This method, widely adopted in agroclimatic studies and irrigation projects, allows water supplies to be adapted to the specific needs of the crop according to local environmental conditions.

RESULTS ET DISCUSSION

Rainfall and temperature analysis

Figure 4 illustrates the interannual variability of precipitation in El Oued over the period 2000-2022. The recorded values range from a maximum of 233.7 mm in 2009 to an extremely low minimum of 13 mm in 2015, with an annual average of 62.21 mm. Adjusting the data using linear regression reveals a downward trend, suggesting a gradual decline in annual precipitation over the last 22 years. This trend confirms signs of increasing aridification in the region. By way of comparison, Khechana (2014) reports

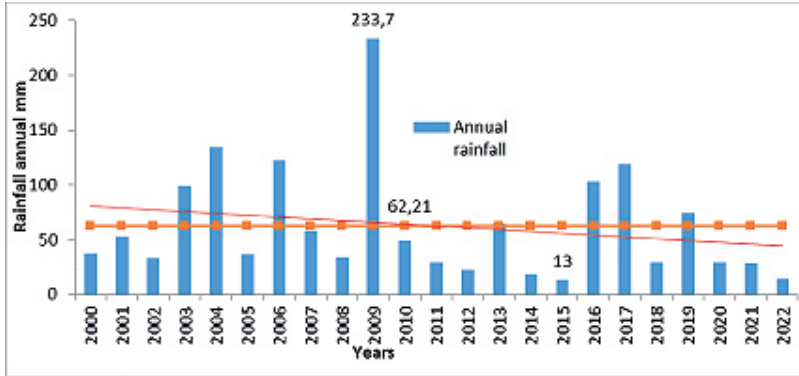


Figure 4. Interannual variation in rainfall in the El Oued region (period, 2000-2022).

an annual average of 72.04 mm for the previous period 1976–2008, which also shows a relative decline in rainfall over time. This gradual decrease in precipitation is a worrying indicator for the sustainability of agricultural systems in the Saharan zone.

The average monthly temperatures are shown in Figure 5, where the average monthly maximum and minimum air temperature values are presented. Maximum and minimum air temperature values peak in July (42.90 C°), while the lowest values are generally recorded in January (8.1 C°).

Reference evapotranspiration

Potential evapotranspiration (ET_0) was estimated using the Penman-Monteith (P-M) formula, recognised for its accuracy in arid climatic conditions. Figure 6 shows the average monthly evolution of ET_0 in El Oued, revealing

marked seasonal variation. Values increase gradually from January, peaking in July at 10.6 mm/day. This summer intensification reflects the combined effect of high temperatures, intense solar radiation and low relative humidity, which are characteristic of the Saharan climate. According to Chong and Deliang (2005), evaporation is mainly influenced by temperature, but it also results from complex interactions with wind speed and atmospheric humidity. These factors act together to modulate the evaporative demand of the atmosphere. Furthermore, Mokhtari *et al.*, (2016) estimated that the average ET_0 in July in the neighbouring region of Oued Righ, also located in south-eastern Algeria, is around 9.7 mm/day over the period 1984-2013. This result corroborates the high evaporative intensity observed in El Oued and highlights the similarity of regional hydrometeorological conditions.

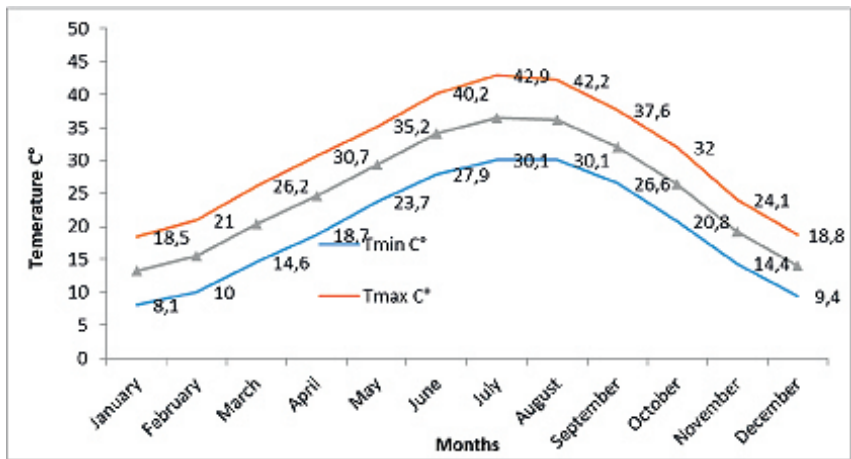


Figure 5. Variability of monthly temperatures over the study period.

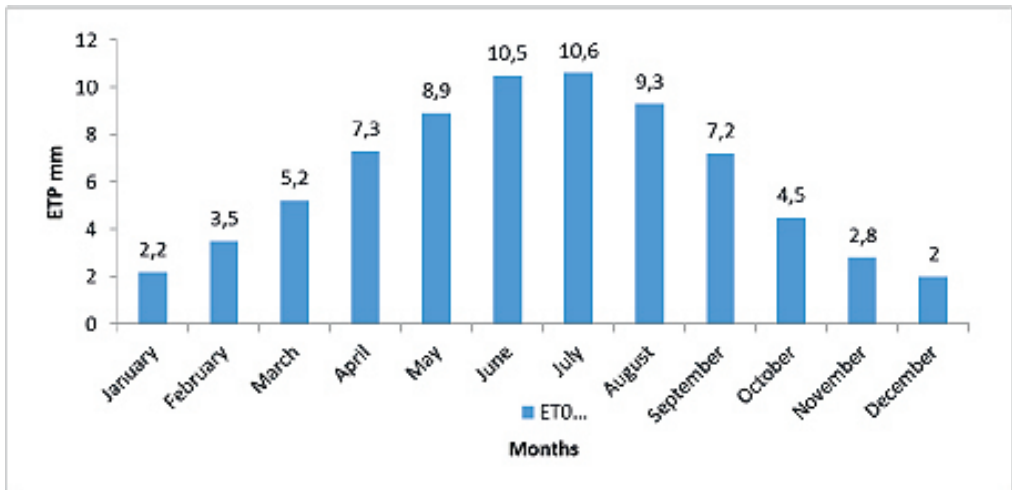


Figure 6. Reference evapotranspiration.

Effective rain

Effective rainfall refers to the portion of rainfall that can actually be used by the crop. It is important to note that not all rainfall is directly available for potato cultivation, as some is lost through

run-off and/or deep infiltration. In arid regions, effective rainfall is relatively low, but an estimate has been made for the sake of accuracy in total water consumption.

Figures 7a and 7b show fluctuations in effective rainfall on an annual

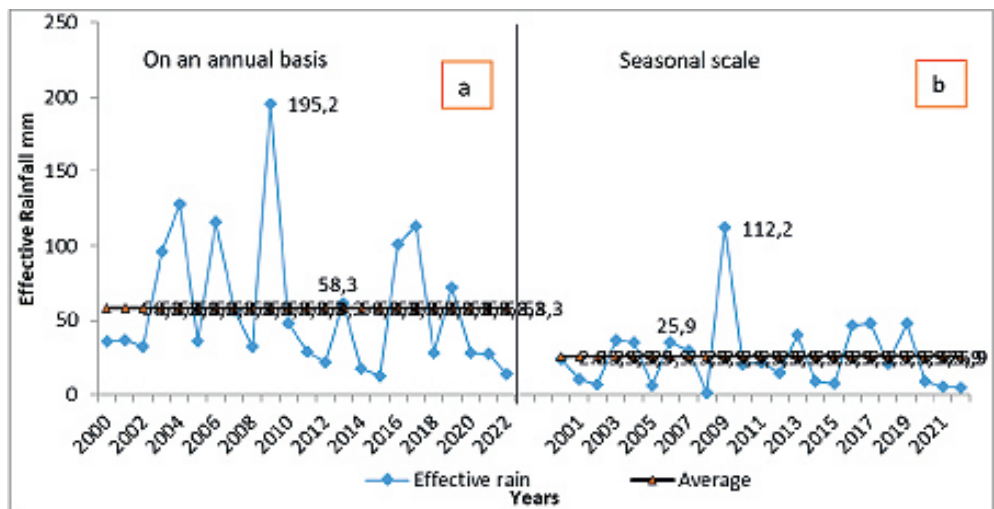


Figure 7. Total (a) and seasonal (b) effective rainfall.

scale (January to December) and on a seasonal scale (February to May). Total effective rainfall is 58.3 mm, fluctuating between 195.2 mm in 2009 and a minimum of 12.9 mm in 2016, while seasonal effective rainfall is around 25.9 mm.

Potato irrigation requirement (PIR)

Figure 8 shows the inter-annual variation in water requirements for potato cultivation (PIR). The average PIR value is 710.5 mm, fluctuating between a minimum of 590.4 mm in 2009 and a maximum of 942.1 mm in 2001. The results obtained are similar to those highlighted by Alataway et al., 2019, having assessed the irrigation water requirements of potato cultivation

under an arid climate in two regions Al Jouf (856.4 mm) and Eastern (713 mm) in Saudi Arabia. According to the FAO, potato water requirements fluctuate between 500 and 700 mm depending on the climate.

The PIRs calculated for the months of February to June show two distinct periods. The first period spans 8 years (2000 to 2007), with PWRs above the average for the study period, fluctuating between 789 mm and 942.1 mm. The second period spans 15 years (2008 to 2022), with below-average PIRs fluctuating between 590.4 mm and 713 mm, with the exception of 2016 (762.6 mm). This distinction is explained by the variability of the climate, which has a major influence on transpiration rates and crop evapotranspiration.

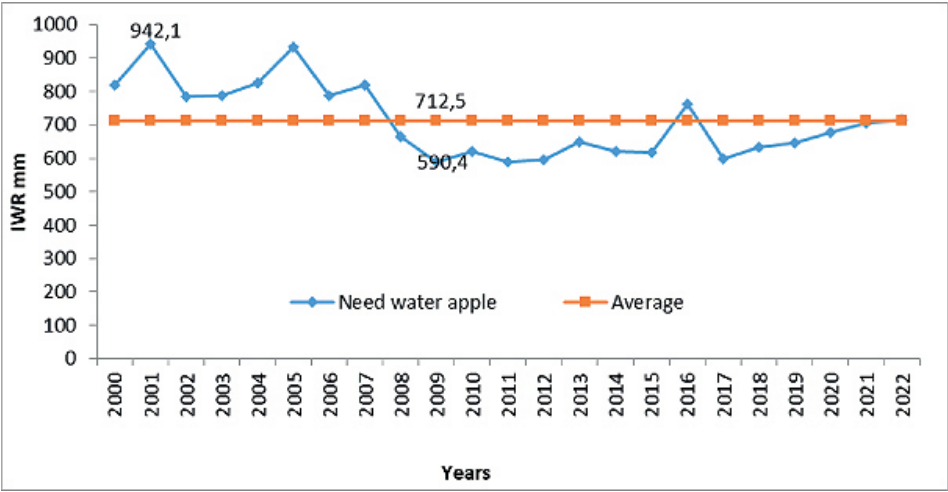


Figure 8. Water requirements of potato crops.

Irrigation water requirements (IWR)

Figure 9 shows the evolution of irrigation water requirements (IWR) for potato cultivation throughout the study period. The results show

marked interannual variability in water requirements, reflecting climatic fluctuations that directly influence irrigation demand. The average IWR value simulated by the CROPWAT model is estimated at 688.7 mm/

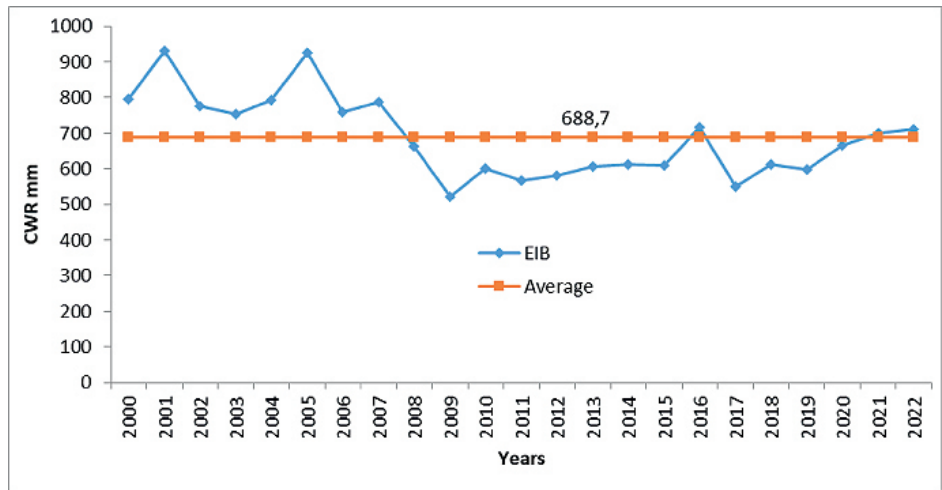


Figure 9. Irrigation water requirements estimated by CropWat.

year. However, this average masks significant variations, with a minimum of 521.2 mm observed in 2009, a year characterised by relatively high rainfall, and a maximum of 923.1 mm recorded in 2001, which can be attributed to drier climatic conditions or higher potential evapotranspiration. These variations demonstrate the sensitivity of potato cultivation to hydrometeorological conditions and highlight the importance of dynamic and adapted irrigation management from one year to the next. Indeed, rigid planning would not allow for an effective response to variability in water demand, which could result in either water stress for the crop or water waste in the event of over-irrigation. The use of simulation tools such as CROPWAT makes it possible to accurately quantify this demand by taking into account specific annual climatic conditions, thereby enabling optimal adjustment of water supply.

CONCLUSION

According to the results of this study, the CROPWAT model proved to be relevant and reliable for simulating the water requirements of potato crops, based on local climate parameters and internationally validated crop coefficients. This modelling capability highlights the crucial importance of adapting farming practices, particularly irrigation, to the specific agroclimatic

conditions of each region and each agricultural season. Optimising irrigation water thus becomes a strategic lever for improving agricultural productivity while ensuring sustainable water resource management.

In arid and semi-arid areas, where rainfall is scarce, irregular and increasingly affected by climate change, it is essential to make the most of every cubic metre of water available. This requires more rigorous irrigation management, the use of water-saving techniques (localised irrigation, probe-based control or water balance) and the modernisation of irrigation equipment. Training farmers and sector managers in simulation tools such as CROPWAT can also strengthen decision-making at the plot level.

We therefore recommend that agricultural development stakeholders, extension agencies and decision-makers incorporate agroclimatic modelling approaches into water management planning. A strategy combining modelling, climate monitoring and sustainable farming practices would reduce the impact of water stress on yields, particularly in a context of increasing water scarcity. In the longer term, these tools could be integrated into national policies for integrated agricultural water resource management in order to promote agriculture that is more resilient to climate change.

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