

Agro-ecological Zoning for Crop Suitability using the AquaCrop Model in the Arid Regions of Khuzestan Province, Iran

Sina Yaghoubi Nejad¹, Seyed Bahram Andarzian², Hamid Reza Javanmard¹, Mohamadreza Naderi Darbaghshahi¹, and Alireza Shokuhfar³ (2025)

¹ Department of Agronomy and Plant Breeding, Isfahan (Khorasgan) Branch, Islamic Azad University, Iran

² Seed and Plant Improvement Department, Research and Education Center of Agricultural and Natural Resources of Khuzestan, Agricultural Research Education and Extension Organization (AREEO), Ahvaz, Iran

³ Department of Agriculture, Islamic Azad University, Ahvaz Branch, Iran

DOI: <https://doi.org/10.14796/JWMM.C542>

ABSTRACT

Climate and weather largely determine the amount and mode of human performance and function in each sector, especially agriculture. However, obtaining agricultural information based on regional climate data can be time-consuming and expensive. Zoning can facilitate access to this information on a wide scale. This issue is particularly essential in areas with water deficit conditions in Iran, and the predominantly arid status of Khuzestan province. Camelina (*Camelina sativa* L.) is a rich source of oil and omega-3 fatty acids. Its unique properties include low water requirement and tolerance to drought, pests, and diseases. The purpose of this study was to apply a simulation strategy using the AquaCrop modeling software to evaluate the effects of various environmental factors on camelina yield. Also, it was aimed to determine the best locations for cultivating this plant using agro-ecological zoning (AEZ) and introduce the plant to Khuzestan province. In this study, the AquaCrop model was used for simulation to estimate the yield potential of camelina plants. It employed weather data to demonstrate how Khuzestan's water deficit condition can affect camelina growth. Before using the model to simulate different factors, the research procedure involved model calibration and verification for the camelina genotype in the province. The findings resulted in plant zoning. A zoning map for camelina cultivation was generated to reveal three zones in terms of camelina yield potential, i.e., very suitable, moderately suitable, and unsuitable. The very suitable zone had a long-term average simulated yield potential of over 1800 kg/ha, encompassing the cities of Omidiyeh and Baghmalek. The moderately suitable zone had a long-term average yield potential of 1700–1800

Nejad, S.Y., S.B. Andarzian, H.R. Javanmard, M.N. Darbaghshahi, and A. Shokuhfar. 2025. "Agro-ecological Zoning for Crop Suitability using the AquaCrop Model in the Arid Regions of Khuzestan Province, Iran." *Journal of Water Management Modeling* 33: C542. <https://doi.org/10.14796/JWMM.C542> www.chijournal.org
ISSN: 2292-6062 © Nejad et al. 2025.

kg/ha and included the cities of Izeh, Dezful, and Shushtar. The unsuitable zone had a long-term average simulated potential yield between 1600–1700 kg/ha, and included the cities of Ahvaz, Behbahan, Khorramshahr, Dasht Azadegan, Ramshir, Ramhormoz, and Shush.

1. INTRODUCTION

There are various determining factors in the production of agricultural products. Weather conditions are among the most important natural variables, and they are the least controllable by mankind, even on a small scale, regardless of expenditures (FAO 2017). These effects can be seen every year in the form of frost damage, heat stress, and pest infestation. Drought has caused the most economic damage, almost equivalent to the cumulative economic damage of earthquakes and floods (Ali et al. 2017). The cultivation of crops in places that are compatible with their conditions can provide maximum productivity and efficiency for farmers. At the same time, they cause the least damage to the agricultural resources of that region in the long run (Dhanaraju et al. 2022).

The climate of Iran is characterized by inappropriate temporal and spatial distribution of rainfall. This irregular distribution has caused irrigated agriculture to become a priority for farmers in each region. Irrigation cultivation occurs more often in provinces with hot and arid climates. In other words, crops with high water requirements are cultivated in these provinces more than in other climates of the country. Meanwhile, experts claim there is no justification for the cultivation of some crops in hot and arid provinces (Madani et al. 2016). Global warming is occurring as a universal phenomenon. Not paying attention to the role of climate in producing appropriate yields can cause irreparable damage to food security in any country. Of course, it is necessary to create appropriate preventive mechanisms and rely on the role of climate in regions like Khuzestan, which has always had its own limitations and potential (Amiji et al. 2020).

In the 1970s, the Food and Agriculture Organization of the United Nations (FAO) announced that Agro-ecological Zoning (AEZ) can be proposed as a method to determine agricultural and environmental capabilities on a regional and national scale. This method was developed by FAO and is now one of the most common methods for determining agro-ecological characteristics in wide geographical areas for crop production (Trnka et al. 2009). The advent of models for plant growth simulation, information banks related to water, soil and climate data, and Geographic Information System (GIS) have provided extensive assistance to researchers in agro-ecological zoning of various products on a regional scale (Amin et al. 2022). Using this method, by dividing a geographical area into homogenous zones with maximum similarity in terms of soil and climate characteristics, the potential yield of agricultural products in each zone can be predicted by a simulation model. By transferring the results to the GIS environment of the potential map, yield is estimated on a regional scale. By knowing the actual production in each region, the yield gap can be estimated and analyzed based on the difference between the potential and actual yield. Then, the yield gap caused by the management method, the set of limiting factors (water and nutrients) and those that reduce production (pests and weeds) can be analyzed. The relative contribution of each of these factors in creating a yield gap is measurable. Thus, suitable solutions can be devised to fill cultivation gaps in different zones (FAO 2002).

To aim for maximum plant yield in an area, we need to consider the climatic conditions of the desired location. Using the simulation of environmental conditions of different regions and plant

simulation models can be a reliable way to predict the impact of various environmental factors. These factors affect the growth and development of the plant, the final yield, and ultimately assist in finding the best region and planting dates for the crop (Hijmans and Graham 2006). Thus, different plant simulation models such as CropWat, CropSyst and WOFOST are common among researchers. Most of these models require a lot of user skill in calibration. In addition, these models require many instruments, which are often difficult to obtain and operate. In this context, one of the programs available is AquaCrop, a precise computer program that employs an easy-to-use model. It enables predictions of product yield by considering drought stress in each region (Salemi et al. 2011).

The value, position, and progressive role of medicinal and industrial plants in sustainable crop management can be a development index in developing countries (Richardson 2010). The cultivation of oil seed plants that are adaptable to various climatic conditions can be a productive endeavor due to the expansion of research programs in this field. Introducing new plants with satisfactory and economic yield in drought conditions is one of the logical solutions to solve the challenges in water management and agriculture. Camelina oilseed is one of these economic plants. It is adaptable to semi-arid climates and has a suitable crop rotation with cereals (Bakhshi et al. 2021). Camelina seeds are a rich source of oil (28–40%) and omega-3 fatty acids (Belayneh et al. 2017). This plant can grow in different weather and soil conditions. Compared to other oilseed plants, camelina needs less water, fertilizers, pesticides, and is more tolerant of cold (Obour et al. 2017). A unique combination of fatty acids in camelina oil has created suitable nutritional and physiological effects. Camelina oil is used to increase the nutritional value of food. Also, adding 10% of camelina meal to livestock and poultry diets reportedly decreased production costs and increased quality of livestock products (e.g., a 3- and 8-fold increase in omega-3 fatty acids in meat and eggs, respectively), followed by higher antioxidant content (Tedone et al. 2022). Camelina is a newly introduced plant in Iran. Considering the vast area of rainfed lands in Iran (about 70%), the development of camelina cultivation in these fields can be given special attention. For this reason, to introduce this new plant to the Khuzestan province of Iran, the current study involved using a reliable model for estimating crop production. To predict the eco-physiological reactions of camelina plants, simulations with the AquaCrop model can provide an opportunity to investigate the effects of various environmental factors in Khuzestan province on product yield. Due to the new capacities that this plant can offer to this province, we attempted to zone the provinces for camelina cultivation using the AquaCrop model.

2. MATERIALS AND METHODS

2.1 Study location

Khuzestan is a province in the southwest of Iran, the south of which is located on the coast of the Persian Gulf. Khuzestan has a total area of 64,057 square kilometers and is located between 47 to 50° east longitude and 29 to 32° north latitude. The province is surrounded from the north and east by the Zagros Mountain Range. When moving from the east to the interior of the province, the height of these mountains decreases and gives its place to the Mahor hills. Khuzestan includes two mountainous and plain regions. Two-fifths of the total area of this province are mountainous and three-fifths are plains. The Khuzestan plain has a slight slope,

and in some places, there are salt domes that can increase the salinity of soil and irrigation water.

2.2 Field experiments

In this experiment, the AquaCrop model was used for simulation to estimate the yield potential of the camelina plant and the effects of water deficit in Khuzestan province using weather data from the region. Before using the model to simulate different factors, the model was calibrated and verified for the camelina genotype used in the province. This research was conducted on an experimental farm at the Khuzestan Agricultural and Natural Resources Research and Education Center, Ahvaz, in the 2021–2022 crop years. The farm is located at 49° 11' east longitude to 31° 50' north latitude, with an altitude of 18 meters above sea level.

Weather data

Vast plains comprise a large part of Khuzestan province. Ahvaz, the central city in the province, is also located on a plain. According to Damarten's classification, which relies on the two variables of average rainfall and average temperature, Ahvaz is categorized as having an arid climate. Arid climates are areas where the amount of precipitation is less than 250 mm per year, or the amount of potential evaporation and transpiration are more than precipitation. Weather data for the research area were obtained from weather station 40811 in Ahvaz (Table 1).

Table 1 Monthly average maximum and minimum temperature, sunshine hours, total rainfall and evaporation at Ahvaz (over wheat cropping season), from 2021 to 2022.

Month	Temperature (°C)		Sunshine (hours)	Rainfall (mm)
	Min	Max		
October	15.57	29.47	7.16	0.384
November	13.18	30.21	6.46	0.656
December	11.11	26.5	6.2	0.839
January	10.97	25.9	6.4	0.257
February	11.4	26	6.49	0
March	12.73	27.7	6.67	0.14
April	13.58	28.5	6.88	0.016

Physical and chemical characteristics of cultivated lands

To check the physical and chemical characteristics of the farm soil, soil samples were taken from four different depths and transported to the laboratory before starting the experiment. First, in the laboratory and using the soil texture triangle, the soil texture type was described. In this case, the soil type was clay (Table 2).

Table 2 Soil properties for experiments conducted in Ahvaz, Iran.

Soil properties	Depth (cm)			
	0–30	30–60	60–90	90–120
Texture	Clay	Clay	Clay	Clay loam
Sand (%)	24	30	22	30
Silt (%)	34	28	30	32
Clay (%)	42	42	48	38
Bulk density (g.cm ⁻³)	1.27	1.28	1.24	1.46
Field capacity (%)	38	37	41	36
Wilting point (%)	24	24	28	24
Saturation (%)	53	52	53	45
Hydraulic conductivity (cm.h ⁻¹)	46	47	51	43

Format and treatments

To evaluate the role of planting date and irrigation on yield and its components in camelina, this experiment was conducted in 2021 on three different planting dates: October 30, November 14, and December 16. It involved three irrigation treatments at three levels: 90%, 55%, and 25% of field capacity. The experiment was conducted as a split plot and in the form of a randomized complete block design in three replications. The plants were irrigated in plots, and each main plot was divided into three irrigation levels based on field capacity. A soil test was used to apply water deficit stress. The soil samples from different test plots were taken to the laboratory and measured the wet weight. Then, the samples were placed in an oven (110°C) for 48 hours. The dry soil weight was recorded, and by subtracting the moist soil weight from dry soil weight, the moisture content was determined. Then, drought stress occurred after the soil moisture reached the desired percentage of field capacity. In this experiment, the field capacity and wilting point were 38.8% and 24.4% of soil moisture, respectively.

2.3 AquaCrop model calibration and verification

The AquaCrop model requires input data in four categories, i.e., weather data, plant species, field management, and soil information. Weather data were obtained from the meteorological station of Ahvaz city. A text file was inserted into a software directory and saved as a file for the model. The purpose of calibrating the model was to adjust the model plant inputs for verification and simulation. In the AquaCrop model, the treatment of the first planting date (October 30) and normal irrigation conditions (90% of field capacity) were used to compare the measured and simulated values regarding canopy cover, dry biomass yield, and soil moisture level (Andarzian et al. 2011). The model was evaluated for the simulation of canopy cover, dry biomass yield, and soil moisture through statistical routes that involved the coefficient of determination (R^2 , Equation 1), root mean square error (RMSE, Equation 2), normalized root mean square error (NRMSE, Equation 3), Nash-Sutcliffe model efficiency coefficient (EF, Equation 4), and Willmott's Index of Agreement (d , Equation 5).

$$R^2 = \frac{\sum_{i=1}^n (O_i - \bar{O})(S_i - \bar{S})}{\sum_{i=1}^n (O_i - \bar{O})^2 \sum_{i=1}^n (S_i - \bar{S})^2} \quad (1)$$

$$RMSE = \left[\sum_{i=1}^n \frac{(S_i - O_i)^2}{n} \right]^{0.5} \quad (2)$$

$$NRMSE = \left[\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2 \right]^{0.5} \left(\frac{100}{\bar{O}} \right) \quad (3)$$

$$EF = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (4)$$

$$d = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)^2}, 0 \leq d \leq 1 \quad (5)$$

Where:

O_i = observed value at the i -th data point,

$\bar{O}$ = average of observed values,

S_i = simulated value at the i -th data point,

$\bar{S}$ = average of simulated values,

P_i = forecast value, and

n = number of data points.

2.4 Model simulation and zoning

After obtaining the results from model calibration and verification, the required historical weather data included maximum and minimum temperatures, relative humidity (%), solar radiation intensity, rainfall, and wind speed between the years 2003 and 2021 of Khuzestan province through NASA's portal. The weather information was stored in a text file with a format that could be entered into the model. Another parameter required for long-term simulation of yield in different cities was the dominant soil type. This parameter was obtained from various sources and described according to the region under study. Other field operations were modeled based on recommended guidelines for planting. To calculate crop yield in irrigated conditions, direct irrigation was defined for plants when not relying on rainfed conditions. For the simulation of rainfed conditions, we selected rainfed irrigation as input into the model. After inserting the verified treatment in the model and changing the planting date, the obtained yields were entered into a table in Microsoft Excel. Eight planting dates were selected for the simulation of the model, from October 10 to December 20 each year with an interval of 10 days. Some crop parameters in AquaCrop were presented in Table 3. After simulating the model in the specified years and months for different cities of the province, the best results were selected based on the average yield of 18 years in each city. Then, the obtained yield base was used for describing the probability of their occurrence in the respective cities (using the Rainbow statistical software version 2.2). The information pertaining to yield in each city was read by the software after preparing the relevant folders. After running the software, the probability of occurrence for each yield was described based on the frequency of yield occurrence (10 to 90%). These results were used to generate diagrams of probability occurrence and curves using

Sigma Plot software (version 15) and in obtaining the results of 50% probability for the zoning performance of camelina cultivation.

Table 3 Conservative parameters used to simulate runs.

Parameter description	Value	Unit or meaning
Base temperature	0	°C
Cut-off temperature	36	°C
Canopy cover per seeding at 90% emergence (CC_0)	1.3	cm ²
Canopy growth coefficient (CGC)	0.7	Increase in CC relative to existing CC per GDD
Maximum canopy cover (CC_x)	80%	Function of plant density
Reference harvest index, H_{lo}	10%	Common for good condition
Building up of HI	15%	Common for good condition
Water productivity	18.5	g (biomass) m ⁻² , function of atmospheric CO ₂
Crop coefficient for transpiration at $CC = 100\%$	1	Full canopy transpiration relative to ET_0
Time from sowing to emergence	6	days
Time from sowing to start senescence	60	days
Crop density	14	Plants.m ⁻²

3. RESULTS

3.1 Model validation

Calibrating is an important step for model verification. It involves a comparison between independent field measurements (data) and output created by the model. Grain yield was considered in this study for model evaluation. The performance of the calibrated model was evaluated against the independent data sets (experimental data of 30 October sowing date) and result are shown in Figure 1. The AquaCrop growth simulation model estimated the crop yield. Model verification and yield simulation pertained to different regions of the Khuzestan province. The preliminary requirement for using this tool was model verification and the precision of estimation in the study area. In this section, AquaCrop evaluation aimed at verifying canopy cover, dry matter accumulation, and soil moisture content in Khuzestan weather conditions, with comparisons in field test results.

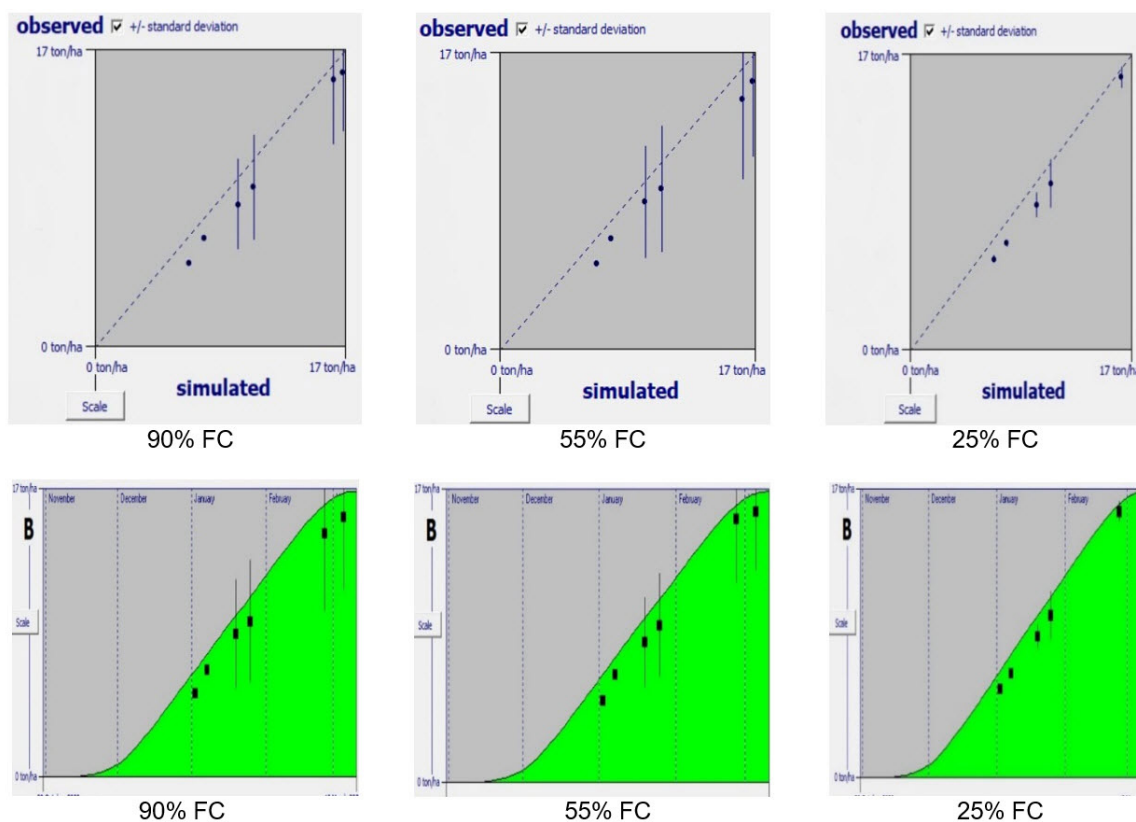


Figure 1 Comparison of simulated and measured grain yield, $t\ ha^{-1}$ for 30 October treatment 2021–2022 growing seasons.

3.2 Canopy cover

The calibrated parameter of canopy cover comprised the results of statistical analysis for simulating this parameter using three planting dates and three humidity levels (Table 4). As can be seen in Table 4, the model simulated the canopy cover with apt accuracy. Also, the comparison of simulated and observed dry-matter yield curves showed that the model simulated the canopy cover acceptably over time.

Table 4 Statistical indices derived for evaluating the performance of AquaCrop model in predicting cover crop, biomass, and soil water content.

Cropping year	Treatment	Cover Crop (%)		Biomass (t ha ⁻¹)		Soil Water Content (mm)	
		Predicted	Observed	Predicted	Observed	Predicted	Observed
30 October	90% FC	46.6	42.6	7.885	8.190	311.0	182.0
	55% FC	46.6	43.1	9.058	8.096	302.2	153.8
	25% FC	46.2	40.6	9.175	7.682	310.1	122.0
14 November	90% FC	71.1	61.1	8.196	9.964	305.0	189.4
	55% FC	47.4	44.4	7.212	6.591	273.0	158.3
	25% FC	43.2	30.5	6.575	5.033	249.8	132.4
16 December	90% FC	43.1	37.6	6.710	5.538	274.4	167.8
	55% FC	43.2	29.2	6.599	4.705	249.8	146.3
	25% FC	43.6	30.5	5.879	5.033	275.5	132.4
Index							
$(R^2)^a$		0.99		0.99		0.89	
RMSE (mm) ^b		3.03		1.07		17.28	
NRMSE (%) ^c		6.77		12.42		6.57	
EF ^d		0.94		0.89		0.71	
d^e		0.96		0.97		0.84	

NOTE: ^aCoefficient of Determination, ^bRoot Mean Square Error, ^cNormalized Root Mean Square Error, ^dNash-Sutcliffe Model Efficiency Coefficient, ^eWillmotts Index of Agreement

3.3 Dry matter yield accumulation

The model's ability to simulate dry matter yield accumulation was evaluated by performance evaluation indices of the model (Table 4). The calculated values of statistical indices included r , RSME, NRSME, EF, and d for total quinoa dry matter accumulation and indicated an acceptable accuracy of the model in simulating predictable parameters (Table 4). The simulated dry matter yield by the AquaCrop model showed good compatibility with previously observed data on quinoa yields. Therefore, the AquaCrop model simulated the dry matter yield agreeably in Khuzestan weather conditions.

3.4 Soil moisture content

According to the values of statistical indices, the model's accuracy in simulating the soil moisture content was lower than in other measured parameters. This finding indicates that the root of the normalized mean square error (NRMSE) was higher when simulating soil moisture content, compared to the other two parameters. It shows the model's moderate ability to simulate soil moisture with high accuracy, compared to canopy cover and dry matter accumulation (Table 4). The measured and simulated values of soil moisture are revealing that

the high value of r indicates the model simulated the soil moisture content with relatively good accuracy.

According to the results of evaluation and verification, the AquaCrop model simulated camelina growth aptly in different regions of Khuzestan. Thus, considering the agreeable accuracy of the model, it can be used for camelina yield potential measurement and zoning studies in different cities of Khuzestan province.

3.5 Simulating the potential yield of camelina in Khuzestan cities

Potential yield is affected by factors such as soil moisture, ambient radiation, and temperature. It is assumed to be a favorable condition when there are no limiting factors that reduce production. Accordingly, the simulation was based on long-term data related to temperature, radiation, and rainfall, which led to the simulation of camelina yield potential in different regions of the province. The areas used in the simulation included the cities of Omidiyeh, Ahvaz, Izeh, Baghmalek, Behbahan, Khorramshahr, Dezful, Dashte Azadegan, Ramshir, Ramhormoz, Shush, and Shushtar. The simulations were related to different planting dates by the AquaCrop model. The results showed that the potential yield of camelina in different regions varied from 1.6 to 1.9 tons per hectare in the province and had considerable diversity. The highest yield potential was 1941.7 kg/ha, simulated for Baghmalek city, and the lowest potential yield was 1639.7 kg/ha, simulated for Ramshir city.

3.6 Production risk analysis

The probability distribution analysis of camelina yield potential in different cities of the province indicated a significant difference in production risks among the different regions (Figure 2). The probability of obtaining camelina yields above 1900 kg/ha is above 60% in Baghmalek and lower than 20% in Izeh. In other cities of the province, yields between 1600 and 1750 kg/ha had a 50% probability of occurrence.

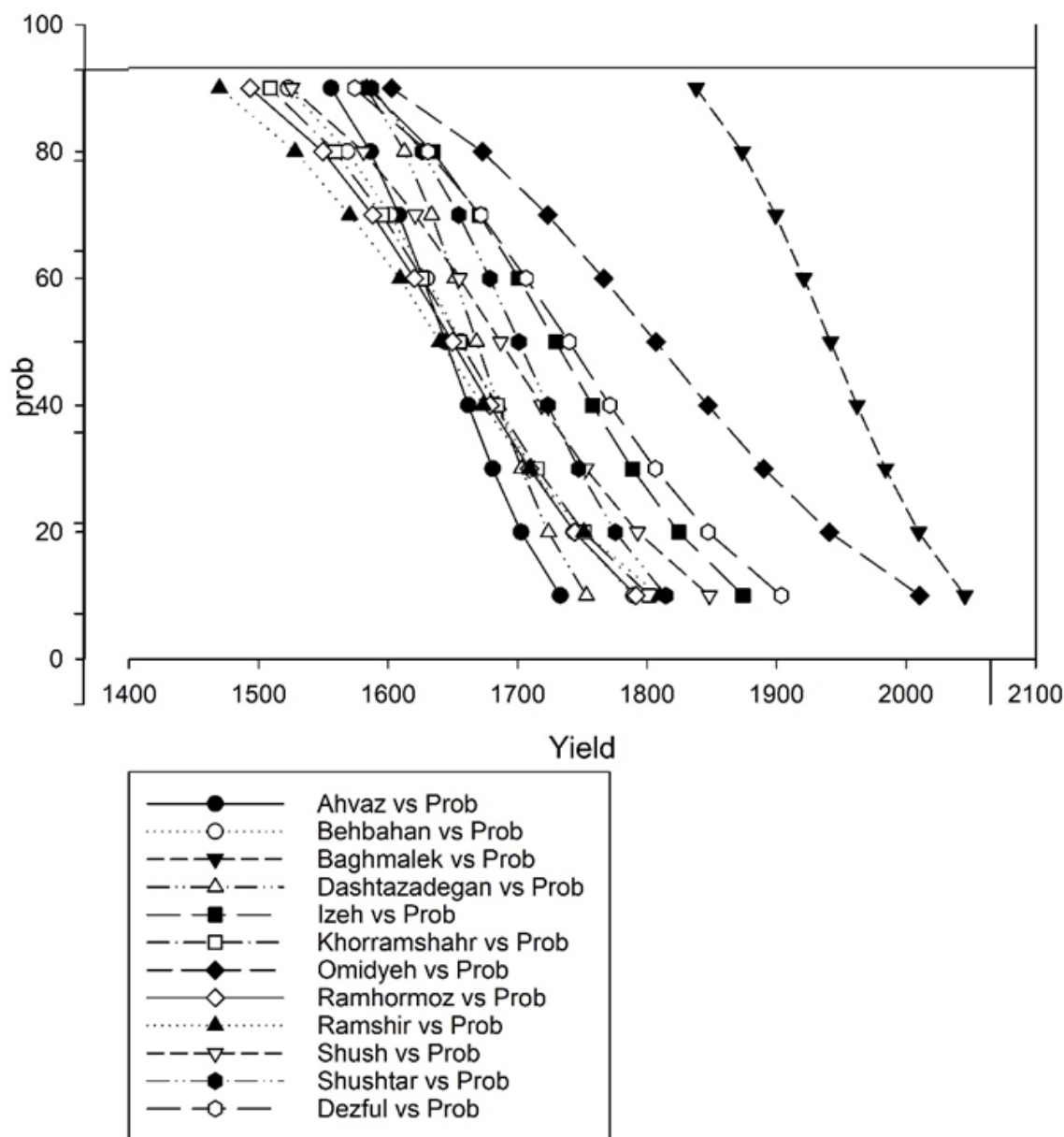


Figure 2 Cultivation area and production of camelina in each region (cities) at Khuzestan province.

3.7 Agro-ecological zoning of Khuzestan province based on camelina yield potential

After simulating camelina yield, we generated a zoning map for camelina cultivation (Figure 3). The map had three zones in terms of camelina yield potential, i.e., very suitable, moderately suitable, and unsuitable. The 'very suitable' zone had a long-term average simulated yield potential of over 1800 kg/ha, encompassing the cities of Omidyeh and Baghmalek. The 'moderately suitable' zone had a long-term average yield potential of 1700–1800 kg/ha and included the cities of Izeh, Dezful, and Shushtar. The 'unsuitable' zone had a long-term average simulated potential yield between 1600–1700 kg/ha and included the cities of Ahvaz, Behbahan, Khorramshahr, Dasht Azadegan, Ramshir, Ramhormoz, and Shush.

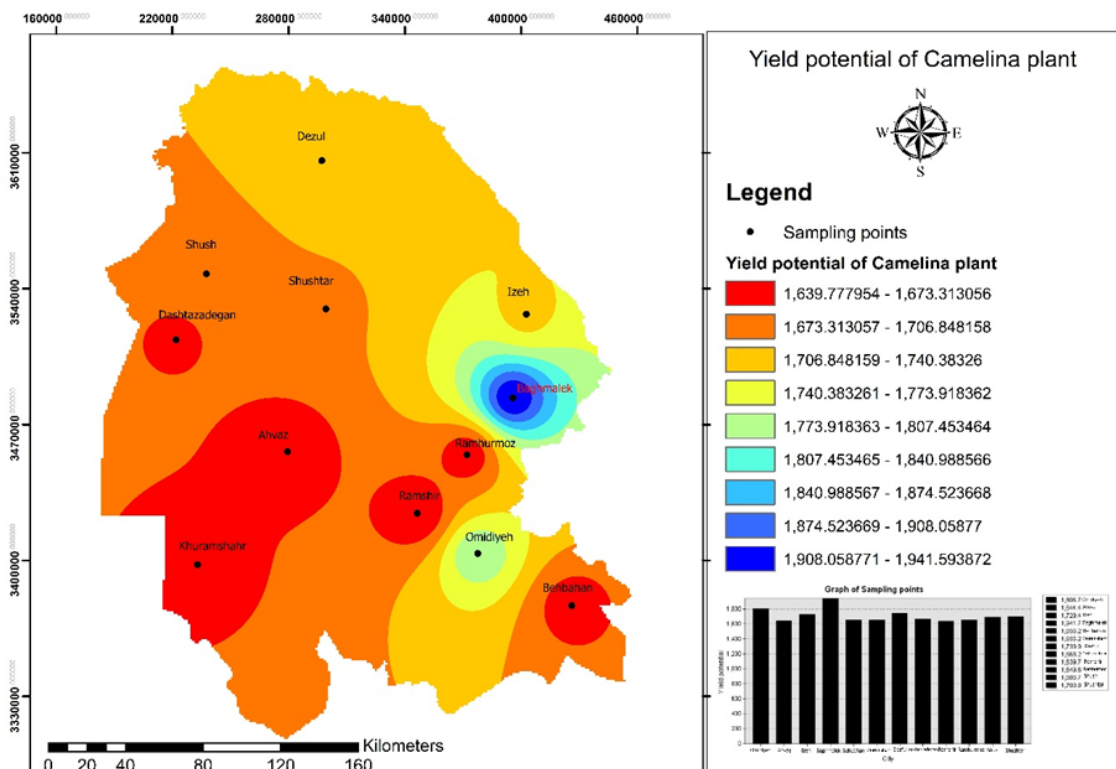


Figure 3 Agro-ecological zoning map of camelina cultivation in Khuzestan province.

4. DISCUSSION

Camelina has several agronomic advantages, such as a higher seed yield in rainfed conditions—averaging 1804 kg/ha—making it a viable option compared to other drought-resistant crops. Camelina seed yields at maturity were reported by Moser (2010) to range from 900 to 2240 kg ha⁻¹. It also demonstrates abiotic stress tolerance and is suitable for poor soils, especially in warm and dry regions like Khuzestan. Its short vegetation cycle (85–100 days) and low requirements for water and nutrients further enhance its suitability. Although, camelina is viewed as a desirable alternative biodiesel crop because of its apparent lower cost of production (i.e., water, fertilizer, pesticides, and seeding rate) relative to other more common oilseeds being produced, such as soybean, canola, and sunflower (Frohlich and Rice 2005; Moser 2010; Pavlista et al. 2011).

Intensifications in water scarcity and other characteristics of climate change substantially affect agricultural productivity on a global scale. Consequently, a significant portion of research endeavors within the agricultural sector is dedicated to examining and forecasting the impact of climate change on crop production (Kimball et al. 2002). Growth simulation models are a powerful tool in yield estimation for farms on regional and national scales (Gohain et al. 2020). In this study, the AquaCrop model assisted in simulating camelina growth. The results showed that this model aptly simulated the growth and development of camelina in Khuzestan. The modeling software reportedly had a good reputation for simulating various crops. Among the results, Hsiao et al. (2009) showed that the AquaCrop model can properly simulate canopy cover, aerial plant biomass growth, and seed yield. The model was applied in conditions where

four corn cultivars were cultivated at different densities and irrigated with different treatments in a series of seasons and planting dates, with varying transpiration rates. Todorovic et al. (2009) compared two agreeable basic models, CropSyst and WOFOST, with the AquaCrop model in the warm Mediterranean conditions of southern Italy. The research involved a comparative study of sunflower cultivation under three different irrigation regimes. The results showed that the AquaCrop model required less input data and simulated plant biomass and yield in the harvest phase like the other two models. Izadfard et al. (2017) evaluated yield potential in six crops, i.e., autumn wheat, autumn barley, autumn sugar beet, cotton, corn, and soybeans in parts of the Moghan plains after calibrating the AquaCrop model and the radiation thermal potential model (FAO). They reported that the AquaCrop model was more accurate than the FAO model. Also, the AquaCrop model required fewer calculations, more output, and wider applications than the FAO model. Using the yield potential of the AquaCrop model, differences in yield were calculated and the products were ranked for cultivation success in the region. In previous research, the accuracy of the AquaCrop model was evaluated for determining the yield and efficiency of sugar beet water consumption. It was reported that the statistical comparison of the simulated results and real data showed that the AquaCrop model has an acceptable accuracy in simulating both yield and efficiency factors (Dirwai et al. 2021). Andarzian et al. (2011) evaluated the AquaCrop model in Ahvaz city for wheat crops under different scenarios of low irrigation at different stages of plant growth and water requirement. The results of this study showed that the AquaCrop model predicted root zone moisture, biomass, and simulated yield with good accuracy. Shamsnia and Pirmoradian (2013) simulated the yield of rainfed wheat using AquaCrop in response to climate change and weather fluctuations in Shiraz. They reported that weather fluctuations affected rainfed wheat yield in the study area, and the model accurately simulated dryland wheat cultivation. Salemi et al. (2011) showed that the AquaCrop model can aptly simulate the wheat yield and biomass under conditions of low irrigation and full irrigation.

In this research, the agro-ecological zoning of camelina also relied on the analysis of climate, topography, water, and soil information in Khuzestan. Since Geographic Information System (GIS) is a powerful tool in spatial data analysis, it described homogeneous zoning according to yield potential simulation. When zoning the Khuzestan province for camelina cultivation, moving from the northeast to the south of the province decreases the suitability of camelina cultivation and yield potential. The reason for this decrease can be attributed to the differences in environmental conditions, rainfall amount and distribution, minimum and maximum temperature, and other climatic variables. The soil is more suitable for camelina cultivation in the northeastern and central parts of Khuzestan province. In the northeastern regions of the province, there are suitable temperatures, adequate rainfall, and good rainfall distribution in the critical periods of plant growth; therefore, a higher yield can be obtained. Moving from the center to the south of the province, higher temperatures can cause problems for the yield of the plant, compared to the northeastern regions. Thus, a drop in yield is inevitable.

Relevant to this context, Roman-Figueroa (2017) conducted research on zoning agro-climatic areas in Chile and found suitable areas for camelina cultivation. Climatic indicators, farm soil requirements, and geographical limitations were evaluated in different regions for this species. The indicators used in this research included the maximum temperature in the hottest month of the year, water deficit, and degree days. The limitations were altitude, regional geomorphology, and common land use, which helped to determine suitable areas for plant cultivation. The

results revealed that 1.3% of the areas in the country (960,664 hectares) were suitable for the cultivation of this plant. Thus, the total suitable areas were described and included about 49% of arable land (471,203 hectares) between Bibio and Las Lagos areas. Nonetheless, the research showed no temperature restrictions, water deficits, or edaphic stress. Therefore, they can be considered centers for camelina plant production. Falasca et al. (2014) conducted research by zoning different regions of Argentina to determine the maximum growth potential of camelina in various areas of Argentina. To determine the agro-climatic potentials for camelina cultivation in Argentina, the weather data were collected from relevant stations and included information between 1981 and 2010. The regions were divided into 5 different classes in terms of plant growth potential. Based on the results obtained, the eastern and northwestern humid regions had rainfall between 500 and 1600 mm and were regarded as optimal cultivation regions for this plant. Also, further attempts to determine the best areas led to the designation of a narrow strip with semi-humid and semi-arid climatic regimes in the west of this country, where a good potential for camelina cultivation reportedly exists. The AquaCrop model was calibrated for grain yield under full irrigation, and all nitrogen levels resulted in a prediction error ranging from 0.67% to 4.1%. Simulated biomass under 75% FC (W3) had the lowest prediction error of 2.5%, whereas rainfed conditions exhibited the highest prediction error of 13.4%. It was observed that the AquaCrop model calibrated the grain yield and biomass with the prediction error statistics of $0.99 < E < 0.95$, $0.29 < RMSE < 0.42$ and $0.17 < MAE < 0.51 \text{ t ha}^{-1}$ for irrigation and nitrogen treatment levels. Subsequently, the model was validated, and the performance was in line (i.e., $0.95 < E < 0.98$, $0.11 < MAE < 1.08$ and $0.1 < 0.75$) with the observed data of yield and biomass for all irrigation and nitrogen levels during the year 2010. Also, the simulations results for canopy cover (CC) and biomass showed a close match with the observed values for all irrigation treatments. It was observed that the AquaCrop model was more accurate in predicting the maize yield under full and 75% FC as compared to the rainfed and 50% FC. The AquaCrop model required a lower number of data inputs when simulating the maize growth and yield under different water and fertilizer availability scenarios, as compared to other crop models. Nonetheless, from the results of field experiments and modeling, it can be concluded that the water driven FAO AquaCrop model could be used to predict the maize yield with acceptable accuracy under variable irrigation and field management situations in the semi-arid regions of northern India.

5. CONCLUSION

Research indicates that camelina serves as a valuable oilseed crop with multiple agronomic advantages for cultivation in dry and unfavorable climatic conditions, particularly in Khuzestan province, Iran. With traits such as high tolerance to abiotic and biotic stress, along with low water and nutrient requirements, camelina emerges as a suitable option for addressing the challenges posed by climate change and water scarcity.

The AquaCrop growth simulation model has proven to be a powerful tool in accurately predicting camelina's performance across various conditions, demonstrating high precision in simulating yield and root zone moisture dynamics. Analyses reveal that the distribution and alignment of climatic and soil conditions in Khuzestan significantly impact camelina's yield potential.

Additionally, studies from other countries, such as Chile and Argentina, further support the viability of camelina in regions with adequate rainfall and favorable soil conditions. The use of the AquaCrop model has also shown enhanced accuracy in predicting crop performance under various irrigation and nitrogen scenarios.

Overall, the cultivation of camelina can contribute to agricultural diversification and improve the livelihoods of farmers in arid and semi-arid regions. The AquaCrop model stands out as an advanced tool for optimizing water resource management and enhancing crop yields in these areas.

REFERENCES

- Ali, S., Y. Liu, M. Ishaq, T. Shah, Abdullah, A. Ilyas, and I.U. Din. 2017. "Climate Change and its Impact on the Yield of Major Food Crops: Evidence from Pakistan." *Foods* 24 (6): 39. <https://doi.org/10.3390/foods6060039>
- Amiji, M.P., M. Hooshmand, O. Raja, and A.M. Liaghat. 2020. "Effective Rain Zoning in Khuzestan Province under Autumn Rainfed Wheat Cultivation." *Journal of Water and Irrigation Management* 9 (2): 211–230. <https://doi.org/10.22059/JWIM.2019.290773.718>
- Amin, M.E.S., E.S. Mohamed, A.A. Belal, M.E.M. Jalhoum, M.A. Abdellatif, D. Nady, and A.M. Ali, et al. 2022. "Developing spatial model to assess agro-ecological zones for sustainable agriculture development in MENA region: Case study Northern Western Coast, Egypt." *The Egyptian Journal of Remote Sensing and Space Science* 25 (1): 301–311. <https://doi.org/10.1016/j.ejrs.2022.01.014>
- Andarzian, B., M. Bannayan, P. Steduto, H. Mazraeh, M.E. Barati, M.A. Barati, and A. Rahnema. 2011. "Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran." *Agricultural Water Management* 100 (1): 1–8. <https://doi.org/10.1016/j.agwat.2011.08.023>
- Bakhshi, B., H. Rostami-Ahmadvandi, and H.R. Fanaei. 2021. "Camelina, an adaptable oilseed crop for the warm and dried regions of Iran." *Central Asian Journal of Plant Science* 1 (1): 39–45. <https://doi.org/10.22034/CAJPSI.2021.01.05>
- Belayneh, H.D., R.L. Wehling, Y. Zhang, and O.N. Ciftci. 2017. "Development of omega-3-rich *Camelina sativa* seed oil emulsions." *Food Science and Nutrition* 6 (2): 440–449. <https://doi.org/10.1002/fsn3.572>
- Dhanaraju, M., P. Chenniappan, K. Ramalingam, S. Pazhanivelan, and R. Kaliaperumal. 2022. "Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture." *Agriculture* 12 (10): 1745. <https://doi.org/10.3390/agriculture12101745>
- Dirwai, T.L., A. Senzanje, and T. Mabhaudhi. 2021. "Calibration and Evaluation of the FAO AquaCrop Model for Canola (*Brassica napus*) under Varied Moisture Irrigation Regimes." *Agriculture* 11 (5): 410. <https://doi.org/10.3390/agriculture11050410>
- Falasca, S.L., M.C. Fresno, and C. Waldman. 2014. "Developing an agro-climatic zoning model to determine potential growing areas for *Camelina sativa* in Argentina." *QScience Connect* 1, 4. <https://doi.org/10.5339/connect.2014.4>

- Food and Agriculture Organization of the United Nations (FAO). 2002. "Global agro-ecological assessment for agriculture in the 21st century." *Land and Water Digital Media Series* 21. Rome.
- Food and Agriculture Organization of the United Nations (FAO). 2017. "The future of food and agriculture – Trends and challenges." Rome.
- Frohlich, A., and B. Rice. 2005. "Evaluation of Camelina sativa oil as a feedstock for biodiesel production." *Industrial Crops and Products* 21 (1): 25–31.
<https://doi.org/10.1016/j.indcrop.2003.12.004>
- Gohain, G.B., K.K. Singh, R.S. Singh, and P. Singh. 2020. "Regional Crop Yield Estimation System (RCYES) using a crop simulation model DSSAT v4.7: Concept, methods, development, and validation." *Journal of Agrometeorology* 22 special issue, 33–38.
- Hijmans, R.J., and C.H. Graham. 2006. "The ability of climate envelope models to predict the effect of climate change on species distributions." *Global Change Biology* 12 (12): 2272–2281. <https://doi.org/10.1111/j.1365-2486.2006.01256.x>
- Hsiao, T.C., L.K. Heng, P. Steduto, B. RojasLara, D. Raes, and E. Fereres. 2009. "AquaCrop—the FAO Crop Model to Simulate Yield Response To Water: III. Parameterization and Testing for Maize." *Agronomy Journal* 101 (3): 448–459. <https://doi.org/10.2134/agronj2008.0218s>
- Izadfard, A., F. Sarmadian, M.R. Jahansooz, G.R. Peikani, and M.R. Chaichi. 2017. "A Comparison between AquaCrop and Radiation-Thermal Production Potential Models for Potential Yield Estimation in Part of Moghan Plain, Ardabil Province, Iran." *Iranian Journal of Soil and Water Research* 48 (4): 853–864. <https://sid.ir/paper/225710/en>
- Kimball, B.A., K. Kobayashi, and M. Bindi. 2002. "Responses of agricultural crops to free air CO₂ enrichment." *Advances in Agronomy* 77, 293–368. [https://doi.org/10.1016/S0065-2113\(02\)77017-X](https://doi.org/10.1016/S0065-2113(02)77017-X)
- Madani, K., A. AghaKouchak, and A. Mirchi. 2016. "Iran's Socio-economic Drought: Challenges of a Water-Bankrupt Nation." *Iranian Studies* 49 (6): 997–1016.
<https://doi.org/10.1080/00210862.2016.1259286>
- Moser, B.R. 2010. "Camelina (*Camelina sativa* L.) oil as a biofuels feedstock: Golden opportunity or false hope?" *Lipid Technology* 22 (12): 270–273.
- Obour, A.K., E. Obeng, Y.A. Mohammed, I.A. Ciampitti, T.P. Durrett, J.A. Aznar-Moreno, and C. Chen. 2017. "Camelina Seed Yield and Fatty Acids as Influenced by Genotype and Environment." *Agronomy Journal* 109 (3): 947–956.
<https://doi.org/10.2134/agronj2016.05.0256>
- Pavlista, A.D., T.A. Isbell, D.D. Baltensperger, and G.W. Hergert. 2011. "Planting date and development of spring-seeded irrigated canola, brown mustard, and camelina." *Industrial Crops and Products* 33 (2): 451–456. <https://doi.org/10.1016/j.indcrop.2010.10.029>
- Richardson, R.B. 2010. "Ecosystem Services and Food Security: Economic Perspectives on Environmental Sustainability." *Sustainability* 2 (11): 3520–3548.
<https://doi.org/10.3390/su2113520>
- Román-Figueroa, C., R. Padilla, J.M. Uribe, and M. Paneque. 2017. "Land Suitability Assessment for Camelina (*Camelina sativa* L.) Development in Chile." *Sustainability* 9 (1): 154.
<https://doi.org/10.3390/su9010154>

- Salemi, H., M.A. Mohd Soom, T.S. Lee, and S.F. Mousavi, A. Ganji, and M. KamilYusoff. 2011. "Application of AquaCrop model in deficit irrigation management of Winter wheat in arid region." *African Journal of Agricultural Research* 610: 2204–2215.
- Shamsnia, S.A., and N. Pirmoradian. 2013. "Simulation of rainfed wheat yield response to climatic fluctuations using AquaCrop model (Case study: Shiraz region in southern of Iran)." *International Journal of Engineering Science Invention* 2 (4): 51–56.
- Tedone, L., F. Giannico, V. Tufarelli, V. Laudadio, M. Selvaggi, G. De Mastro, and M.A. Colonna. 2022. "Camelina sativa (L. Crantz) Fresh Forage Productive Performance and Quality at Different Vegetative Stages: Effects of Dietary Supplementation in Ionica Goats on Milk Quality." *Agriculture* 12 (1): 91. <https://doi.org/10.3390/agriculture12010091>
- Todorovic, M., R. Albrizio, L. Zivotic, M. Abi Saab, C. Stöckle, and P. Steduto. 2009. "Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes." *Agronomy Journal* 101 (3): 509–521. <https://doi.org/10.2134/agronj2008.0166s>
- Trnka, M., J. Eitzinger, P. Hlavinka, M. Dubrovský, D. Semerádová, P. Štěpánek, S. Thaler, et al. 2009. "Climate-driven Changes of Production Regions in Central Europe." *Plant, Soil and Environment* 55 (6): 257–266. <https://doi.org/10.17221/1017-PSE>