EVALUATION OF THE AQUACROP MODEL PERFORMANCE AND THE IMPACT OF FUTURE CLIMATE CHANGES ON POTATO PRODUCTION UNDER DIFFERENT SOIL MANAGEMENT SYSTEMS

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ABSTRACT:

This study was aimed to investigate the effect of surface sprinkler and drip irrigation systems using a model AquaCrop, irrigation intervals, bio-organic fertilizers and polymers in desert soils. Two field experiments were conducted during the spring season 2020 at Karbala governorate. The experiment included three factors: 1-Irrigation system surface drip T_1 and sprinkler T_2, 2- The Irrigation interval: every 2 days I_1, 4 days I_2 and 6 days I_3, 3- Addition of soil conditioners: control without any addition C, bio-organic fertilizers (seek) B, polymer (zeba) P, and polymer+ bio-organic fertilizers P+B. The experiment was designed according to the nested design with three replicates results of regional climate models and AquaCrop model. The results showed that there was an increase in the amount of annual precipitation and seasonal during the periods (2016-2035) and (2046-2065) under RCP4.5 scenario, compared to the base period (1985-2005). With an increase in the amount of annual precipitation and seasonal during the period at scenario RCP8.5 with a slight decrease during the period (2046-2065) compared to the base period. Moreover, an increase in the maximum and minimum temperatures according to scenario RCP4.5 and RCP8.5 scenario during the period (2016-2035) and (2046-2065) compared to the base period. The expected productivity using the AquaCrop, as R^2 was 0.85 and 0.81 for twelve years, under surface drip irrigation systems and sprinkler, respectively. The correlation coefficient (r) was 0.95 and 0.90, the root means square error (RMSE) 2.43 and 2.19, and the efficiency coefficient 0.66 and 0.42 for the surface drip and sprinkler systems, respectively. Finally, the increase in water productivity and productivity in the scenario RCP4.5 and RCP8.5 for the treatment of BP and the irrigation interval $I_1$and treatment C and the irrigation interval I_3 when comparing the base period with the periods (2016-2035) and (2046-2065) For surface drip irrigation systems and sprinkler.

Key words: RCP4.5 and RCP8.5; scenario; Aquacrop; polymers.

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تقييم أداء نموذج AquaCrop وأثر التغيرات المناخية المستقبلية في محاكاة إنتاج البطاطا تحت نظم إدارة تربة مختلفة

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المستخلص

أجريت تجربتين حقليتين خلال الموسم الربيعي 2020 في محافظة كربلاء، لدراسة تأثير أنظمة الري بالرش والتنقيط السطحي بإستخدام أنموذج AquaCrop وفواصل أرواء بإستخدام تقنيةأضافة المخصب الحيوي والبوليمرات في الترب الصحراوية. شملت التجربة دراسة ثلاثة عوامل:1– نظام الري: التنقيط السطحي T_1 والرش T_2.2– فاصلة الإرواء: الارواء كل 2 أيام I_1 و4 أيام I_2 و6 أيام I_3. 3–إضافة محسنات التربة: المقارنة بدون اي اضافة C ومخصبات حيوية عضوية B أضافة البوليمر P وأضافة البوليمر+مخصبات حيوية عضوية P+B. صممت التجربة وفق التصميم التجميعي بثلاث مكررات، بأستخدم نتائج النماذج المناخية الإقليمية وأنموذج AquaCrop. اظهرت النتائج: زيادة في كمية التساقط المطري السنوي والموسمي خلال الفترتين (2016–2035) و(2046–2065) عند السيناريو RCP4.5 مقارنةً بفترة الاساس (1985–2005) وزيادة في كمية التساقط المطري السنوي والموسمي خلال الفترة (2016–2035) عند السيناريو RCP8.5 مع انخفاض بسيط خلال الفترة (2046–2065) بالمقارنةً مع فترة الاساس. وزيادة في درجات الحرارة العظمى والصغرى وفقاً لسيناريو RCP4.5 وRCP8.5 خلال الفترة (2016–2035) و(2046–2065) بالمقارنةً مع فترة الاساس. وتقارب الإنتاجية الحالية لمحصول البطاطا مقارنة بالإنتاجية المتوقعة بأستخدام نموذج AquaCrop، أذ بلغت R^2 قيمة 0.85 و0.81 لمدة أثني عشر سنة تحت نظامي الري بالتنقيط السطحي والرش، على التتابع. كما بلغ معامل الارتباط (r) 0.95 و0.90 وجذر متوسط مربع الخطأ (RMSE) 2.43 و2.19 ومعامل الكفاءة 0.66 و0.42 لنظامي الري بالتنقيط السطحي والرش، على التتابع. بالاضافة الى زيادة الإنتاجية والانتاجية المائية عند السيناريو RCP4.5 وRCP8.5 لمعاملة BP ولفاصلة الإرواء I_1 ومعاملة C ولفاصلة الإرواء I_3 عند مقارنة فترة الاساس مع الفترتين (2016–2035) و(2046–2065) لنظامي الري بالتنقيط السطحي والرش.

الكلمات المفتاحية: مسارات التركيز النموذجية للمناخ RCP، سيناريو، أنموذج AquaCrop، بوليمر.

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INTRODUCTION

Water resources constitute the basic lifeline for the environment of arid and semi-arid areas. Water resources in Iraq have faced many threats, especially in the second half of the last century, as large areas dried up and water resources shrank due to the establishment of irrigation projects in Syria, Turkey, and Iran. The current consumption of water for agricultural purposes is 53.70 billion m^3, while drinking consumption, domestic and industrial uses are estimated at 5.1 billion m^3, in addition to the requirements for maintaining the marshes of 6 billion m^3. The strategic study of water and land resources according to the future expectations of water revenues and their quality in Iraq indicated that Iraq will suffer from a decrease in water revenues that will affect meeting water needs. The amount of expected water revenues in 2035 is estimated (59.73 billion m^3) compared to revenues in 2015 (77.37) billion m^3, that is, a decrease of 17.64 billion m^3. Besides, by comparing the revenues available in 2035 with the estimated water needs (in the absence of implementation of the basic reforms of the water and agriculture sector) 70.67 billion m^3, there is an expected deficit of 10.94 billion m^3 (25). Combined with, the erratic and uncertain water supply will exacerbate the situation in areas that are currently experiencing water stress, and generate water stress in areas that have abundant water resources at present. Water stress is already affecting all continents, where climate change is likely to cause changes in seasonal water availability throughout the year in several places (41). These change forecasts point to a warmer world over the next 50 years and the ranges of maximum and minimum temperatures are expected to increase, leading to a significant decrease in crop yields with an increase in temperature of 1-2°C. While projected rainfall patterns will not have distinct patterns by 2080 (23). The use of a drip irrigation system would be one of the important methods that lead to rationalization of added water amount compared to traditional irrigation, drip irrigation is known as adding water directly to the soil in small quantities by emitters, The water added in quantity is equivalent to evapotranspiration, move from these emitters horizontally and vertically in soil profile without big loss because the water applied less than the range of infiltration rate in soil (4).The irrigation methods with high efficiencies applied to using irrigation water included drip irrigation, Irrigation efficiency has reached more than compared with the traditional method at conditions in the middle of Iraq (31). Many studies have tried to find different methods in programming irrigation operations by controlling the quantities of added irrigation water, and scheduling the addition using modern irrigation methods, especially in areas of limited water because of limited water resources and losing large quantities of them during conventional irrigation operations (3). Irrigation scheduling is the process of determining the irrigation time, amount of water added, and all the practices for managing irrigation and water use with high efficiency and rationing the water added (36). Irrigation management factors are related to two basic principles, which include the timing of irrigation and determining the amount of water required in each irrigation cycle in a way that ensures the plant's need for water in the root zone for the purpose of economic production accompanied by a minimum of water losses (18). Furthermore, (39) showed that the management of irrigation water through irrigation scheduling depends on the foundations of combining soil information with climate and vegetation, and this is through direct monitoring of soil water and forecasts of water balance to estimate evapotranspiration. The sprinkler system offers a great application potential as a highly efficient irrigation system (22) The sprinkler irrigation systems are characterized by many features that make them spread. And the most eminent of these features is its high efficiency if its design, execution and operating are done well compared with the methods of irrigation by immersion, and the possibility of using them in the undulating lands being without need to the settlement processes, and it's also characterized by irrigating the gypsiferouslands, the lands whose light sandy textures and the lands that the groundwater levelmayraises in it and that requires special management for the irrigation processes, plus many features (2).The Food and Agriculture Organization (FAO) has developed a program called AquaCrop (30) that helps in planning irrigation and optimizing the use of resources to increase water productivity. Focuses on simulating achievable crop biomass and harvestable yield, providing a simulation of plant physiological processes and crop growth and development (8). AquCrop is a program that simulates the interrelationship between the plant and the soil (Fig.1). The program takes into account the factors of field management, such as soil fertility and irrigation management, and the factors affecting the interrelationship between the plant and the soil account the relationship with the atmosphere, and the evapotranspiration (ET_0), and the supply of carbon dioxide (CO_2), and the energy required for plant growth is calculated. The simulation of dry biomass of potato crop using AquaCrop program with the measured values for the period 2009-2010 agrees well with the measured values with a low mean error, as it gave the correlation coefficient of 0.74 and 0.72. Moreover, it can also emphasize that the special features that distinguish AquaCrop from other crop models are its focus on water, the use of vegetation coverage of the land instead of the leaf area index. Along with, the use of water productivity values that depend on the evaporation and carbon dioxide concentration, which gives the model an expansion of the ability to extrapolate to various locations and seasons (5).

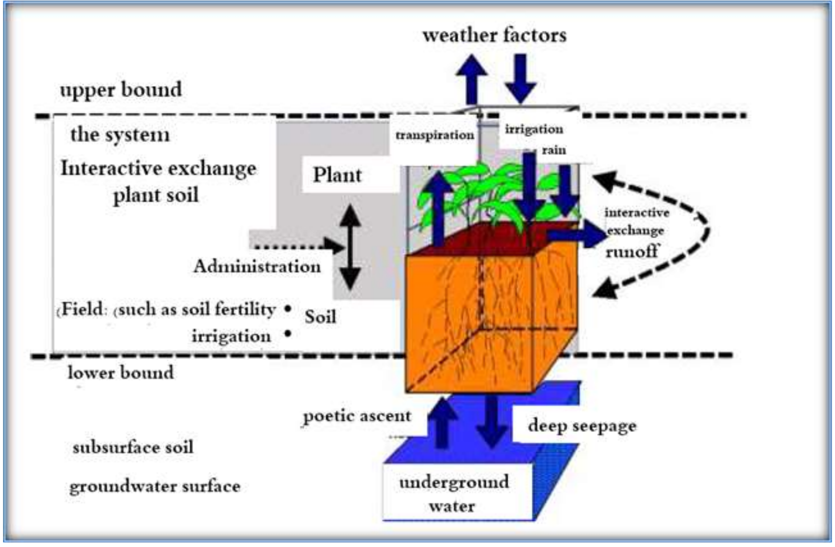

Figure 1. Part AquCrop simulates from the real world

That the calibrations for the validity of the Aquacrop model to simulate the growth and development of a potato crop with a centre pivot irrigation system in 2011 (calibration year) and 2012 (validation year) in a semi-arid region of Spain, with four irrigation treatments 60, 80, 100 and 120% of the water requirement. Statistical indicators such as Willmott's d index and R2 coefficient of determination showed good values of d and R2 > 0.90 (26). Similarly, (16) test the sensitivity of potato plants to water stress under semi-arid conditions in Tunisia for two full and incomplete irrigation treatments in sandy loam soils using AquaCrop the model is well evaluated for predicting soil water content and vegetation development. Relatively little is known about climate change in the Arab region and one of the first regional studies on climate trends focused on extreme indicators was prepared by, which they investigated the trends in extreme heat and rain phenomena in the period 1950-2003, using national data drawn from 52 stations in 15 countries in the eastern part of the Arab region. The results showed statistically significant trends towards warming based on temperature indicators that indicate a noticeable increase in the frequency of warm days. In addition to a gradual decrease in the number of cold days, on the other hand, precipitation trends are characterized by extreme variability. The most accurate study of extreme climate trends in the Arab region that has been prepared in recent times is the one prepared by (9), where the daily data from more than 100 meteorological stations in the Arab region were collected were analyzed after evaluating their quality and homogeneity, and they gave evidence of trends towards warming in the whole region, with the increase in the frequency of warm days and nights, and the high temperatures and the change were in precipitations are less important and vary from place to another. The results of regional climate models are used to highlight how climate change is affected by using Representative Concentration Pathways scenarios, including the high emissions scenario RCP8.5: which assumes that things remain as they are and that no actions are taken to mitigate emissions and medium emissions scenario RCP4.5, which is a relatively optimistic scenario in terms of gas emissions reduction, as it assumes a small future increase in CO_2 emissions before it begins to decline by 2040 (20). The IPCC conducts climate simulations based on two future time periods or three periods compared to a past reference period (21,34). The 20 years is used which includes the reference period (1986-2005), the near future (2035-2016), the medium future (2046-2056), and the distant future (2100-2081). The simulations were based on reduced-scale scenarios on three global climate models to compare climate models, which are the Earth system model based on the EC-Earth model systems (19). Along with, the CNRM-CM5 fifth climate model. (43), and the Earth System Model II was developed by the GFDL-ESM2M Geophysical Fluid Dynamics Laboratory (10). In Iraq, the temporal and spatial changes in precipitation and temperature were evaluated in the period 1980-2011. Trends towards an increase in minimum and maximum temperatures, and trends towards a decrease in precipitation (ranging from 1.3-6.2 mm per year) were observed. The results showed that there were no differences between one site and another (1). Therefore, this research aims to evaluate the performance of the AquaCrop model to simulate the productivity of the potato crop using irrigation systems (drip and sprinkler) with an irrigation interval (2, 4, and 6 days). Besides, the use of polymers and bio-organic fertilizers in desert soils and to determine the impact of future climate changes on the potato crop until the year 2065.

MATERIALS AND METHODS

Two field experiments were carried out during the spring of 2020 within the Shariah area in the holy governorate of Karbala, 84 km southwest of Baghdad, at coordinates N 32° 42̀ 13.8‶ and E 43° 54 36.6‵, at an altitude of 27 m above sea level. The field soils were classified as sedimentary loamy-sand texture, classified to the level of *Typic Torrifluvent* according to the classification of (37). Soil samples were taken at a depth of 0-0.30 m, dried aerobically, then passed through a sieve with a diameter of 2 mm. Some soil physical and chemical properties of soil were determined shown in tables (1 and 2). The class of irrigation water (C_1S_1) was determined according to the FAO classification of irrigation water (30).

The Experimental treatments and statistical design

1- Irrigation system:

a- Surface Drip Irrigation (T_1)

b- Sprinkler Irrigation (T_2)

2- Irrigation interval

a- Irrigation every 2 days (I_1).

b- Irrigation every 4 days (I_2).

c- Irrigation every 6 days (I_3).

3- Soil conditioners

a- Control treatment without any addition (C).

b- Bio-organic fertilizers (B).

c- Water conservation technology (polymer) (P).

d- Water conservation technology + bio-organic fertilizers (P+B).

The experiment was designed according to the nested design, with three replications, the main plot includes the irrigation system and within it, the irrigation intervals are distributed, then the soil conditioner treatments and the replicates are within the blocks. The data were analyzed using the Gen Stat Discovery Filition4 program (2012), where the least significant difference was tested at the 0.05 level (3). The experiment was designed of 2832 m^2 area and its dimensions are 59x48 m, as the land was plowed orthogonally.

Table 1. Some physical properties of field soil before planting

Property	Units	Soil Depth (0.00-0.30m)
Sand	**g kg^{-1} soil**	**790**
Silt		**122**
Clay		**88**
Soil texture		**Loamy Sand**
Bulk density	**Mg m^{-3}**	**1.40**
Particle density		**2.65**
Porosity	**%**	**0.47**
Volumetric moisture content at saturation	**cm^3 cm^{-3}**	**0.32**
Volumetric moisture content at 10 kPa		**0.23**
Volumetric moisture content at 1500 kPa		**0.07**

Table 2. Some chemical properties of field soil before planting

Property	Units	Soil Depth (0.00-0.30 m)
Electrical conductivity $EC_{1:1}$	**Ds m^{-1}**	**2.71**
pH	**---**	**7.64**
Organic matter	**g kg^{-1} soil**	**0.7**
Carbonate minerals		**300**
Bicarbonate	**Mmol charge L^{-1}**	**2.5**
Calcium		**23.5**
Magnesium		**5.4**
Sodium		**3.3**
Potassium		**2.69**
Chloride		**5.0**
Available nitrogen	**Mg kg^{-1} soil**	**18.21**
Available potassium		**72.23**
Available phosphorous		**8.30**
Cation exchange capacity	**Cmole charge kg^{-1} Soil**	**13.25**

It was divided into two sections with a distance of 4 m between one section and another, each section was divided into three main blocks with dimensions of 59x6m with a distance of 2m between one block and another. Each block was divided into 12 experimental units of dimensions 6x4m, leaving a distance of 1m between each experimental unit and another. The number of experimental units was 36 units for each irrigation system. Bio-fertilizers, polymers and bio-fertilizers +polymer were added together to the treatments at a rate of 1200 kg ha^{-1}, 12 kg $ha^{-1}$and 1200+12 kg ha^{-1}, respectively, at a depth of 0.2 m from the soil surface. The characteristics of the additives for the experiment are SEEK bio-organic fertilizer: granular organic fertilizer composed of charcoal, bamboo ash, microorganism 100% certified organic by IMO and USDA. It improves soil and increases fertility, effectively dissolves, reduces soil salinity, insect infestation, pesticides, neutralizes pH, activates the plant's immune system, prevents root rot, strengthens them, and enhances symbiotic nitrogen fixation (15). Besides, the Zeba polymer that made from natural cornstarch, as an inorganic compound, where the molecular structure is modified to be able to store and release water. Potato tubers class (Hermosa), rank E, were planted on 10/1/2020 at a distance of 0.25 m between one tuber and another, at a depth of 0.10 m. The experimental soil was fertilized with triple superphosphate (20%P), urea (46%N), Potassium sulfate fertilizer was added in three batches and according to the fertilizer. The tubers were uprooted on 12/5/2020, then the drip irrigation and sprinkler irrigation systems were calibrated at an operational pressure of 50 and 150 kPa, for the two systems, respectively, to achieve the best homogeneity of water distribution.

AquaCrop application for potato crop simulation

AquaCrop calibration: The study was conducted during the spring season of 2020 in the period 2009-2020 (climate data period). To simulate the AquaCrop program, the model was calibrated under climate change conditions, where this step was performed according to the following sequence (14).

1- Preparing climate files CLI file.
2- Preparing the soil SOL file.
3- Prepare the crop CRO file.
4- Preparing the irrigation file IRR file
5- Preparing the field management MAN file
6- Create projects PRM files.

Project files were created to include the previous files for each simulation case, according to the approved treatments of the crop, to simulate 12 consecutive years of reference productivity data. The project settings were adjusted to start the simulation at the same planting date for the potato crop.

Statistical analysis of AquaCrop data

1- Root Mean Square Error (RMSE) according to (24) equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \quad \cdots\cdots\cdots (1)$$

Where: S_i = Simulated value, O_i = measured value, N = number of observations, $\overline{O_i}$= average value of Oi, $\overline{S_i}$= average value of S_i

2- Nash-Sutcliffe model efficiency coefficient (E): The efficiency coefficient E was calculated using the equation of (27).

$$E = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O_i})^2} \quad \cdots\cdots\cdots (2)$$

3- Correlation coefficient (r)

The Pearson Correlation Coefficient was determined according to (22).

$$r = \frac{\sum_{i=1}^{N}\left((O_i - \overline{O_i})(S_i - \overline{S_i})\right)}{\sqrt{\sum_{i=1}^{N}(O_i - \overline{O_i})^2 \sum_{i=1}^{N}(S_i - \overline{S_i})^2}} \quad \cdots\cdots\cdots (3)$$

According to (32), the AquaCrop model estimates the dry crop value, so the potato tuber yield values are multiplied by the tuber dry matter percentage. The percentage of dry matter in potato tubers represents a quality standard that is directly proportional to the percentage of starch (33). Its proportion varies between 17% and 22% (13).

Regional Climate Model (RCM)

The regional climate model is a climate model with high spatial accuracy (spacing less than 50 km) that is applied to a specific area and uses the outputs of the GCMs (Global Climate Model or General Circulation Model) as initial and oceanic conditions. Regional climate models take into account changes in topography and land use with better accuracy than global climate models.

The climate models used

In this study, the RCA4 regional climate model was run for three cases:

- Regional model RCA4 using oceanic conditions from the Global Circulation Model EC-EARTH.
- Regional model RCA4 using oceanic conditions from the Global Circulation Model CNRM
- Regional model RCA4 using oceanic conditions from the Global Circulation Model GFDL-ESM

Climate modeling results

The results of climate changes were adopted daily, for future climate models and the expected change in the average annual precipitation and the maximum and minimum temperatures during the two periods:

- The near future (2016-2035).
- The distant future (2046-2065).

The reference period (1986-2005) compared to the base period. In order to assess the impact of climatic changes on the productivity of the potato crop, the AquaCrop model will be run for the three climate models, Then, the average of the three results is calculated to estimate (average productivity, water consumption, growth period .... etc.) as shown in Fig.2 for both the medium emissions scenario RCP4.5 and the high emissions scenario RCP8.5 with 144 simulations. The main source of these data is the bias-corrected data from the Regional Climate Model (RCM) adapted from the RICCAR Regional Coordinating Experiment for Regional Climate Model Downscaling (CORDEX).

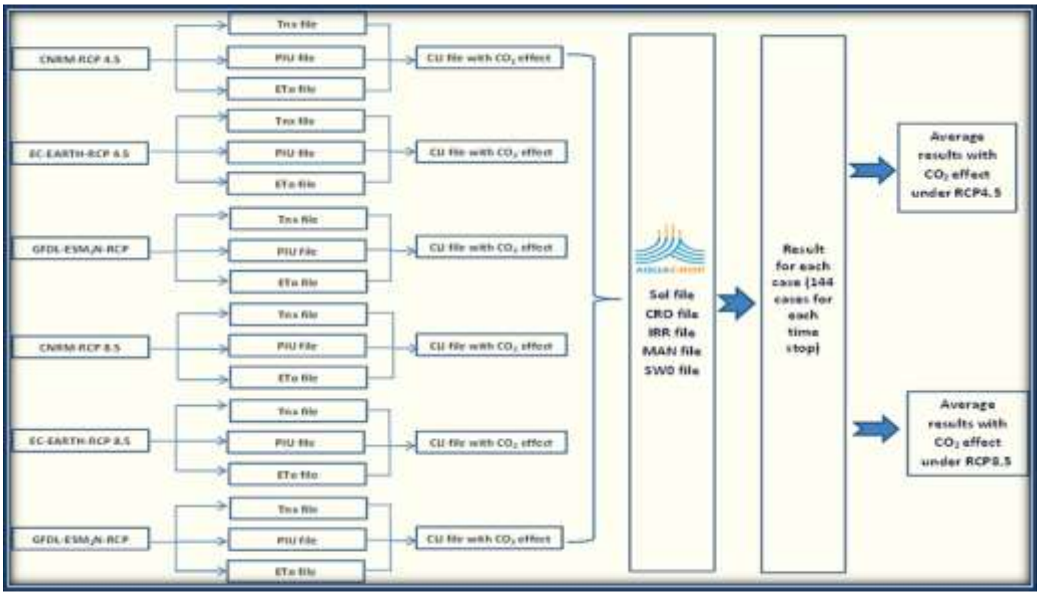

Figure 2. The scheme of the simulations to study the impact of climate change on the potato crop (the same cases were applied for each of the three-time periods (1985-2005), (2016-2035) and (2046-2065) for the climatic data) for two scenario (4.5 and 8.5)

RESULT AND DISCUSSION

Expected future climate changes until the end of 2065 (simulation period): Table 3 shows the impact of the expected climate changes for each of the annual and seasonal precipitation. Besides, the minimum and maximum temperatures for the two periods which included (2016-2035) and (2046-2065) the near future and the medium future, respectively, compared to the base period (1985-2005) according to the three climate models EC-Earth, CNRM-CM5, GFDL-ESM2M at the RCP4.5 climate change scenario (medium emissions scenario) for the potato crop. It is shown from Table (3) that there is an increase in the amount of rain precipitation, especially for seasonal rain during the two periods (2016-2035) and (2046-2065), amounting to 11.91 and 9.06 mm, respectively, compared to the base period (1985-2005). It can be observed an increase in the amount of annual precipitation during the two periods (2016-2035) and (2046-2065) amounted to 17.00 and 9.42 mm, respectively, compared to the base period (1985-2005). Table (3) shows that there is an increase in both the maximum and minimum temperatures, according to the climate change scenario RCP4.5. This increase amounts to 0.81 and 0.75°C (as an average value of climate models) for the maximum and minimum temperatures, respectively, during the period (2016-2035), compared with the base period (1985-2005) with a clear increase in temperatures during the period (2046-2065) compared to the base period (1985-2005) amounting to 1.65 and 1.55°C (as an average value of climate models) for maximum and minimum temperatures, respectively.

Table 3. Expected climatic changes of precipitation, minimum and maximum temperatures for the periods (2016-2035) and (2046-2065) compared to the base period (1985-2005) for the models EC-Earth, CNRM-CM5, GFDL-ESM2M according to the scenario RCP4.5 for the potato crop

Parameter	2016-2035	2046-2065
CNRM-CM5		
Rain (mm), Annual	**+17.53**	**+15.51**
Rain (mm), Seasonal	**+19.19**	**+32.06**
Maximum temperature (◦C)	**+1.00**	**+1.65**
Minimum temperature (◦C)	**+0.93**	**+1.65**
EC-Earth		
Rain (mm), Annual	**-12.56**	**-3.46**
Rain (mm), Seasonal	**-7.10**	**-10.52**
Maximum temperature (◦C)	**+0.85**	**+1.86**
Minimum temperature (◦C)	**+0.68**	**+1.65**
GFDL-ESM2M		
Rain (mm), Annual	**+46.04**	**+16.21**
Rain (mm), Seasonal	**+23.65**	**+5.63**
Maximum temperature (◦C)	**+0.59**	**+1.45**
Minimum temperature (◦C)	**+0.63**	**+1.35**

Table (4) shows the impact of the expected climate changes for each of the annual and seasonal precipitation. Along with, minimum and maximum temperatures for the two periods (2016-2035) and (2046-2065), the near future and the medium future, respectively, compared to the base period (1985-2005) according to the three climatic models EC-Earth, CNRM-CM5, GFDL-ESM2M, based on the RCP8.5 climate change scenario (high emissions scenario) for the potato crop. It can be noticed an increase in the amount of precipitation, especially for seasonal rain, during the period (2016-2035) amounting to 4.51 mm with a slight decrease for the period (2046-2065) amounting to -2.57 mm compared to the base period (1985-2005) for the agricultural season of the potato crop. It is evidently an increase in the amount of annual precipitation during the period (2016-2035) amounting to 3.97 mm and a decrease during the period (2046-2065) -3.78 mm compared to the base period (1985-2005). Furthermore, Table (4) shows that there is an increase in both the maximum and minimum temperatures according to the climate change scenario RCP8.5. It reached 1.1 and 0.98°C (as the average values of climate models) for the maximum and minimum temperatures, respectively, during the period (2016-2035) compared to the base period (1985-2005) with an increase in temperatures during the period (2046-2065) compared to the base period (1985-2005) amounting to 2.33 and 2.14°C (as the average values of climate models) for the maximum and minimum temperatures, respectively. This is consistent with what was mentioned in the report of (12), which showed that the change in average temperatures in the Euphrates River will record an overall rise that will follow the same trend as the change in the Tigris River in terms of height by the end of the century, with a rise of 1.9°C for the scenario RCP4.5 in the middle of the century and 2.3°C. However, there are higher changes under the scenario RCP8.5, where the temperature will increase by 2.6°C in the middle of the century and 4.8°C by the end of the century. As for precipitation rates, they are expected to increase under the RCP4.5 scenario, (about 4% in the middle and 3% at the end of the century). Conversely, no significant change is expected under the RCP8.5 scenario, as for the level of extreme precipitation rates, four out of six projections show a trend towards their height in the Tigris River, while all projections show an increase in the Euphrates River.

Table 4. Expected climatic changes of precipitation, minimum and maximum temperatures for the periods (2016-2035) and (2046-2065) compared with the base period (1985-2005) for the models EC-Earth, CNRM-CM5, GFDL-ESM2M according to the scenario RCP8.5 for potato crop

Parameter	2016-2035	2046-2065
CNRM-CM5		
Rain (mm), Annual	**+14.09**	**-13.50**
Rain (mm), Seasonal	**+12.37**	**-6.45**
Maximum temperature (◦C)	**+1.03**	**+2.30**
Minimum temperature (◦C)	**+0.94**	**+2.07**
EC-Earth		
Rain (mm), Annual	**-12.02**	**-19.62**
Rain (mm), Seasonal	**- 2.35**	**-11.18**
Maximum temperature (◦C)	**+1.36**	**+2.58**
Minimum temperature (◦C)	**+1.17**	**+2.36**
GFDL-ESM2M		
Rain (mm), Annual	**+9.85**	**+21.79**
Rain (mm), Seasonal	**+3.50**	**+9.93**
Maximum temperature (◦C)	**+0.91**	**+2.11**
Minimum temperature (◦C)	**+0.83**	**+1.98**

AquaCrop Model Calibration of Potato Crop: Figures (3 and 4) show the convergence of the current productivity of potato crops compared to the expected productivity using the AquaCrop model. Thus, the two figures show the presence of small, insignificant differences in production for the study area between the expected data for the productivity of the model compared to the measured data (total productivity of the potato crop for the study area/ Ministry of Planning) for a period of 11 years (2009-2019). Plus, the base year for the study 2020) when comparing the productivity of the comparison treatment (without addition) using the surface drip irrigation system with the estimated productivity of the mathematical model used as it represents a treatment of the agricultural situation reality in the region. The farmer in those areas does not depend on the cultivation on the addition of conditioners or polymers at planting, so the comparison treatment was adopted. The results showed that the yield of dry potato tubers was well simulated, so the model efficiency was high, and there was a good correlation between the yield of the measured and simulated tubers, as the R^2 gave 0.85,0.81 for the drip and sprinkler irrigation systems. This is consistent with (7) who found that the production of dry potato tubers was well simulated by the model, by using data of regional climate models RCMs representing the region, with a spacing of 50 km, to give climate simulation results with higher accuracy than the General Circulation Models (GCMs). In order to evaluate the accuracy of these models, it was compared with the period 1/1/2009 to 31/12/2020, for the study site, which was used to calibrate the AquaCrop model. The comparison between the data resulting from the models and the actual data was conducted using the statistical coefficients root mean square error (RMSE), correlation coefficient (r), and efficiency coefficient (EF).

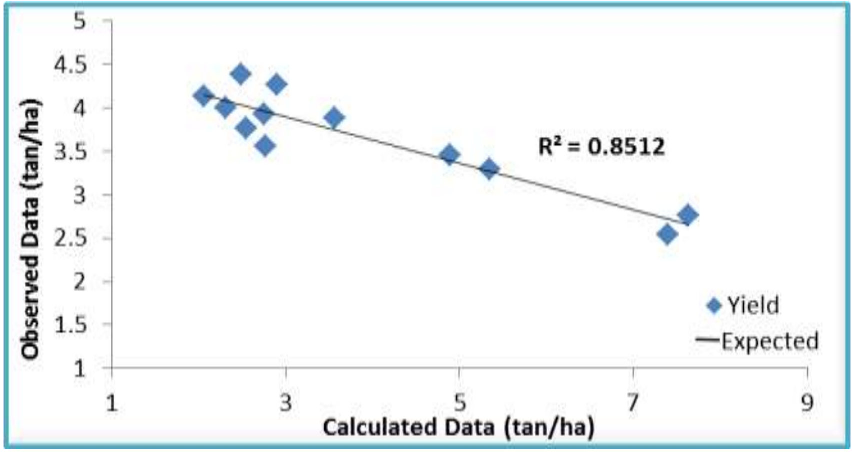

Figure 3. Comparison between the measured and expected productivity of the potato crop for the surface drip irrigation system

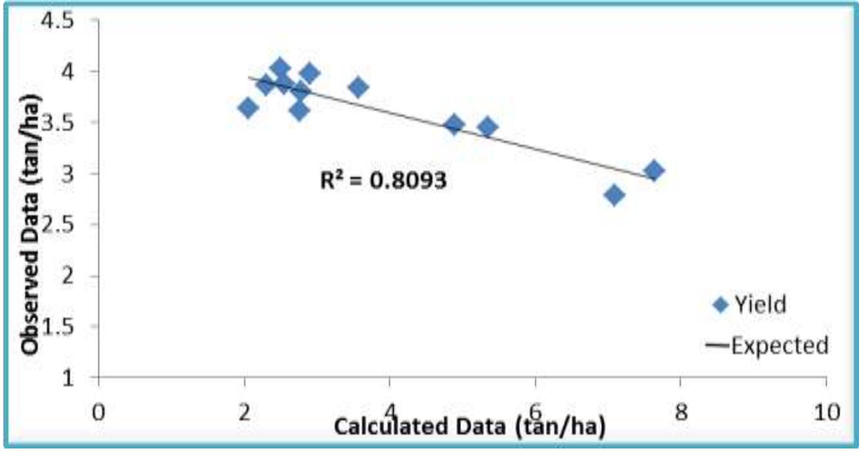

Figure 4. Comparison between the measured and expected productivity of the potato crop for the sprinkler irrigation system

Statistical standards

Table 5 shows the calibration of productivity for the potato crop to compare the measured productivity and the expected productivity when using the surface drip irrigation system and sprinkler irrigation using the control treatment. It gave good agreement for most of the approved standards, where the correlation coefficient between the data reached a very good agreement of 0.95 and 0.90 for the two irrigation systems, respectively. The root means square error (RMSE) gave a good agreement of 2.43 and 2.19 for the two irrigation systems, respectively. Similarly, the value of the statistical efficiency coefficient for comparing the measured and expected productivity showed good agreement at the surface drip irrigation system and moderately good agreement at the sprinkler irrigation system, which amounted to 0.66 and 0.42 for the two irrigation systems, respectively.

Table 5. Statistical criteria for comparison between the measured and expected productivity of the potato crop when using the surface drip irrigation system and sprinkler irrigation

Standards	Value	Interpretation	Value	Interpretation
r	0.951	very good	0.900	very good
RMSE	2.426	good	2.187	good
EF	0.659	good	0.415	moderate good

The AquaCrop model was able to simulate the total dry productivity of potatoes and this is reflected by the good agreement between the measured and simulated productivity in the statistical analysis of r, RMSE, and EF. The productivity simulation gave an efficiency coefficient that ranged from 0.42 to 0.66, as the simulation productivity was very close to the actual crop production according to the coefficient of r and RMSE when compared the control treatment with the rest of the treatments. The discrepancy between the measured and simulated results could be due to soil depth and variable moisture retention and this is consistent with (Patel, N. 2010; Zhang et al. 2005). AquaCrop's ability to simulate the moderate water stress that occurs at different stages in the growth period makes it very useful for designing and evaluating deficient irrigation strategies and water management options, and for studying the impact of the site, soil type, and irrigation management on plant production in agriculture.

The effect of climate change on the potato crop: The results of climate changes for climate scenarios RCP4.5 and RCP8.5 were applied to only two treatments represented by the best treatment and the worst treatment. Each of the bio-fertilizers and polymer treatment at the irrigation interval I_1 and the control treatment at the irrigation interval I_3 for the surface drip irrigation and sprinkler irrigation systems for comparison and to identify the effect of future climate changes in productivity and water productivity of the potato crop.

The average future total productivity of the potato crop: Average productivity when applying RCP4.5 and RCP8.5 scenarios to surface drip irrigation system and for I_1 irrigation interval of bio-fertilizer and polymer treatment

Table (6) shows the increase in productivity at the RCP 4.5 scenario of BP treatment for surface drip irrigation and at the irrigation interval I_1 when comparing the base period with the periods (2016-2035) and (2046-2065). In addition to an increase in the relative change in productivity with the presence of non-significant differences between productivity during the base period and the simulation period. Thus, the highest value of the productivity in the period (2016-2035) was 10.96 ton ha^{-1} based on the dry weight of the potato crop during the simulation period, where the increase in the production rate between (2016-2035) and (2046-2065) compared to the base period amounted to 37.65 and 36.90%. Whereas when applying the RCP 8.5 scenario for the BP treatment for surface drip irrigation at the irrigation interval I_1 when comparing the base period with the periods (2016-2035) and (2046-2065), it was observed that there is an increase in productivity. In addition to an increase in the relative change of productivity with insignificant differences between productivity during the base period and the simulation period. Therefore, the highest productivity value recorded in the period (2016-2035) was 9.95ton ha^{-1} based on the dry weight of the potato crop during the simulation period. The increase in the production rate between (2016-2035) and (2046-2065) compared to the base period amounted to 37.24 and 36.14%. It can also be noted that the increase was higher in the RCP4.5 scenario than in the RCP8.5 scenario for the same simulation period.

Table 6. Average potato productivity and expected change in productivity at scenario RCP4.5 and RCP8.5 for bio-fertilizer and polymer treatment at irrigation interval I_1 for surface drip irrigation

	Average change over the period (2035-2016)	Average change over the period (2065-2046)
RCP 4.5		
Production in the base period (ton ha^{-1})	7.96	
Absolute change (ton/ha)	+3.00	+2.94
Relative change (%)	37.65	36.90
T-test	2.50 E-5	9.87 E-12
RCP 8.5		
Production in the base period (ton ha^{-1})	7.25	
Absolute change (ton/ha)	+2.70	+2.62
Relative change (%)	37.24	36.14
T-test	1.73 E-7	2.23 E-12

Average productivity when applying RCP4.5 and RCP8.5 scenarios for surface drip irrigation system and irrigation interval I_3 for control treatment

Table (7) shows the increase in productivity at the RCP 4.5 scenario of treatment C for surface drip irrigation and at the irrigation interval I_3 when comparing the base period with the periods (2016-2035) and (2046-2065). Besides, an increase in the relative change of productivity in the presence of non-significant differences between productivity during the base period and the simulation period, as the highest value of productivity in the period (2016-2035) was 3.49ton ha^{-1} based on the dry weight of the potato crop during the simulation period. The increase in the production rate between (2016-2035) and (2046-2065) compared to the base period amounted to 21.85 and 20.80%. Applying the scenario RCP 8.5 of the treatment C for surface drip irrigation and at the irrigation interval I_3 when comparing the base period with the periods (2016-2035) and (2046-2065), it was observed that there is an increase in productivity and the relative change in productivity with the presence of insignificant differences between productivity during the base period and the simulation period. In the same role, the highest value of productivity in the period (2016-2035) was 3.43ton ha^{-1} based on the dry weight of the potato crop during the simulation period. The increase in production rate between (2016-2035) and (2046-2065) compared to the base period amounted to 20.89 and 19.13%, it can be noted that the increase was higher for scenario RCP4.5 than for scenario RCP8.5 for the same simulation period.

Table 7. Average potato productivity and the expected change in productivity at the scenario RCP4.5 and RCP8.5 for the control treatment at the irrigation interval I_3 for surface drip irrigation

	Average change over the period (2035-2016)	Average change over the period (2065-2046)
RCP 4.5		
Production in the base period (ton ha^{-1})	2.86	
Absolute change (ton/ha)	+0.63	+0.60
Relative change (%)	21.85	20.80
T-test	1.69 E-6	3.12 E-15
RCP 8.5		
Production in the base period (ton ha^{-1})	2.84	
Absolute change (ton/ha)	+0.59	+0.54
Relative change (%)	20.89	19.13
T-test	4.35 E-8	7.25 E-19

Average productivity when applying RCP4.5 and RCP8.5 scenarios for sprinkler irrigation system and irrigation interval I_1 for bio-fertilizer and polymer treatment

Table 8 shows the increase in productivity at the RCP 4.5 scenario of BP treatment for sprinkler irrigation and at the irrigation interval I_1 when comparing the base period with the periods (2016-2035) and (2046-2065). In addition to an increase in the relative change in productivity with the presence of insignificant differences between productivity during the base period and the simulation period, as the highest value of productivity was recorded in the period (2016-2035) amounted to 10.35ton ha^{-1} based on the dry weight of the potato crop during the simulation period. The increase in the production rate between (2016-2035) and (2046-2065) compared to the base period amounted to

37.45 and 35.99%. However, when applying the scenario RCP 8.5 for the BP treatment of sprinkler irrigation at the irrigation interval I_1 when comparing the base period with the periods (2016-2035) and (2046-2065). It was found that there was an increase in productivity in addition to an increase in the relative change of productivity with insignificant differences between productivity during the base period and the simulation period, as the highest value of productivity was recorded in the period (2016-2035) amounted to 9.76ton ha^{-1} based on the dry weight of the potato crop during the simulation period. The increase in the production percentage between (2016-2035) and (2046-2065) compared to the base period amounted to 36.89 and 34.22%. It can also note that the increase was higher in the RCP4.5 scenario than in the RCP8.5 scenario for the same simulation period.

Table 8. Average potato productivity and expected change in productivity at scenario RCP4.5 and RCP8.5 for bio-fertilizer and polymer treatment at irrigation interval I_1 for sprinkler irrigation

	RCP 4.5	
	Average change over the period (2035-2016)	**Average change over the period (2065-2046)**
Production in the base period (ton ha^{-1})	**7.53**	
Absolute change (ton/ha)	**+2.82**	**+2.71**
Relative change (%)	**37.45**	**35.99**
T-test	**5.94 E-10**	**2.96 E-19**
	RCP 8.5	
Production in the base period (ton ha^{-1})	**7.13**	
Absolute change (ton/ha)	**+2.63**	**+2.44**
Relative change (%)	**36.89**	**34.22**
T-test	**1.34 E-10**	**2.73 E-21**

Average productivity when applying RCP4.5 and RCP8.5 scenarios for sprinkler irrigation system and irrigation interval $I_3$for control treatment

Table (9) shows the increase in productivity at the RCP 4.5 scenario of BP treatment for sprinkler irrigation at the irrigation interval I_1 when comparing the base period with the periods (2016-2035) and (2046-2065). Likewise, the relative change in productivity with the presence of insignificant differences between productivity during the base period and the simulation period, as the highest value of productivity in the period (2016-2035) was 10.35ton ha^{-1} based on the dry weight of potato crop during the simulation period. The increase in the production rate between (2016-2035) and (2046-2065) compared to the base period was 37.45 and 35.99%. It was observed that there is an increase in productivity and the relative change of productivity with the presence of insignificant differences between productivity during the base period and the simulation period during the applying the RCP 8.5 scenario for the BP treatment for the same with the periods (2016-2035) and (2046-2065). Thus, the highest value of productivity in the period (2016-2035) was 9.76ton ha^{-1} based on the dry weight of potato crops during the simulation period. The increase in the production percentage between (2016-2035) and (2046-2065) compared to the base period amounted to 36.89 and 34.22%. It can also note that the increase was higher in the RCP4.5 scenario than in the RCP8.5 scenario for the same simulation period.=

Table 9. Average potato productivity and the expected change in productivity in the scenario RCP4.5 and RCP8.5 for the control treatment at the irrigation interval I_3 for sprinkler irrigation

	RCP 4.5	
	Average change over the period (2035-2016)	**Average change over the period (2065-2046)**
Production in the base period (ton ha^{-1})	**2.62**	
Absolute change (ton/ha)	**+0.55**	**+0.52**
Relative change (%)	**20.99**	**19.85**
T-test	**4.98 E-8**	**1.67 E-16**
	RCP 8.5	
Production in the base period (ton ha^{-1})	**2.47**	
Absolute change (ton/ha)	**+0.48**	**+0.45**
Relative change (%)	**19.43**	**18.22**
T-test	**1.02 E-6**	**1.99 E-17**

Moreover, it was evident from the previous results the impact of future climate changes on the potato productivity in the surface drip irrigation and sprinkler systems that at the irrigation interval I_3 with the control treatment, there was no decrease in future productivity. But rather it increased as a result of the increase in the amounts of precipitation during the periods (2016-2035) and (2046-2065) compared to the base period (1985-2005) within the study area, especially at the climate scenario RCP4.5. The increase in seasonal precipitation amounts helped to fill the water shortage during the stages of plant growth, and the average temperature is the main factor determining the size of the final tuber and the concentration of dry matter at harvest. Besides, the optimum temperature threshold for potato growth coincides with day and night temperatures ranging from 15-27°C. At higher temperatures, potato growth decreases due to increased respiration (34). By applying the climate change scenarios RCP4.5 and RCP8.5, there will be a change in the carbon dioxide concentration and when it coincides with increasing temperatures for the future periods (2016-2035) and (2046-2065). These scenarios will have a direct impact on the length of the growth cycle and the crop evapotranspiration value, as the increase in carbon dioxide concentrations reversed the negative impact of higher temperatures on crop productivity, the productivity of the two independent periods increased. However, there was an increase in water productivity values for the two future periods compared to the base period as a result of the increase in crop productivity. This is consistent with what studies have indicated that crop productivity under future climate forecasts is expected to be affected by future climate fluctuation (6,17). Maximum and minimum temperatures and precipitation will affect the future climate on crop production. Climate scenarios are alternative images of how the future will develop and an appropriate tool for analyzing how driving forces affect future emissions outcomes and for assessing the uncertainties associated with them (38). It was observed that with the temperature increasing, the metabolic efficiency increases to a maximum and then decreases, while the respiration rate continues to increase more or less until the point where the plant dies at its critical limits (42). All plants use atmospheric carbon dioxide and convert it into sugars and starches through photosynthesis in various ways via the Calvin cycle. These interactions affect the number and type of carbon molecules a plant produces, where these molecules are stored, and most importantly for the study of climate change, and the plant's ability to tolerate low carbon climates, high temperatures, and low water and nitrogen levels. Photosynthesis is directly relevant to global climate change studies because C_3 and C_4 plants respond differently to changes in the concentration of carbon dioxide in the atmosphere, changes in temperature and water availability, and because the potato is a C_3 plant, this leads to improved photosynthesis performance and increased water use efficiency and nitrogen (11,28). Climate change affects the water balance and photosynthesis of crops directly or indirectly by directly affecting physiological processes and indirectly by affecting various crop growth factors such as relative humidity, wind speed, soil temperature and evapotranspiration.

REFRENCES

1. Agha, Omar M.A.Mahmood, and Nermin Şarlak. 2016. ‘Spatial and Temporal Patterns of Climate Variables in Iraq’. Arabian Journal of Geosciences 9(4).

2. Al-Mehmdy, Sh M.H., and M. M. Yacoub. 2019. ‘Some Methods for Calculating Losses of Fixed Sprinkler Irration under the Influence of Operation Pressure and Sprayers’ Arrangement’. Iraqi Journal of Agricultural Sciences 50(1): 487–94

3. Al-Shamari, M. F., B. A.A.H. Alkhateb, and S. A.W. Mahmoud. 2020. ‘Role of Compost and Irrigation Water Quantity on Some Physical Properties of Soil Under Surface, Subsurface Drip Irrigation’. Iraqi Journal of Agricultural Sciences 51(5): 1300–1307

4. Aldulaimy, S. E.H., SH M.H. Al-Mehmdy, and M. A.A. Aljanabi. 2018. ‘Evaluation of Used Exudative Irrigation Tubes and Drip Irrigation for Some Soil Water Parameters and Consumptive Use of Cucumber’. Iraqi Journal of Agricultural Sciences 49(5): 921–31

5. Andreas Phocaides. 2007. ‘CHAPTER 7: Water Quality for Irrigation’. Handbook of Pressurized Irrigation Techniques: 1–33

6. Araya, A. et al. 2017. 'The Challenges and Opportunities for Wheat Production under Future Climate in Northern Ethiopia'. Journal of Agricultural Science

7. Bitri, M, S Grazhdani, and A Ahmeti. 2014. 'Validation of the Aquacrop Model for Full and Decifit Irrigation Potato Production in Environmental Condtion of Korca Zone, South-Eastern Albania'. International Journal of Innovative Research in Science, Engineering and Technology 3(5): 12013–20

8. Boote, Kenneth J. et al. 2013. 'Putting Mechanisms into Crop Production Models'. Plant, Cell and Environment 36(9): 1658–72

9. Donat, M. G. et al. 2014. 'Changes in Extreme Temperature and Precipitation in the Arab Region: Long-Term Trends and Variability Related to ENSO and NAO'. International Journal of Climatology 34(3): 581–92

10. Dunne, John Patrick et al. 2012. 'GFDL's ESM2 Global Coupled Climate-Carbon Earth System Models. Part I: Physical Formulation and Baseline Simulation Characteristics'. Journal of Climate

11. Ehleringer, J R, and T E Cerling. 2002. 'C3 and C4 Photosynthesis'. Encyclopedia of Global Environmental Change.The earth system: biological and ecological dimensions of global environmental change

12. ESCWA, ACSAD and GIZ. 2017. '(United Nations Economic and Social Commission for Western Asia; Arab Center for the Studies of Arid Vones and Dry Lands; Deutsche Gesellschaft Für Internationale Zusammenarbeit). Integrated Vulnerability Assessment: Arab Regional Applications. RICCAR Tec'. United Nations economic and social commission for western Asia (ESCWA).

13. Esendal, E. 1990. 'Starch Sugar Plants and Their Breeding'. Potato, OMÜ, Ziraat Fak. 1(49).

14. FAO. 2016. 'Forests 1 and Agriculture: Land-Use Challenges and Opportunities. Rome, Italy, Http://Www.Fao.Org/3/a-I5588e.Pdf.' State of the World's Forests

15. Gebremedhin, Yibrah, Araya Berhe, and Amsalu Nebiyu. 2015. 'Performance of AquaCrop Model in Simulating Tuber Yield of Potato (Solanum Tuberosum L .) under Various Water Availability Conditions in Mekelle Area , Northern Ethiopia'. Journal of Natural Sciences Research 5(5): 123–31

16. Ghazouani, Hiba et al. 2019. 'Using AquaCrop Model to Simulate Irrigation Water Use Efficiency of Potato Crop under Semi-Arid Conditions of Central Tunisia'. Brazilian Journal of Biological Sciences 6(12): 223–31

17. Hadgu, Gebre, Kindie Tesfaye, and Girma Mamo. 2015. 'Analysis of Climate Change in Northern Ethiopia: Implications for Agricultural Production'. Theoretical and Applied Climatology

18. Hajim, A. Y. and Haqi, I. Y. 1992. 'Field Irrigation Systems Engineering'. House of books for printing and publishing. University of Al Mosul. conductor. Iraq

19. Hazeleger, Wilco et al. 2010. 'EC-Earth: A Seamless Earth-System Prediction Approach in Action'. Bulletin of the American Meteorological Society 91(10): 1357–63

20. Inventory of Shared Water Resources in Western Asia. 2013. Inventory of Shared Water Resources in Western Asia

21. IPCC. 2014. 'Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. Intergovernmental Panel on Climate Change (March): 1–44. http://www.citeulike.org/group/15400/article/13497155

22. Khattab, E. A., and E. A. El-Housini. 2019. 'Evaluation of Some Lentil Varieties under Sprinkler and Dripping Irrigation Systems in Newly Reclaimed Sandy Soil'. Iraqi Journal of Agricultural Sciences 50(3): 753–58

23. Loague, Keith, and Richard E. Green. 1991. 'Statistical and Graphical Methods for Evaluating Solute Transport Models: Overview and Application'. Journal of Contaminant Hydrology 7(1–2): 51–73

24. Matsuoka, Makoto, Robert T. Furbank, Hiroshi Fukayama, and Mitsue Miyao. 2001. 'Molecular Engineering of C4 Photosynthesis'. Annual Review of Plant Biology 52: 297–314

25. Montoya, F. et al. 2016. 'Evaluation of Aquacrop Model for a Potato Crop under Different Irrigation Conditions'. Agricultural Water Management 164: 267–80

26. Nash, J. E., and J. V. Sutcliffe. 1970. ‘River Flow Forecasting through Conceptual Models Part I - A Discussion of Principles’. Journal of Hydrology 10(3): 282–90

27. Patel, N., P. Kumar and Singh N. 2010. ‘Performance Evaluation of Aquacrop in Simulating Potato Yield under Varying Water Availability Conditions’. Indian Agricultural Research Institute, New Delhi –110012, India

28. Planning, Ministry of. 2018. ‘The Agricultural Sector Production Report (Water and Land, Plant and Animal Production) for the Year 2017. Planning Department/ Agricultural Planning Department.’

29. Raes, Dirk. 2017. AquaCrop training handbooks AquaCrop Training Handbooks - Book I: Understanding AquaCrop

30. Raes, Dirk, Pasquale Steduto, Theodore C. Hsiao, and Elias Fereres. 2009. ‘Aquacrop-The FAO Crop Model to Simulate Yield Response to Water: II. Main Algorithms and Software Description’. Agronomy Journal 101(3): 438–47

31. Rasheed, Z. K. 2020. ‘Analysis The Wetted Area for Subsurface Drip Irrigation in Different Soils Texture’. Iraqi Journal of Agricultural Sciences 51(2): 712–22

32. Schippers, P. A. 1976. ‘The Relationship between Specific Gravity and Percentage Dry Matter in Potato Tubers’. American Potato Journal 53(4): 111–22

33. Shahnazari, Ali et al. 2007. ‘Effects of Partial Root-Zone Drying on Yield, Tuber Size and Water Use Efficiency in Potato under Field Conditions’. Field Crops Research 100(1): 117–24

34. Smith, P., J. Nkem, K. Calvin, D. Campbell, F. Cherubini, G. Grassi, V. Korotkov, A.L. Hoang, S. Lwasa, P. McElwee, and M.A. Taboada E. Nkonya, N. Saigusa, J.-F. Soussana. 2007. ‘Interlinkages between Desertification, Land Degradation, Food Security and GHG Fluxes: Synergies, Trade-Offs and Integrated Response Options’. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (January): 1–11

35. Smith, B. 2006. ‘The Farming Handbook’. University of KwaZulu-Natal Press, Pietermaritzburg, RSA, Section 12.8.3 Potato Yield Estimation: 395–97

36. Soil Survey Staff. 2016. Web Soil Survey Natural Resources Conservation Service, United States Department of Agriculture. http://websoilsurvey.nrcs.usda.gov/app

37. Steduto, Pasquale, Theodore C. Hsiao, Dirk Raes, and Elias Fereres. 2009. ‘Aquacrop-the FAO Crop Model to Simulate Yield Response to Water: I. Concepts and Underlying Principles’. Agronomy Journal 101(3): 426–37

38. Stocker, Thomas F. et al. 2013. Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

39. Testa, G., F. Gresta, and S. L. Cosentino. 2011. 34 European Journal of Agronomy Dry Matter and Qualitative Characteristics of Alfalfa as Affected by Harvest Times and Soil Water Content

40. Turral, H., J. Burke, J. M. Faures, and J M Faures. 2011. ‘Climate Change, Water and Food Security’. Rome: Food and Agriculture Organization of the United Nations

41. Vinet, Luc, and Alexei Zhedanov. 2011. ‘A “missing” Family of Classical Orthogonal Polynomials’. Journal of Physics A: Mathematical and Theoretical 44(8).

42. Voldoire, A. et al. 2013. ‘The CNRM-CM5.1 Global Climate Model: Description and Basic Evaluation’. Climate Dynamics

43. ‘Www.Seekfertilizer.Com.’

44. Zhang, Xiying et al. 2005. ‘Improved Water Use Efficiency Associated with Cultivars and Agronomic Management in the North China Plain’. Agronomy Journal 97(3): 783–90.