Al-Qadisiyah Journal For Agriculture Sciences (QJAS)
ISSN : 2618-1479 Vol.13, Issue. 1 ,(2023), pp. 50-58
https://jouagr.qu.edu.iq/

Modelling of Water Use Efficiency Using CropWat and AquaCrop : Case of Potato in Semi-Arid Region

Amirouche Mawhoub[1], Smadhi Dalila[2] and Zella Lakhdar[3]

[1]University of Saad Dahlab, Faculty of Nature and Life Sciences, Department of Biotechnology, Ouled Yaiumlch, 09000 Blida, Algeria.
[2]Bioclimatology and Agricultural Hydraulics Research Division, National Institute of Agronomic Research, Algiers.
[3]Biotechnology and Agro Ecology Department, Faculty of Life and Nature Sciences, University of Saad Dahlab Blida1, Blida, Algeria.

[1]E-mail: mawhoub.amirouche@gmail.com
[2]E-mail: dalsamdhi@yahoo.fr
[3]E-mail: lakhdarz@yahoo.fr

Abstract. In Algeria, vegetable crops are dependent on irrigation. In this context, the present study is oriented towards the efficient management of agricultural water that contributes to the improvement of crop production. The approach is based on the calculation of the water requirements of the potato in order to control the efficiency of the water supply in relation to the crop water requirements. This efficiency of use is imperative for a better yield and a healthy agricultural environment. In this study, we used two agronomic models CropWat (v8.0) and AquaCrop (v6.1), which were developed by FAO, to evaluate the water use efficiency (WUE) in a semi-arid climate (Wilaya of Tiaret) over a 31-year period (1990-2021). And this, by estimating the irrigation water requirements (IWR) and crop water requirements (CWR). The results obtained showed that there is a very close relationship between the estimates produced by the two models CropWat and AquaCrop. These estimates are for IWR, CWR and WUE, which are in the order of 395.91 mm, 517.24 mm, 6.47 kg m^{-3} using CropWat and 385.46 mm; 507.38 mm, 6.37 kg m^{-3} using AquaCrop. Crop growth simulation models have become important tools for evaluating and developing deficit irrigation strategies, especially in arid and semi-arid regions.

Keywords. Potato, AquaCrop, CropWat, Crop water requirment, Water use efficiency.

1. Introduction

The scarcity of water resources and the increasing global demand for water, particularly in the agricultural sector which accounts for 70% of global water consumption [1], is fuelling the debate on how to improve water use efficiency and productivity [2]. Irrigation managers need indicators on irrigation efficiency and water productivity in order to develop appropriate strategies for sustainable water resources management.
Agriculture requires a large amount of water, and in the future, the volumes of water needed for irrigation will increase dramatically due to growing food demand. Best practice agriculture, defined as

DOI: 10.33794/qjas.2022.135143.1071

agriculture that optimizes water use, is a key to overcoming this problem by improving water use efficiency (WUE).

In Algeria, water consumption in the agricultural sector is about 7 billion m^3 on average per year, knowing that the overall national consumption (consumption of the population in drinking water, the needs of the industrial and agricultural sectors) is 10.6 billion m^3 $year^{-1}$ [3]. Therefore, a more efficient use of water in agriculture must be the top priority. It is estimated that in semi-arid and arid regions, water remains a major constraint for improving agricultural production. Despite the scarcity of water, the observation made on the management of irrigation water highlights a lack of simple water management methods accessible to farmers to guide the programming of irrigation. Indeed, in the face of the total absence of decision support tools (steering tools and irrigation warning bulletins) mastered by farmers.

Irrigation timing and rates are usually decided based on visual observation. For this reason, it is important that the water needs of crops are known at different levels of management in these regions to achieve an efficient management of irrigation. The market garden crops which represent strategic crops in the country, know an important development, notably, the 'Potato' which represents the second sole, in Algeria. The surfaces which are reserved to him annually, approach the 150 000 hectares, that is to say 30% of the market gardening surface [4]. The potato is cultivated in most regions of the country, and at any season of the year. It is a staple product for the Algerian consumer, the availability per capita and per year, is 100 to 110 kg [4]. The production estimated at nearly one billion dollars [5], and benefiting from the support of the state, has experienced a record of 5 million tons in the last decade. The potato growing season coincides with the dry season for which irrigation is necessary. In this context, FAO has developed crop models, CropWat and AquaCrop, to better manage irrigation water.

Both models have been widely and successfully used by several researchers around the world under various environmental conditions. For vegetable crops, have been tested for potato [6-8], also have been used for tomato [9-11], for pepper [12,13]. For cereal crops, wheat [14,15], barley [16,17]. The main objective of this study is to evaluate the water use efficiency, based on the calculation of irrigation water requirements, using the CropWat and AquaCrop model with a comparative analysis of the results of the different models that will allow the selection of the appropriate crop model for the climatic context of the study area.

2. Materials and Methods

2.1. Description of the Study Area

The study area covers an area of approximately 20 673 km^2. It is located between 35°22' North of Latitude and 1°19' East of Longitude and at an altitude ranging from 970 m to 1143 m. It is bounded to the north by the wilayas Tissemsilt and Relizane, to the east by the wilaya of Djelfa, to the west by the wilayas of Mascara and Saida and to the south by the wilayas of Laghouat and El Bayadh (Fig. 1).

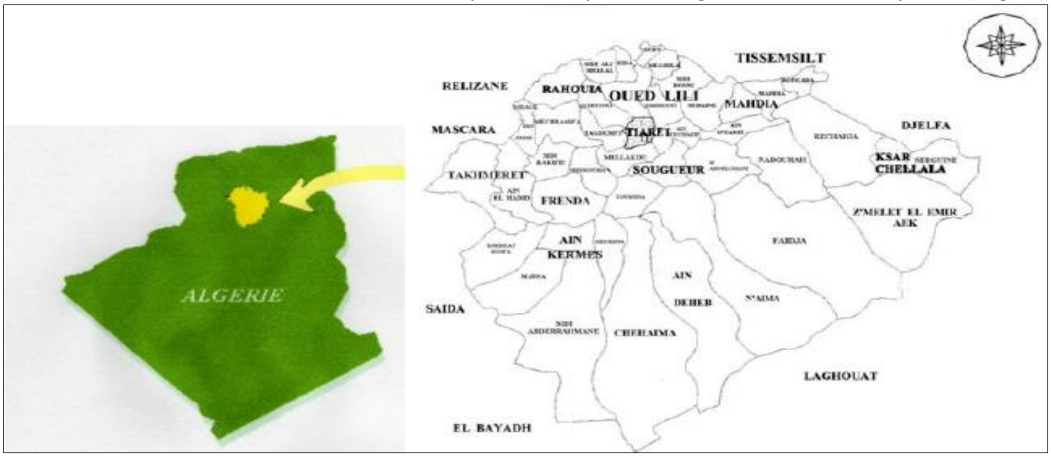


Figure 1. Location of the study area.

Al-Qadisiyah Journal For Agriculture Sciences (QJAS)
ISSN : 2618-1479 Vol.13, Issue. 1 ,(2023), pp. 50-58
https://jouagr.qu.edu.iq/

2.2. Climatic and Pedological Context

The region of Tiaret is characterized by a continental climate with harsh winters and hot, dry summers. Rainfall is low and irregular, it is about 387 mm year^{-1} over a period of 31 (1990-2021). The average monthly temperatures over the same period are between 5.92 °C and 26.45 °C and the average monthly relative humidity over the same period is between 36.49% and 76.44%. High average monthly insolation values are observed during the dry season with a maximum of (11.67 hours) in June, while during the rainy season, insolation reaches a minimum of 6.20 hours in December.
Regarding the type of soil in the region of Tiaret, according to the work done in the Department of Pedology of the Institute of Agronomic Sciences of Tiaret from 1990 to 1996, it was found that the most dominant class is that of Vertisols [18]. This type of soil is a soil that is rich in clay.

2.3. Model Requirements

The CropWat and AquaCrop models require three major components (Table 1) to be functional: the climate, with its thermal regime, rainfall, evaporative demand (ET0), then the crop with its development, growth and yield constitution processes; finally the soil with its water balance

Table 1. Input data for the CropWat and AquaCrop models.

<table>
<tr><th></th><th>AquaCrop</th><th>CropWat</th></tr>
<tr><td>Climat</td><td colspan="2">- Rainfall (mm)
- Minimum and maximum temperature (C°)
- Relative humidity (%)
- Wind speed (m/s)
- Insolation (hours)</td></tr>
<tr><td rowspan="2">Crop</td><td colspan="2">- Planting and harvesting date
- Phenological stages
- Rooting depth
- Crop coefficient (kc)
- Height of the crop
- Crop cycle</td></tr>
<tr><td>- Vegetation zero
- Duration of flowering stage
- Plant density
- Type of crop C3 or C4
- Time of emergence
- Maximum canopy coverage
- Harvest index
- Planting method</td><td></td></tr>
<tr><td>Soil</td><td colspan="2">- Number of horizons
- Bulk density
- Permeability
- Soil water contents at saturation (Θ_{sat}), field capacity (Θ_{FC}), and permanent wilting point (Θ_{PF}).</td></tr>
<tr><td>Initial conditions</td><td colspan="2">- Initial water content</td></tr>
</table>

2.4. Procedure to Evaluate Irrigation Water Requirements

2.4.1. Reference Evapotranspiration

The climatic data required by the AquaCrop and CropWat models are minimum, maximum temperatures (°C), precipitation (mm), wind speed (m s^{-1}) at 2 m above ground level, solar radiation (W m^{-2}) and relative humidity (%). These data were collected through bulletins of the National Meteorological Office and meteorological sites spread over a period of 31 years (1990-2021). The measurements taken, at a monthly time step. These climatic parameters allow the evaluation of the reference evapotranspiration (ET0) using the Penman-Monteith method of the FAO [19].

DOI: 10.33794/qjas.2022.135143.1071

2.4.2. Effective Rainfall

To account for losses due to reseeding, the USDA method was chosen to calculate the effective rainfall. It is estimated using the following formula:

$$Peff = Pmonth \times (125 - 0.2 \times Pmonth) / 125 \text{ for } Pmonth < 250 \text{ mm}$$

$$Peff = 125 + 0.1 \text{ x } Pmonth \text{ for } Pmonth > 250 \text{ mm}$$

Where: Pmonth = Monthly rainfall and Peff = Effective rainfall

2.4.3. Crop Water Requirment (CWR)

As far as irrigation is concerned, it is always preferable to conduct the crop at the maximum evapotranspiration (ETc), which is a point value linked to the ET0 that is relative to a region by a cultural coefficient (Kc). It is calculated by the following formula:

$$ETc = Kc * ET0$$

2.4.4. Irrigation Water Requirment (IWR)

The basic formula for determining the irrigation water requirement (IWR) is derived from the water balance method, which is expressed as follows

$$\sum \text{Inputs} = \sum \text{Outputs}$$

$$IWR + P\ eff = ETc \pm \Delta S$$

$$\text{Where: } IWR = ETc - Peff \pm \Delta S$$

2.4.5. Water use Efficiency (WUE)

Water use efficiency (WUE) is defined as the ratio of yield to water consumed by the crop, According to [20] it is given by the following formula:

$$\text{Water Use Efficiency} = \text{Yield} / \text{Total water used (ETc)}$$

Where, Y is crop tuber yield in ton ha-1 and ETc is total actual crop evapotranspiration in mm.

3. Results And Discussion

3.1. Rainfall Analysis

The analysis of interannual rainfall variability over the study period (1990-2021) resulted in the graph shown in Fig. 2.

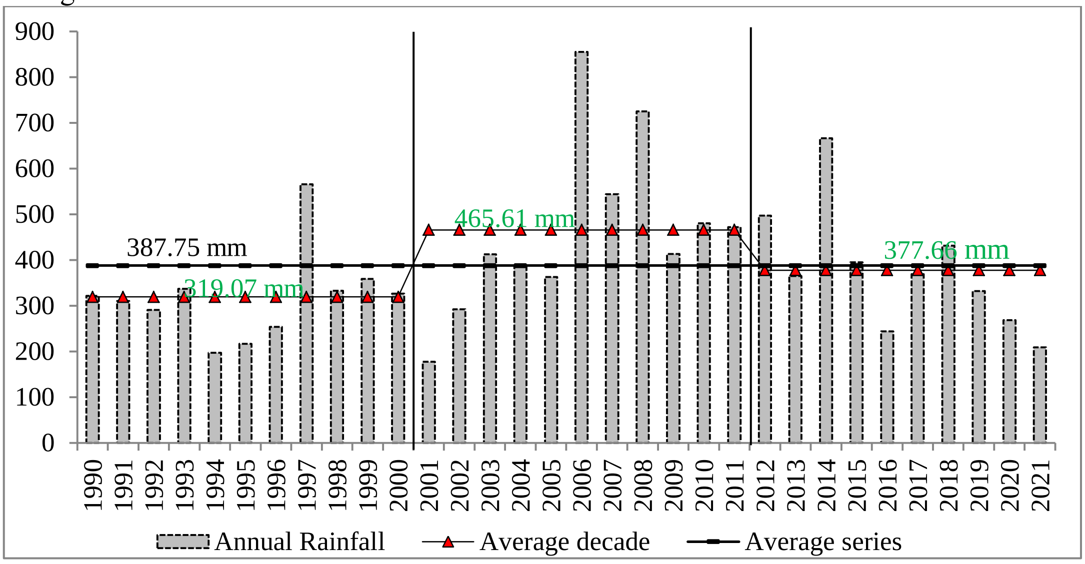


Figure 2. Interannual variation in rainfall (1990-2021).

The results obtained show a heterogeneous distribution of rainfall intensities over the study area. The average rainfall value over the study period (1990-2021) is about 387.75 mm, fluctuating between a minimum of 177. 32 mm and a maximum of 855.41 mm. The graph showed three distinct decades, namely: (1990-2000) with an average of 319.07 mm, followed by a decade (2001-2011) well watered (465.61 mm) compared to the average, and finally the last decade (2012-2021) which coincides with the average of the series (377.66 mm).

3.2. Calculation of Reference Evapotranspiration

3.2.1. Annual Scale

The calculation of reference evapotranspiration requires as inputs: temperature (minimum and maximum), humidity (minimum and maximum) as well as solar radiation and wind speed at 2 meters above ground.

Fig. 3 shows the interannual variation of reference evapotranspiration (ET0) over a 31-year period (1990-2021). It is found that the annual average ET0 is about 971.47 mm, fluctuates between a minimum of 791.13 mm and a maximum of 1064.80 mm.

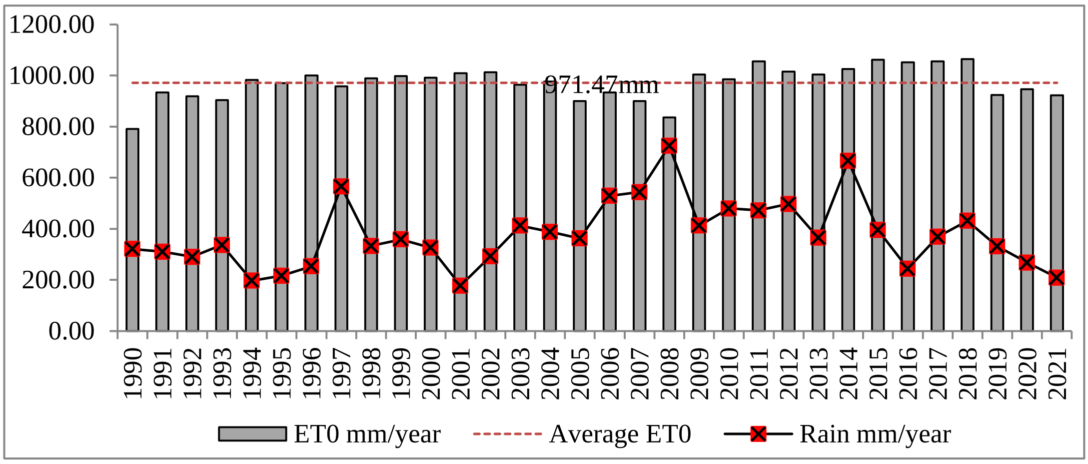
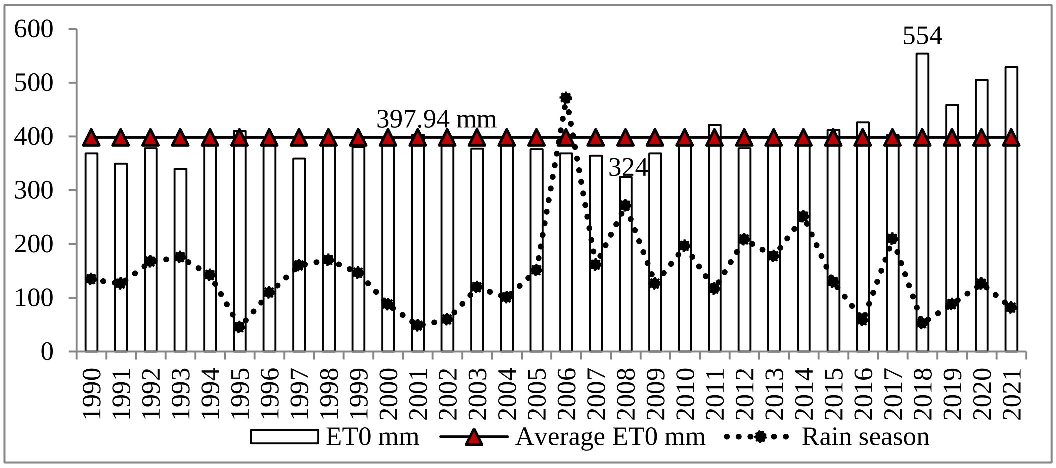


Figure 3. Interannual variation of reference evapotranspiration, period (1990-2021).

3.2.2. Seasonal Scale

Fig. 4 shows the interannual variation in reference evapotranspiration (ET0) at the growing season scale of the potato crop over a 31-year period (1990-2021). It is found that the annual average ET0 of potato is 397.94 mm. The reference evapotranspiration (ET0) recorded during the potato growing season (February - June) is less important because its vegetative cycle coincides with the period (spring - summer) when temperatures keep increasing and rainfall is negligible.



DOI: 10.33794/qjas.2022.135143.1071

Figure 4. Interannual variation of reference evapotranspiration on a seasonal scale, period (1990-2021).

3.3. Effective Rainfall Calculation

3.3.1. Annual Scale

For agricultural production, effective precipitation refers to the fraction of precipitation that can be effectively used by crops. Not all of the rainfall is available for crops, as some of it is lost through runoff and/or deep percolation.

Figure 5 shows the inter-annual variation of total effective rainfall during the study period (1990-2021). It is found that the average total effective rainfall over this period is about 336.31 mm, fluctuating between a minimum of 168.80 mm (2001) and a maximum of 649 mm (2008).

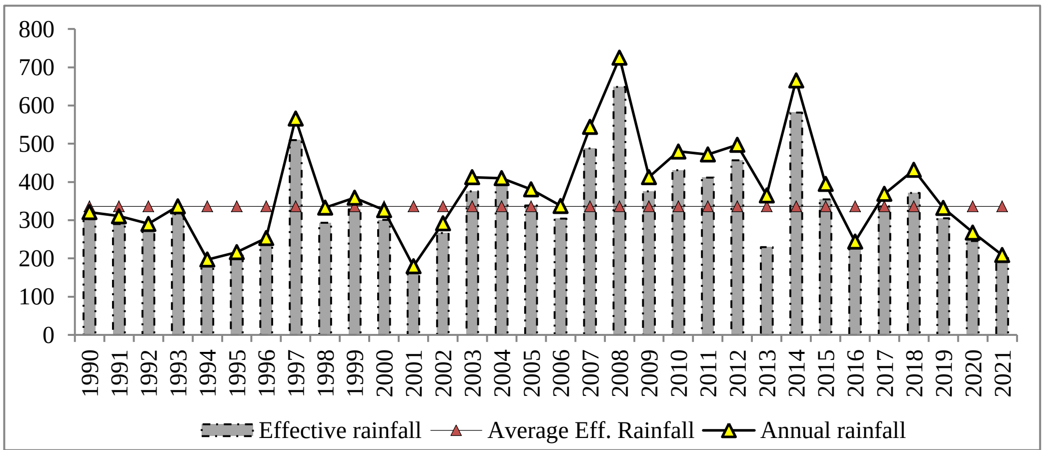


Figure 5. Interannual variation of total effective rainfall, period (1990-2021).

3.3.2. Seasonal Scale

The effective rainfall benefited by the potato crop is shown in Fig. 6. It is found that the average effective rainfall during the potato growing season is 123.85 mm, fluctuating between 19.6 mm (1994) and 228.9 mm (2008).

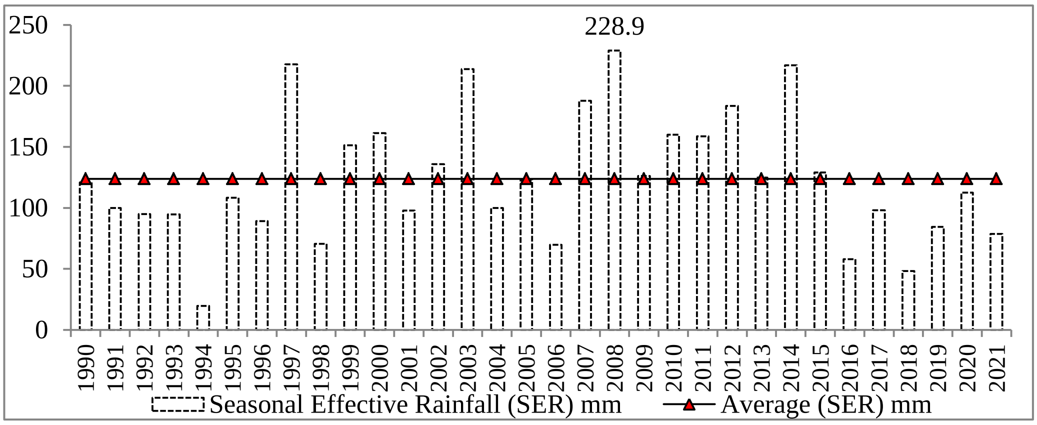


Figure 6. Interannual variation in effective rainfall on a seasonal scale, period (1990-2021).

3.4. Crop Water Requirements

The crop water requirements (CWR) of potato estimated by the CropWat and AquaCrop model are shown in Fig. 7. From this figure, it is found that the average values of CWR of potato estimated by the CropWat and AquaCrop model are, respectively, in the range of 517.24 mm and 507.38 mm. These values are within the range reported by FAO which varies from 500 to 700 mm depending on the climate. [6] found that CWR of potato in Shelled region (Ethiopia) is 500.87 mm. According to

DOI: 10.33794/qjas.2022.135143.1071

[21] the water requirement of potato varies from 350 to 550 mm depending on the length of the growing season, atmospheric demand, soil type, crop variety.

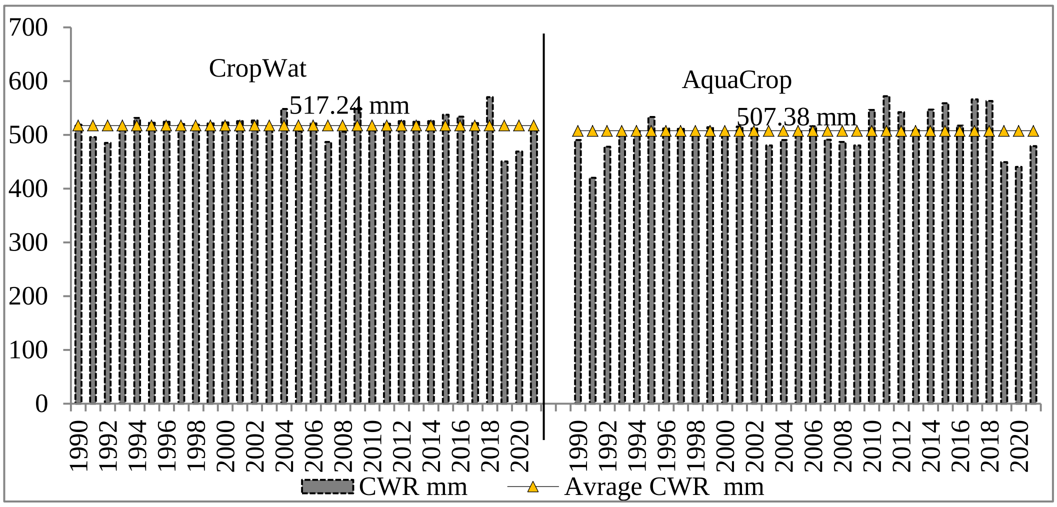


Figure 7. Interannual variation in potato water requirement (CWR) estimated by the CropWat and AquaCrop model.

3.5. Irrigation Water Requirement

The total irrigation water requirements (IWR) of potato estimated by the CropWat and AquaCrop model are shown in Fig. 8. It is found that the average IWR values of potato estimated by both CropWat and AquaCrop models are respectively, in the range of 395.91 mm and 385.46 mm. From this figure, it is clear that both models followed the same trend. These results are consistent with those reported by [6] who found 379.45 mm.

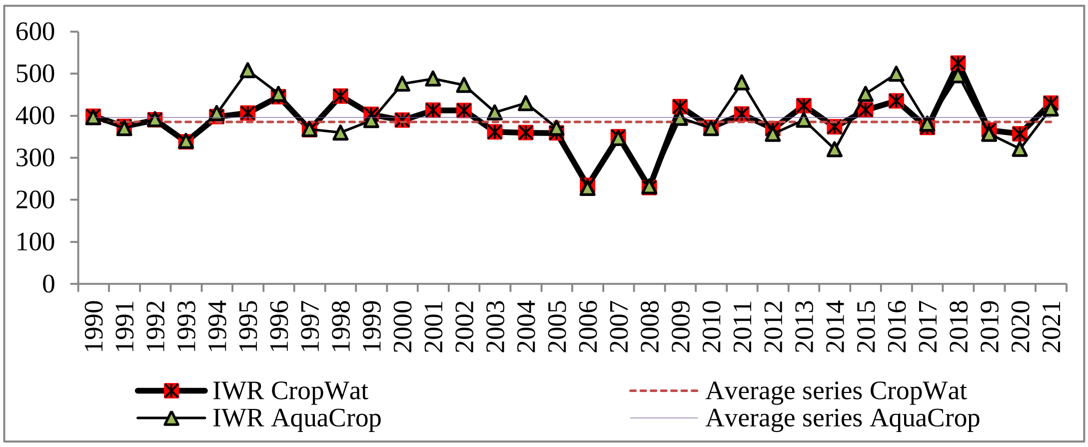


Figure 8. Interannual variation in irrigation water requirement (IWR) for potato estimated by the CropWat and AquaCrop model.

3.6. Water Use Efficiency

To record the yields of the potato crop in the wilaya of Tiaret, we used the "B 1 series" of the Ministry of Agriculture and Rural Development [22].
Fig. 9 shows the interannual fluctuation of WUE for potato cultivation for a period of 23 years (1998-2021). It is found that the annual average WUE values estimated over the entire period by the CropWat and AquaCrop models are, respectively, in the range of 6.47 and 6.37 kg m^{-3}. It is found that the WUE value estimated by the CropWat and AquaCrop models is higher for the year 2008 and lower for the year 2001. This is explained by the amount of rainfall received during the growing season (February - June) which are, respectively, 293.50 (2008) and 52 mm (2001). Several parameters can

DOI: 10.33794/qjas.2022.135143.1071

affect water use efficiency, including water availability, interaction with other factors, such as cultivar, agronomic management or soil characteristics, can also affect this efficiency.
In this regard, [23] Nagaz et al. (2007) reported that WUE varied from 6 to 14 kg m^{-3} for potatoes planted in fall, winter, and spring. [24] Wright and Stark (1990) noted that WUE of potato crops ranged from 5.4 to 12.0 kg/m^3 depending on the region, irrigation management, and the amount of fertilizer applied. [25] Fabeiro et al (2001) reported that WUE values of potato crops in Spain ranged from 6.3 to 8.6 kg m^{-3}, while [26] Ünlü et al (2006) reported values between 4.8 and 7.4 kg m^{-3}, depending on both irrigation method and nitrogen level.

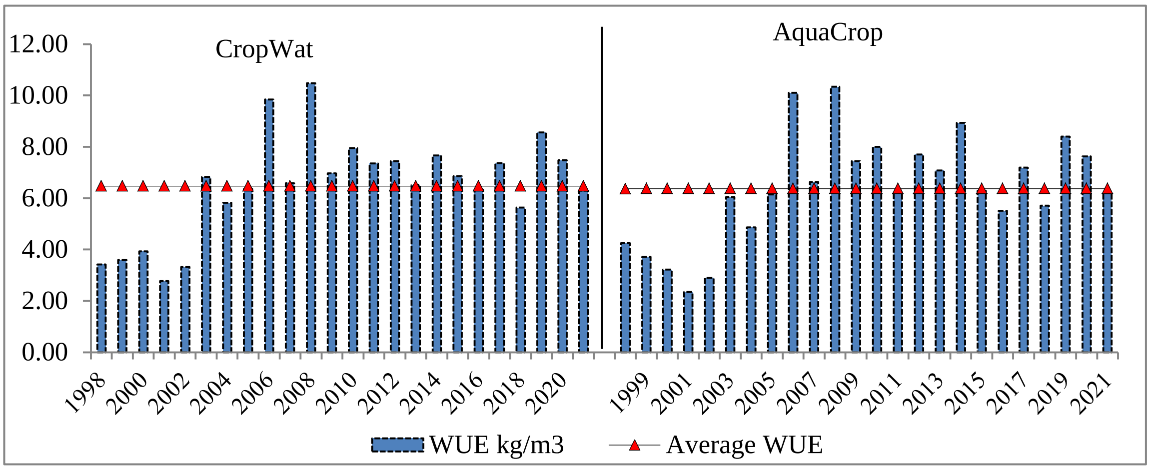


Figure 9. Water use efficiency for potato crops estimated by the CropWat and AquaCrop model

Conclusion

For the entire development cycle of the potato crop, the irrigation water requirements (IWR) estimated by CropWat and AquaCrop are, respectively, 395.91 mm and 385.46 mm. On the other hand, the crop water requirements of these crops (CWR), are about 517. 24 mm and 507.38 mm. The average values of these parameters, IWR and CWR, fluctuate throughout the development cycle of this crop depending on the weather conditions. These results on IWR and CWR provided a practical assessment for irrigation scheduling of this crop in semi-arid environments. Understanding CWR, IWR and irrigation scheduling during shortage months help farmers to make the right decision to avoid any yield reduction in their farm. This study showed that there is a very close relationship between the parameters estimated by the two models, CropWat and AquaCrop. Compared to the CropWat model, the AquaCrop model takes into account several cropping practices including fertilization and salinity that are related to irrigation for better water productivity. This encourages the use of the AquaCrop model as a decision support tool.

References

[1] Food and Agriculture Organization of the United Nations, (2020). The State of Food and Agriculture, ISBN 978-92-5-133645-8, 234 pages
[2] Van Halsema G.E. and Vincent L., (2012). Efficiency and productivity terms for water management: a matter of contextual relativism versus general absolutism". Agricultural Water Management, 108: 9-15. https://doi.org/10.1016/j.agwat.2011.05.016
[3] Algeria Press Service, (2018). Nearly 70% of water consumption taken up by agriculture, Retrieved July 15, 2018. https://www.aps.dz/economie/76268-pres-de-70-de-la-consommation-d-eau-accapares-par-l-agriculture.
[4] Ministry of Agriculture, Rural Development (2020). Potato sector: market regulation and export are the main objectives. https://www.aps.dz/economie/112228
[5] Bessaoud, O., (2019). Summary report on agriculture in Algeria. https://hal.archive-ouvertes.fr>document.
[6] Kassua T., Tilahunb H., Yareda D., Watanabec H., (2017). Effect of irrigation regimes on yield and water use efficiencies of potato. International Journal of Plant Production, 11, 3, 391-405.

[7] Lata Vishnoi, Sumana roy, N.S. Murty and A.S. Nain, 2012. Study on water requirement of Potato (Solanum tuberosum L.) using CropWatModel for Tarai Region of Uttarakhand, Journal of Agrometeorology [ISSN: 0972-1665]4, 14, Special Issue, 180-185.
[8] Atefeh Afshar, Gholam Reza Afsharmanesh, Mohsen Adeli and Ashraf Malekian, (2014). Assessment of AquaCrop Model in the Simulation of Potato Yield and Water Use Efficiency under Different Water Regimes. Journal of Biological and Environmental Sciences, 8, 23, 79-86.
[9] Maie Kabbashi Alla Jabow, Ahmed Ali Salih, Abdel Hadi Abdel Wahab Mohamed and Bashir Mohammed Ahmed, (2013). Crop water requirements for tomato, common bean and chick pea in Hudeiba, River Nile State Sudan. Sudan Journal of Agricultural Sciences, 22, 11- 22. https://doi.org/10.18502/sjms.v16i3.9703
[10] Karuku G.N., Gachene C.K.K., Karanja N., Cornelis W. and Verplancke H., (2014). Use of cropwat model to predict water use in irrigated tomato production at kabete, kenya, East African. Agricultural and Forestry Journal, 80, 3,175-183. https://doi.org/10.1080/00128325.2016.1261986
[11] Memon A. V., Jamsa S., (2018). Crop Water Requirement and Irrigation scheduling of Soybean and Tomato crop using CropWat 8.0. International Research Journal of Engineering and Technology (IRJET), 5, 9, 669-671.
[12] Abousrie A. Farag, (2018). Irrigation management of pepper crop under surface and sub-surface drip irrigation systems by using expert system, irrimet and cropwat. Misr Journal of Agricultural Engineering, 35, 4, 1293 – 1308. https://doi.org/10.21608/mjae.2018.95276
[13] Demeke Tamene Mitku, (2021). Application of Aquacrop and CropWat Models for Estimating Crop Water Requirements and Irrigation Scheduling for Hot Pepper in Metekel Zone. Advances. 2, 3, September 2021, 50-63. doi: 10.11648/j.advances.20210203.13 https://doi.org/10.59122/13518ef
[14] Andarzian B., Bannayan M., Steduto P., Mazraeh H., Barati M.E., Barati M.A., Rahnama A., (2011). Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran, Agricultural Water Management, 100, 1– 8. https://doi.org/10.1016/j.agwat.2011.08.023
[15] Mirko Knežević, Natalija Perović, Ljubomir Životić, Mirjana Ivanov and Ana Topalović, (2013). Simulation of winter wheat water balance with cropwat and isareg models. Agriculture & Forestry, 59, 1, 41-53.
[16] Araya, A., Habtub, S., Hadguc, K.M., Kebedea, A., Dejened, T., (2010). Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (Hordeum vulgare). Agricultural Water Management, 97, 1838–1846. https://doi.org/10.1016/j.agwat.2010.06.021
[17] Laouisset, M. B. and Dellal, A. (2016). Estimation of Barley (Hordeum Vulgare L.) Crop Water Requirements Using Cropwat Software in Ksar-Chellala Region, Algeria", AGRIS on-line Papers in Economics and Informatics, 8, 3, 91-102. ISSN 1804-1930
[18] Oulbachir Karima, (2010). Microbial ecology of soils under different granulometric compartments and different bioclimatic stages, PhD thesis, defended on 07/10/2010, University of Oran, Algeria.144.
[19] Allen R, Pereira LS, Raes D. et Smith, M, (1998). Crop evapotranspiration: guidelines for computing crop water requirements. In: FAO Irrigation and Drainage Paper N. 56, Rome, Italy. 300pp.
[20] Zhang, H., Oweis, T., Garabet, S., Pala, M., (1998). Water use efficiency and transpiration efficiency of wheat under rain-fed and irrigation conditions in Mediterranean environment. Plant Soil, 201, 295-300. https://doi.org/10.1023/a:1004328004860
[21] Sood, M. and Sharma (1993). Water optimization and requirement. Advances in Horticulture. Chanda, K.L. and Grewal, J.S. (Eds.). Malhotra Publishing House. New Delhi -64.
[22] MADR. 2021. Ministry of Agriculture and Rural Development. Series B, Agricultural Statistics
[23] Nagaz, K., Masmoudi, M.M., Mechlia, N.B., (2007). Soil salinity and yield of drip-irrigated potato under different irrigation regimes with saline water in arid conditions of southern Tunisia. Journal of Agronomy, 6, 324-330. https://doi.org/10.3923/ja.2007.324.330
[24] Wright, J.L., Stark, J.C., (1990). Potato. In: Stewart, B.A., Neilsen, D.R. (Eds.), Irrigation of variability. Fungal Biology, 115, 335-342.
[25] Fabeiro, C., Martin de Santa Olalla, F., de Juan, J.A., (2001). Yield and size of deficit irrigated potatoes. Agricultural Water Management, 48, 255-266. https://doi.org/10.1016/s0378-3774(00)00129-3
[26] Ünlü, M., Kanber, R., Senyigit, U., Onaran, H., Diker, K., (2006). Trickle and sprinkler irrigation of potato (Solanum tuberosum L.) in the Middle Anatolian Region in Turkey. Agricultural Water Management, 79, 43-71. https://doi.org/10.1016/j.agwat.2005.02.004

DOI: 10.33794/qjas.2022.135143.1071