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CROP SUITABILITY MODELING UNDER CLIMATE CHANGE SCENARIOS IN THE NEAR EAST

by

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The Near East region is an arid region susceptible to climate-induced effects on food security and water resources. Climate change will lead to major shifts in areas suitable for agriculture. The aim of this research is to predict the suitability of the major crops grown in this region. The suitability analysis was performed using the EcoCrop model considering the precipitation and temperature thresholds using an aggregation procedure. The main objectives of this study are to determine 1) changes in suitable areas for cultivation and 2) changes in evapotranspiration and yield for major agricultural crops in the Near East region. Crop suitability maps were derived using the EcoCrop model for the benchmark period (based on average climatic data for 1970-2000) and a future period (based on climatic forecasts for year 2050) under RCP8.5 emission scenario (RCP stands for Representative Concentration pathway and it is a greenhouse gas concentration trajectory) for 19 crops. Crop evapotranspiration, yield and water productivity for the both the benchmark and future periods were derived using the Food and Agriculture Organization (FAO) AquaCrop model. The outputs of the two models were compared and assessed to check for possible correlations in changes of yield and suitability. Globally, results show that the major gains in crop suitability of wheat, barley, coffee, rice, cotton and tobacco will be in Europe, while reductions in suitability will be spread over the continents depending on the climate and location. The suitability of fruit trees, legumes, oil producing crops, vegetables and wheat & barley will decrease (by 22-58%) by year 2050 in the croplands of the Jordan, Orontes and Litani river basins. The suitability of oil producing crops in the croplands of Euphrates-Tigris (ETRB) will increase (+15% in ETRB) with no change within the Nile River Basin (NRB). The suitability of other crop groups in ETRB & NRB is projected to decrease. AquaCrop results show that evapotranspiration will increase in the Jordan (4 - 24%), Litani (2 - 15%), and Orontes (2 - 14%) river basins. Comparison between the two models show that it is important to distinguish between rainfed and irrigated crops and changes in crop growing season to arrive at conclusive results. Unless major interventions in agricultural and water policies take place in response to scientific information, food and water security in the Near East region will continue to be threatened.

Keywords: Climate change, emission scenarios, general circulation models, RCP8.5, crop suitability, AquaCrop, EcoCrop, crop yield, evapotranspiration, water productivity, Near East, modelling, croplands, and Jordan, Orontes, Litani, Nile, and Euphrates-Tigris River Basins

CONTENTS

ILLUSTRATIONS

TABLES

ABBREVIATIONS

%	Percentage
°	Degrees
°C	Degrees Celsius
AR	Assessment Report
a_{R1}	Intercept of the regression curve between [R_{MIN-C}, 0] and [$R_{OPMIN-C}$, 100]
a_{R2}	Intercept of the regression curve between [$R_{OPMAX-C}$, 100] and [R_{MAX-C}, 0]
ASCII	American Standard Code for Information Interchange
ASME	Agricultural Sector Model of Egypt
a_{T1}	Intercept of the regression curve between [T_{MIN-C}, 0] and [$T_{OPMIN-C}$, 100]
a_{T2}	Intercept of the regression curve between [$T_{OPMAX-C}$, 100] and [T_{MAX-C}, 0]
B	Biomass

CCCMA	Canadian Center for Climate Modelling and Analysis
CCSM4	Community Climate System Model version 4
CERES	Crop Environment Resource Synthesis
CMIP	Coupled Model Intercomparison Project
CMWU	Coastal Municipalities Water Utility
CO_2	Carbon Dioxide
CSV	Comma Separated Values
CWP	Crop Water Productivity
DEM	Digital Elevation Model
DSSAT	Decision Support System for Agrotechnology Transfer
e_a	Actual vapor pressure
ECHAM5	European Centre Hamburg Model version 5
EPIC	Explicit Planetary Isentropic Coordinate
EROS	Earth Resources Observation and Science
e_s	Saturation vapor pressure
ET	Evapotranspiration

ET_0	Reference Evapotranspiration
ETRB	Euphrates-Tigris River Basin
FAO	Food and Agriculture Organization
FT	Fruit Trees
G	Soil Heat Flux Density
g/m^2	Gram per Square Meter
GCM	General Circulation Model
GFDL-CM3	Geophysical Fluid Dynamics Laboratory Climate Model version 3
GHG	Greenhouse Gas
GIS	Geographic Information System
GISS	Goddard Institute for Space Studies
HadCM3	Hadley Center Coupled Model version 3
HadGEM2-ES	Hadley Center Global Environment Model version 2 Earth Model
HI	Harvest Index
HWSD	Harmonized World Soil Database
IPCC	Intergovernmental Panel on Climate Change

JRB	Jordan River Basin
Kg/ha	Kilograms per Hectare
Kg/m^3	Kilogram per Cubic Meter
Km	Kilometer
Km^2	Kilometer Square
kPa	Kilopascal
kPa/°C	Kilopascal per degree Celsius
K_s	Stress Coefficient
L	Legumes
Lat	Latitude
LLB	Lower Litani Basin
Long	Longitude
LRB	Litani River Basin
m	Meter
m/s	Meter per Second
m^3/ha	Cubic Meter per Hectare

MJ/m^2day	Mega Joule per square meter per day
mm	Millimeter
mm/year	Millimeter per Year
MODIS	Moderate Resolution Imaging Spectroradiometer
m_{R1}	Slope of the regression curve between [R_{MIN-C}, 0] and [$R_{OPMIN-C}$, 100]
m_{R2}	Slope of the regression curve between [$R_{OPMAX-C}$, 100] and [R_{MAX-C}, 0]
m_{T1}	Slope of the regression curve between [T_{MIN-C}, 0] and [$T_{OPMIN-C}$, 100]
m_{T2}	Slope of the regression curve between [$T_{OPMAX-C}$, 100] and [T_{MAX-C}, 0]
NRB	Nile River Basin
OP	Oil Producing Crops
ORB	Orontes River Basin
P	Precipitation
ppm	Parts per Million

PWP	Permanent Wilting Point
R^2	Coefficient of Determination
RCP	Representative Concentration Pathway
RGF	Raster Group File
RH	Relative Humidity
R_{MAX-C}	Maximum Absolute Precipitation
R_{MIN-C}	Minimum Absolute Precipitation
Rn	Net Radiation
$R_{OPMAX-C}$	Maximum Optimal Precipitation
$R_{OPMIN-C}$	Minimum Optimal Precipitation
R_s	Solar Radiation
RST	ReStructured Text
R_{SUIT}	Precipitation Suitability
$R_{TOTAL-P}$	Total rainfall of the crop’s growing season at site P
SWAP	Soil-Water-Atmosphere-Plant
T	Temperature

t/ha	Tons per Hectare
TIF	Tagged Image File
T_{KILL}	Kill Temperature
T_{KILL-M}	Crop’s killing temperature plus 4 degrees Celsius
T_{max}	Maximum Temperature
T_{MAX-C}	Maximum Absolute Temperature
T_{mean}	Mean Temperature
$T_{MEAN-Pi}$	Mean temperature of the month i
T_{min}	Minimum Temperature
T_{MIN-C}	Minimum Absolute Temperature
T_{MIN-Pi}	Minimum temperature of the month i at site P
$T_{OPMAX-C}$	Maximum Optimal Temperature
$T_{OPMIN-C}$	Minimum Optimal Temperature
Tr	Transpiration
T_{SUIT}	Temperature Suitability
U_2	Windspeed at two meters height

ULB	Upper Litani Basin
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USDA	United States Department of Agriculture
V	Vegetables
V_p	Vapor Pressure
VWC	Volumetric Water Content
W/m^2	Watt per Meter Square
WB	Wheat and Barley
WP	Water Productivity
W_s	Wind Speed
WUE	Water Use Efficiency
Y	Yield
γ	Psychrometric constant
Δ	Slope vapor pressure curve
ΔP	Change in Precipitation

ΔT	Change in Temperature

CHAPTER I

INTRODUCTION

Global crop production is usually affected by environmental factors which makes it vulnerable to climate change (Stocker, 2014). Climate plays a vital role in crop development and growth by which any change in climate parameters will threaten global food production and safety (Wheeler & Von Braun, 2013). Agriculture has been cited to be the most economic vulnerable sector affected by fluctuations of precipitation and temperature (Brown & Funk, 2008). The main schemes to obtain future food demands require the following: increasing water productivity, reducing the waste of food, decreasing land degradation, reducing the current yield gap, utilizing other natural resources, and implementing more sustainable regimes (Foley et al., 2011; Steduto, Hsiao, Fereres, & Raes, 2012).

The Near East region is expected to experience lower precipitations and higher temperatures in the future which may deliver more threats to the agricultural productivity (IPCC, 2013). Additionally, as the demand for water is increasing for socioeconomic sectors, water availability for agricultural practices is decreasing (Iglesias & Garrote, 2015; Iglesias, Garrote, Flores, & Moneo, 2007).

In the absence of precise evaluation of crop response to climate change in terms of suitability and yield, there are numerous crops that have stayed poorly investigated and studied (Ramirez-Villegas, Jarvis, & Läderach, 2013). The suitability indices are used among researchers as a representation to assess the response of a crop to a set of meteorological factors (Lane & Jarvis, 2007; Schroth et al., 2009). The EcoCrop model, used in this research, can be used to assess the crop suitability. Hence, these indices are used to quantify the relationship between crop performance and climate where information are unavailable (Ramirez-Villegas et al., 2013).

Dynamic crop models mimic crop responses to soil properties, crop physiological responses, and management practices to atmospheric conditions; an example is AquaCrop (Steduto, Hsiao, Raes, & Fereres, 2009). AquaCrop implements a water-driven procedure, supposing a linear relationship between crop transpiration and biomass production (Steduto, Hsiao, & Fereres, 2007). There is little implementation of AquaCrop in studies relating to climate change impacts in the Near East.

Substantial amount of research has been performed to evaluate the connection/relationship between climate change and crop yield via climate & crop models (Challinor, Ewert, Arnold, Simelton, & Fraser, 2009; White, Hoogenboom, Kimball, & Wall, 2011). This has been and will continue to be studied for various types of crops and under different climate scenarios. Earlier studies tackled the impacts of climate change on water resources in the Near East region (Feitelson, Tamimi, & Rosenthal, 2012; Haddad, Farajalla, Camargo, Lopes, & Vieira, 2014; Hammouri, Al-Qinna, Salahat, Adamowski, & Prasher, 2015; Teklesadik et al., 2017; Wagena et al., 2016), and few studies targeted global and regional water use in agricultural production and found that total crop production will decrease in the developing countries including the Middle East and other regions (Agrawala et al., 2004; Calzadilla et al., 2013). Yet, most of these studies were performed with little emphasis on the relationship between changes in crop suitability and changes in crop water productivity and yield under climate scenarios. The need to properly assess the crop production for the Middle East in the future, particularly the Near East, is vital to deal with population increase and food security. The yield, suitability, evapotranspiration, and water productivity of many crops are not modeled under current and future climate scenarios.

The objectives of this research were to:

- Develop crop suitability maps for the major crops grown in the Near East and identify the most affected ones
- Perform analysis on change in suitability at the basin and cropland level of Jordan, Litani, Orontes, Euphrates-Tigris and Nile River Basins
- Estimate potential benchmark (average of the years 1970-2000) and future (2050) evapotranspiration, yield and water productivity for the major crops in the study area under climate scenario RCP8.5
- Compare the results from the two crop models AquaCrop and EcoCrop by assessing a relationship between crop suitability and yield in the Jordan, Litani and Orontes River Basins

CHAPTER II

LITERATURE REVIEW

This research tackles climate change which is one of the different chief features of global environmental changes that affects crop yields and water productivity. In this chapter, literature on climate change impacts and challenges on crop production in the Near East will be thoroughly reviewed. This will be headed with a description of the climate change emission scenarios and crop models used in climate studies. The different models used in simulating yield and water productivity will also be discussed. The previous work on suitability analysis done across different parts of the globe will further be presented. At last, this review will offer a summary of the climate change studies in assessing the impacts on crop yields, water productivity, and crop suitability in the Near East region.

A. Climate change in the Near East

One of the ultimate environmental changes the world is facing today is climate change. Its effects jeopardize water resources, ecosystems, economic stability, and food security. Based on the Intergovernmental Panel on Climate Change (IPCC), climate change denotes the changes of the climate’s state which can be quantified by realized changes in the variability of its properties over a prolonged duration of time. The results of human activities and natural variability lead to climate change regimes worldwide. Moreover, the United Nations Framework Convention on Climate Change (UNFCCC) in its first article

(1992) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (Bernstein et al., 2008).

The natural environment has been unstable and ever-changing in the Near East in response to human intervention and changes in the sea level and climate (Hole, 2007). The Near East is characterized by a semi-arid to arid climate (Tolba & Saab, 2009). Particularly, this region is increasingly susceptible to future climate change due to its accelerating population growth. The northern part of the Mediterranean basin will be facing drier conditions where the most significant reductions in precipitation are projected over the Eastern Mediterranean, namely Jordan, Syria and Lebanon. The annual precipitation is expected to decline by more than 100 mm by 2050 compared to present averages (Evans, 2009) which represents a 24-32 % reduction in winter precipitation (Verner, Lee, & Ashwill, 2013). Since water resources in rivers are degrading in quality and quantity, the Fertile Crescent which extends over Palestine, Lebanon, Syria, Iraq, and Jordan would lose its fertility and probably vanish by the end of the 21st century (Tolba & Saab, 2009). The main reason behind this situation is human interference and the projected implications of climate change are expected to aggravate this degradation (Bou-Zeid & El-Fadel, 2002). In fact, several studies proved that climate change led to a water shortage and decrease in agricultural production throughout the Middle East and namely the Near East. All these changes will affect the agricultural production in the Near East region in the absence of adaptation policies (Ibrahim, 2014).

B. Climate change challenges on global crop production

The change in precipitation patterns and the simulated increases in temperature and carbon dioxide ($CO_{2)}$ concentrations influence crop yields in different ways (Asseng et al., 2015; Porter et al., 2014), which can decrease or improve depending on the area (Challinor, Parkes, & Ramirez-Villegas, 2015; Wheeler & Von Braun, 2013). Heat waves can cause plant stress, which in turn can result in decreased biomass accumulation (Barlow, Christy, O'leary, Riffkin, & Nuttall, 2015) with declined grain produce (Stone & Nicolas, 1995). Increasing temperatures will lead to changes in the phenological growth and development of crops and make them susceptible to adverse weather conditions (Rezaei, Siebert, & Ewert, 2015). This will shift the sensitive plant periods (i.e. flowering stage) making them prone to drought, frost, critical heat, or heavy precipitation (Trnka, Hlavinka, & Semenov, 2015).

1. Climate factors affecting crop production

There are four factors affecting crop production: (1) variation in precipitation regimes, (2) global warming, and (3) increase in CO_2 concentration. A brief examination of these factors will be discussed in the follow paragraphs.

a. <u>Variation in precipitation regimes</u>

In response to climate change, the dry zones in the tropics are projected to become drier and the temperate areas are projected to become wetter (FAO, 2008). The precipitation regimes are forecasted to become unpredictable and irregular. The soil moisture content, which is one of the significant factor for determining crop yields, will be affected by the changing precipitation. Hence, rainfall reduction in the Near East will lead to increased aridity, decreased soil water content, and amplified groundwater depletion, and the resultant effect is the loss of arable land in this region (Bals, Harmeling, & Windfuhr, 2008). Therefore, the influence of climate change in altering the precipitation pattern would restrict agricultural production.

b. Global warming

As a result of climate change, maximum, minimum, and average temperatures are projected to increase across the world (FAO, 2008). Regions located in low latitudes will experience increases in temperature, where crop yields will be at risk in response to 1-2 °C increase in temperature (M. Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007). This is due to the accelerated evapotranspiration and decreased soil moisture content (Bals et al., 2008). Slight increases in temperature will cause some improvements in the growth of crops only when the temperature is below the optimum level, while it will negatively affect crops if the temperature approaches or exceeds its maximum limit (Baker & Allen, 1993). If the temperature exceeds the tolerated maximum level of the crop, reductions will occur to crop yields due to insufficient vernalization where the seeds upon germination will not be cooled enough to accelerate the flowering stage (Trnka et al., 2015). Other reasons proving yield reductions are increased transpiration and reduced photosynthesis (Long, Ainsworth, Rogers, & Ort, 2004) and shortening of growing seasons (Baker & Allen, 1993). Consequently, some arable lands in the tropics will become unsuitable for agriculture and projected yields will consequently decline due to this phenomenon (Bals et al., 2008). The degree of yield reduction in the future is uncertain and some researchers predict that severe reductions may occur to agricultural production (Bals et al., 2008).

c. Increase in CO_2 concentration

The elevated CO_2 concentration effects (CO_2 fertilization) on plants have been globally simulated and analyzed. It is estimated that the atmospheric CO_2 concentration will reach 550 ppm by 2100 under RCP2.6 (lowest emission scenario) (Schmidhuber & Tubiello, 2007). This increase in CO_2 concentration plays a beneficial effect to plants via promoting plant's growth and development (Eamus, 1991). It will enhance photosynthesis and increase the water-use efficiency, and the resultant effect is an increase in both the biomass and yield of crops (Bazzaz & Sombroek, 1996). Despite this beneficial effect of CO_2 fertilization, it will globally enhance the greenhouse effect and global warming (Bals et al., 2008).

2. *Climate Change impacts on global crop production*

In spite the increase in crop yields due to technological advances, the United States Global Change Research Program report states that extreme weather variations have adversely impacted crop production (USGCRP, 2009). This report indicates that warmer temperatures not only limit the growth phases, but also lower crop yields. Shortened periods of growth can be suitable in areas where the soils have low water content; conversely this leads to rapid growth and development in some crops such as corn through shortening the seed germination period, crop maturity, and crop growth. Eventually, for a given portion of land, the accelerated growth of the crops leads to a substantial decline in crop yields. Tubiello, Rosenzweig, Goldberg, Jagtap, and Jones (2002) is in accordance with the concept that agricultural production is highly affected by the climate change although the magnitude will vary from crop to crop and from place to another mainly due to different anthropogenic and natural factors that contribute to this change. Kimball (1983) discovered that crop yields will increase due to the high amounts of carbon dioxide. On the other hand, this can lead to temperature rise which will decrease the crop yield eventually.

The influence of climate change on crop productivity thoroughly depends on the plant species and climatic variability of the region (Bernstein et al., 2008). The sensitivity of crops to variations in temperature, solar radiation, atmospheric CO_2 concentration, and precipitation are proved by the results of experimental studies and crop simulation models (Southworth et al., 2002). These variations will affect the crop productivity through changes in, crop yield, planting date, harvesting date, and time to maturity (Baker & Allen, 1993; Bowes, 1993).

a. <u>Wheat</u>

Several studies have been conducted to assess the impacts of climate change on crop production worldwide, namely wheat. The yields of wheat in the drylands of Pacific Northwest US were projected using future under RCP4.5 and RCP8.5 emission scenarios and baseline data sets (Karimi, Stöckle, Higgins, & Nelson, 2017). Their study concluded an overall increase in wheat yield in the Pacific Northwest US since the precipitation patterns will be favorable to wheat crop, but this increase will not be homogenous all over the region due to meteorological variations. In northwestern Turkey, a study was established to point out that the winter wheat yields might drop by more than 20% due to the change in climate that causes shorter growth periods and precipitation reduction (Özdoğan, 2011). Similar studies in Turkey concluded that increases in temperatures positively affects the yield of some crops. This is correct for the varieties that are grown today. For example, rice, potato, corn, and winter wheat yields could grow with increasing temperature and precipitation under climate change in northern China plain (Chaves, Flexas, & Pinheiro, 2009). To avoid or reduce this problem, new varieties should be produced with shorter growing seasons.

b. Maize

Srivastava, Mboh, Zhao, Gaiser, and Ewert (2017) simulated the yield of maize in central Ghana where they found a substantial mean increase in the biomass and yield of maize under the same emission scenarios used by Karimi et al. (2017) for simulating wheat yield. It is known that maize production is controlled by the dominant radiation and temperature levels in central Ghana region (Nendel, Rötter, Thorburn, Boote, & Ewert, 2018). The increase in the yield and biomass of maize, as projected by Srivastava et al. (2017), is investigated to be due to the fertilization effect of increasing ambient CO_2 concentrations and its effect on the water use efficiency of maize. Cuculeanu, Tuinea, and Bălteanu (2002) studied the rainfed maize yield in Romania by CERES-Maize using CCCM and GISS climate models under doubling present CO_2 concentration; they concluded that the dry matter can increase 1.4–2.1 t/ha with the CCCM model but 3.5–5.6 t/ha by the GISS model. Also, Akpalu, Hassan, and Ringler (2008) studied the climate impacts on maize yield in the Limpopo Basin of South Africa and explained that increased temperature and rainfall are encouraging for the crop yield, and that precipitation effect influences the crop yield in a more significant way than temperature.

c. Rice

Droogers and Aerts (2005) studied climate change impacts on rice yield in seven basins with the SWAP and HadCM3 climate model under A2 and B2 scenarios for the years 2070-2099 in the Volta Basin, and the results showed that rice yields are expected to increase by around 45% and 30% for A2 and B2 scenarios, respectively. Krishnan, Swain, Bhaskar, Nayak, and Dash (2007) evaluated the effects of elevated CO_2 and temperature on irrigated rice yield in eastern India by ORYZAI and InFoCrop-rice models, and the outcome expressed that increased CO_2 concentration can increase the rice yield, which is concerned with the sterility of rice spikelet at higher temperature, the sowing time and the selection of genotypes. Moreover, Yao, Xu, Lin, Yokozawa, and Zhang (2007) examined CO_2 level impacts on rice yield with the CERES-Rice model in Chinese main rice production areas, and indicated that rice yield will increase with CO_2 effect, otherwise it will decrease.

d. <u>Corn</u>

Cai, Wang, and Laurent (2009) evaluated the impacts of climate change on rainfed corn production in central Illinois, USA. The results showed that corn yields will drop by 23-34% in 2055 under the rainfed conditions. If there is no implementation of adaptation strategies, the estimated yield decreases will be between 32-70%, by which this reduction in yield will not meet the 50% probable yield by the year 2055. With higher temperature, Tao and Zhang (2013) revealed that corn yields will drop by 2.4% to 45.6% in Northern China plain. Additionally, the time to crop maturity is unfavorably affected by the shorter growing season where it's the result of higher temperature and evapotranspiration rates in spite of constant precipitation (Schlenker & Lobell, 2010).

In addition, a current study assessed the different agricultural responses to climate change in Iran's Zayandeh- Rud River Basin for the periods 2015-2035. It considered four types of crops: rice, corn, wheat, and barley. The study determined that crop production could drop as follows: 2.1-9.5% for rice, 5.7-19.1% for corn, 2.5-20.7% for wheat, and 1.4-17.2% for barley taking into consideration an increase in average monthly temperature of 1.1-1.5 °C and precipitation decrease of 11-31% within the basin (Gohari et al., 2013).

It's not only the Near East region that will be affected by the impact of climate change but also the whole globe. The work previously done by researchers was at the crop, country, or continental level. This work will provide an assessment of the yield of major crops grown in this region at the river basin and cropland level. Moreover, the results of scholars indicated an overall decrease in the yield of major agricultural crops grown in the

Near East region. Therefore, it's important to have a glimpse about the future of agricultural production in the Near East region to meet the escalated population demand.

C. Climate change emission scenarios

In the modern eras, future projections of meteorological data are estimated using General Circulation Models (GCMs) (Bernstein et al., 2008). GCMs are numerically coupled models that characterize the several aspects of the earth system including land surfaces, atmosphere, sea-ice land, and oceans (Ramirez, Jarvis, Van den Bergh, Staver, & Turner, 2011). They are based on physical laws of energy, mass and momentum and are employed to downscale meteorological data and simulate climate change using the forecasted atmospheric greenhouse gases concentrations and aerosols (Dowling, 2013). GCMs simulate & predict current and future climate conditions, respectively, under different climate scenarios (H. Li, Feng, & Zhou, 2011; McAfee, Russell, & Goodman, 2011; Miao, Duan, Sun, & Li, 2013). According to IPCC, a climate scenario can practically describe the future climate based on a range of climatological relationships and assumptions of radioactive forcing. The new generation of GCMs, called Phase 5 of the Coupled Model Intercomparison Project (CMIP5), has been involved in the preparations of the IPCC 5th Assessment Report (AR5). The new emission scenarios, called representative concentration pathways (RCPs), were used in several experiments included in the CMIP5 (Meinshausen et al., 2011; Moss et al., 2010). Recently, researchers are using the AR5 to simulate future climate change under RCP scenarios (Kelley, Ting, Seager, & Kushnir, 2012; Liu, Allan, & Huffman, 2012; Ma, Pan, Wang, Liao, & Xu, 2016; Zhao, Xu, Powell, & Jiang, 2015).

Based on the radiative forcing level by 2100, the RCPs are named (Afshar, Hasanzadeh, Besalatpour, & Pourreza-Bilondi, 2017). “The radiative forcing due to a perturbation in the concentration of a gas is defined by the net radiative flux change induced at the tropopause. The forcing is usually interpreted as a gain (positive) or a loss (negative) for the surface-troposphere system as a whole” (Ramaswamy et al., 2001). Four RCPs represent the emission scenarios in AR5: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Van Vuuren et al., 2011). The lowest emission scenario is RCP2.6 and its radiative forcing will peak at 3 W/m^2 (~490 ppm CO_2 equivalent) by 2050 and decline afterward. The radiative forcing of RCP4.5, which is known as a stabilization scenario, will increase till 2070, after which its greenhouse gas (GHG) concentration will remain stable after 2070. Moreover, the radiative forcing of RCP8.5, which is the highest emission scenario, will reach its stability at 8.5 W/m^2 by the end of 21st century (Chong-Hai & Ying, 2012). To sum up, an overview by Van Vuuren et al. (2011) for the RCPs is presented in Table 1.

Table 1. Overview of representative concentration pathways (RCPs)

RCP	Emission Scenario
RCP2.6	Peak in radiative forcing at 3 W/m^2 (~490 ppm CO_2 equivalent) before 2100 and then decline to 2.6 W/m^2 by 2100
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 equivalent) at stabilization after 2100
RCP6.0	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 equivalent) stabilization after 2100
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 equivalent) by 2100

Coupled GCMs provides an appropriate opportunity to simulate future climate conditions under various radiative forcing scenarios (Afshar et al., 2017). GCMs, however, face errors and lack the spatial and temporal accuracy that is crucial for a detailed regional analysis (Bonan et al., 2002; Thomas, 2008). Therefore, as mentioned by Cuculeanu et al. (2002), more than one model will be better for dealing with the accurate projection problem.

D. Crop models

Different studies have been performed using crop simulation models to assess the climate change impacts on the production of crops.

1. Crop models used in climate change research

Some of the crop models that have been often employed include the following: DSSAT (Decision Support System for Agrotechnology Transfer) (Hoogenboom et al., 1994), CERES-Wheat (Crop Environment Resource Synthesis) (P. G. Jones & Thornton, 2003), CERES-Maize (Crop Environment Resource Synthesis) (C. A. Jones, Kiniry, & Dyke, 1986), SWAP (Soil-Water-Atmosphere-Plant) (Dam et al., 1997), Crop Syst (Stöckle, Donatelli, & Nelson, 2003), InFoCrop (Singh, Govindakrishnan, Lal, & Aggarwal, 2005) and CropWat (Allen, Pereira, Raes, & Smith, 1998). Out of the preceding models, there is a strong interaction between water, climate change, and crop, particularly in: (1) AquaCrop, (2) SWAP, and (3) CropWat models (Droogers & Aerts, 2005). These particular models have been extensively used and verified in several worldwide climate change researches, are freely accessible, and are user-friendly (Hunink & Droogers, 2011).

2. AquaCrop Model

The AquaCrop model, developed by the FAO in 2007, was extensively used worldwide to study many crop responses to climate change, irrigation and fertilization treatments, and irrigation scheduling.

a. <u>Assessments using the AquaCrop model in the Near East</u>

The AquaCrop model was used to parameterize and validate the yields of few crops in this region. This model was not used to assess the crop evapotranspiration, biomass, and yield under climate scenarios in the Near East region and neighboring countries (Iran, Iraq, Lebanon, Morocco and Syria). For instance, Andarzian et al. (2011) evaluated the AquaCrop model in Ahvaz region (south Iran) by simulating the wheat yield under deficit and full irrigation in a hot climate. The measured wheat yield was in agreement with the simulated wheat yield, where the measured wheat yield varied between 4.0 to 6.0 t/ha for deficit and full irrigation and the simulated wheat yield ranged between 4.4 to 6.3 t/ha.

Three crop models: SWAP, AquaCrop & SALTMED were used by Hassanli, Ebrahimian, Mohammadi, Rahimi, and Shokouhi (2016) to study the soil salinity effect on forage maize yield in Karaj region of Iran for the year 2012. The coefficient of determination (R^2) between the simulated and observed data of maize yield were determined to be 0.594, 0.733 & 0.846 for the SWAP, AquaCrop & SALTMED models, respectively. They concluded that SWAP and SALTMED estimated the maize yield better than the AquaCrop did. Moreover, Salemi et al. (2011) studied the application of AquaCrop in a deficit irrigation application for winter wheat in the Gaykhuni River Basin in Iran (Isfahan province). Their results show that the water productivity of wheat ranged between 0.91 and 1.49 Kg/m^3 in this watershed where the maximum water productivity was achieved at 40% deficit irrigation treatment.

Seyed Raoufi, Soufizadeh, Amiri Larijani, AghaAlikhani, and Kambouzia (2018) assessed the ability of AquaCrop model in assessing the growth of three rice genotypes under different seedling ages for two growing seasons (2008 & 2009) in Amol (Iran). Their results showed that AquaCrop was able to simulate the biomass and yield of rice by comparing the simulated values to measured ones. The results showed that the mean observed and simulated biomass was 1,339.9 and 1,331 g/m^2 for the year 2008 and 1,176.3 and 1,299.3 g/m^2 for the year 2009, respectively. The average rice yields of the three cultivars was 5.5 t/ha and 4.6 t/ha for the years 2008 & 2009, respectively. They also reported the AquaCrop model was able to identify the decrease in rice yields in 2009 relative to the year of 2008.

Taher, Hussian, and Khalaf (2017) conducted an experiment over the growing season of 2015-2016 in the research farm of University of Duhok in Kurdistan region (Iraq) to assess the yield and water productivity of three wheat varieties under 3 irrigation treatments (rainfed, 50% and 100% field capacity) aided by the help of AquaCrop model. Results suggested that total field capacity irrigation yielded the highest rice grain yield (3.78 t/ha). The mean simulated and measured biomass of the three varieties 11.9 & 12.5

t/ha, respectively. The authors also depicted an average of 5.6 Kg/m^3 for the crop water productivity of rice.

The AquaCrop model was also applied and tested by Saab, Albrizio, Nangia, Karam, and Rouphael (2014) on sunflower (*Helianthus annuus* L.) and soybean (*Glycine max* L. Merril) in Lebanon (Bekaa Valley). They found that the model accurately simulated the yield of both crops. The simulation results showed that soybean yields varied between 2.01 - 3.16 t/ha while the sunflower yields varied between 1.74 - 1.97 t/ha.

In Tensift Al Haouz (Marrakech, Morocco), the AquaCrop model was used by Toumi et al. (2016) to simulate the biomass and grain yield of winter wheat and their results were successfully validated using field data from the years 2003-2004. Several simulations were performed, and results depicted that early sowing is more suitable than late sowing since it results in water saving and higher yields. The simulations results showed that the biomass and yield varied between 5.5-17.3 t/ha and 2.4-8 t/ha, respectively. This large interval in their results was a result of several simulations of winter wheat under early and late sowing conditions.

In Syria (South-East of Damascus), AquaCrop model was also applied by Hussein, Janat, and Yakoub (2011) to simulate the response of cotton to deficit irrigation (50%, 65% and 80% of full irrigation) over the growing seasons of 2007-2009. The simulation results for cotton were as follows: evapotranspiration of 440-760 mm/season and grain yield of 2.8-5.2 t/ha for the year 2007, evapotranspiration of 430-790 mm/season and grain yield of 3-5.4 t/ha for the year 2008, and evapotranspiration of 400-710 mm/season and grain yield of 2.4-5.3 t/ha for the year 2009. Moreover, an average of 0.67 Kg/m^3 (for 2007 and 2008) and 0.72 Kg/m^3 (for 2009) for water use efficiency were also simulated by the AquaCrop model. Another assessment for cotton in Syria was done using AquaCrop by Farahani, Izzi, and Oweis (2009) to simulate the yield of cotton under deficit irrigation in northern Syria for the year of 2006. Under full irrigation treatment, the simulated and observed ET of cotton were simulated to be 815 and 798 mm/season, respectively, while the observed and simulated ET values under 80% deficit irrigation treatment were 686 and 657 mm/season, respectively. Regarding the biomass and yield simulations, the model predicted an average of 14.5 and 3.5 t/ha, respectively.

b. Worldwide assessments of AquaCrop model

There are several validation assessments for the AquaCrop model that have been globally performed. The tests have permitted the reliability of AquaCrop where the input data are available and accessed (Mainuddin et al., 2010).

The AquaCrop model has been assessed for several crops in different parts of the world, examples are: cotton (García-Vila, Fereres, Mateos, Orgaz, & Steduto, 2009), barley (Abrha et al., 2012; Alemie Araya, Habtu, Hadgu, Kebede, & Dejene, 2010), wheat (Andarzian et al., 2011; Mkhabela & Bullock, 2012; Soddu et al., 2013), tomato (Rinaldi, Garofalo, Rubino, & Steduto, 2011), sunflower (Todorovic et al., 2009), quinoa (Geerts et al., 2009), cabbage (Wellens et al., 2013), maize (Heng, Hsiao, Evett, Howell, & Steduto, 2009; Hsiao et al., 2009; Shrestha, Raes, & Sah, 2013), teff (A Araya, Keesstra, & Stroosnijder, 2010), sugarbeet (Stricevic, Cosic, Djurovic, Pejic, & Maksimovic, 2011), and canola (Zeleke, Luckett, & Cowley, 2011).

The AquaCrop model has been parameterized for maize using experimental data for six growing seasons and tested in University of California Davis (USA) (Hsiao et al., 2009); the results analyzed by them showed that AquaCrop was able to simulate biomass development, canopy cover, and grain yield for the six growing seasons of maize. Another evaluation was performed by Alemie Araya et al. (2010) in northern Ethiopia to assess the ability of AquaCrop model to simulate the biomass and yield of irrigated and deficient barley. Moreover, maize yield was simulated by Erkossa and Awulachew (2011) using AquaCrop model under rainfed conditions for varying soil fertility conditions in the Blue Nile Basin. They concluded that maize grain yield increased from 2,500 kg/ha to 9,200 kg/ha under optimal soil conditions and 6,400 kg/ha under poor soil conditions. In the following sections, climate change impact findings using AquaCrop model will be discussed further.

E. Projected impacts of climate change on crop yields in the Near East

The regional changes in crop yields under climate change emission scenarios are due to the effects of elevated CO_2 concentration on crop growth and development and changes in precipitation and temperature (M. L. Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004). Climate variability has a significant impact on the yield of major crops (Ciais, Reichstein, Viovy, & Granier, 2005; Iizumi et al., 2014). A recent study conducted by the International Food Policy Research Institute for the Near East proposed that crop yields up to 2050 will severely be affected by climate change leading to decreases in yield of wheat (20%), rice (30%), and maize (47%) (Nelson et al., 2009). There is a considerable amount of studies performed for the Near East region on the impacts of climate change on crop production, but these studies don't include all the major crops grown in this region. The effects of climate change on the major crops grown in the Near East region are not explicitly assessed in terms of impacts on evapotranspiration, biomass, yield, and water productivity. The researcher's findings of the impacts of climate change on crop yields are presented in the sub-headings below.

1. ***Simulating rice yields under climate change emission scenarios in the Mediterranean region***

The existing simulations performed on rice yields in the Mediterranean predicted conflicting results, ranging from an increase of yield by 10-15% in 2020 (Tao & Zhang, 2013) to a decrease by 7-10% in yield for every 1 °C temperature increase (Krishnan et al., 2007; Peng et al., 2004). Bregaglio et al. (2017) projected the yield of rice under climate scenarios (RCP2.5 and RCP8.5) in Italy and France under two rice models (WARM & STICS) for 2030 and 2070. The rice yield was simulated under two conditions: with and without adaptation measures. They found that rice yields with no adaptation measures will decrease by 8% and 12% in 2030 and 2070, respectively. On the other hand, rice yields with adaptation measures will increase by 28% in 2030 and 25% in 2070. Therefore, simulations confirm that rice yield will decrease among the Mediterranean countries and the adaptation measures can shift this decrease into an increase till 2070.

2. Simulating the impacts of climate change on agricultural production in Jordan

Rainfed agriculture in Jordan will be most affected by climate change impacts. The current studies conducted in Jordan include country and watershed level assessments. In fact, “the impact of climate change on agriculture was indirectly investigated by assessing the adverse impacts on water budget and irrigation water demand and supply” (Al-Bakri, Suleiman, Abdulla, & Ayad, 2011).

a. Country-level assessment on yield changes for Jordan under climate change

Al-Bakri et al. (2011) used the DSSAT (Decision Support System for Agrotechnology Transfer) model to predict the current and future yield of wheat and barley. The model predicted an average yield of 927 kg/ha for barley compared to observed data of 922 kg/ha collected from the Jordanian department of statistics. On the other hand, the model predicted an average yield of 1,176 kg/ha for wheat compared to 1,173 kg/ha which is the observed yield taken from the department of statistics, too. Barley and wheat yield under different climate scenarios were also studied by Al-Bakri et al. (2011) and the results showed that a reduction in precipitation by 10-20% will decrease the expected yield by 10-20% and 4-8% for wheat and barley, respectively. However, an increase in precipitation of 10-20% will increase the yield of both crops by 9-18% and 3-5% for wheat and barley, respectively. Moreover, temperature increase in winters of Jordan will lead to earlier maturity of crops (Wilby, 2010). Such changes in temperature regimes will lead to reduced crop yields in some regions. For instance, favorable temperature for barley and wheat in the winter season will lead to boosted crop development, decreased grain-filling period, and henceforth reduced yield (Verner et al., 2013).

b. River basin-level assessment for Jordan on yield projections under climate change

Crop production and agriculture in the Jordan River Basin are considered to be sensitive to climate change; this is evident by the variability in crop production. Substantial climatic risks have been faced by Jordanian farmers in the period between 1996 and 2006 where the mean ratio of harvested to cultivated areas was 44% for barley and 68% for wheat (Verner et al., 2013) and the risk will continue to increase in the future years. Peet, Willits, and Gardner (1997) illustrated that tomato production is highly vulnerable to temperature. An increase of 2 ^{0}C in temperature above 27 ^{0}C will result in 50% reduction in fruit setting and 75% reduction in fruit biomass per plant. Al-Bakri et al. (2011) ran a crop-climate model for Jordan's Second National Communication to the UNFCCC to examine how predicted changes in temperature and precipitation would alter barley and wheat yields. The results showed that barley yields will decrease by 14-28% while wheat yield will increase in response to an increase of 1-2 ^{0}C in temperature if the rainfall remains steady or rises. Consequently, the agricultural production in Jordan River Basin will be altered under climate change scenarios, where tomato, wheat, and barley yields will reduce in the future decades.

3. Climate change impacts on yields in Egypt at the crop level

In similar manner, the impact of climate change on agricultural production in Egypt was examined by few researchers. A considerably few studies targeted the impacts of global warming on Egyptian crop yields, and this research comes to explore and assess the effects of climate change on crop yields at the basin level for futuristic adaptation strategies. The researchers showed that the yield of many crops, including barley, maize, wheat, soybeans, rice & sunflower, will be directly influenced by climate change impacts, and the projected decline in their yields is 10-30% (Abou-Hadid, 2006; El-Ramady, El-Marsafawy, & Lewis, 2013). The results of M. L. Parry et al. (2004) also reported reductions in the yield of maize under all climate change emission scenarios. Due to temperature increases and precipitation decreases, the agricultural activities are projected to decline by a range of 10-60% (Smith et al., 2013). McCarl et al. (2015) used the Agricultural Sector Model of Egypt (ASME) to assess expected crop yields for 2030 & 2060 and propose adaptation strategies for the Egyptian agricultural sector. The results showed a decrease in the agricultural production by 6% for 2030 & 2060 climate scenarios due to temperature increases.

The yield of vegetables, legumes and oil producing crops in Egypt are also expected to decrease due to the impacts of climate change. An increase of temperature by 2 $^{\circ}$C in 2050 will decrease the expected yield of rice by 11% (H. Eid & El-Marsafawy, 2002; Hassan, 2013), barley by 20% (H. Eid et al., 1995), wheat by 15% (Medany & Hassanein, 2006), soybean by 28% (H. Eid & El-Marsafawy, 2002), and maize by 19% (H. Eid, El-Marsafawy, Salib, & Ali, 1997; Hassan, 2013). Moreover, the yield of tomato will decline by 14% and 50% after an increase in temperature by 1.5 ^{0}C and 3.5 ^{0}C, respectively (Fawaz & Soliman, 2016). On the other hand, an increase in cotton yield by 17% and 31% will occur with an increase in temperature by 2 ^{0}C and 4 ^{0}C, respectively (H. Eid et al., 1997; Fawaz & Soliman, 2016). Furthermore, studies showed that potato and cotton yields, grown in the main seasons, are likely to be increased by 15-40% under climate scenarios (Abou-Hadid, 2006; El-Ramady et al., 2013). Besides, D. L. Phillips, Lee, and Dodson (1996) used the Explicit Planetary Isentropic Coordinate (EPIC) model to assess the impacts of climate change on soybean and corn yields in Egypt. The results indicated that the expected soybean and corn yields will both decrease by 3% in response to an increase of 2 ^{0}C in temperature from a precipitation baseline level. However, the negative influence of 2 ^{0}C increase in temperature is well-adjusted by an increase of 10% in precipitation. Likewise, sunflower yield under climate change scenarios was investigated by El-Marsafawy and El-Samanody (2009). They reported that the expected sunflower seed yield will decrease by 27%. Therefore, the results confirm that climate change in Egypt, characterized by an increase in temperature, will decrease the yields of rice, wheat, barley, soybean, maize, sunflower, & tomato. The simulation results of cotton yield are contradicting, and potato yield is expected to increase in Egypt.

4. *Climate change impacts on crop yields in the Bekaa Valley (Lebanon)*

A few similar studies were performed in the Bekaa Valley, Lebanon, to assess crop yields under climate change scenarios. Recent observed increases in temperatures in the Bekaa Valley damaged the peach, apple, cherry, and grape crops which was translated into a reduction in their current yields (Verner et al., 2013). The production of cherry and apple in the Bekaa Valley are projected to be extremely vulnerable under climate change scenarios where the chilling requirements can be insufficient and deficient in 2024 & 2100, respectively (Verner et al., 2013). Besides apples and cherries, the sugar beet is known to be tolerant to high temperatures, yet its yield will also be affected by the impacts of climate change due to water stress. On the contrary, wheat and barley can't tolerate variations in temperatures (i.e. high temperatures) leading to crop failure (Ober & Rajabi, 2010). In addition, the frequent low precipitation in Bekaa will make wheat yields sensitive to climate change in most regions of the Valley. The same applies for the irrigated tomato and potato in Bekaa where their production is highly related to water availability (Verner et al., 2013). Consequently, the results confirm that the yields of major crops grown in the Bekaa Valley will be decreased by climate change impacts including peach, apple, cherry, grape, sugar beet, tomato and potato.

5. Climate change impacts on crop yields in Syria and Palestine

The studies related to crop modelling performed in Syria and Palestine are very few (Mason, Mimi, & Zeitoun, 2010), but these inputs can give a glimpse about the current and future situation in this region. There is a need to assess the impacts of climate change on their agricultural production due to changing climate regimes in their region and neighboring areas. There are no direct estimates of the losses or gains from global warming at the country and watershed level for these countries. This research will fill this gap by providing estimates for the yields of major crops grown in that regions at the watershed and cropland level. In Syria, a study conducted by the UNFCCC (2009) in the Hassakeh governorate using the CROPWAT model to assess the effect of climate change on cotton and wheat (rainfed and irrigated) yields (Ibrahim, 2014). The results showed that cotton yields will be decreased by 7.5% under water shortage conditions, while the wheat yields will be reduced by 30% due to climate change and water stress. Moreover, the Coastal Municipalities Water Utility (CMWU) assessed the crop water requirements in the Gaza Strip and the same model was used for this purpose (CROPWAT model). The results showed that the crop water requirements will increase by 6-11% in response to a mean annual increase in temperature by 1 ^{0}C.

F. Climate change impacts on crop evapotranspiration and water productivity

As the agriculture sector is the most consumer of water, besides the fact that water availability is decreasing, water productivity is becoming a concern among researchers. The importance of assessing water productivity comes with the rising competition of water resources, the uncertainties linked to climate change, and increasing demand for agricultural products, is to increase water productivity to achieve food and water security, and increasing demand for agricultural products, is to increase water productivity to achieve food and water security. The agricultural sector is facing a challenge to produce more food from less water; this can be achieved by increasing crop water productivity (Zwart & Bastiaanssen, 2004).

1. *Crop water productivity (CWP)*

Kijne, Barker, and Molden (2003) described the concept of Water Productivity (WP) to convey the superior context of water consumption in relation to a variety of services and benefits produced including crops, fisheries, agroforestry, and livestock (i.e. calories, kg). CWP emerged from WP and water use efficiency (WUE). It defines the fresh crop yield per unit of water consumed (Kg/m^3) (Bastiaanssen & Steduto, 2017). It is used as the final indicator for efficient agricultural water use (Molden, 2007; Tolk & Howell, 2012). The CWP is calculated according to equation (1).

$$CWP = \frac{Y}{\sum ET} \tag{1}$$

where Y (kg/ha) is the actual crop yield and $\sum ET$ (m^3/ha) represents the actual evapotranspiration (ET) accumulated for the crop growing season.

2. *Possible climate impacts on evapotranspiration*

Under climate scenarios, the evapotranspiration will be affected by the changes in weather variables. Climate change can alter the evapotranspiration due to the increase in vapor deficit, radiation and temperature (Abtew & Melesse, 2013). Thus, an increase in the temperature, CO_2 concentration and solar radiation will result in a rise in crop water use and productivity. There is an absolute relationship between the evapotranspiration on one hand and the air temperature and solar radiation on the other hand (Abtew, 1996).

The summer temperature in three Alpine River Basins were simulated by Calanca, Roesch, Jasper, and Wild (2006) using a global climate model (ECHAM5). Their results indicated that a temperature increase of 3-4 °C will rise the potential evapotranspiration by 20%. In Florida, the IPCC simulated the mean annual evaporation to increase by 15% in 2080-2099, relative to the benchmark period 1980-1999 (Bates, Kundzewicz, & Wu, 2008).

Several researches showed that crop transpiration will increase in response to increased temperature, but an increase in CO_2 concentration will reduce this temperature-induced transpiration increase (Hatfield & Prueger, 2015). Abtew and Melesse (2013) stated that when ample soil water and nutrients exist, the evapotranspiration will be reduced in the United States under a climate change scenario whereby its CO_2 concentration is 550 ppm. Moreover, an assessment of climate change impacts in India depicted a possibility if increased potential ET over this region (Chattopadhyay & Hulme, 1997). This is in accordance with the findings of Goyal (2004) where he depicted a marginal increase in evapotranspiration which will have a noteworthy impact on the arid region of India.

To our knowledge, evapotranspiration has never been computed at the crop and basin level in the Near East region (H. Jaafar et al., 2016). There is, to the author's knowledge, no scholarly research on simulating the crop evapotranspiration under climate change emission scenarios. However, few evapotranspiration assessments were performed in the Near East for hydrological water balance studies.

3. Evidence of impacts on CWP in the Near East

CWP is "an important indicator for expressing water use efficiency during crop production" (Ali & Talukder, 2008). The recent study by Bastiaanssen and Steduto (2017) illustrates that climate is the most significant element of agricultural productivity, mostly through its effects on temperature and precipitation regimes. Many factors affect the climate change impacts on crop water productivity such as the uncertainty in global climate model predictions, especially regarding climate variability (New & Hulme, 2000). Other factors include soil characteristics such as soil water storage (Oberforster, 2001), long-term condition in soil fertility (Sirotenko, Abashina, & Pavlova, 1997), climate variables and enhanced atmospheric CO_2 levels (Amthor, 2001).

Ever since increasing water resources in arid and semi-arid regions (i.e. Iran) is inadequate, water productivity improvement for such regions can be an adaptive and realistic solution. Dehghanisanij, Nakhjavani, Tahiri, and Anyoji (2009) assessed irrigated maize and wheat water productivities in Iran and their results showed that WP of maize is low in the southwest regions of Iran and high in the northwest. They reported broad ranges of productivities: 0.3-2.3 Kg/m^3 and 0.5-1.8 Kg/m^3 for maize and wheat, respectively, in the Iranian regions vulnerable to climate change impacts.

Future temperature projections for Egypt will likely increase the water requirements of the major crops and decrease their production; thereby reducing their crop water use efficiency (Attaher, Medany, Abdel Aziz, & El-Gindy, 2006). Several studies assessing the Egyptian agricultural sector under climate change scenarios revealed decreases in both water use efficiency and yields relative to the current climatological conditions (H. M. Eid, El-Marsafawy, & Ouda, 2007). It is commonly known that wheat water productivity is lower than that of maize. This is in contradiction with the situation of Egyptian climate conditions; WP of maize (a summer crop) is higher than wheat (winter crop) due to higher irrigation water applied for maize (El Afandi, Khalil, & Ouda, 2010).

G. Crop suitability analysis

With the prevailing climate change affecting the growing conditions of the crops, spatial suitability models are significant tools for planning and developing agricultural production (Junior, Pinto, & Assad, 2006; Zabel, Putzenlechner, & Mauser, 2014). The model used for this research is the EcoCrop model which only takes meteorological (precipitation and temperature) inputs.

1. Crop suitability

The term crop suitability has no straightforward definition in the scientific literature (Piikki, Winowiecki, Vågen, Ramirez-Villegas, & Söderström, 2017), and it is hard to distinguish this term form the following: yield potential, productivity, and attainable yield. In this research for the Near East, crop suitability means how a specific location has the mean meteorological conditions to meet the crop requirements. The suitability score ranges from 0 to 1, where a suitability of 1 indicates a high crop suitability for a specific site (Pawar-Patil & Mali, 2015; Ramirez-Villegas et al., 2013). A suitability score of 0 means that the crop can’t tolerate the mean climate conditions for a certain region. In fact, a suitability score of 1 has nothing to do with the yield level for a specific region and it is just an indication that the site has the suitable biophysical conditions to grow a certain crop (Piikki et al., 2017). Therefore, a crop simulated to have a high suitability will successfully perform better than that of a low suitability score. On the contrary, there is a possibility of crop failure in an extreme year even if the model predicted a high suitability score, and vice versa (Piikki et al., 2017).

2. *Crop suitability models*

Simulating the suitability of crops under current and future climate change scenarios is performed to assess if a crop can undergo agricultural production given the meteorological components (Piikki et al., 2017). It also helps in identifying adaptation strategies and alternative locations for crop production based on climate and land factors that will suit the growth and development of the crops (Jarvis, Ramirez-Villegas, Campo, & Navarro-Racines, 2012; Zabel et al., 2014). Examples of existing tools serving that purpose are remote sensing software (i.e. GIS) and complex crop simulation models and tools (i.e. Maxent and EcoCrop).

a. EcoCrop as a crop suitability model

The EcoCrop model is a simple model used to simulate the climate change effects on crops based on environmental ranges for precipitation and temperature as inputs (Lane & Jarvis, 2007; Makinano-Santillan & Santillan, 2015). The output of this model is a suitability index for any specific region. A suitability index measures the fraction of each grid cell that is suitable for production for any specific crop (Lane & Jarvis, 2007).

EcoCrop model has been formerly used to assess the climate change impact on various crops, including sorghum (Ramirez-Villegas et al., 2013), cassava (Ceballos, Ramirez, Bellotti, Jarvis, & Alvarez, 2011; Jarvis et al., 2012), groundnut (Vermeulen et al., 2013), and banana (Ramirez et al., 2011; Van den Bergh et al., 2010). In fact, consistency analysis for EcoCrop results was performed and results reported reliable and uniform data comparing with other approaches (Ramirez-Villegas et al., 2013; Vermeulen et al., 2013). Moreover, the EcoCrop model was widely used by researchers to assess the climate suitability of crops for production in an area.

i. Global suitability modelling of wheat, oats, strawberry, rye and apple

The EcoCrop model was applied by Lane and Jarvis (2007) to globally assess the climate change impact on several crops using HadCM3 and CCCMA current and future climate scenarios. The results showed that cold weather crops will have significant decreases in suitable areas for the cultivation of wheat (18%), oats (12%), strawberry (32%), rye (16%), and apple (12%). "The biggest gains are in areas suitable for pearl millet (31%), sunflower (18%), common millet (16%), chick pea (15%) and soy bean (14%), although many of the gains in suitable area occur in regions where these crops are currently not an integral component of food-security" (Lane & Jarvis, 2007).

ii. Crop suitability of cassava, pearl millet, yam, sorghum, banana, maize and common bean in Africa

Ramirez-Villegas and Thornton (2015) provided an overview of projected climate change impacts on crop suitability and production across Africa using the EcoCrop model and their results showed that cassava, pearl millet, yam and sorghum suitability will increase or decrease depending on the region, whereas banana, maize, finger millet and common bean suitable areas are projected to considerably decrease by 30-50%. A reduction in areas suitable for coffee plantation by approximately 50% will occur due to climate change; with coffee Arabica being most affected.

iii. Crop suitability of maize and groundnut in West Africa

Nyabako and Manzungu (2012) evaluated the adaptability of maize varieties to climate change in Zimbabwe using climate change scenarios for the following years: 2010, 2020, 2050, and 2080. They used the EcoCrop model to assess the suitability of rainfed maize due to the decreased precipitation the region is receiving. The study concluded that Zimbabwe's maize will not be suitable under climate change scenarios. The effect of cropping intensity on groundnut and maize yields was evaluated by Challinor et al. (2015) and they further assessed the suitability of these two crops in West Africa. Their results showed that "the areas in which groundnut and maize are grown are areas where the model simulates high suitability" (Challinor et al., 2015). Maize suitability is higher than that of groundnut in West Africa, while groundnut is predicted to be cultivated over a range of suitability environments than maize.

iv. Crop suitability of banana

Climate change impact on banana production in subtropical areas was assessed by Van den Bergh et al. (2010) using the EcoCrop model under climate change scenarios for the years 2020 and 2050. The modeling results suggested that current banana suitability in the tropics is higher than in the subtropics; with great suitability variations within the subtropics.

v. Crop suitability of sugarcane in India

Pawar-Patil and Mali (2015) carried an analysis on the suitability of sugarcane in Bhogawati river basin (India) using the EcoCrop model. The basin was given suitability indices as follows: marginal, suitable, very suitable, and excellent suitability. Their results showed that most of the basin was shown to have an excellent suitability. Upon EcoCrop simulations, the upper and middle reaches of Bhogawati basin showed very suitable and excellent suitability for sugarcane production.

vi. Crop suitability of Sago palm in Philippines

Makinano-Santillan and Santillan (2015) used the EcoCrop model to forecast suitable areas for Sago palms in the Philippines under current and future climate scenarios (RCP2.6 emission scenario) using the CCSM4 model. The results showed a positive impact on Sago palm suitability characterized by an increase of 6% in suitable areas up to 2050, and 40 % out of this 6% increase in suitable areas have an excellent suitability.

vii. Crop suitability of ryegrass in Korea

Kim, Hyun, and Kim (2014) analyzed the potential suitable areas for Italian ryegrass production in Korea using the EcoCrop model. Their results indicated that major areas in Korea will be suitable for Italian ryegrass cultivation, except for the mountainous region where suitability will be low due to the variety's lack of cold tolerance. "It was predicted that suitability of Italian ryegrass would increase until 2050s but decrease in 2080s in a relatively large number of regions due to high temperature" (Kim et al., 2014).

To sum up, the literature presented shows that agricultural production worldwide and in particular the Near East is affected by the impacts of climate change. The Near East region is considered to be a "climate change hot spot facing multiple challenges" (Constantinidou, Hadjinicolaou, Zittis, & Lelieveld, 2016). Despite the input of literature on the impacts of climate change on water resources and climatic variables in the Near East, there is, to the author's knowledge, no research on assessing crop suitability analysis using the EcoCrop model for this region. Hence, predicting the future suitability of the major crops grown in this region will add inputs to the suitability analysis gap in this region and provide an estimate of the impacts of climate change on the agricultural production using crop models to further assess the impacts on evapotranspiration, yield, and water productivity in the Near East using the AquaCrop model. At last, there is a lack of research for the Near East on finding a relationship between the crop suitability and yield where this study will also cover this gap.

CHAPTER III

MATERIALS & METHODS

The study in this thesis was designed to spatially examine the effect of climate change on crop suitability, evapotranspiration, yield, and water productivity for 19 crops grown in the Near East. The research was mainly conducted using two models: EcoCrop and AquaCrop. This chapter will explain the methodology carried out in this study.

A. Methodology overview

This research focuses on assessing changes in crop suitability, evapotranspiration, biomass, yield and water productivity for the major crops grown in the Near East region at the watershed level. Crop suitability was modelled using the EcoCrop model while the evapotranspiration, yield and water productivity were modelled using the FAO AquaCrop model V6.0. The benchmark (average years of 1970-2000) and future (2050) climatic data were used for this analysis under a high emission scenario RCP8.5. A comparison of the results of both models is provided to find a relationship between crop suitability and yield. The Litani, Jordan, Orontes, Nile, and Euphrates-Tigris river basins are considered as a case study with five crop categories analyzed. The overall methodology is based on generating the suitability maps for the complete evaluation of the selected crops, as shown in Figure 2, and determining their yield and water productivity, as shown in Figure 3, to check for the presence of a relationship. The analysis is based on three components: (1) environmental; (2) ecological; and (3) physical. These components are composed of different inputs as shown in Figure 1. Moreover, the evapotranspiration, biomass, yield, and water productivity of the studied crops were simulated using the AquaCrop model. A flowchart summary for the methodology of AquaCrop is presented in Figure 3.

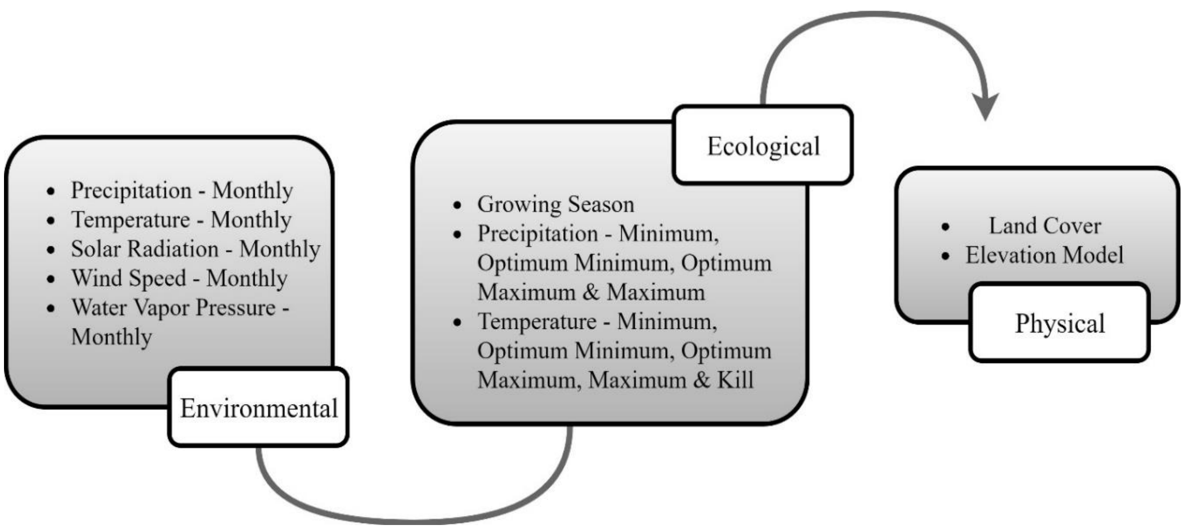


Figure 1. Illustration of data requirements and factors involved in the simulations of AquaCrop & EcoCrop models

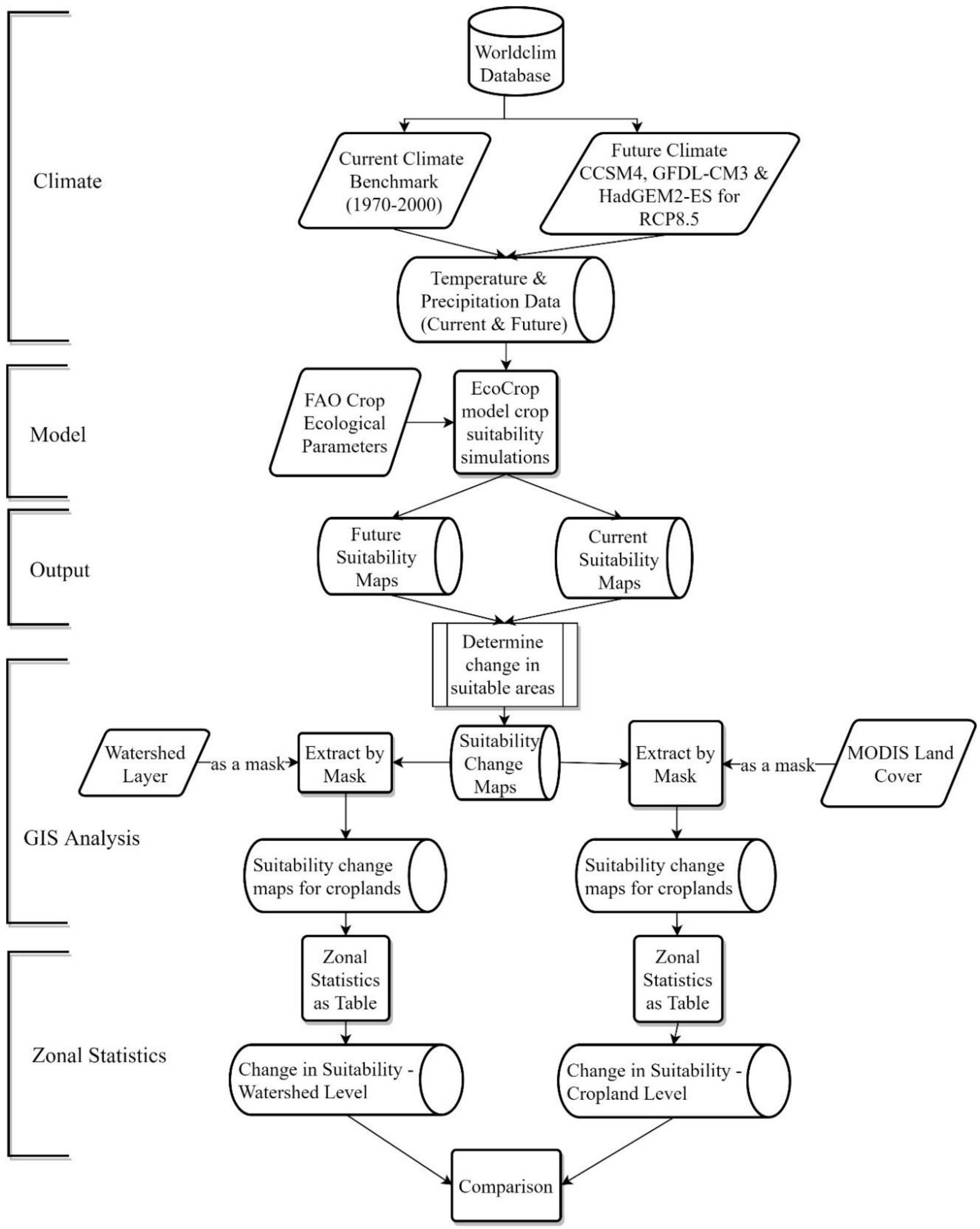


Figure 2. Flow chart of the steps performed for the crop suitability analysis. The model runs twice, one for every climate dataset: current benchmark (1970-2000) and future climate (2050) with RCP8.5 emission scenario

1. EcoCrop algorithm

The EcoCrop model was used to model the suitability of the selected crops. EcoCrop, the basic mechanistic model used, considers the environmental ranges as inputs that would allow the determination of the main niche of a crop after which a suitability index is generated as the output. Originally, this model was developed by Hijmans et al. (2005) and is based on the FAO-EcoCrop database (Ramirez-Villegas et al., 2013).

The model has two ecological ranges for each of the crops and each one is defined by a pair of parameters for each variable (i.e. temperature and rainfall). Primarily, the absolute range which is defined by T_{MIN-C} and T_{MAX-C} (minimum and maximum absolute temperatures at which the crop can grow, respectively) for temperature and R_{MIN-C} and R_{MAX-C} (minimum and maximum absolute precipitation at which the crop can grow, respectively) for precipitation (Ramirez-Villegas et al., 2013). Secondly, $T_{OPMIN-C}$ and $T_{OPMAX-C}$ (minimum optimum and maximum optimum temperatures, respectively) define the optimum ranges for temperature and $R_{OPMIN-C}$ and $R_{OPMAX-C}$ (minimum optimum and maximum optimum rainfall, respectively) define the optimum ranges for precipitation. Furthermore, T_{KILL}, an additional parameter for temperature, is used illustrating the effect of a month's minimum temperature (Ramirez-Villegas et al., 2013).

When the temperature and rainfall values are beyond the absolute threshold, the crop will have a zero suitability score. On the other hand, when the conditions of the rainfall and temperature are within the absolute and optimum thresholds, it could be said the conditions are suitable for plant growth; in other words, there is a range of suitability conditions (from 1-99 %). In addition, the range expresses a high suitable condition when it is within the optimum conditions specified, and the suitability score is 100%. There is an additional constraint that if any monthly minimum temperature is below T_{KILL+4} ^{0}C, the temperature suitability is set to be 0. Moreover, this model performs two separate calculations, one for precipitation, and the other for the temperatures. The model would further calculate the interactions via multiplication or choosing the minimum of the scores. For this work, we chose the interaction to be calculated using the minimum of scores.

In calculating the temperature suitability, the EcoCrop model assumes each month a potential growing season and thus it assumes 12 potential growing seasons. The final temperature suitability is the minimum value of the all 12 potential growing seasons. The equations for calculating temperature suitability are listed in equation (2) (Ramirez-Villegas et al., 2013).

$$T_{SUITi} = \begin{cases} 0 & T_{MIN\text{-}Pi} < T_{KILL\text{-}M} \\ 0 & T_{MEAN\text{-}Pi} < T_{MIN\text{-}C} \\ a_{T1} + m_{T1} * T_{MEAN\text{-}Pi} & T_{MIN\text{-}C} \le T_{MEAN\text{-}Pi} < T_{OPMIN\text{-}C} \\ 100 & T_{OPMIN\text{-}C} \le T_{MEAN\text{-}Pi} < T_{OPMAX\text{-}C} \\ a_{T2} + m_{T2} * T_{MEAN\text{-}Pi} & T_{OPMAX\text{-}C} \le T_{MEAN\text{-}Pi} < T_{MAX\text{-}C} \\ 0 & T_{MEAN\text{-}Pi} \ge T_{MAX\text{-}C} \end{cases} \qquad (2)$$

where T_{SUITi} is the temperature suitability index for the month i, $T_{MIN\text{-}C}$, $T_{OPMIN\text{-}C}$, $T_{OPMAX\text{-}C}$ and $T_{MAX\text{-}C}$ are defined on a crop basis, a_{T1} and m_{T1} are the intercept and slope (respectively) of the regression curve between [T_{MIN-C}, 0] and [$T_{OPMIN-C}$, 100], a_{T2} and m_{T2} are the intercept and slope (respectively) of the regression curve between [$T_{OPMAX-C}$, 100] and [T_{MAX-C}, 0]. T_{MIN-Pi} is the minimum temperature of the month i at the site P, $T_{MEAN-Pi}$ is the mean temperature of the month i, T_{KILL-M} is the crop's killing temperature plus 4 °C (Ramirez-Villegas et al., 2013).

The precipitation suitability is calculated only once, using the total precipitation of the growing season. It doesn't take into consideration the length of the growing season. Hence, it is independent from where the season begins and ends. The equations for calculating precipitation suitability are listed in equation (3) (Ramirez-Villegas et al., 2013).

$$R_{SUIT} = \begin{cases} 0 & R_{Total-P} < R_{MIN-C} \\ a_{R1} + m_{R1} * R_{TOTAL-P} & R_{MIN-C} \leq R_{TOTAL-P} < R_{OPMIN-C} \\ 100 & R_{OPMIN-C} \leq R_{TOTAL-P} < R_{OPMAX-C} \\ a_{R2} + m_{R2} * R_{TOTAL-P} & R_{OPMAX-C} \leq R_{TOTAL-P} < R_{MAX-C} \\ 0 & R_{TOTAL-P} \geq R_{MAX-C} \end{cases} \qquad (3)$$

where $R_{TOTAL-P}$ is the total rainfall of the crop's growing season at site P, R_{SUIT} is the rainfall suitability score, the crop parameters (R_{MIN-C}, $R_{OPMIN-C}$, $R_{OPMAX-C}$ and R_{MAX-C}) are defined on a crop basis, a_{R1} and m_{R1} are the intercept and the slope of the regression curve between [R_{MIN-C}, 0] and [$R_{OPMIN-C}$, 100], and a_{R2} and m_{R2} are the intercept and the slope of the regression curve between [$R_{OPMAX-C}$, 100] and [R_{MAX-C}, 0] (Ramirez-Villegas et al., 2013). Finally, the total suitability score is calculated by multiplying the rainfall and temperature suitability.

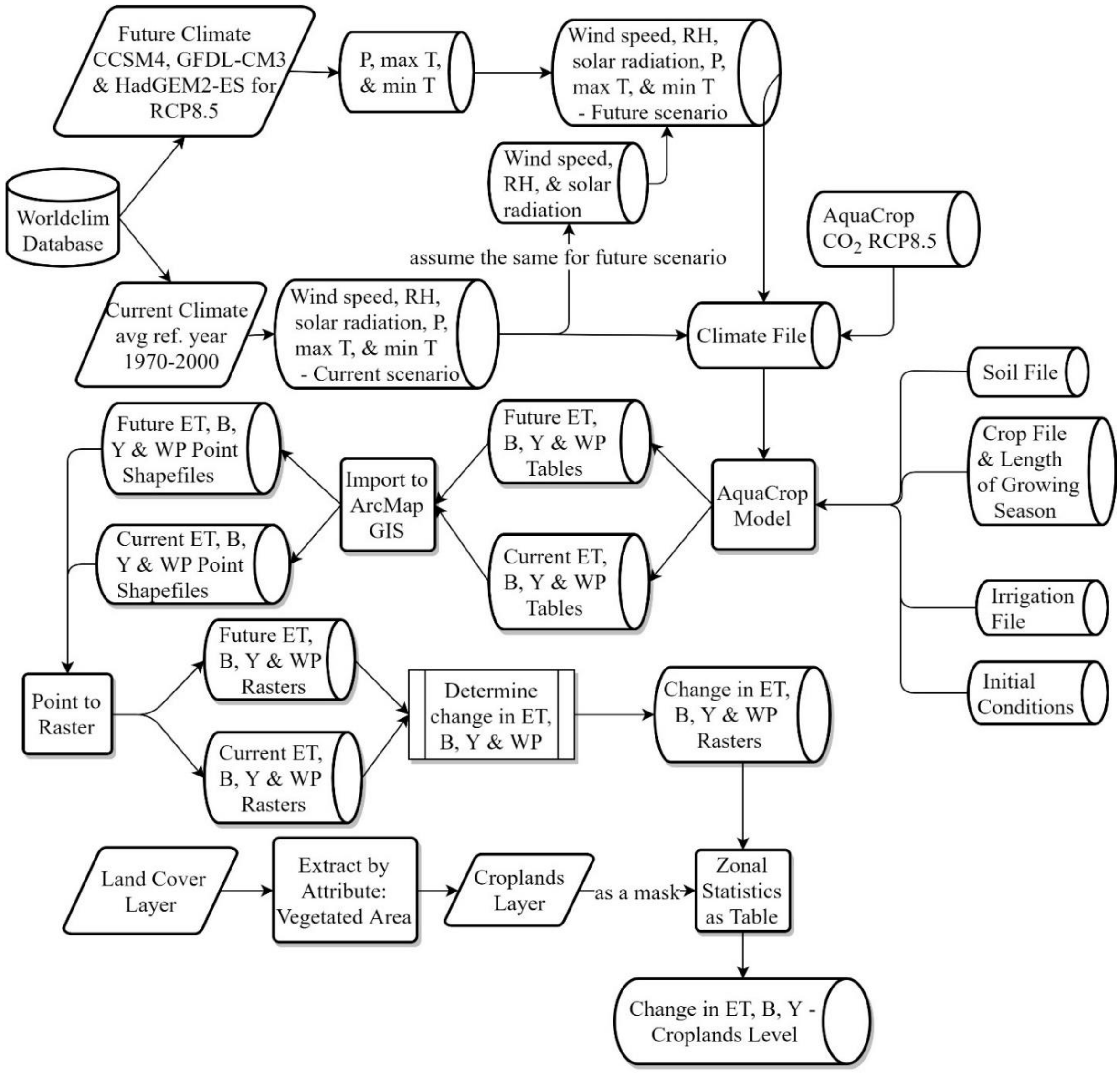


Figure 3. Flow chart of the steps performed for the evapotranspiration, yield, biomass, and water productivity simulations for the two climate datasets: current benchmark (1970-2000) and future climate (2050) with RCP8.5 emission scenario

2. AquaCrop Algorithm

The AquaCrop, which demonstrates yield response to water, was developed from the Doorenbos and Kassam (1979) K_y approach in the FAO Irrigation and Drainage Paper No. 33. AquaCrop separates the evapotranspiration into transpiration and evaporation

(Alemie Araya et al., 2010). In fact, the transpiration component is directly associated to the canopy cover while evaporation is related to the area of the uncovered soil (Steduto et al., 2009). This model incorporates four stress coefficients: (1) stomata closure, (2) canopy senescence, (3) leaf expansion & (4) change in harvest index (HI). The transpiration is calculated from the transpiration taking into consideration the canopy cover development & expansion, HI, and senescence (Alemie Araya et al., 2010).

AquaCrop converts the simulated transpiration directly into daily biomass by the means of the normalized water productivity constant (normalized for atmospheric CO_2 concentration and climate) using equation (4) (Jin et al., 2014). Thus, the model can be able to perform simulations for diverse locations under climate change scenarios (Hsiao et al., 2009; Steduto et al., 2009).

$$B = WP * \sum Tr/ETo \tag{4}$$

where B is the biomass (t/ha), WP is the normalized water productivity for atmospheric CO_2 concentration and climate (g/m^2), ET_0 is the reference evapotranspiration (mm) and Tr is the transpiration (mm). The value of water productivity (g/m^2) will be converted to t/ha by multiplying 0.01.

Moreover, the yield is computed by the product of the harvest index and biomass using equation (5). AquaCrop simulates the HI over the period from flowering till maturity as a linear increase with time (Steduto et al., 2009). Factors affecting the HI are duration, severity and timing of water stress (Raes, Steduto, Hsiao, & Fereres, 2009; Steduto et al., 2009). Therefore, this index is adjusted for the five water stress coefficients: (i) stomata inhibition, (ii) biomass reduction due to pollination failure, (iii) canopy cover decline due to senescence, (iv) biomass reduction due to stomata closure and (v) leaf growth inhibition (Raes et al., 2009; Steduto et al., 2009).

$$Y = HI * B \tag{5}$$

where Y is the yield (t/ha), HI is the harvest index (%) and B is the biomass (t/ha)

B. Study Area

The following river basins of the Near East have been selected as a study area for this work: Orontes, Jordan, Litani, Euphrates-Tigris, and Nile basins. This research is divided into two parts:

1. Crop suitability analysis, which includes all the five River Basins.
2. Crop water productivity and yield analysis, which includes three of the five basins: Orontes, Litani, and Jordan River Basins.

The basins are located at the following latitudes and longitudes: 33.5^0 North & 35.8^0 East, 35.7^0 North & 37.1^0 East, and 32.6^0 North & 36.2^0 East for Litani, Orontes, and Jordan River Basins respectively. The Near East district used in this study is shown in Figure 4. The MODIS land cover and vegetation for the studied river basins are presented in figures 5 and 6, respectively. This area is largely arid to semi-arid and it is increasingly susceptible to future climate change due to the accelerating population and greenhouse gas emissions increase (Evans, 2009). Moreover, it is among the least steady and most fragile regions (Feitelson et al., 2012).

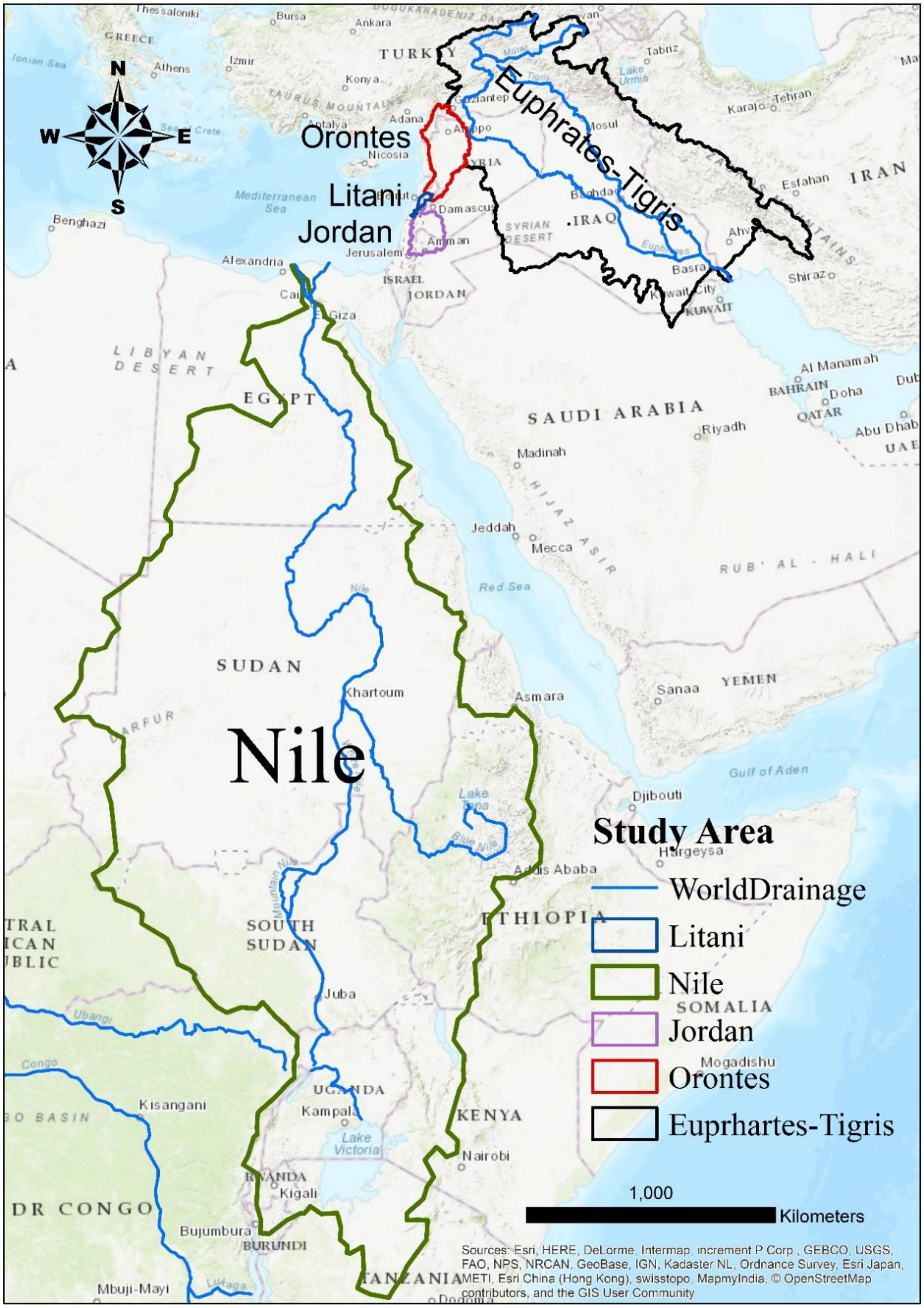


Figure 4. Study area showing the Nile, Euphrates-Tigris, Litani, Orontes, and Jordan basins

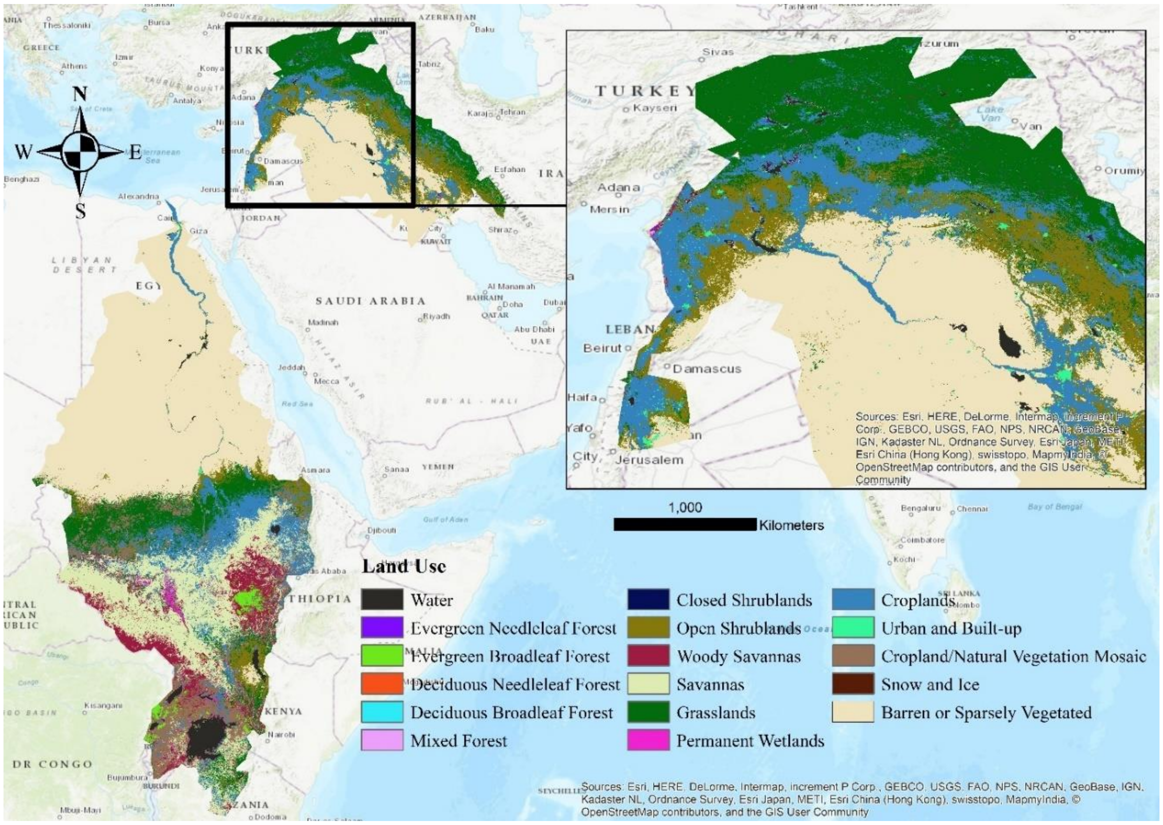


Figure 5. MODIS land use and vegetation cover of the study area (NASA, 2012, MCD12Q1. V051. NASA EOSDIS Land Processes DAAC, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov), accessed [06, 22, 2017])

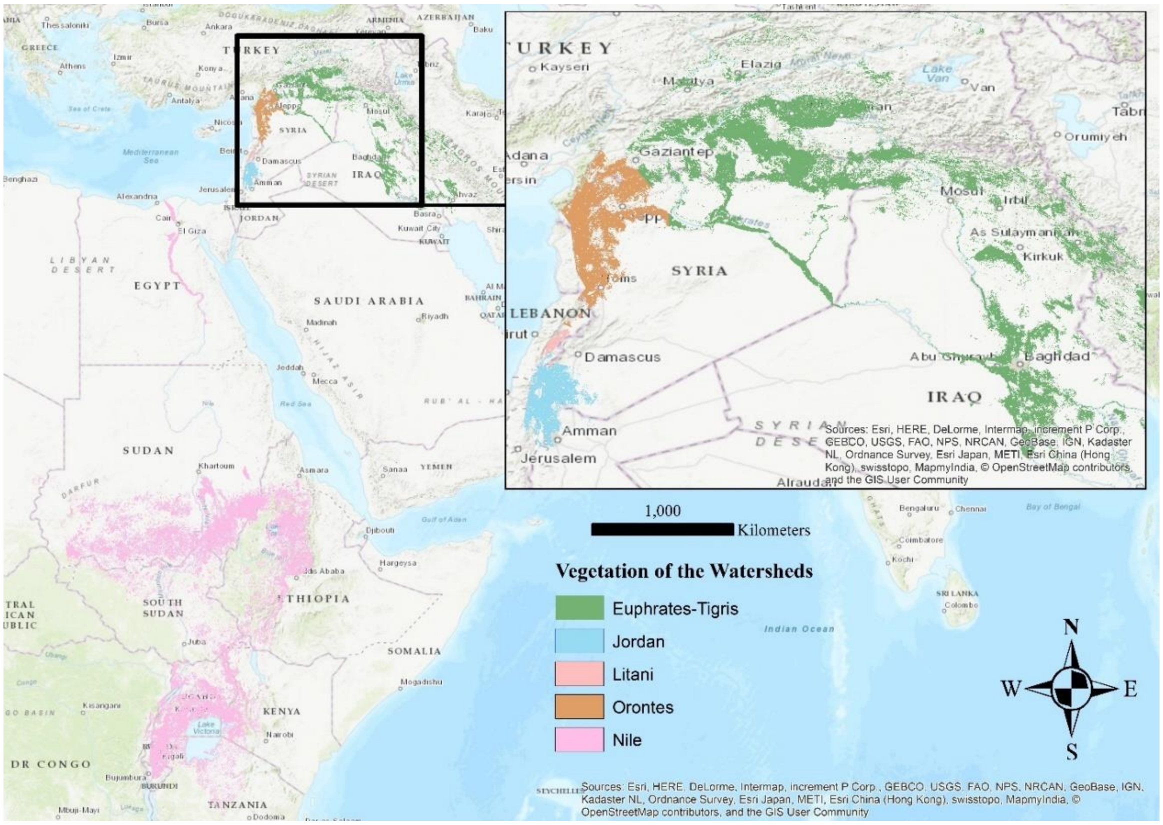


Figure 6. Croplands of the study area (NASA, 2012, MCD12Q1. V051. NASA EOSDIS Land Processes DAAC, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov), accessed [06, 22, 2017])

1. Litani Basin

The Litani basin is located in the East Mediterranean region; a water scarce region exposed to water scarcity. It is considered the largest river in Lebanon and it's the most significant water resource (Assaf & Saadeh, 2008), rising West of Baalbeck in the Beqaa Valley at an altitude of 1,000 meters (Ramadan, Ramamurthy, & Beighley, 2012). Additionally, the Litani basin is characterized by wet & short winters and dry & long summers (Ramadan et al., 2012). Moreover, a sub-arid climate dominates the Upper Litani

Basin (ULB) covered with snow for around 9 months per year. On the contrary, a sub-humid coastal Mediterranean climate dominates the Lower Litani Basin (LLB) and little amount of snow covers this basin during the winter season. Note that the mean annual precipitation is about 700 mm for the whole basin, in which 550 mm of the total amount occur at the river's origin (Ramadan et al., 2012). The major crops grown in this basin are barley, cabbage, cucumber, eggplant, grapes, lettuce, olives, onion, potato, tomatoes, watermelon, and wheat (H. Jaafar et al., 2016; Verner et al., 2013). In the work of H. Jaafar et al. (2016), the irrigated areas in the ULB was estimated to be 45,700 ha during the irrigation seasons between April and October. Out of these irrigated areas, 10,000 ha were planted in the ULB with cereals under supplemental irrigation.

2. *Orontes Basin*

The Orontes basin passes through the territories of three countries: an upstream flow in Lebanon, midstream flow in Syria, and downstream flow in Turkey; from which it drains into the Mediterranean (Scheumann, Sagsen, & Tereci, 2011). The share of each country from this basin is as follows: 36% by Turkey, 56% by Syria, and 8% by Lebanon (H. H. Jaafar, Zurayk, King, Ahmad, & Al-Outa, 2015). Furthermore, the Orontes River rises in the springs of the Labweh area (near Baalbeck) and flows exceptionally in the North direction to enter the Syrian territory and drain in the Qattaneh reservoir. The river crosses the Turkish territory and drains into the Mediterranean Sea in the province of Hatay in Turkey. Therefore, the total flow length of the Orontes River is 448 km divided as follows: 88 Km in Turkey, 325 Km in Syria, and 35 Km in Lebanon (Scheumann et al., 2011). The Orontes basin in the Lebanese territory is characterized by a semi-arid to arid climate, where the annual precipitation is 400 mm and below. In the Syrian portion of the basin, the eastern mountains get rainfall ranging from 400 to 600 mm while in the western mountains it is much higher, ranging from 600 to 1500 mm. The annual precipitation regimes vary along all parts of the basin, with an annual mean precipitation of 644 mm. Regarding the temperature regimes, the entire basin's annual mean temperature is estimated to be 16 ^{0}C (FAO, 2009a). Besides, the rainy season begins in October and finishes in April (H. H. Jaafar et al., 2015). The major crops grown in the Orontes River Basin are apple, barley, cabbage, chickpeas, cotton, cucumber, eggplant, olives, onion, soybean, sugar beet, tomato, watermelon and wheat (Ibrahim, 2014; H. Jaafar et al., 2016; H. H. Jaafar & Woertz, 2016; H. H. Jaafar et al., 2015).

3. Jordan Basin

The Jordan basin is a transboundary basin of an area of approximately 18,500 km^2 (Lehner, Verdin, & Jarvis, 2008). Phillips et al. (2007) stated that the Jordan River has been known for long as a critical water body to the Middle East, regardless of its small size. This basin is shared by: Jordan (40%), Palestine (46%), Lebanon (4%), and Syria (10%) (Lehner et al., 2008). Among these five countries, Palestine and Jordan suffer acute water deficiencies. The climate regimes in this basin are highly diverse, extending from arid environments to sub-humid Mediterranean climates across short distances (FAO, 2009c). The mean annual precipitation is approximately 380 mm, taking into consideration the variations along the basin (New, Lister, Hulme, & Makin, 2002). Moreover, the mean annual temperature over the entire basin is approximately 18 ^{0}C (FAO, 2009c). The major crops grown in this river basin are alfalfa, apple, barley, cabbage, cucumber, eggplant, olives, onion, pepper, potato, tomato, watermelon, and wheat (Al-Bakri et al., 2011; Verner et al., 2013).

4. Nile Basin

Frenken and Karen (1997) stated that the Nile River, with an overall length of 6,800 Km and area of 3.4 million Km^2 (FAO, 2009d), is the longest flowing river from south to north. The two main river systems feeding the Nile basin are the Blue Nile and White Nile. Moreover, the climate in the feeding rivers is humid, with a mean annual precipitation of more than 1,000 mm. Aridity in the Nile basin starts in Sudan where this country can be divided into three rainfall zones: (i) the desert in the Northern part with mean annual precipitation of 20 mm, (ii) the fertile plain with clayey soils with mean annual precipitation ranging from 400 to 800 mm, and (iii) the extreme south with a mean annual precipitation ranging from 1200 to 1500 mm. The Northern part of Egypt has very little annual precipitation of approximately 20 mm/year (Frenken, 1997). The major crops grown in this river basin are barley, chickpeas, cotton, cucumber, apple, eggplant, grape, lettuce, maize, olives, sugar beet, tomato, wheat, and onion (Beaumont, 1996; Heidari & Omid, 2011; Ibrahim, 2014; Schnepf, 2003).

5. Euphrates-Tigris

The Euphrates-Tigris basin is a transboundary basin with an area of 879,790 km^2, and it is shared by the following countries: (i) Jordan (0.03%), (ii) Syria (11%), (iii) Turkey (22%), (iv) Iraq (46%), (v) Saudi Arabia (1.9%), and (vi) Iran (19%) (Lehner et al., 2008). The Euphrates and Tigris rise in the eastern mountains of Turkey; the basin extensive lowlands in the eastern and southern parts and high mountains in the western and northern parts (FAO, 2009b). The climate of the Euphrates-Tigris basin is characterized by sub-topical Mediterranean climate along with dry summers and wet winters (FAO, 2009b). The climate of the northern parts of Iraq and Syria as well as the southeastern Turkey is dominated by dry warm summers and wet winters. Furthermore, the mean annual precipitation in the basin is approximately 335 mm, varying along the whole basin (New et al., 2002). The summer days are dry and hot with temperatures reaching 50 ^{0}C (FAO, 2009b). Likewise, the mean annual temperature of the basin is around 18 ^{0}C (New et al., 2002). The major crops grown in this river basin are cotton, maize, sorghum, wheat, chickpeas, coffee, cucumber, potato, tomato, sunflower, cabbage, and sugar beet (Gaafar, Salih, Luukkanen, El Fadl, & Kaarakka, 2006; Lemenih, Karltun, & Olsson, 2005; Mahmoud, 2017; McCarl et al., 2015).

C. Meteorological Data

1. WorldClim database

WorldClim is a set of gridded global climate data with a spatial resolution of around 1 km^2 at the equator. These data are derived from the IPCC 5^{th} Assessment report projections from general circulation models (GCMs) for 4 representative concentration pathways (RCPs). These datasets are the most recent GCM climate projections used in the IPCC 5^{th} Assessment report (Hijmans et al., 2005). These climate projection outputs were downscaled and calibrated by means of WorldClim 1.4 as baseline current climate by Hijmans et al. (2005).

The WorldClim database consists of two versions: (i) version 1.4 and (ii) version 2.0. Version 1.4 has mean monthly meteorological data for precipitation and for mean, maximum, and minimum temperature, representative of 1960-1990 as a baseline current period. On the other hand, the current scenario data of version 2 of WorldClim is representative of 1970-2000 as a baseline current period. As the current data are present in the two databases and the data for future projections (2050) are only available on the 1.4 version of the database, we resorted to downloading the current data from the version 2 of the database. On the other hand, the future meteorological projections data (2050) were downloaded from version 1.4 database.

2. Downloading weather data

a. Characterizing the current climate data

Historical climate data was used as the current climate (baseline) scenario. Observed interpolated gridded data, downloaded from WorldClim website (http://worldclim.org), were used as inputs for the crop suitability analysis and yield prediction under current (baseline) climate conditions, which is representative of 1970-2000. The meteorological data (rasters) needed are mean monthly minimum temperature (T_{min}) in °C, maximum temperature (T_{max}) in °C, precipitation (P) in mm, solar radiation (R_s) in MJ/m^{2}day, wind speed (W_s) in m/s and vapour pressure (V_p) in kPa. The spatial resolution of the gridded climate data is 30 arc-seconds (~ 1 km^2 at equator) and 10 arc-minutes (~ 18.5 km^2 at equator) for suitability analysis and crop yield, respectively. The low resolution considered in crop yield analysis is due to the fact of huge data that will be manually simulated and generated from the 30 seconds rasters. In fact, each grid cell will be considered as a weather station for the crop yield analysis in AquaCrop. Therefore, the use of 10 arc-minutes resolution will produce 239 stations along the three basins (Orontes, Litani, and Jordan river basins) for this work.

b. Characterizing the future climate data

For the suitability analysis under future (2050) climate conditions, downscaled spatial bias-corrected ensemble climate projections from three GCMs were used which are averages for the period 2041-2060. All these data are based on the representative concentration pathway RCP8.5 from the Coupled Model Intercomparison Project Phase 5

(Stocker, 2014). Based on literature for the study area mentioned above, the GCMs used for this work are: CCSM4, GFDL-CM3, and HadGEM2-ES (Bozkurt & Sen, 2013; Bozkurt, Turuncoglu, Sen, Onol, & Dalfes, 2012; El Afandi et al., 2010; Evans, 2010; Giannakopoulos et al., 2013). The spatial resolution of the gridded climate data is 30 arc-seconds (~ 1 km^2 at equator) and 10 arc-minutes (~ 18.5 km^2 at equator) for suitability analysis and crop yield, respectively. Based on IPCC report, RCP8.5 emission scenario is characterized by increasing greenhouse gas emissions over time up to 2100 leading to high GHG concentration levels; it is the highest emission scenario used by IPCC.

D. Preparing meteorological data

1. For crop suitability analysis

The meteorological data provided by WorldClim are in TIF format. However, Terrset software, housing the EcoCrop model, recognizes raster files in RST format. Henceforth, the TIF rasters were converted into ASCII format (American Standard Code for Information Interchange), which in turn the ASCII files were imported in Terrset using the import tool specifying the output reference system as Lat/Long. To automate the process of converting the rasters from TIF to ASCII format, an iterator was used. An iterator is a Model Builder tool in ArcGIS that will run the same process repeatedly until all inputs have been examined. The model used for automation is represented in Figure 7.

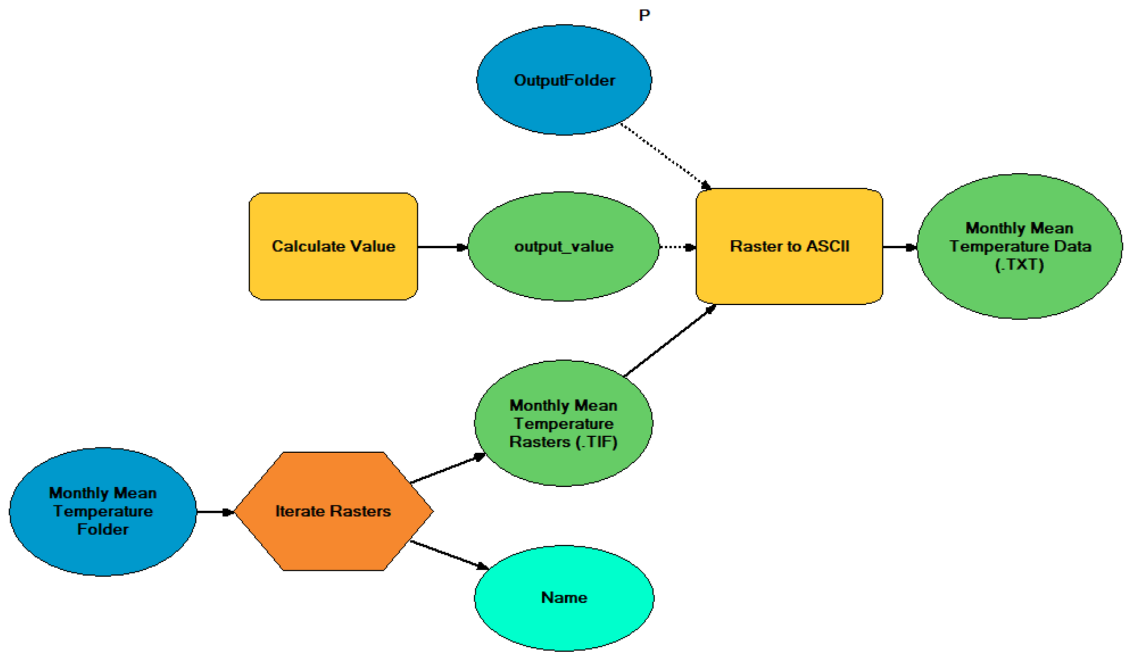


Figure 7. A sample of the TIF/ASCII converter model in ArcGIS used to convert the monthly mean temperature data into ASCII format (the same model for mean monthly data)

Moreover, the values of the downloaded temperature rasters are in the form of real value multiplied by 10. For instance, a pixel value of 230 represents 23 ^{0}C. Therefore, the “scalar” tool in Terrset software was used to divide each raster by 10 so that the values become realistic and compatible with the EcoCrop model. Another input data required by the EcoCrop model is mean temperature. WorldClim database provides minimum and maximum temperature rasters. Equation (6) was used to calculate the mean temperature via “raster calculator” tool in ArcGIS for each month.

$$Tmean = \frac{Tmin + Tmax}{2} \quad (6)$$

where T_{mean} is the mean temperature (^{0}C), T_{min} is the minimum temperature (^{0}C), and T_{max} is the maximum temperature (^{0}C)

Afterwards, the “Extract by Mask” tool in ArcGIS was used to make the current baseline and future (2050) raster data sets match the same number of rows and columns. To automate the process, an iterator was used along with the “Extract by Mask” tool and are represented in Figure 8. The current data rasters have 43,200 columns and 21,600 rows, while the 2050 rasters have 43,200 columns and 18,000 rows; the deleted rows represent the Antarctic area. In addition, the EcoCrop model recognizes each of the T_{min}, T_{mean}, and P rasters as raster group files (RGFs). Therefore, the 12 rasters for mean temperature were placed in a raster group file; the same applies for minimum temperature and precipitation rasters.

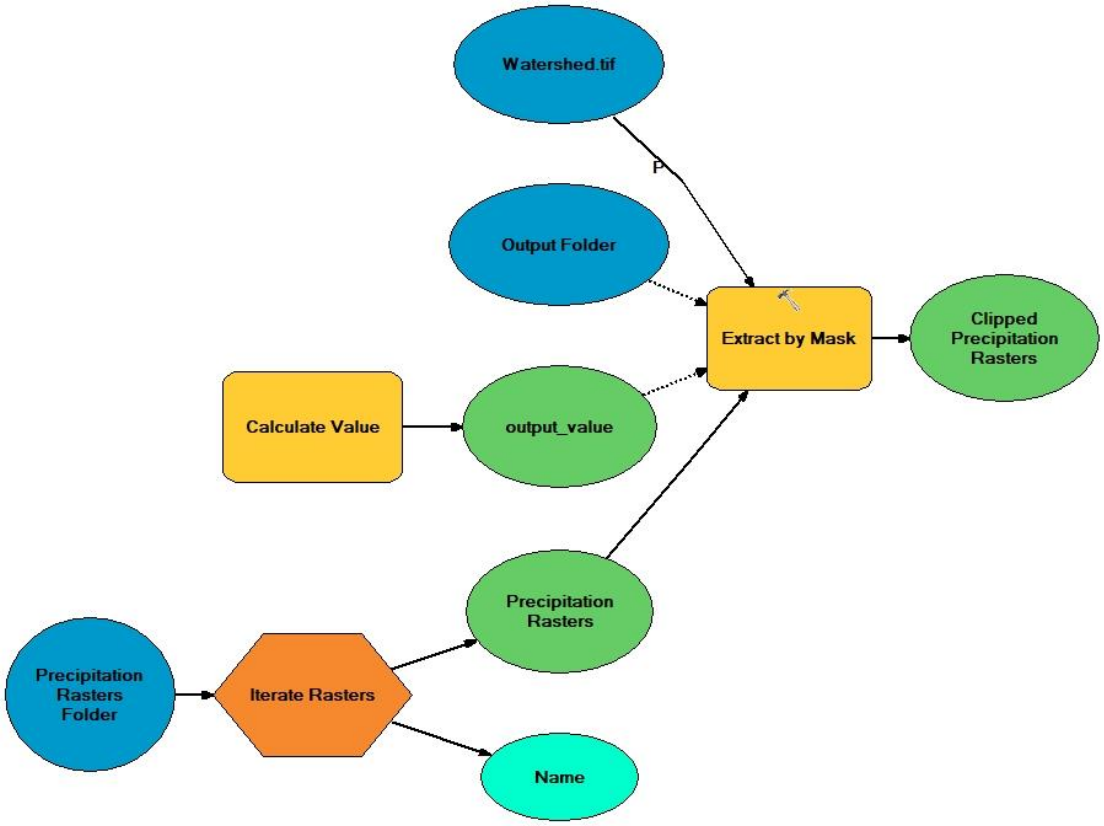


Figure 8. A sample of the clip model in ArcGIS used to clip the mean monthly precipitation rasters to the extent of the watershed mask (the same model for mean monthly data)

2. For crop yield and water productivity analysis

The AquaCrop model doesn't take rasters as inputs for its climate file. The following procedure was done to prepare the meteorological input data for the AquaCrop model. The meteorological raster data provided by WorldClim were clipped to the area of the three selected river basins: Orontes, Litani, and Jordan using the "extract by mask" in ArcGIS with the watershed raster acting as a mask for the region of study. Then, the “sample” tool in ArcGIS was used to extract the data for each point location (grid cell) into tables, where the data in each raster image will be displayed in tables.

As mentioned earlier, the parameters required for AquaCrop are the following: wind speed (m/s), relative humidity, solar radiation (KJ/m^2day), precipitation (mm), and maximum & minimum temperature (^0C). However, relative humidity factor has not been provided by WorldClim database, hence it was calculated using formula (7).

$$RH = \frac{actual\ vapor\ pressure\ (kPa)}{saturation\ vapor\ pressure\ (kPa)} \quad (7)$$

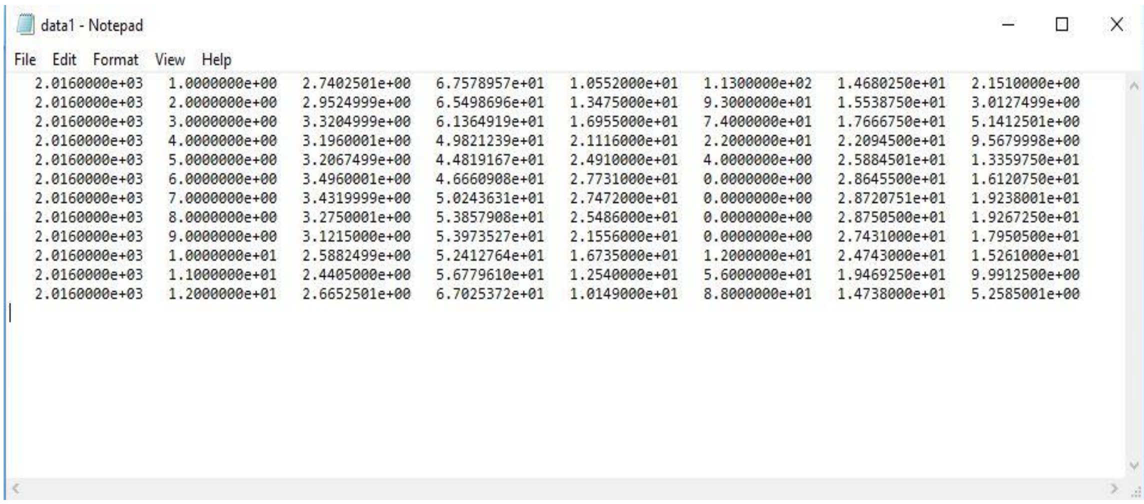
The actual vapor pressure data was downloaded from the WorldClim database, while the saturation vapor pressure was estimated by an empirical formula using the mean temperature data, represented by equation (8) (Jorenoosh & Sepaskhah, 2018).

$$saturation\ vapor\ pressure = 0.6108e^{\left(\frac{17.27T}{T+237.3}\right)} \quad (8)$$

where T is the mean temperature (^0C)

Data for the solar radiation, relative humidity, and wind speed are not provided by the WorldClim database for the future scenario (2050). Hence, the solar radiation and wind speed values for the year 2050 were assumed same as those for the current condition. The relative humidity for 2050 was calculated using equation 7 and based on the actual vapor pressure data of the current scenario and the saturation vapor pressure, calculated from the mean temperature of the future scenario using equation 8. After that, two excel files was established for each of the following: (i) current (baseline) and (ii) future (RCP8.5). A code

(Figure 29) was written using Matlab software to generate the input climate data for the AquaCrop model in the format presented in Figure 9. The columns from left to right are defined as follows: year, month, wind speed, RH, solar radiation, rain, Tmax, and Tmin.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2.0160000e+03	3.0000000e+00	3.3204999e+00	6.1364919e+01	1.6955000e+01	7.4000000e+01	1.7666750e+01	5.1412501e+00
2.0160000e+03	4.0000000e+00	3.1960001e+00	4.9821239e+01	2.1116000e+01	2.2000000e+01	2.2094500e+01	9.5679998e+00
2.0160000e+03	5.0000000e+00	3.2067499e+00	4.4819167e+01	2.4910000e+01	4.0000000e+00	2.5884501e+01	1.3359750e+01
2.0160000e+03	6.0000000e+00	3.4960001e+00	4.6660908e+01	2.7731000e+01	0.0000000e+00	2.8645500e+01	1.6120750e+01
2.0160000e+03	7.0000000e+00	3.4319999e+00	5.0243631e+01	2.7472000e+01	0.0000000e+00	2.8720751e+01	1.9238001e+01
2.0160000e+03	8.0000000e+00	3.2750001e+00	5.3857908e+01	2.5486000e+01	0.0000000e+00	2.8750500e+01	1.9267250e+01
2.0160000e+03	9.0000000e+00	3.1215000e+00	5.3973527e+01	2.1556000e+01	0.0000000e+00	2.7431000e+01	1.7950500e+01
2.0160000e+03	1.0000000e+01	2.5882499e+00	5.2412764e+01	1.6735000e+01	1.2000000e+01	2.4743000e+01	1.5261000e+01
2.0160000e+03	1.1000000e+01	2.4405000e+00	5.6779610e+01	1.2540000e+01	5.6000000e+01	1.9469250e+01	9.9912500e+00
2.0160000e+03	1.2000000e+01	2.6652501e+00	6.7025372e+01	1.0149000e+01	8.8000000e+01	1.4738000e+01	5.2585001e+00

Figure 9. Sample input text file for AquaCrop climate file

E. Generating suitability maps using EcoCrop model

1. Crops and their parameters

For this work, 19 major crops growing in the study area were selected to perform our analysis (Al-Bakri et al., 2011; H. M. Eid et al., 2007; Ibrahim, 2014; Mahmoud, 2017; McCarl et al., 2015; Medany & Hassanein, 2006; Verner et al., 2013). Table 2 represents the crops used in this work, along with their scientific name & ecological parameters required for EcoCrop model. The crop parameters required as inputs for the EcoCrop model were obtained by the Food and Agriculture Organization (FAO) through its EcoCrop database (http://ecocrop.fao.org). The crop parameters required for the crop suitability modeling are:

1) Length of the growing season (days)

2) Precipitation (mm): minimum, optimum minimum, optimum maximum, and maximum

3) Temperature (^{0}C): minimum, optimum minimum, optimum maximum, maximum, and kill

Table 2. A list of crops included in the crop suitability analysis using the EcoCrop model with their input ecological parameters

Crop	Growing Season (days)	P min	P Opt. min	P Opt. max	P max	T min	T Opt. min	T Opt. max	T max	T kill
Alfalfa	155	350	600	1200	2700	5	24	26	40	-25
Apples	250	400	900	1200	1800	6	10	30	35	-2
Barley	165	200	500	1000	2000	2	15	20	40	-4
Cabbage	130	300	500	1000	2500	7	15	24	32	-10
Chickpeas	135	300	600	1000	1800	7	15	29	35	-9
Cotton	175	450	750	1200	1500	15	22	36	42	0
Cucumber	110	400	1000	1200	4300	6	18	32	38	0
Eggplant	95	800	1200	1600	4000	9	20	35	40	0
Grapes	215	400	700	850	1200	10	18	30	38	0
Lettuce	60	900	1100	1400	4100	5	12	21	30	-1
Maize	215	400	600	1200	1800	10	18	33	47	0
Olives	365	200	400	700	1200	5	20	34	40	-10
Onion	130	300	350	600	2800	4	12	25	30	0
Pepper	120	500	600	1250	1700	8	17	30	35	0
Potato	125	250	500	800	2000	7	15	25	30	-1

Sugarbeet	180	500	650	900	1200	4	15	25	35	-2
Tomato	110	400	600	1300	1800	7	20	27	35	0
Watermelon	120	400	500	750	1800	15	20	30	35	0
Wheat	170	300	750	900	1600	5	15	23	35	-10

2. Simulating the crop suitability maps

The suitability rasters for each crop was modelled on a per pixel basis using current baseline and future (2050) climatic scenarios (for the GCMs under RCP 8.5 emission scenario) based on the combination of precipitation & temperature parameters choosing minimum of scores as the aggregation procedure. The final suitability scores are classified and grouped to designate suitability categories: (1) 0 to 0.2: very marginal, (2) 0.2 to 0.4: marginal, (3) 0.4 to 0.6: medium suitable, (4) 0.6 to 0.8: very suitable, and (5) 0.8 to 1: highly suitable (Pawar-Patil & Mali, 2015; Piikki et al., 2017). Then, the suitability scores for each crop were averaged for the 3 GCM models for the RCP 8.5 scenario. The major crops grown in the Near East were divided into five crop categories based on the FAO crop classification scheme (Table 3). Hence, their rasters were averaged to their corresponding crop categories using the raster calculator in ArcGIS. Henceforth, the change in suitability was calculated on a per pixel basis using “Raster Calculator” tool in ArcGIS for each crop by subtracting the future suitability scores from the current one using equation (9).

$$Change\ in\ suitability\ for\ crop\ = Future\ Suit\ of\ X - Current\ Suit\ of\ X \qquad (9)$$

Table 3. Crop categories for the major crops grown in the Near East

Crop Category	**Fruit Trees**	**Legumes**	**Oil Producing Crops**	**Vegetables**		**Wheat & Barley**
Crops/each category	Apple	Alfalfa	Cotton	Cabbage	Pepper	Wheat
	Grape	Chickpeas	Maize	Cucumber	Potato	Barley
			Olives	Eggplant	Sugarbeet	
				Lettuce	Tomato	
				Onion	Watermelon	

As mentioned earlier, this research is performed at the basin level. The basin boundaries for this work were obtained from the work of King and Jaafar (2015). Also, crop suitability was assessed in the croplands of the studied river basins. For this, land cover data Type 1 (year: 2013) for the study area were obtained from MODIS products (MCD12Q1) and available on https://earthexplorer.usgs.gov/ website (NASA, 2012, MCD12Q1. V051. NASA EOSDIS Land Processes DAAC, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov), accessed [06, 22, 2017]). MCD12Q1 land cover data are 500 m gridded annual global land cover images with land cover type information existing in five land cover classification schemes (Gaur, Eichenbaum, & Simonovic, 2018). The land cover classification scheme used for this research is Type-1 (the detailed classification scheme). Due to the large size of the study area, several land cover rasters were downloaded to cover the whole study area, henceforth they were merged and clipped to the five river basins. The "extract by attributes" tool in ArcGIS was used to extract the vegetation portion of the land cover.

The “Zonal Statistics as Table” tool was used to summarize the mean difference in suitability scores at the basin and cropland level for all the river basins. An iterator was also used to automate the process and the model used is represented in Figure 10. The percentage suitability change was calculated for each crop to assess the suitability change from the initial value. This provides a further proof for assessing the suitability change rather than knowing the suitability change alone. This was done using equation (10).

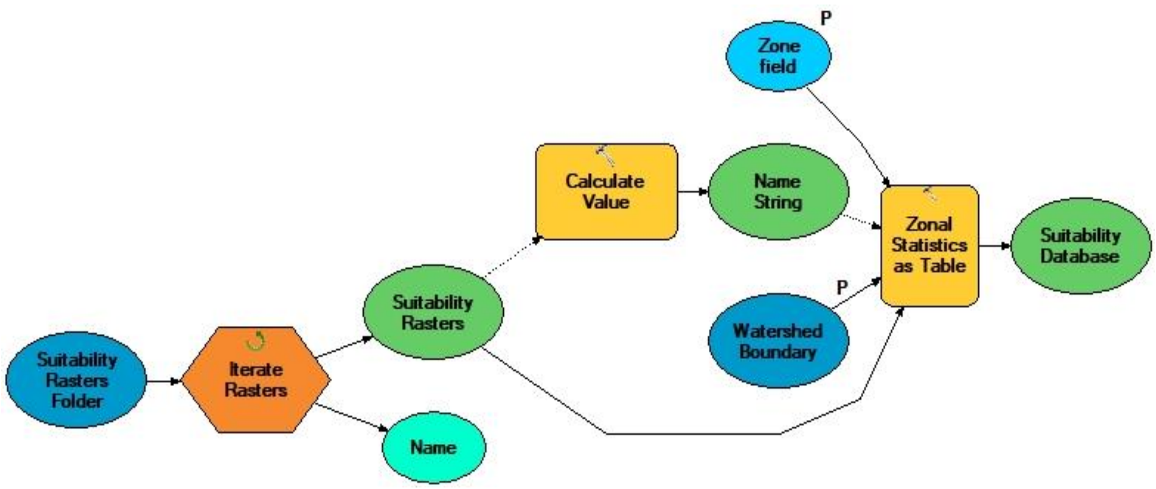

Figure 10. Model used to export the suitability results as a database

$$\% \, suitability\ change\ for\ crop = \frac{(Future\ Suit\ of\ X - Current\ Suit\ of\ X)}{Current\ Suit\ of\ X} * 100 \quad (10)$$

F. Estimating crop yield and water productivity using AquaCrop model

The major crops grown in the Near East will be assessed in terms of ET, biomass, crop yield and water productivity using the FAO AquaCrop model for the current and future climate scenarios. Again, this assessment was performed for the Litani, Jordan, and Orontes River Basins at the basin level.

1. AquaCrop model input

AquaCrop was run using the following meteorological data: rainfall, ET_0, minimum and maximum temperature, and CO_2 concentration. These data were extracted from the rasters that were downloaded from WorldClim website. The ET_0 was calculated by the model using the FAO Penman-Monteith equation using equation (11) based on minimum and maximum temperature, RH, wind speed (at 2 m height) and R_s.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (11)$$

where:

a. ET_0 is the reference evapotranspiration (mm/day)

b. Rn is the net radiation at the crop surface (MJ/m^2day)

c. G is the soil heat flux density (MJ/m^2day)

d. T is the mean monthly air temperature at 2 m height (^0C)

e. U_2 is the wind speed at 2 m height (m/s)

f. e_s is the saturation vapor pressure (kPa)

g. e_a is the actual vapor pressure (kPa)

h. $e_s - e_a$ is the saturation vapor pressure deficit (kPa)

i. Δ is the slope vapor pressure curve (kPa/^{0}C)

j. γ is the psychrometric constant (kPa/^{0}C)

2. *Creating input files for AquaCrop and their parametrization*

a. Climate file

To create a climate file, precipitation, temperature, CO_2, and ET_0 files need to be selected or created. The ET_0 files were created by the model using the FAO Penman Monteith equation. While creating the climate files, the user need to specify the type of climate data (monthly, 10-daily, or daily), the time span of the data, and the data themselves; i.e. define each column of the eight columns present in the text files so that the model can recognize the data. Also, the latitude of each weather station (grid cell) and its altitude should be specified. ASTER Global Digital Elevation Models (DEMs) were downloaded from the earth explorer portal (https://earthexplorer.usgs.gov) (METI/NASA, 2009) and the altitude values were extracted for each of the grid cells. Moreover, the CO_2 file supplied by AquaCrop was used, representing the climate change effect. The assumptions taken into consideration for this work are that the wind speed, actual vapor pressure, and solar radiation used for meteorological calculations are the same for current and future scenarios, because the WorldClim database doesn't present these data for the future scenario but only for the current one.

b. Crop file

Creating a crop file requires the selection of the type of crop (Root and Tuber crops, Fruit/Grain producing crops, or Leafy Vegetable crops), planting method (sowing or transplanting), cropping period, and length of the growing season. These input information help AquaCrop to generate the whole set of mandatory crop parameters, which were kept as default.

c. Irrigation file

For simplicity only one irrigation file was created for all the simulations for this analysis where a net irrigation water requirement approach was adopted based on the allowable root zone depletion value of 50%.

d. Soil file

The soil files supplied by AquaCrop were used in this analysis. Soil texture classes inaugurated in the USDA triangle are set as default in the model. The user has the chance to modify the values of the soil characteristics such that to meet the requirements of the study area (i.e. hydraulic conductivity, drainage coefficient, volumetric water content (VWC) at saturation, VWV at field capacity, and VWC at permanent wilting point (PWP)) (Steduto et al., 2009). The soil texture for the basins was determined from the Harmonized World Soil Database v1.2 (HWSD). The HWSD is of immediate use in the context of the Climate Change Convention and the Kyoto Protocol for soil carbon measurements and for the FAO/IIASA Global Agro-ecological Assessment studies (I. FAO & ISRIC, 2012). The soil files used in this analysis are: clay for the Litani basin and clay loam for the Orontes and Jordan basins (I. FAO & ISRIC, 2012), and their parameters were kept default.

e. Initial conditions

The initial condition for all simulations was set as DryWet; dry top soil (10% by Volume) and wet subsoil (30% by volume). This file is also supplied by AquaCrop and its parameters were kept as default.

After running the simulations of AquaCrop for the studied crops, the data were tabulated in an excel sheet, where each point location (pixel) has its value of ET, B, Y, and WP. The excel sheets where exported to CSV (Comma Separated Values) files whereby they got imported into GIS specifying the latitude and longitude values to get point locations for each crop. These point shapefiles were then converted to rasters using the "point to raster" tool. Afterwards, "zonal statistics as table" was used to compute the mean ET, Y, B, & WP for each of the three river basins: Orontes, Jordan and Litani. Moreover, changes for these data were spatially calculated using ArcMap raster calculator via equations 12, 13, 14 & 15 and the calculations for percentage changes were calculated using equations 16, 17, 18 & 19.

$$Change\ ET = Future\ ET - Current\ ET \tag{12}$$

$$Change\ B = Future\ B - Current\ B \tag{13}$$

$$Change\ Y = Future\ Y - Current\ Y \tag{14}$$

$$Change\ WP = Future\ WP - Current\ WP \tag{15}$$

$$\%\ in\ Change\ ET = (Future\ ET - Current\ ET)/Current\ ET \tag{16}$$

$$\%\ in\ Change\ B = (Future\ B - Current\ B)/Current\ B \tag{17}$$

$$\%\ in\ Change\ Y = (Future\ Y - Current\ Y)/Current\ Y \tag{18}$$

$$\%\ in\ Change\ WP = (Future\ WP - Current\ WP)/Current\ WP \tag{19}$$

G. Comparison and relationship between suitability and yield in the Jordan, Litani & Orontes River Basins

Using the outputs of the EcoCrop and AquaCrop models, the percentage change of crop suitability (EcoCrop) and yield (AquaCrop) of the 5 crop categories (including 19 crops) was calculated using equations 10 & 18. It was done for the Orontes, Litani & Jordan River Basins. The “Zonal Statistics as Table” tool in ArcGIS was used to compute the mean values of percentage change for each of yield and suitability for the 5 crop categories. The simulated yield from AquaCrop model was compared to the simulated suitability from the EcoCrop model to see if a relationship exists between the two variables or not. If both variables increase or decrease simultaneously, a relationship could be said to exist. For each crop category and river basin, these comparisons were performed to assess if this relationship can be generalized for all the watersheds or not.

CHAPTER IV

RESULTS & DISCUSSION

In this chapter, the results of crop suitability, ET, biomass, yield, and WP will be illustrated and thoroughly discussed indicating climate change effect on the suitability of major crops in the region and comparing changes in suitability to changes in yield and WP for current and future scenarios.

Part I - EcoCrop

A. Current and Future Climatic Regimes for the Near East

1. Climate change impact on annual temperature and precipitation in the Near East

The climate regime in the Near East region is projected to experience a decrease in precipitation and increase in temperature by 2050 relative to the average of the years 1970-2000 (Table 4) across 4 of the studied watersheds: Orontes River Basin (ORB), Jordan River Basin (JRB), Litani River Basin (LRB), and Euphrates-Tigris River Basin (ETRB), which is in accordance with the results of Bou-Zeid and El-Fadel (2002) for the Middle East region. The temperature and rainfall in the Nile River Basin (NRB) will both increase (Table 4). This agrees with the findings of Beyene, Lettenmaier, and Kabat (2010) that the mean annual precipitation and temperature will increase across the NRB. Moreover, the LRB will have the highest projected decrease in the amount of annual precipitation (-136 mm), corresponding to a 2.7 mm/year decrease till 2050. On the other hand, the average temperature increase ranges from 3 to 4 °C in the Near East by 2050 under a high emission scenario (RCP8.5) (Table 4).

Table 4. Annual precipitation (mm) and temperature (°C) regimes for the Orontes, Jordan, Litani, Euphrates-Tigris, and Nile river basins under current and future climate scenarios

River Basins	Orontes	Jordan	Litani	Euphrates-Tigris	Nile
Annual Current Precipitation	446	348	782	338	536
Annual Future Precipitation	374	278	646	316	589
ΔP	-72	-70	-136	-22	53
% Δ in Annual P	-16	-20	-17	-7	10
Mean Annual Current Temperature	17.1	17.8	14.5	18.2	25.0
Mean Annual Future Temperature	20.1	21.3	17.3	21.7	28.1
ΔT	3	4	3	4	3
% Δ in Annual T	18	20	19	19	12

Current: is representative of the average of the years 1970-2000
Future: is representative of the year 2050
ΔP = Annual Future Precipitation – Annual Current Precipitation
% Δ in Annual P = ΔP / Annual Current Precipitation
ΔT = Annual Future Temperature – Annual Current Temperature
% Δ in Annual T = ΔT / Annual Current Temperature

2. *Climate change impact on seasonal temperature and precipitation in the Near East*

The Near East region is renowned for holding four seasons. The winter and autumn are wet seasons, the spring is warm with some rain showers, and the summer is hot and dry. For each season, the precipitation magnitude is projected to decrease by 2050 along the river basins, except for the NRB where the seasonal precipitation will increase (Table 5). However, there is precipitation variability across the watersheds and this rainfall increase is not representative for all the watersheds (Figures 11 & 12). The Lower Nile Basin will experience gains in precipitation (i.e. Ethiopia) while the Upper Nile Basin (i.e. Egypt) will still have very marginal precipitation (Figure 12). Similar results were obtained by Beyene et al. (2010), where they simulated that the mean annual precipitation will increase over the entire NRB. Moreover, Zandalinas, Mittler, Balfagón, Arbona, and Gómez-Cadenas (2018) stated that the equatorial Pacific and high latitudes will experience gains in annual mean precipitation, which is the case in Ethiopia where precipitation will increase in its high latitudes, and hence explaining the net positive increase in precipitation in the NRB even though the Upper Nile Basin will still have very marginal precipitation. The highest rainfall decrease will take place in the LRB, and the least precipitation decrease will take place in the ETRB (Table 4). Moreover, the northern parts of the ETRB are projected to have more precipitation decrease than the southern parts (Figure 11, c). The decrease in precipitation by 2050 in the ORB and LRB will move towards the western parts of the basins (Figure 11, c). Therefore, the only winner from the climate change scenario is the NRB which will witness a 10% increase in rainfall than the current situation (Table 4).

It is predicted that the temperature will increase in the five river basins. The meteorological data for the current and future (RCP8.5) scenarios suggest a hotter winter where the average temperature increase is projected to be 3 ^{0}C (Table 6). On the other hand, the summer season's temperature is projected to increase by an average of 4 ^{0}C under high emission scenario RCP8.5 (Table 6). All these findings are in accordance with the IPCC 5th Assessment Report where the global change in surface temperature is likely to exceed 2°C by the end of the 21st century (Zandalinas et al., 2018). The upper boundary of the Nile River Basin and the northern & eastern borders of the Euphrates-Tigris are projected to have increases in temperature regimes (Figures 13,c & 14,c).

Table 5. Seasonal annual precipitation (mm) regimes for the Orontes, Jordan, Litani, Euphrates-Tigris, and Nile river basins under current and future climate scenarios

	River Basin				
	Orontes	Jordan	Litani	Euphrates-Tigris	Nile
Seasonal Current P - Winter	211	204	445	153	52
Seasonal Current P - Spring	67	26	73	72	153
Seasonal Current P - Summer	19	1	3	5	250
Seasonal Current P - Autumn	149	117	260	107	81
Seasonal Future P - Winter	187	166	379	142	62
Seasonal Future P - Spring	62	21	65	72	157
Seasonal Future P - Summer	7	0	3	4	273
Seasonal Future P - Autumn	118	90	199	99	96
Δ Seasonal P - Winter	-24	-38	-66	-11	10
Δ Seasonal P - Spring	-5	-5	-8	0	4
Δ Seasonal P - Summer	-12	-1	0	-1	23
Δ Seasonal P - Autumn	-31	-27	-61	-8	15
% Δ in Seasonal P - Winter	-11	-19	-15	-7	19
% Δ in Seasonal P - Spring	-7	-19	-11	0	3
% Δ in Seasonal P - Summer	-63	-100	0	-20	9
% Δ in Seasonal P - Autumn	-21	-23	-23	-7	19

Current: is representative of the average of the years 1970-2000
Future: is representative of the year 2050
Δ Seasonal P = Seasonal Future Precipitation – Seasonal Current Precipitation
% Δ in Seasonal P = Δ Seasonal P / Seasonal Current Precipitation

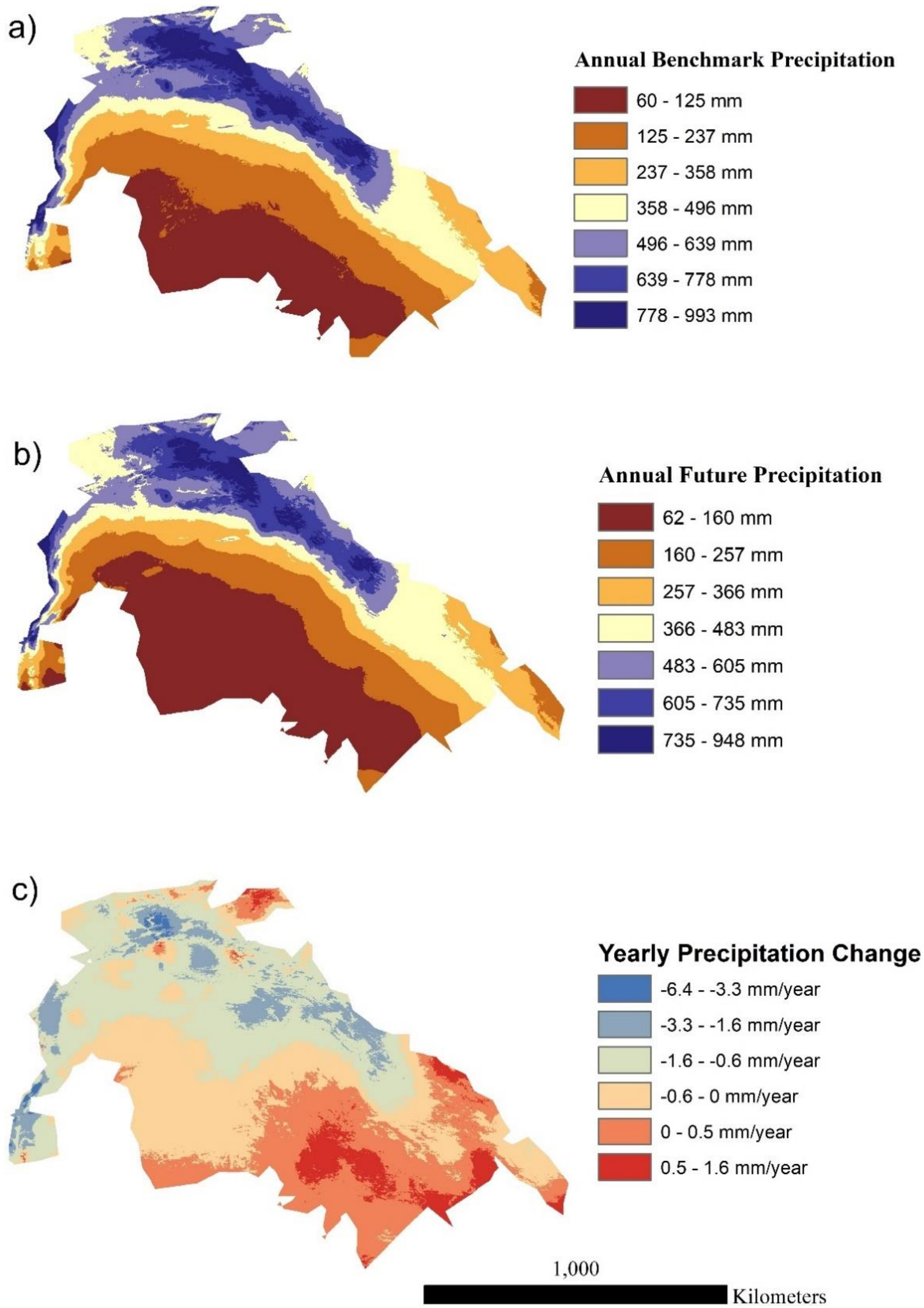

Figure 11. Annual benchmark (average 1970-2000) (a), annual future 2050 (b), and yearly change (c) precipitation (mm) representation for the Litani, Orontes, Euphrates-Tigris and Jordan River Basins

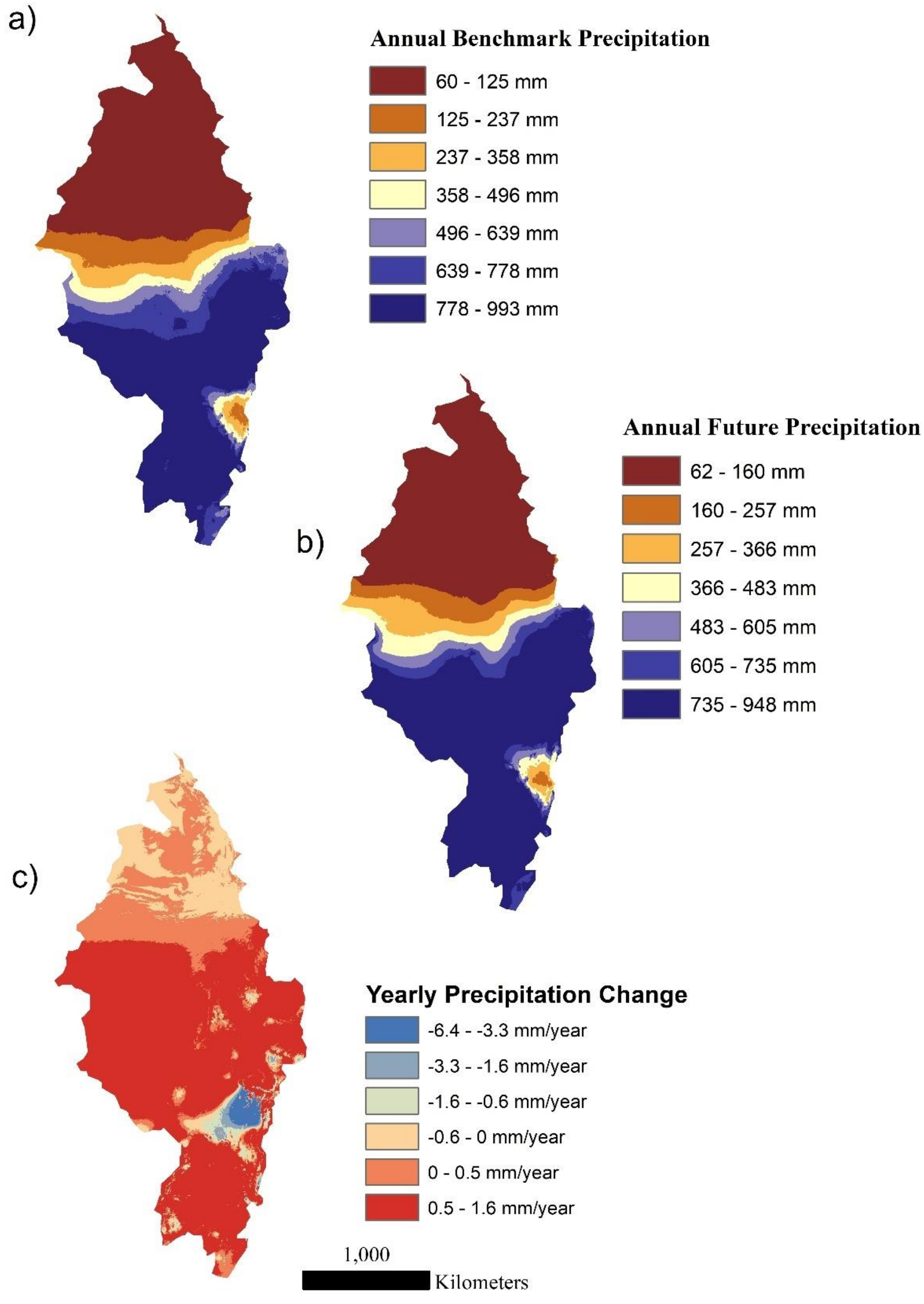

Figure 12. Annual benchmark (average 1970-2000) (a), annual future 2050 (b), and yearly change (c) precipitation (mm) representation for the Nile River Basin

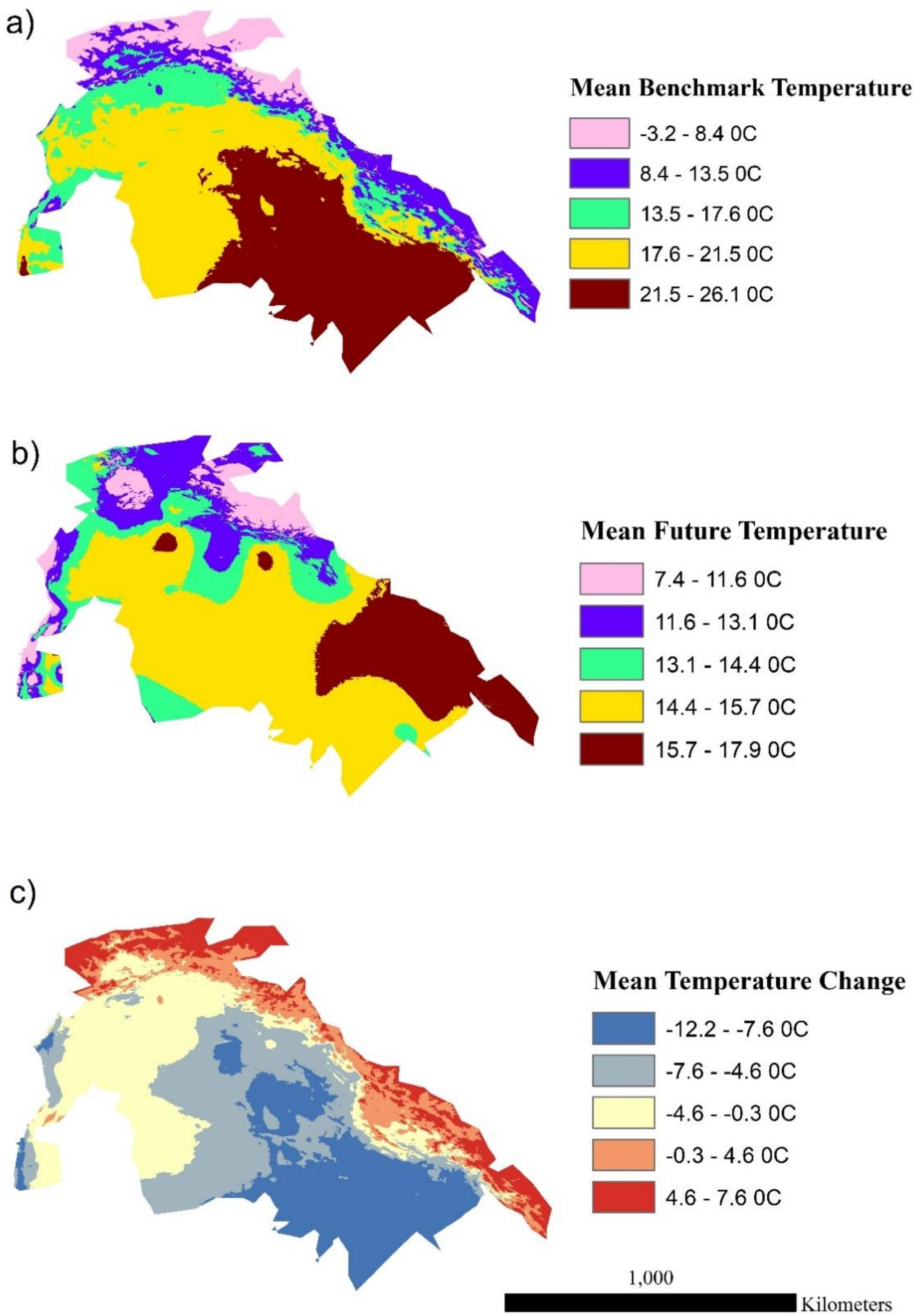

Figure 13. Mean benchmark (average 1970-2000) temperature (a), mean future 2050 temperature (b), and mean temperature change (c) (°C) representation for the Litani, Orontes, Euphrates-Tigris and Jordan River Basins

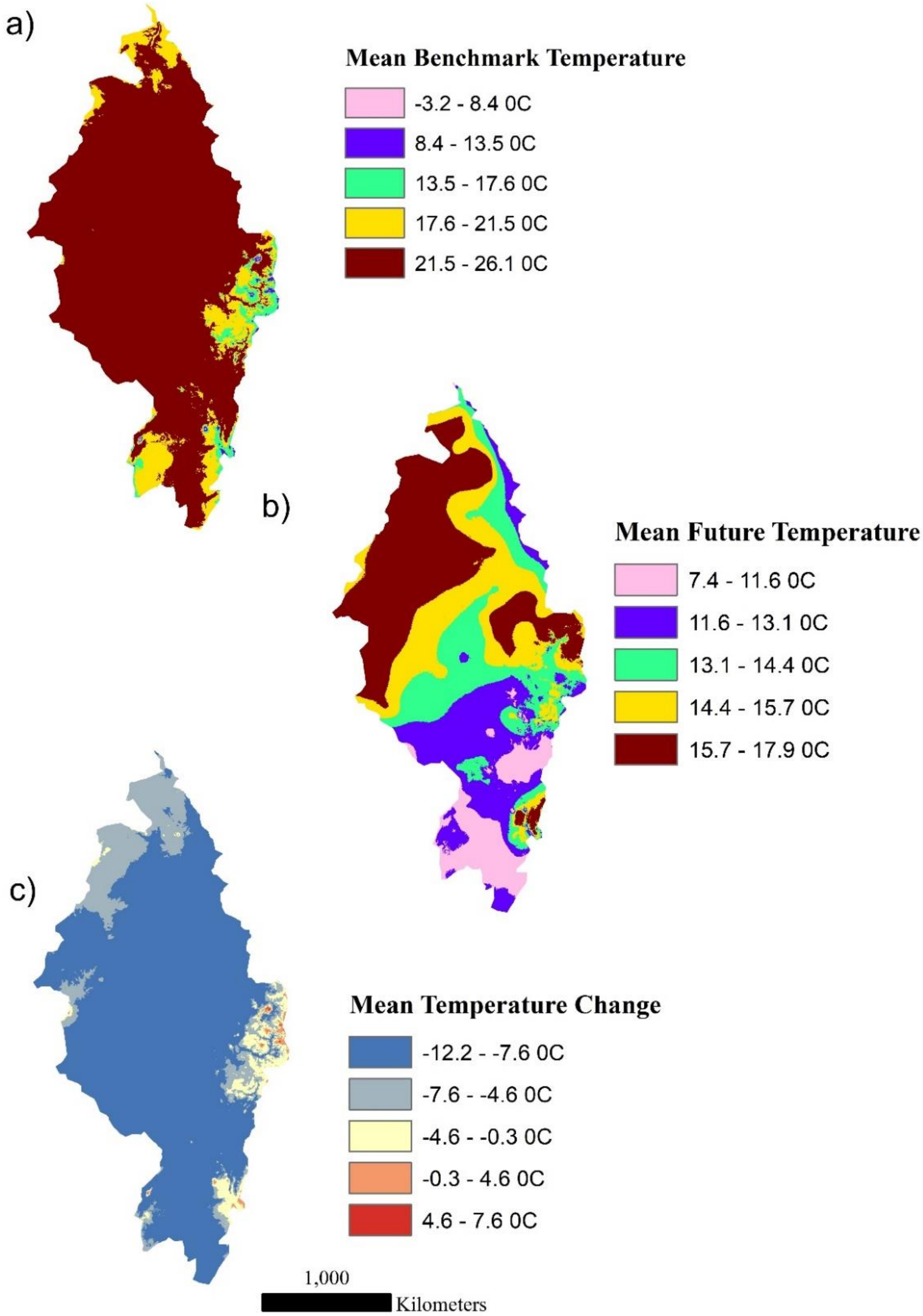

Figure 14. Mean benchmark (average 1970-2000) temperature (a), mean future 2050 temperature (b), and mean temperature change (c) (°C) representation for the Nile River Basin

Table 6. Seasonal temperature (°C) regimes for the Orontes, Jordan, Litani, Euphrates-Tigris, and Nile river basins under current and future climate scenarios

	River Basin				
	Orontes	Jordan	Litani	Euphrates-Tigris	Nile
Mean Current T – Winter	8	10	7	8	23
Mean Current T – Spring	21	21	17	22	27
Mean Current T – Summer	27	25	22	29	27
Mean Current T – Autumn	13	15	12	13	24
Mean Future T – Winter	11	13	9	11	25
Mean Future T – Spring	23	24	19	25	30
Mean Future T – Summer	30	29	26	33	30
Mean Future T – Autumn	17	19	15	17	27
Δ Mean T – Winter	3	3	2	3	2
Δ Mean T – Spring	2	3	2	3	3
Δ Mean T – Summer	3	4	4	4	3
Δ Mean T - Autumn	4	4	3	4	3
% Δ Mean T - Winter	38	30	29	38	9
% Δ Mean T - Spring	10	14	12	14	11
% Δ Mean T - Summer	11	16	18	14	11
% Δ Mean T - Autumn	31	27	25	31	13

Current: is representative of the average of the years 1970-2000
Future: is representative of the year 2050
Δ Mean T = Mean Future Temperature – Mean Current Temperature
% Δ in Mean T = Δ Mean T / Mean Current Temperature

Figure 15 displays the results of the ANUSPLIN interpolation model used in predicting the mean temperature and monthly precipitation datasets in the benchmark (1970-2000) and future (2050) under RCP8.5 climate scenarios (Hijmans et al., 2005). The projected values are the average of the output of the three GCMs: CCSM4, GFDL-CM3 & HadGEM2-ES of the monthly values for the two climate datasets. As shown in this figure, the mean temperature will increase in 2050 than the benchmark period in the future climate scenario under RCP8.5 for all the watersheds. Analogous to these findings, Özdoğan (2011) revealed an increasing pattern in the mean temperature in the 21st century in North-western Turkey.

The climatic data showed that temperature increase will be higher in the warm months than in the cold ones. The highest increase in mean temperature in all the watersheds was observed in July & August. The results of neighboring areas (i.e. Iran) by Zarghami, Abdi, Babaeian, Hassanzadeh, and Kanani (2011) showed that mean temperature will increase under A1B and A2 scenarios in the years of 2046-2065. Also, the simulation results for the Zayandeh-Rud River Basin (Iran) revealed temperature increases across the watershed (Gohari et al., 2013). The work of Islam et al. (2012) showed increases in the mean monthly temperature of the Colorado Central Great Plains.

Regarding the precipitation projections, it will decrease in all the months over the Jordan, Litani, Orontes, and Euphrates-Tigris River Basins. However, the precipitation in the Nile River Basin will increase in August, September and October while it will remain the same April, May and June under RCP8.5 emission scenario (Figure 15). The highest precipitation decrease will occur in January and December by 2050 for all the watersheds except for Nile River Basin. The following section presents the global suitability change of the major strategic crops.

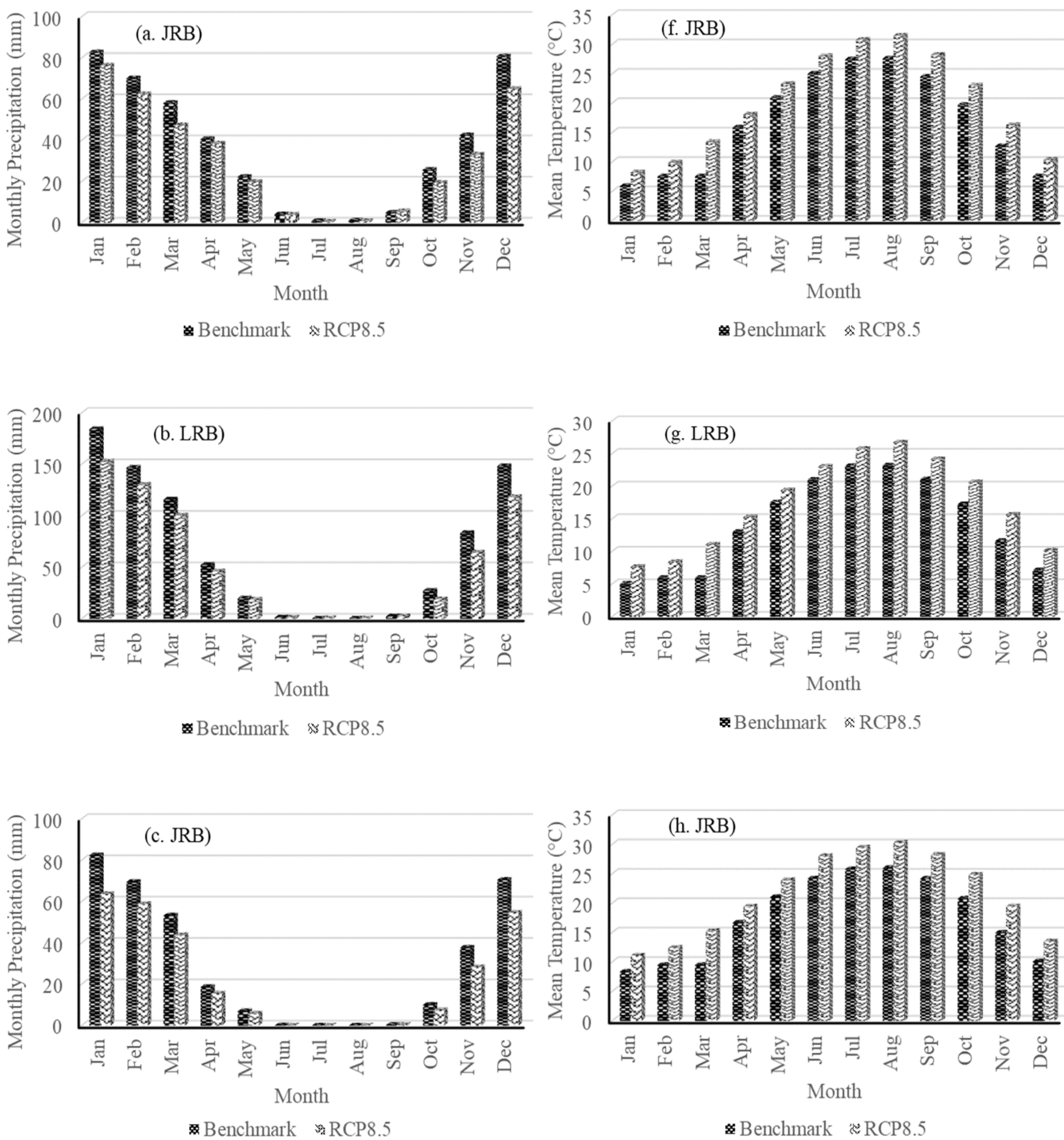

Figure 15. Comparison of the annual precipitation (mm) (a to e) and mean temperature (°C) (f to j) in the periods of benchmark (1970-2000) and future (2050) under RCP8.5 for the Orontes (a & f), Litani (b &g), Jordan (c & h), Euphrates-Tigris (d & i), and Nile (e & j) River Basins

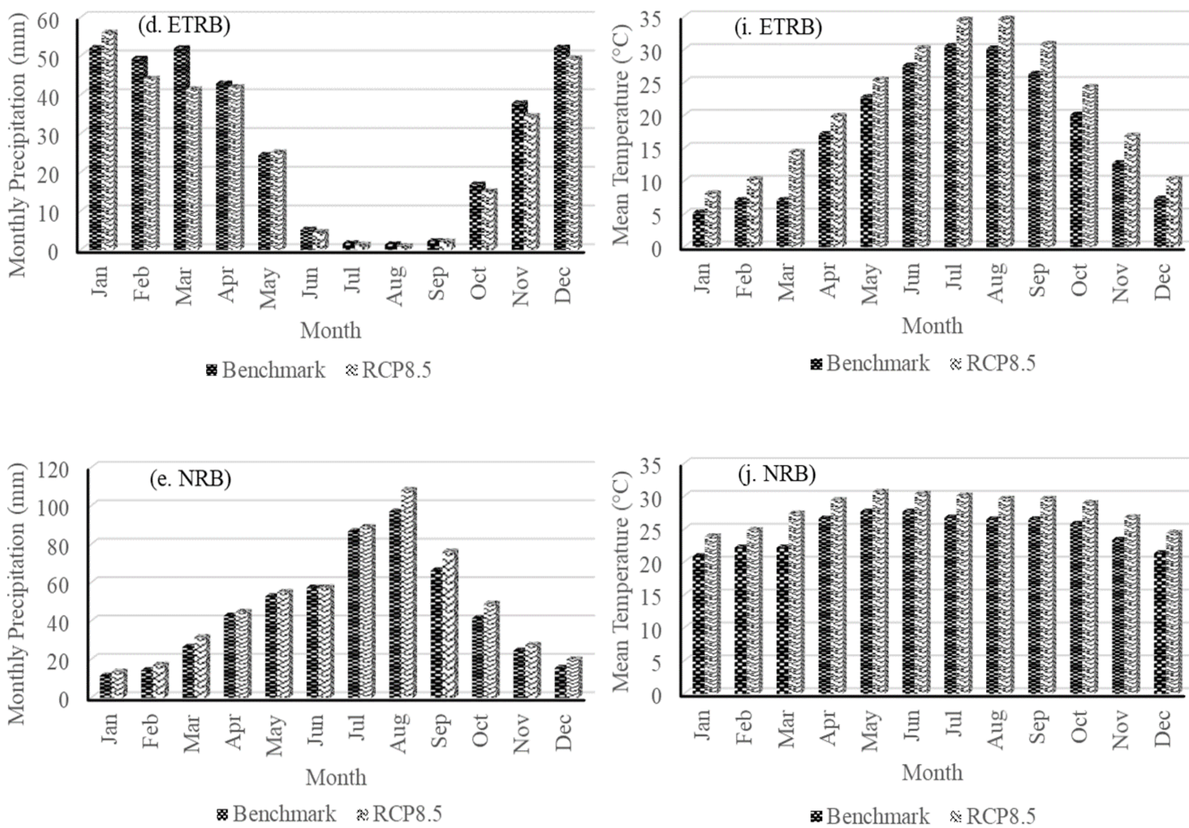

Figure 15. Comparison of the annual precipitation (mm) (a to e) and mean temperature (°C) (f to j) in the periods of benchmark (1970-2000) and future (2050) under RCP8.5 for the Orontes (a & f), Litani (b &g), Jordan (c & h), Euphrates-Tigris (d & i), and Nile (e & j) River Basins

B. Global Change in Suitability of the Strategic Crops

This section presents a qualitative description of the suitability change of the global strategic crops: wheat, barley, coffee, cotton, rice, and tobacco. In the IPCC 5th Assessment Report, it is stated that the northern part of the hemisphere will experience the most gains in suitability for a variety of crops (Stocker, 2014). The figures presented in this section geographically illustrates the areas of suitability gain or loss. The major gains in suitability for the six mentioned strategic crops are mainly in Europe while the losses are spread all over the continents depending on the location and climate (Figure 16 to 20).

1. *Global change in suitability of wheat and barley*

The EcoCrop model predicted that the major increases in barley and wheat suitability is in Europe, North America, and Western Russia for the year 2050 as represented in figure 16. Located in North America, Canada is one of the biggest wheat and barley producers worldwide and their suitability over Canada is projected to increase due to a slight increase in annual precipitation and a decrease in annual temperature by 1.5 ^{0}C. In the United States and South America, wheat and barley are likely to experience decreases in suitability with some gains in Brazil due to an annual temperature increase of 2.34 ^{0}C, which is considered among the producing countries. Although it is projected to have a decline in precipitation rate in 2050, wheat and barley are projected to have gains in suitability in Europe, mainly in the following countries: Austria, Belarus, Bulgaria, Germany, Poland, and Ukraine where the temperature is expected to increase by 3.18, 4.13, 2.88, 0.4, 2.7, and 1.98 ^{0}C, respectively. On the other hand, the western countries and southern coastal areas of Europe: Portugal, Spain, and Italy are projected to have decreases in barley and wheat suitability due to decreases in annual temperature by 4.62, 1.33, and 4.94 ^{0}C and annual precipitation by 19.16, 11.1, and 2.41 mm.

Morocco, Algeria, and Libya occupy the northern west of Africa. These countries are expected to have a decrease in suitability in 2050 for both wheat and barley due to the decrease in annual precipitation by 6.61, 0.67, and 0.2 mm and increase of annual temperature by 1.93, 3.34, and 3.02 ^{0}C in Morocco, Algeria, and Libya, respectively. Moreover, the majority of Africa's southern countries will experience slight decreases in areas suitable for barley and wheat cultivation. On the contrary, the western part of Russia is projected to gain suitable areas due to an increase in annual temperature and precipitation by 0.5 ^{0}C and 7.38 mm. In addition, the suitability over Asia is not likely to change except for the southern coastal areas where the suitability is projected to decrease. In specific, the Middle East region will suffer in 2050 a decrease in barley and wheat suitability, with an exception in Iran where extended colder areas will become warmer and will have increases in suitability due to an increase in temperature by 1.84 ^{0}C. Additionally, Australia is also among the largest producers of barley and wheat where the suitability is probable to slightly decrease in the northern parts and increase in the southern parts. The projected changes in annual temperature and precipitation in Australia for the year 2050 are -0.33 ^{0}C and -1.1 mm.

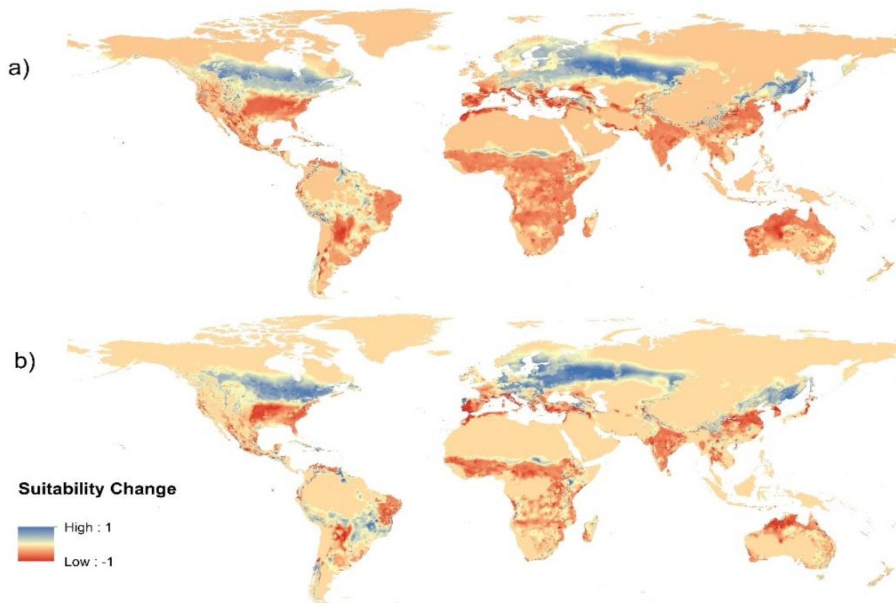

Figure 16. Global change in suitability for barley (a) and wheat (b)

2. *Global change in suitability of coffee*

The EcoCrop model predicted only a limited expansion of coffee suitability across the globe in 2050. The suitability is predicted to increase in southeast north America, south Africa, and southern coastal region of Asia due to annual temperature and precipitation increase (Figure 17). For instance, India and United States will experience increases in temperature by 1.09 ^{0}C and 0.42 ^{0}C and annual precipitation by 7.51 and 3.24 mm. On the other hand, the main decrease in coffee suitability is concentrated in Mexico and south America mainly in Colombia, Venezuela, and Brazil; the countries of large-scale coffee production. The simulated precipitation changes for these countries show a decrease in annual precipitation by 10.62, 10.51, and 2.59 mm in Brazil, Venezuela, and Mexico.

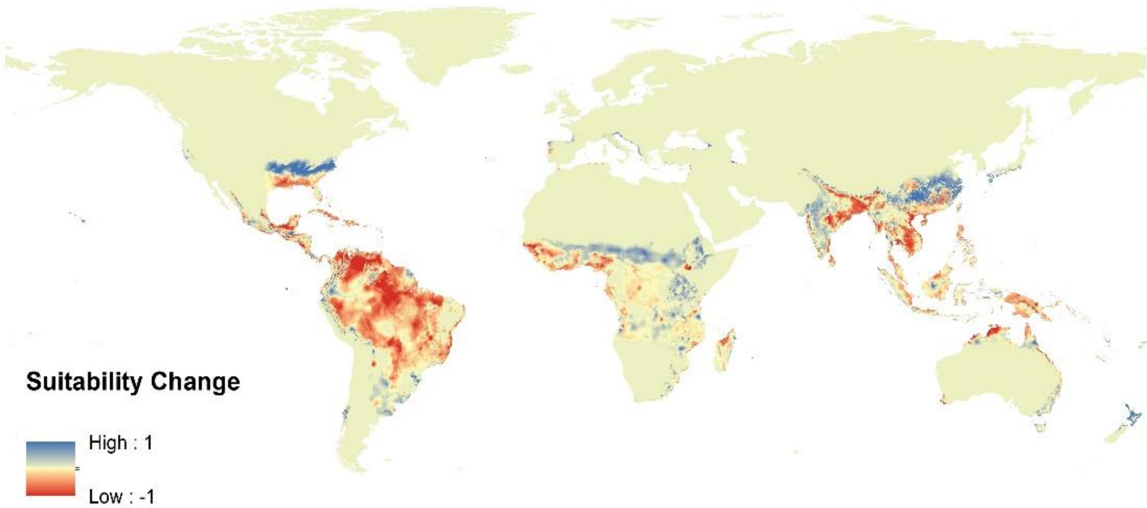

Figure 17. Global change in suitability for coffee

3. Global change in suitability of rice

The change in suitability results for rice, represented in Figure 18, shows that the gains are more than the losses for rice in 2050. There is a small decline in rice suitability worldwide, however, the major losses are centralized in Brazil due to the decrease in annual precipitation by 10.62 mm. Suitability gain will take place in southeast of the United States, south Asia (India, Thailand, and Vietnam), and central Africa (Sudan, Chad, and Nigeria) mainly due to increase in precipitation. China, which is a large consumer and producer of rice, is predicted to have no change in suitability for rice cultivation, although it is predicted to experience a 2.93 ^{0}C and 3.31 mm increase by 2050.

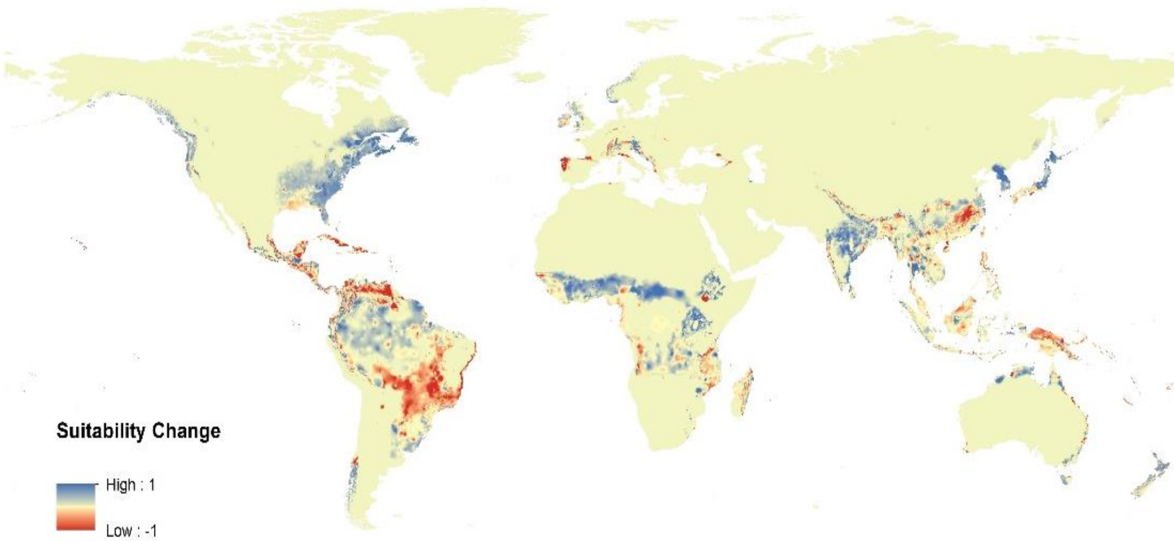

Figure 18. Global change in suitability for rice

4. Global change in suitability of cotton

The major gains in cotton suitability in 2050 will occur in the southern part of the hemisphere (Figure 19). The suitability change of cotton, as predicted by the EcoCrop model for the year 2050, will experience some gains and losses worldwide. The major gains will occur in the southeast of United States due to increase in precipitation, South America (i.e. Brazil and Argentina) due to increase in temperature, and east of Asia (China) due to the increase of both precipitation and temperature. On the other hand, the major losses will occur in south Asia (India) and some parts of Africa (i.e. Sudan and Nigeria) due to an extra increase in temperature in these relatively warm countries.

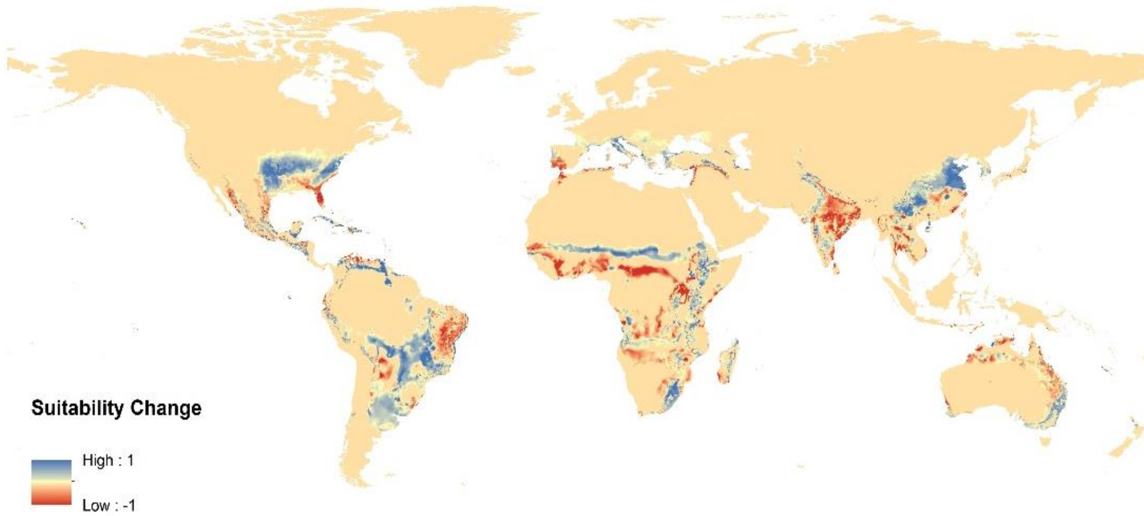

Figure 19. Global change in suitability for cotton

5. Global change in suitability of tobacco

Unlike cotton, the major gains in tobacco suitability in 2050 will occur in the northern hemisphere (Figure 20). Europe, Russia, and Canada are the most regions gaining suitability for tobacco production due to an increase in precipitation. In fact, the gains are way more than the losses in tobacco suitability; hence, more areas can be used for tobacco production. The minor losses in suitability that is projected to occur in 2050 will take place in Spain due to decreases in annual temperature and precipitation by 1.33 ^{0}C and 11.1 mm, respectively.

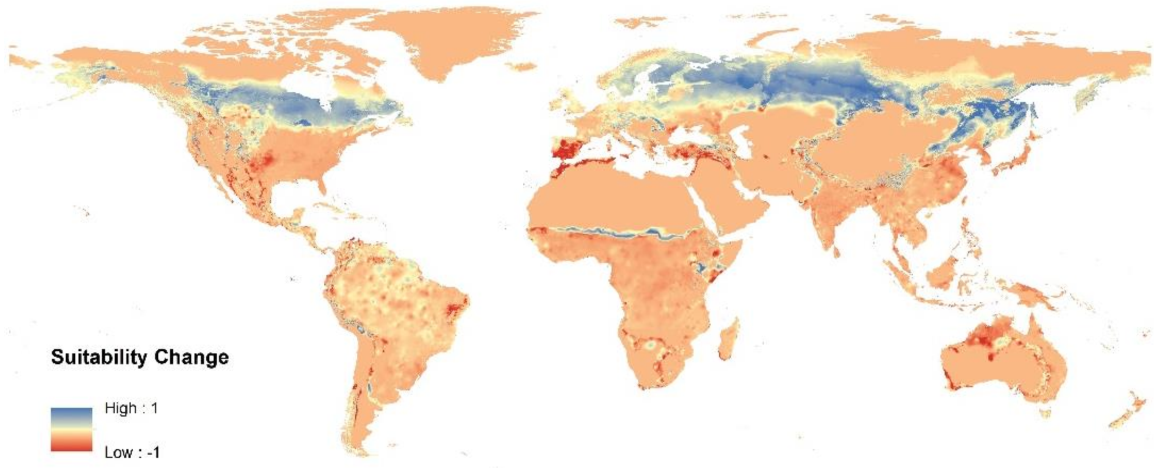

Figure 20. Global change in suitability for Tobacco

C. Regional Change in Suitability of Crops

In this section, the suitability modeling results of the major crops grown in each of the Litani, Orontes, Jordan, Euphrates-Tigris, and Nile River Basins are averaged and grouped in five crop categories: fruit trees, legumes, oil-producing crops, vegetables, and wheat & barley. The suitability of the studied crops was simulated using the EcoCrop model at the land use and basin level. The results consist of current suitability, future (2050) suitability, change in suitability magnitude, and percentage change of suitability for the various crop categories. They are displayed as an average for each category per watershed or croplands of the three watersheds. The transition of suitability for each crop category will be displayed at the end of this section at the watershed and cropland levels.

1. *Crop suitability at the croplands level*

The results presented in table 7 are the averages of each crop category for each of the five studied watersheds at the croplands level. These tables are the summary of the suitability scores for each crop of the five crop categories presented in the appendix (Tables 14 to 18).

a. Crop suitability of the croplands of the Jordan River Basin (JRB)

Based on the ecological parameters for the JRB croplands, the highest suitability decrease that is probable to occur by 2050 goes to legumes, followed by wheat & barley, vegetables, fruit trees, and oil producing crops, respectively (Table 7, a). The suitability values for the current scenario are small and are decreasing over the croplands of the JRB. This is due to the decrease in annual precipitation and increase in temperature in the JRB (Table 4). This river basin is projected to receive the lowest precipitation by 2050 among the five studied watersheds. Low rainfall values make it harder to fit within the FAO ecological ranges in the EcoCrop model. Therefore, the regression suitability equations in the model will assign low suitability values for these pixels (equations 2 & 3). Truly, the model predicted the highest percentage of suitability change in suitable areas to be for fruit trees where more than half of the Jordanian basins' croplands will decrease in suitability. Other crops that will decrease in suitability from their currently suitable areas are: legumes (around half), vegetables (around half), oil producing crops (one third) and wheat & barley (one third). As for the shift from current to future suitability (

Table 9), wheat & barley is projected to shift from medium suitable (0.423) to marginal (0.282). The fruit trees and oil producing crops will remain very marginal with a suitability score of less than 0.2. Moreover, legumes and vegetables will both shift from marginal (0.354 and 0.289 respectively) to very marginal (0.189 and 0.159 respectively). All these shifts in suitability are explained by the fact that the projected future temperature and rainfall values per each pixel are projected to decrease by the effect of global warming which makes it harder to fit within the fixed ecological ranges assigned in the EcoCrop model.

b. Crop suitability of the croplands of the Litani River Basin (LRB)

As for the croplands of the LRB (Table 7, b), the suitability of the crops is decreasing due to the decrease in rainfall and increase in temperature (Table 4). The decrease in suitability magnitude is the greatest in the LRB among the five river basins, since this river basin has primarily the highest magnitude decrease in annual precipitation; along with a 3 °C increase in temperature (Table 4). All five crop categories, except oil producing crops (marginal), are currently very suitable to highly suitable. Although all four categories are very suitable, the highest suitability score (more than 0.8) goes for legumes and wheat & barley. Note that in this case, the precipitation and temperature input data for the LRB fall within the ecological ranges of the EcoCrop model and meet the suitability regression equations (equations 2 & 3), hence justifying these high suitability values. Regarding the future suitability (

Table 9), the model simulates that wheat & barley will shift from highly suitable to medium suitable, legumes will shift from highly suitable to very suitable, vegetables will shift from very suitable to medium suitable, fruit trees from very suitable to marginal, oil producing crops will remain marginal. Again, the projected future temperature and rainfall values per pixel are projected to decrease under a changing climate which makes it harder to fit within the fixed ecological ranges assigned in the EcoCrop model. Moreover, the highest suitability change in magnitude is illustrated to be for fruit trees and vegetables; knowing that comparing both, vegetables are forecasted to have a higher current and future suitability. Subsequently to fruit trees and vegetables, wheat & barley, legumes and oil producing crops will decrease in magnitude respectively. As in the JRB, fruit trees in the LRB are projected to have the highest percentage suitability change, where almost half of their current suitable areas will lose their suitability. Concerning the other crops, they will lose around 25% of their current suitable areas.

c. Crop suitability of the croplands of the Orontes River Basin (ORB)

In the croplands of the ORB, the suitability of the crops is decreasing as well due to the temperature increase and precipitation decrease (Table 7, c). In this river basin, wheat & barely as well as legumes currently have a medium suitability whereas fruit trees, oil producing crops and vegetables have a marginal suitability; which means that their rainfall and temperature values are close to the lower end of the ecological ranges where a low suitability value is simulated by the EcoCrop model based on the suitability regression equations (equations 2 & 3). The highest current suitability score is simulated to be for legumes followed by wheat & barley, vegetables, fruit trees and oil producing crops respectively. Regarding the transition from the current to the future suitability (

Table 9), the model simulates that legumes and wheat & barley will shift from medium suitable to marginal, whereas fruit trees and oil producing crops will shift from marginal to very marginal, lastly vegetables will remain marginal. Under a changing climate, the meteorological data of P and T are less likely to fit within the ecological ranges of the EcoCrop model. Additionally, the highest suitability change in magnitude is illustrated to be for legumes whereas oil producing crops will have an almost minimal suitability change in magnitude. Indeed, the highest percentage change in suitability will be experienced by the fruit trees as in the Jordan and Litani river basins. The experienced decrease in fruit trees represents around half of the currently suitable areas, whilst the other crops will lose one third of their suitable areas.

d. <u>Crop suitability of the croplands of the Euphrates-Tigris River Basin (ETRB)</u>

As for the croplands of the ETRB, the suitability of the crops is decreasing except for the oil producing crops, where a slight increase in suitability is projected to occur by 2050 (Table 7, d). This slight increase in suitability of the oil producing crops is due to the increase in temperature suitability (even if the precipitation will slightly decrease), where the final suitability score is the product of both: precipitation and temperature suitability. The ETRB will have the least decrease in precipitation among the five watersheds. However, an average of 320 mm annual precipitation will be translated to low suitability values of crops (as in the JRB) (Table 7). The temperature increase of 4 °C (Table 4) also leads to decreases in suitability in the ETRB. Moreover, the highest suitability decreases in magnitude that are probable to occur by 2050 goes to legumes, followed by wheat & barley, fruit trees, and vegetables, respectively. As for the shift from current to future suitability (

Table 9), the fruit trees, oil producing crops, and vegetables will remain very marginal, with a suitability score of less than 0.2. The legumes and wheat & barley are projected to remain marginal. In this river basin, it is noted that the suitability change is small compared to other watersheds, where no suitability shifts are noticed. This is due to the small decrease in precipitation magnitude in the ETRB. Higher precipitation decreases will have higher impacts in decreasing crop suitability.

e. <u>Crop suitability of the croplands of the Nile River Basin (NRB)</u>

Lastly, in the croplands of the NRB, the suitability of the major crops will either slightly decrease or remain unchanged (Table 7, e). The wheat & barley and vegetables will have a slight decrease in their suitability while fruit trees, legumes, and oil producing crops will retain their current suitability by 2050. The NRB is the only river basin among the studied watersheds that will experience an increase of around 55 mm in annual precipitation by 2050, along with a temperature increase of 3 °C (Table 4). However, this small increase in precipitation will not be enough to increase the suitability of the crops in the NRB. This river basin includes large areas of Sahara with high temperatures, and this is depicted from the average mean temperature (Table 4). Thus, the temperature suitability will countereffect the positive impacts of precipitation increase which will prevent the overall suitability to increase. In addition, the temperature and precipitation values fall within the ecological ranges in the EcoCrop model, where this is translated to higher suitability values in comparison to other river basins. As for the shift from current to future suitability (

Table 9), the fruit trees and vegetables will remain medium suitable, while legumes and oil producing crops will remain very suitable by 2050. The wheat & barley will shift from very suitable to medium suitable in the NRB.

Table 7. The suitability results of the different crop categories in the croplands of the Jordan, Litani, Orontes, Euphrates-Tigris, and Nile River Basins

	River Basin	Crop Category	Current Suitability	Future Suitability	Suitability Change	% in Change Suitability
a	Croplands of Jordan River Basin (JRB)	Fruit Trees	0.168	0.070	-0.098	-58
		Legumes	0.354	0.189	-0.166	-47
		Oil Producing Crops	0.200	0.129	-0.072	-36
		Vegetables	0.289	0.159	-0.130	-45
		Wheat & Barley	0.423	0.282	-0.142	-33
b	Croplands of Litani River Basin (LRB)	Fruit Trees	0.612	0.342	-0.270	-44
		Legumes	0.861	0.686	-0.175	-20
		Oil Producing Crops	0.360	0.248	-0.113	-31
		Vegetables	0.747	0.478	-0.269	-36
		Wheat & Barley	0.805	0.570	-0.235	-29
c	Croplands of Orontes River Basin (ORB)	Fruit Trees	0.329	0.190	-0.139	-42
		Legumes	0.534	0.355	-0.179	-34
		Oil Producing Crops	0.276	0.197	-0.079	-29
		Vegetables	0.367	0.251	-0.116	-32
		Wheat & Barley	0.457	0.355	-0.102	-22
d	Croplands of Euphrates-Tigris River Basin ETRB)	Fruit Trees	0.147	0.105	-0.042	-29
		Legumes	0.347	0.256	-0.091	-26
		Oil Producing Crops	0.120	0.137	0.018	15
		Vegetables	0.187	0.162	-0.025	-14
		Wheat & Barley	0.291	0.236	-0.055	-19
e	Croplands of	Fruit Trees	0.544	0.542	-0.002	0
		Legumes	0.733	0.703	-0.030	-4

Nile River Basin (NRB)	Oil Producing Crops	0.616	0.623	0.007	1
	Vegetables	0.566	0.502	-0.064	-11
	Wheat & Barley	0.601	0.512	-0.090	-15

2. *Crop suitability at the watershed level*

The results presented in Table 8 are the averages of each crop category for each of the five studied watersheds at the watershed level. These tables are the summary of the suitability scores for each crop of the five crop categories presented in the appendix (Tables 19 to 23). The suitability results at the watershed level are lower than those at the croplands level. This is due to the fact that if all the basin is considered in the analysis, the areas of the croplands will get masked with other parts of the basin that might not be suitable; thus, lowering the overall suitability average score of the watershed.

a. Crop suitability of the Jordan River Basin (JRB)

To start with, by 2050, the JRB will experience a decrease in suitability for all the major crops grown in that area (Table 8, a). This decrease is reasonable where it is projected in the Jordan watershed that the yearly precipitation will decrease, and the temperature will increase by 3 ^{0}C (Table 4). The output of the EcoCrop model shows that wheat & barley will have the highest suitability decrease in magnitude, followed by legumes, vegetables, fruit trees, and oil producing crops. Moreover, the model predicted the highest percentage of suitability change to be for fruit trees where almost more than half of the Jordan basin's area will decrease in suitability. The fruit trees, oil producing crops, and vegetables are predicted to stay very marginal (with a suitability score less than 0.2) from the watershed level perspective (Table 10). The legumes and wheat & barley will shift from marginal to very marginal.

b. Crop suitability of the Litani River Basin (LRB)

As for the LRB, the suitability of the crops will also decrease by the year 2050 (Table 8, b). All five crop categories, except oil producing crops (marginal) and fruit trees (medium suitable), are currently very suitable to highly suitable. Concerning the future suitability (Table 10), the model simulates that legumes will shift from highly suitable to very suitable, wheat & barley and vegetables will shift from very suitable to medium suitable, and fruit trees will shift from medium suitable to marginal. The oil producing crops is projected to stay marginal in the Litani watershed. Furthermore, vegetables will have the highest suitability change in magnitude while fruit trees and vegetables will have the highest percentage change in suitability where approximately one-third of its currently suitable locations will become not suitable. Regarding wheat & barley, they will lose around 25% of their currently suitable areas while legumes and oil producing crops will lose less than 20% of their current suitable areas.

c. Crop suitability of the Orontes River Basin (ORB)

Similarly, the suitability of the crops will decline in the ORB, as shown in Table 8, c. All the crops hold a current marginal suitability, for the exception of oil producing crops which hold a very marginal suitability. Categories holding the greatest suitability change score in a decreasing order are: legumes followed by wheat & barley, fruit trees, vegetables, and oil producing crops. As for the transition from the current to the future suitability (Table 10), the model simulates that legumes and wheat & barley will remain marginal, whereas fruit trees and vegetables will shift from marginal to very marginal. To end, oil producing crops will remain very marginal. Additionally, the highest suitability change in magnitude is illustrated to be for legumes whereas oil producing crops will have a slight suitability change in magnitude. Indeed, as in the Jordan and Litani river basins, the highest percentage change in suitability will be experienced by fruit trees.

d. Crop suitability of the Euphrates-Tigris River Basin (ETRB)

As for the ETRB (Table 8, d), the suitability of the crops will also decrease by the year 2050, except for fruit trees and oil producing crops. This slight increase in their suitability is due to the increase in temperature suitability (even if the precipitation will slightly decrease), where the final suitability score is the product of both: precipitation and temperature suitability. Concerning the future suitability (Table 10), the EcoCrop model simulated that fruit trees, oil producing crops, and vegetables will remain very marginal in the ETRB. Furthermore, the legumes and wheat & barley will shift from marginal to very marginal.

e. Crop suitability of the Nile River Basin (NRB)

Lastly, in the NRB, the suitability of the major crops will decrease. The fruit trees, legumes, and oil producing crops will almost have the same suitability score as in the current scenario, while the vegetables and wheat & barley are projected to have a small decline in suitability magnitude by 2050 (Table 8, e). Concerning the future suitability (Table 10), the EcoCrop model simulated that fruit trees, oil producing crops, vegetables, and wheat & barley will remain marginal, while legumes are projected to remain medium suitable in the NRB.

Table 8. The suitability results of the different crop categories in the Jordan, Litani, Orontes, Euphrates-Tigris, and Nile River Basins at the watershed level

	River Basin	Crop Category	Current Suitability	Future Suitability	Suitability Change	% in Change Suitability
a	Jordan River Basin (JRB)	Fruit Trees	0.091	0.041	-0.050	-55
		Legumes	0.207	0.113	-0.094	-46
		Oil Producing Crops	0.119	0.075	-0.043	-44
		Vegetables	0.173	0.097	-0.076	-46
		Wheat & Barley	0.274	0.171	-0.103	-40
b	Litani River Basin (LRB)	Fruit Trees	0.507	0.349	-0.158	-30
		Legumes	0.822	0.700	-0.122	-15
		Oil Producing Crops	0.297	0.246	-0.050	-5
		Vegetables	0.711	0.533	-0.178	-30
		Wheat & Barley	0.767	0.599	-0.168	-22
c	Orontes River Basin (ORB)	Fruit Trees	0.208	0.125	-0.083	-40
		Legumes	0.354	0.241	-0.113	-32
		Oil Producing Crops	0.169	0.127	-0.042	-9
		Vegetables	0.254	0.174	-0.080	-35
		Wheat & Barley	0.334	0.241	-0.093	-29
d	Euphrates-Tigris	Fruit Trees	0.063	0.065	0.002	4
		Legumes	0.223	0.194	-0.029	-13
		Oil	0.058	0.070	0.012	18

	River Basin (ETRB)	Producing Crops				
		Vegetables	0.144	0.132	-0.012	-25
		Wheat & Barley	0.210	0.191	-0.018	-10
e	Nile River Basin (NRB)	Fruit Trees	0.309	0.302	-0.007	-3
		Legumes	0.420	0.404	-0.016	-4
		Oil Producing Crops	0.351	0.356	0.005	1
		Vegetables	0.329	0.286	-0.044	-13
		Wheat & Barley	0.334	0.291	-0.043	-13

Table 9. Crop Suitability transitions of the fruit trees (FT), oil producing crops (OP), vegetables (V), wheat & barley (WB), and legumes (L) for the croplands of: Jordan (JRB), Litani (LRB), Orontes (ORB), Euphrates-Tigris (ETRB), and Nile (NRB) River Basins

Suitability From\To (JRB)	VM	M	MS	VS	HS
VM	FT, OP				
M	L, V				
MS		W&B			
VS					
HS					

Suitability From\To (LRB)	VM	M	MS	VS	HS
VM					
M		OP			
MS					
VS		FT	V		
HS			W&B	L	

Suitability From\To (ORB)	VM	M	MS	VS	HS
VM					
M	FT, OP	V			
MS		W&B, L			
VS					
HS					

Suitability From\To (ETRB)	VM	M	MS	VS	HS
VM	FT, OP, V				
M		L, W&B			
MS					
VS					
HS					

Suitability From\To (NRB)	VM	M	MS	VS	HS
VM					
M					
MS			FT, V		
VS			W&B	L, OP	
HS					

Table 10. Crop Suitability transitions of the fruit trees (FT), oil producing crops (OP), vegetables (V), wheat & barley (WB), and legumes (L) for: Jordan (JRB), Litani (LRB), Orontes (ORB), Euphrates-Tigris (ETRB), and Nile (NRB) River Basins at the watershed level

Suitability From\To (JRB)	VM	M	MS	VS	HS
VM	FT, OP, V				
M	L, W&B				
MS					
VS					
HS					

Suitability From\To (LRB)	VM	M	MS	VS	HS
VM					
M		OP			
MS		FT			
VS			W&B, V		
HS				L	

Suitability From\To (ORB)	VM	M	MS	VS	HS
VM	OP				
M	FT, V	L, W&B			
MS					
VS					
HS					

Suitability From\To (ETRB)	VM	M	MS	VS	HS
VM	FT, OP, V				
M	L, W&B				
MS					
VS					
HS					

Suitability From\To (NRB)	VM	M	MS	VS	HS
VM					
M		FT, OP, V, W&B			
MS			L		
VS					
HS					

3. Variations in crop suitability

The suitability of the major crops grown in the five listed river basins was simulated at the land use and river basin level. The results suggest that there were croplands that weren't suitable and there were croplands that are suitable, but their suitability is decreasing. Averaging over the full basin will mask the areas of croplands with other parts of the basin that might be not suitable. On the contrary, including only the croplands mask other areas of the watershed that were not suitable and may become suitable in the future (2050).

Note that suitability score variations were observed across both the watershed and the croplands. This variation could be explained by two reasons. First, the EcoCrop model detains fixed ecological ranges for both precipitation and temperature (Ramirez-Villegas et al., 2013). Some precipitation and temperature pixel values fall outside their respective ecological ranges in the EcoCrop model. This means that values outside these ranges will have low suitability scores, while the values falling between the lower and upper ranges will get a suitability score based on the regression equations for precipitation and temperature (equations 2 & 3). Second, the EcoCrop model does not consider irrigation as an input in the simulations. Consequently, it assumes that the crops receive water solely from the rainfall. This limits the amount of water to the precipitation which makes it harder to fit within the FAO ecological ranges. Ecocrop doesn't consider irrigation as an input. When a crop (classified as irrigated crop) is not suitable, then its suitability will decrease where an increase in the irrigation water requirement will occur in the future.

As simulated by the EcoCrop model, the mean current suitability results are relatively low. On the other hand, some pixels of the suitability rasters have high suitability scores (up to a suitability score of 1), while other pixels, where their corresponding rainfall and temperature inputs fall outside their FAO ecological ranges, have low suitability scores reaching zero (based on the regression equations 2 & 3). There is a spatial variation in the suitability rasters. For example, the average suitability of lettuce is zero, however, some individual point locations have high suitability (i.e. magnitude suitability of 1). This is due to the variation of the ecological input data of precipitation and temperature. There are areas that are suitable for the production of a certain crop whereas others aren't. Hence, this explains why the mean suitability values are not very high for the watersheds. Nevertheless, the model succeeded to depict a decrease in the suitability of the major crops in the Near East region under a high emission scenario RCP8.5, and the decrease varies from one crop category to the other and from one watershed to the other.

As for the crops whose average suitability is low (i.e. lettuce), the suitability mean of these crops implies that they are not suitable, however, there are areas which are suitable, but these areas that are suitable will not be suitable in the future. Therefore, their suitability will decrease by 2050. Here comes the power of spatial analysis where suitable areas can be easily identified using the tools in the geographic information system (GIS) software even if the average suitability is close to zero or zero by itself. This kind of assessment using remote sensing techniques provides a visual graphical representation of the spatial variation of suitability change where certain areas can be easily identified as hotspots of climate change.

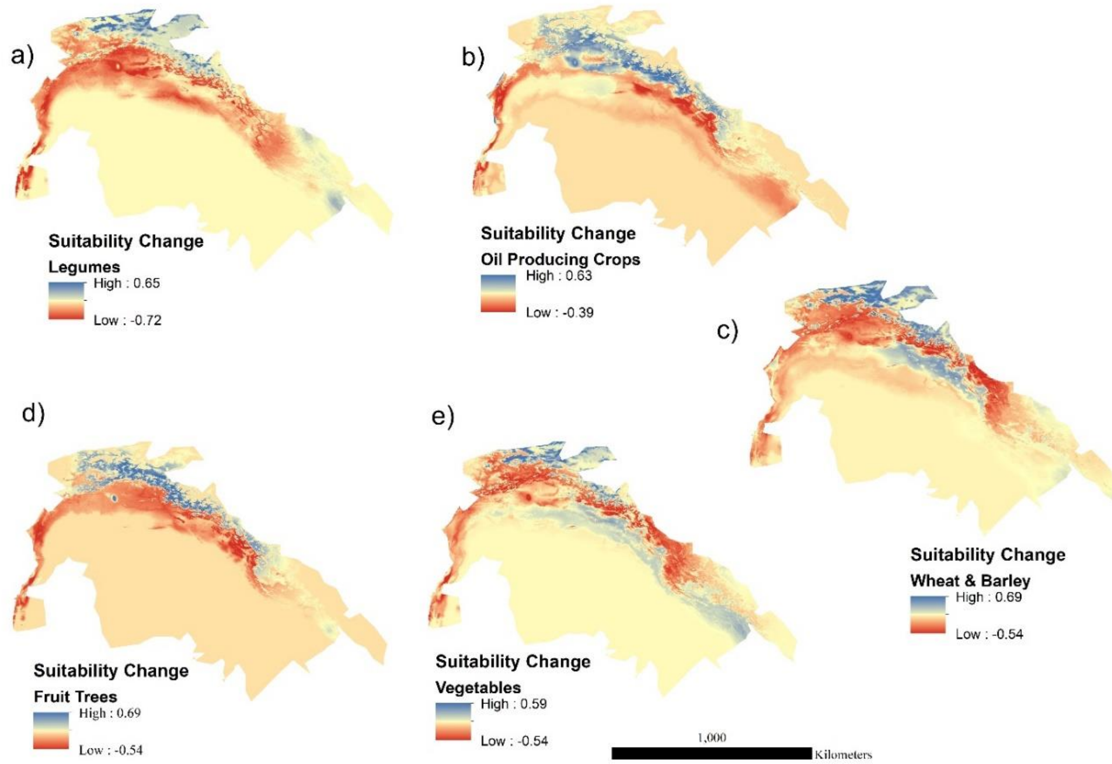

Figure 21. Suitability change of legumes (a), oil producing crops (b), wheat & barley (c), fruit trees (d), and vegetables (e) in the Orontes, Litani, Euphrates-Tigris & Jordan River Basins

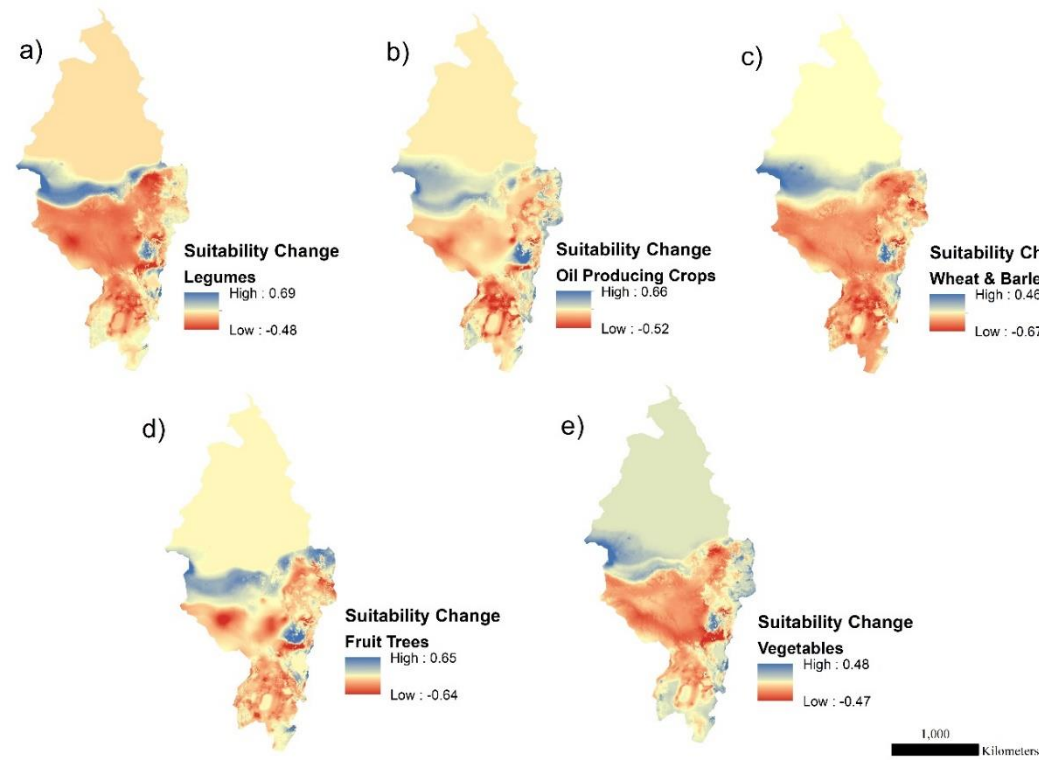

Figure 22. Suitability change of legumes (a), oil producing crops (b), wheat & barley (c), fruit trees (d), and vegetables (e) in the Nile River Basin

As mentioned earlier, the tables above show the average suitability results of each watershed. The rasters of the suitability change for the five crop categories are displayed in Figures 21 & 22. The suitability of legumes, oil producing crops and fruit trees under climate change scenarios will increase mainly in the NRB (South of Sudan and West Ethiopia) and ETRB (areas of East Turkey) (Figure 22). The suitability of vegetables will increase in some areas of West Sudan and East Turkey. Moreover, the suitability of wheat & barley will have major increases in some areas of West Sudan, besides the areas located in North Iraq and Eastern Turkey. Country-specific discussions in the ORB will be thoroughly analyzed in the following section. In addition, the use of geospatial analysis helps to precisely identify locations of high or low suitability via the graphical representation of the data. Nevertheless, the average of the watershed may not be representative of the whole watershed. For instance, the Litani river basin is smaller in size than the Orontes river basin; hence, the average suitability values for the Litani basin is greater than that of the Orontes basin. Truly, this is mainly due to the small number of pixels of the Litani basin where the average suitability can be representative of the whole basin. Contrarily to that, this is not the case in the Orontes river basin where the pixel number is higher, and the average of the watershed misleads the interpretation of the results in which there are areas with high suitability and areas with very low suitability reaching a suitability score of zero.

4. Country-specific discussions – The case of the Orontes River Basin

The ORB is shared by Lebanon and Syria, and Syria occupies the majority of this watershed. The annual temperature by 2050 is projected to increase by 1.5-2 °C in Lebanon and 1-3 °C in Syria (Figure 13). The annual precipitation is projected to decrease in both countries however the decrease will be higher in Lebanon (Figure 11). The annual rainfall will decrease by 75-250 mm in Lebanon (the decrease in rainfall declines downwards the ORB) while it will decrease by 50-150 mm in Syria (the decrease in rainfall increases upwards the ORB) (Figure 11). The Bekaa Valley in ORB will have more precipitation decreases than Syrian part of the ORB. As mentioned earlier, the suitability of the major crops grown in the ORB will decrease (Figure 21). The Bekaa Valley of the ORB will have decreases in suitability of the major crops. The suitability of fruit trees and legumes will decrease in both countries with some suitability increases in Hermel region (Hermel parts in the mountains of Lebanon and Anti-Lebanon mountains) (Figure 21). Decrease in fruit trees suitability is the north-western part of Syria, while the eastern part will have no suitability change (Figure 21, d). The western half of the ORB in Syria will have suitability changes while the eastern half will have no suitability change in legumes. Moreover, the oil producing crops will still grow in the mountainous areas of the lower ORB. Regarding wheat & barley, the region between Hamah and Ladiqiyah, besides the eastern half of the Syrian part of ORB, will have zero suitability change and it will not be affected by global warming (Figure 21, c). Also, their suitability in the Bekaa Valley of ORB will decrease by 2050. At last, the vegetables suitability will increase in the western part of the Lebanese portion of ORB, while the eastern part of the Syrian portion of ORB will have no suitability change for vegetables (Figure 21, e). On the contrary, the Syrian western part of ORB will have decreases in suitability. To sum up, the decrease in suitability trend follows the precipitation decrease trend. The trend of precipitation decrease is upwards in the Syrian part of ORB while its downwards in the Lebanese part of ORB (Figure 11, c). Syria will have larger areas affected by global warming than Lebanon in the ORB, due to the higher temperature increase and precipitation decrease in Syria.

Part II – AquaCrop

D. Yield, ET, and WP analysis for the crops within the JRB, LRB, & ORB using the FAO AquaCrop model

In this section, the AquaCrop simulation results of the major crops grown in each of the three river basins: Litani (LRB), Orontes (ORB), & Jordan (JRB), are averaged and grouped into the five categories listed above. The results presented in tables 11 to 13 show the summary of the mean evapotranspiration, biomass, yield, and water productivity values of every crop category for each of the three watersheds at the croplands level. The simulations of the studied crops were done over a fixed growing season. Note that tables 24 to 35 (available in the appendix) indicate the individual results for every crop in each crop category.

1. AquaCrop Results for the Jordan River Basin (JRB)

In the croplands of the JRB, there will be an overall increase in the evapotranspiration rate for the major crops grown in this watershed (Table 11). The AquaCrop model simulations show that legumes, followed by oil producing crops, will have the highest current and future ET rate by 2050 (reasons are previously stated). The wheat and barley crops will have the lowest current and future ET projections, but they will experience the highest percentage increase in ET in this watershed. Slight increases in ET rates will be experienced by the fruit trees and vegetables. Moreover, wheat & barley crops will have increases in their biomass under climate change scenario. The legumes and oil producing crops will experience some increases in their biomass. Only the fruit trees and vegetables will have decreases in the production of biomass because they are most likely to be subjected to water stress which will effect mainly the expansion of canopy cover (Bradford & Hsiao, 1982; Steduto, Raes, Hsiao, & Fereres, 2012). The AquaCrop model uses a stress coefficient (K_s) to modulate this process and decrease the biomass (Steduto, Raes, et al., 2012). Also, temperature increase in the JRB influences crop growth and development by reducing the biomass accumulation and reducing pollination. In addition, simulations for fruit trees, oil producing crops, and vegetables show decreases in their yields; with vegetables having the highest decrease, since it also has the highest decrease in biomass. The decrease in yield is due to water stress from increased temperature and decreased precipitation that will inhibit pollination and reduce fruit set to decrease the HI and reduce the yield (Steduto, Raes, et al., 2012). This stress is simulated using another stress factor in the AquaCrop model every day based on the water depletion. On the other hand, wheat and barley will have increases in their yields, where their yield is projected to double by 2050. This increase in yield corresponds to the increase in ET which led to higher biomass production and accumulation where the meteorological conditions will be favored for these increases. The legumes will experience a minimal increase in yield under a high emission scenario simulation; this is due to some heavy precipitation events during the flowering and grain filling growth stages that will temporarily break the soil moisture stress. Regarding the water productivity simulations, the major crops in the croplands of the JRB will have decreases in their WP, except for wheat & barley whose WP will slightly increase by 2050.

Table 11. ET (mm/season), Biomass (t/ha), yield (t/ha), and WP (Kg/m^3) of the different crop categories in the croplands of Jordan River Basin (JRB)

River Basin	Parameter	Crop Category	Current	Future	Change	% Change
Croplands of Jordan River Basin (JRB)	ET (mm/season)	Fruit Trees	776	810	34	4
		Legumes	991	1167	176	18
		Oil Producing Crops	892	1015	123	14
		Vegetables	588	628	40	7
		Wheat & Barley	498	618	120	24
	Biomass (t/ha)	Fruit Trees	12.6	11.4	-1.2	-10
		Legumes	21.8	22.2	0.4	2
		Oil Producing Crops	17.0	18.0	1.0	6
		Vegetables	11.0	9.6	-1.4	-13
		Wheat & Barley	9.2	14.1	4.9	53
	Yield (t/ha)	Fruit Trees	6.7	5.7	-1.0	-15
		Legumes	9.2	9.3	0.1	1
		Oil Producing Crops	8.6	7.9	-0.7	-8
		Vegetables	6.9	5.1	-1.8	-26
		Wheat & Barley	4.7	7.1	2.4	51
	WP (Kg/m^3)	Fruit Trees	0.9	0.7	-0.2	-22
		Legumes	0.9	0.8	-0.1	-11
		Oil Producing Crops	1.1	0.8	-0.3	-27
		Vegetables	1.2	0.9	-0.3	-25
		Wheat & Barley	1.0	1.1	0.1	10

2. AquaCrop Results for the Litani River Basin (LRB)

As in the JRB, simulations for the croplands of the LRB illustrate an increase in the ET of the studied crops (Table 12). Legumes, followed by oil producing crops, will have the highest current and future ET rate and the highest percentage change in ET rate;

reasons for this increase are explained at the beginning of this section. The seasonal ET of fruit trees, wheat & barley, and vegetables will slightly increase. Due to the resulting changes in weather variables based on the high emission scenario and elevated CO_2 concentrations, the biomass production of wheat & barley crops will increase, while some increases in biomass production will occur for legumes and oil producing crops; these increases are due to the increase in the evapotranspiration. Only the fruit trees and vegetables will have a minimal decrease in their production of biomass. As in the JRB, AquaCrop will use the stress coefficient (K_s) in response to a water stress that will impact the biomass accumulation through minimizing the canopy cover expansion for vegetables and fruit trees. Due to scarce water resources and increasing global warming effects, the JRB will have more water stress than the LRB, and this is shown by comparing the biomass change results of fruit trees and vegetables between the two river basins. In addition, simulations for fruit trees, oil producing crops, and vegetables show decreases in their yields, with vegetables having the highest decrease (same as the Jordan watershed). This is due to the decrease in pollination and reduction of fruit set. The AquaCrop model uses the stress coefficient to reduce the HI and hence decrease the yield. Note here that the yield of wheat and barley are much lower than that in the JRB. The most probable reason is that a water stress during the grain filling stage occurred which led to this low grain yield, knowing that wheat and barley are very sensitive to water stresses during this stage. Moreover, the yield of wheat and barley will increase by 2050, because the increase in ET results in more biomass production and the model didn’t encounter any stress to reduce the HI. The legumes are predicted to have a minimal increase in yield, also for the same reason. Regarding the water productivity simulations, the WP of wheat and barley will increase due to the increase in crop productivity whereas the WP of oil producing crops and vegetables will decrease due to their yield decrease.

Table 12. ET (mm/season), Biomass (t/ha), yield (t/ha), and WP (Kg/m^3) of the different crop categories in the croplands of Litani River Basin (LRB)

River Basin	Parameter	Crop Category	Current	Future	Change	% Change
Croplands of Litani River Basin (LRB)	ET (mm/season)	Fruit Trees	795	813	18	2
		Legumes	876	1009	133	15
		Oil Producing Crops	816	914	98	12
		Vegetables	566	603	37	7
		Wheat & Barley	449	472	23	5
	Biomass (t/ha)	Fruit Trees	13.8	13.5	-0.3	-2
		Legumes	18.0	20.2	2.2	12
		Oil Producing Crops	15.8	17.9	2.1	13
		Vegetables	10.8	10.5	-0.3	-3
		Wheat & Barley	2.6	5.6	3.0	115
	Yield (t/ha)	Fruit Trees	7.2	7.1	-0.1	-1
		Legumes	8.0	8.6	0.6	8
		Oil Producing Crops	8.2	7.9	-0.3	-4
		Vegetables	6.8	5.6	-1.2	-18
		Wheat & Barley	1.2	2.8	1.6	133
	WP (Kg/m^3)	Fruit Trees	0.9	0.9	0.0	0
		Legumes	0.9	0.9	0.0	0
		Oil Producing Crops	1.2	0.9	-0.3	-25
		Vegetables	1.2	1.0	-0.2	-17
		Wheat & Barley	0.3	0.6	0.3	100

3. AquaCrop Results for the Orontes River Basin (ORB)

The climate change effects in the ORB is characterized by an overall increase in evapotranspiration (Table 13). Therefore, all the three studied watersheds are predicted to have increases in the ET, with legumes having the highest current and future ET. In all watersheds, the most noticeable increase in the percentage change of ET will be perceived in legumes (Tables 11 to 13), whereas slight increases in ET will be experienced by the fruit trees and vegetables. Additionally, the biomass production of wheat & barley is projected to increase, where their biomass is expected to double by the year 2050. Legumes and oil producing crops will also have an increase in their biomass, however this increase will be small. The increase in biomass is due to the canopy cover expansion and increase in ET. On the other hand, biomass reduction will occur for the fruit trees and vegetable crops, because the model sensed a water stress during the crop development which will affect the canopy expansion. As in the JRB, the yield simulations for the ORB depict a decrease in the yields of oil producing crops, vegetables, and fruit trees, with vegetables having the highest decrease. On the contrary, the legumes will have a minimal yield increase while the yields of wheat & barley are predicted to double. Moreover, water productivity simulations show that it will decrease for the major crops, except for the wheat & barley, where their WP will increase by the year 2050.

Table 13. ET (mm/season), Biomass (t/ha), Yield (t/ha), and WP (Kg/m3) of the different crop categories in the croplands of Orontes River Basin (ORB)

River Basin	Parameter	Crop Category	Current	Future	Change	% Change
Croplands of Orontes River Basin (ORB)	ET (mm/season)	Fruit Trees	829	846	17	2
		Legumes	959	1094	135	14
		Oil Producing Crops	888	977	89	10
		Vegetables	602	634	32	5
		Wheat & Barley	463	518	55	12
	Biomass (t/ha)	Fruit Trees	13.3	12.2	-1.1	-8
		Legumes	20.8	21.7	0.9	4
		Oil Producing Crops	17.1	18.4	1.3	8
		Vegetables	11.0	9.9	-1.1	-10
		Wheat & Barley	7.4	11.1	3.7	50
	Yield (t/ha)	Fruit Trees	7.0	6.3	-0.7	-10
		Legumes	8.8	9.0	0.2	2
		Oil Producing Crops	8.8	8.1	-0.7	-8
		Vegetables	6.9	5.3	-1.6	-23
		Wheat & Barley	3.9	5.8	1.9	49
	WP (Kg/m^3)	Fruit Trees	0.8	0.7	-0.1	-13
		Legumes	0.9	0.8	-0.1	-11
		Oil Producing Crops	1.2	0.9	-0.3	-25
		Vegetables	1.2	0.9	-0.3	-25
		Wheat & Barley	0.8	1.1	0.3	38

The simulations for the evapotranspiration in the JRB, LRB, and ORB reveal an increase in ET for the major crops grown in the Near East region. The ET rates differ from one crop to another under the same environmental conditions, due to differences in crop height, groundcover, resistance to transpiration, and crop roughness (Song et al., 2018). Moreover, the soil water content and plant density affect the ET. The AquaCrop model is set to apply an irrigation once the percentage allowable water depletion reaches 50%. Even if the meteorological projections for the studied region indicates an overall decrease in the annual rainfall and increase in temperature (Table 4), along with irrigation applications, will lead to increases in the evapotranspiration rates. In fact, the ET is higher in wooden trees rather than in the herbaceous crops (Leuning, Kelliher, Pury, & Schulze, 1995). The reason is that higher leaf area increases the transpiration rate, and the transpiration at the top of the canopy is higher than that of the ground level canopy. As shown in tables 11 to 13, the legumes and oil producing crops are simulated to have the highest evapotranspiration, which in contrary, the highest ET should be for fruit trees for the above-mentioned reasons. In fact, the AquaCrop model over-estimated the ET for these two crop categories. More precisely, the ET of alfalfa (in legumes category) and olives (in the oil producing crops category) were over-estimated (check the appendix for the data in the three watersheds). The length of their growing season used in the simulations is 365 days. Hence, AquaCrop model assumed a year-round simulation for these two crops, and this is the reason for their over-estimation of ET. Based on literature, the average ET for alfalfa and olives are 900 mm and 600-800 mm/season, respectively (Masmoudi, Masmoudi-Charfi, Mahjoub, & Mechlia, 2007; Shewmaker, Allen, & Neibling, 2011). The simulations for this research indicate a doubling effect for ET due to the length of the growing season used for simulations. Moreover, by comparing ET results for fruit trees, vegetables, and wheat & barley, the fruit trees will have higher ET rates than the vegetables and wheat & barley in all of the three studied river basin; which is in accordance to the theory that wooden trees have higher ET than herbaceous plants stated by Leuning et al. (1995).

Note that all the suitability results generated by the EcoCrop model are based on the assumption that crops are rainfed while the AquaCrop model (yield and evapotranspiration) is based on an irrigation component in the model, where the model automatically generate the schedule based on the user selection of the percentage allowable water depletion (set as 50% in this research). The AquaCrop model simulations are also based on the start and end of the growing season. The simulation results of oil producing crops (including maize) showed decreases in their yields. This is in accordance with the findings of Nelson et al. (2009) where they studied the Near East region under climate change scenarios and found that the yield of maize will decrease up to 47%. In the research done by Nelson et al. (2009) and Verner et al. (2013), their findings contradict the outcomes of this research where they predict decreases of 20% in wheat production, while AquaCrop simulations predict increases in wheat production. Also, Al-Bakri et al. (2011) studied the effects of climate change on wheat and barley where their yield are prodected to increase in the Near East region; the wheat and barley simulations for the Near East region using AquaCrop model are in accordance with their results. Cotton wheat was simulated by Ibrahim (2014) in Syria (ORB) where they found decreases in cotton yield (oil producing crops); AquaCrop simulations for cotton are in accordance with his results. Moreover, the decrease in the yields of major crops grown in LRB and JRB is in accordance with the findings of Wilby (2010) where he stated decreases in crop yields due to temperature increases of the winters of Lebanon and Jordan. Peet et al. (1997) and Verner et al. (2013) simulated a decrease in the yield and biomass of tomato, grape, apple, and potato for the Near East region as a response to temperature increase, which is in accordance with the simulations of this research. In addition, the simulation results of fruit trees yield in the

LRB and ORB are in accordance with the results of Verner et al. (2013), in which yields of apple and grapes will decrease.

Precipitation, temperature, and CO_2 concentration changes affect the crop productivity. Increasing atmospheric CO_2 concentration affects the crop productivity through the photosynthetic pathway of the plants where C_3 crops will have a greater response than the C_4 crops (Olesen & Bindi, 2002). The primary effect of CO_2 fertilization is the reduction of stomata opening, increasing photosynthesis and reducing crop transpiration (Olesen & Bindi, 2002; M. L. Parry et al., 2004). Therefore, the resulting effect is increasing water use efficiency. The increase in CO_2 concentration is not only the environmental factor that may affect agriculture in the future. The temperature increase, illustrated as global warming, will expand the length of the growing season; increasing the spring season and decreasing the summer season (earlier maturation) (Olesen & Bindi, 2002). In warmer areas, plant respiration will increase in response to increased temperature (Olesen et al., 2011). This will lead to hastened plant growth and development, accelerated maturation of crops, and reduced yields (Rötter & Van de Geijn, 1999). In addition, the irrigation water requirement is simulated to increase in a warmer climate where precipitation will decrease and peak irrigation demands will grow (M. L. Parry et al., 2004).

4. Spatial assessment of AquaCrop results

The results above are numerical representation and analysis for ET, B, Y, and WP data. As for the crop suitability results, the average results of yield and ET may not be representative of the whole watershed due to variations in environmental conditions. The use of geospatial analysis makes it easier to spatially assess and visualize the results. Figures 23 to 26 represent the spatial data for yield, ET, biomass, and WP derived from AquaCrop for the five different categories of crops studied in the JRB, LRB, and ORB.

The ET simulations reveal an increasing trend of the ET by 2050 (Tables 11 to 13), this is in accordance with the findings of Abu Jamous (2008). Although the mean ET of the watersheds is positive, some regions will have increases in ET while others will encounter ET decreases. As shown in Figure 23 (a), the fruit trees will only have decreases in Turkey in the northern parts of the ORB, where the AquaCrop model encountered a stress and applied the stress coefficient to reduce the ET.

This decrease is due to a decrease in annual rainfall (around 100 mm) (Figure 11, c) and hence water stress will reduce the ET. On the other hand, fruit trees will have increases in ET ranging from 30 to 100 mm in the JRB and LRB (Figure 23, a). The oil producing crops will have some decreases in their ET in the eastern part of the ORB (Figure 23, c). As shown in Figure 23 (b, d, & e), the legumes, wheat & barley, and vegetables will have minimal decreases in ET across the three watersheds, whereas small increases in ET are projected to occur. The highest increase in their ET is projected to occur in the western part of the lower JRB (Figure 23). This is mainly contributed to an average increase in temperature of 4 °C in those regions.

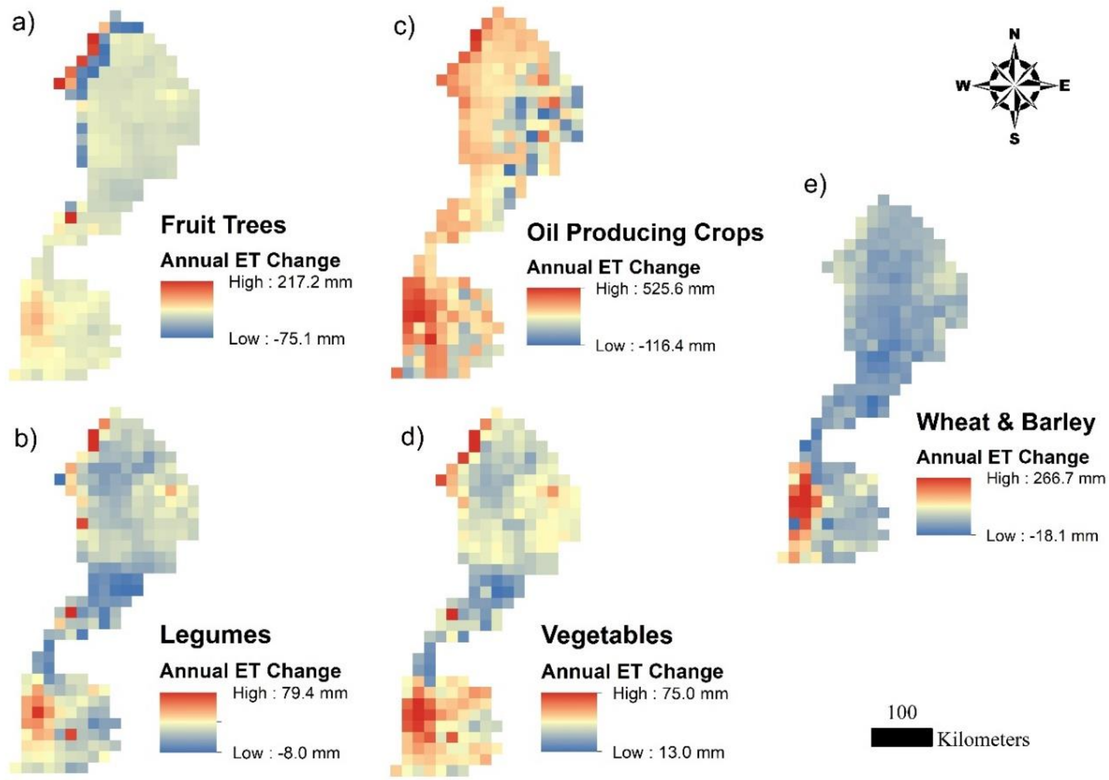

Figure 23. ET change (mm/season) for fruit trees (a), legumes (b), oil producing crops (c), vegetables (d), and wheat & barley (e) in the Jordan, Litani, and Orontes River Basin

The simulation results suggest a decrease in the biomass of fruit trees and vegetables in the three watersheds (Figure 24, a & d). The AquaCrop model also sensed a water stress and applied the stress coefficient to reduce the biomass of these crops by reducing the canopy expansion. The highest increase in biomass will be encountered by legumes in the lower ORB (Figure 24, b) and wheat and barley in the JRB (Figure 24, e) where the environmental conditions will be favorable for increased photosynthesis and canopy growth.

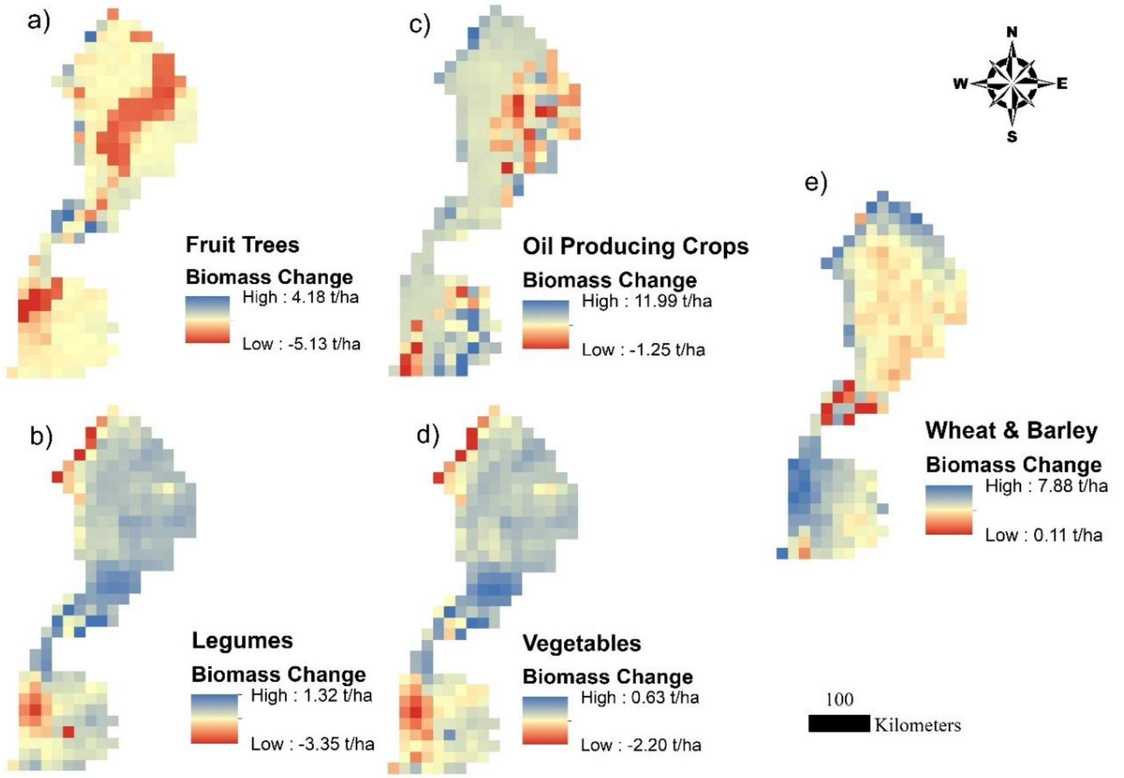

Figure 24. Biomass change (t/ha) for fruit trees (A), legumes (B), oil producing crops (C), vegetables (D), and wheat & barley (E) in the Jordan, Litani, and Orontes River Basin

Regarding the yield simulations, the AquaCrop model predicted a decrease in the yield of fruit trees, oil producing crops, and vegetables (Figure 25: a, c, & d). These decreases are spatially distributed along the watersheds and represented in Figure 25. The projected decrease in fruit trees biomass will lead to a decrease in the yield, where the fruit set of fruit trees will be reduced due to water stress and hence reducing the HI. At last, the WP will decrease for all the crops, except for wheat and barley where their WP is projected to increase (Figure 26).

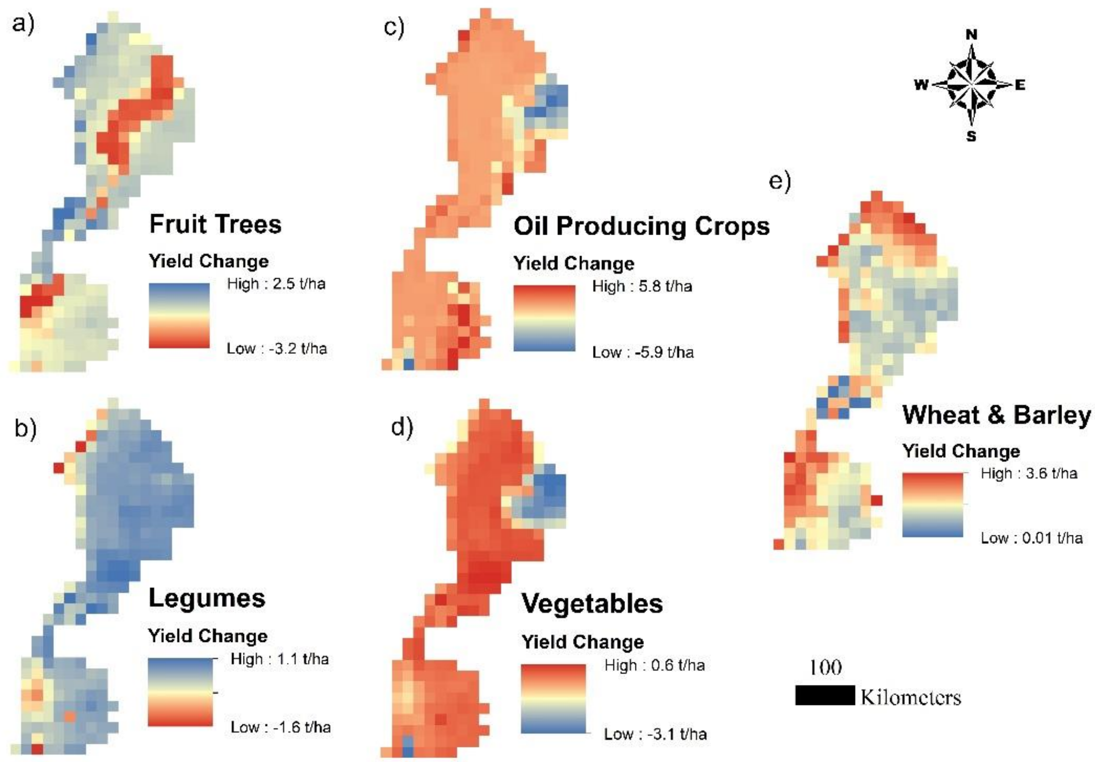

Figure 25. Yield change (t/ha) for fruit trees (A), legumes (B), oil producing crops (C), vegetables (D), and wheat & barley (E) in the Jordan, Litani, and Orontes River Basin

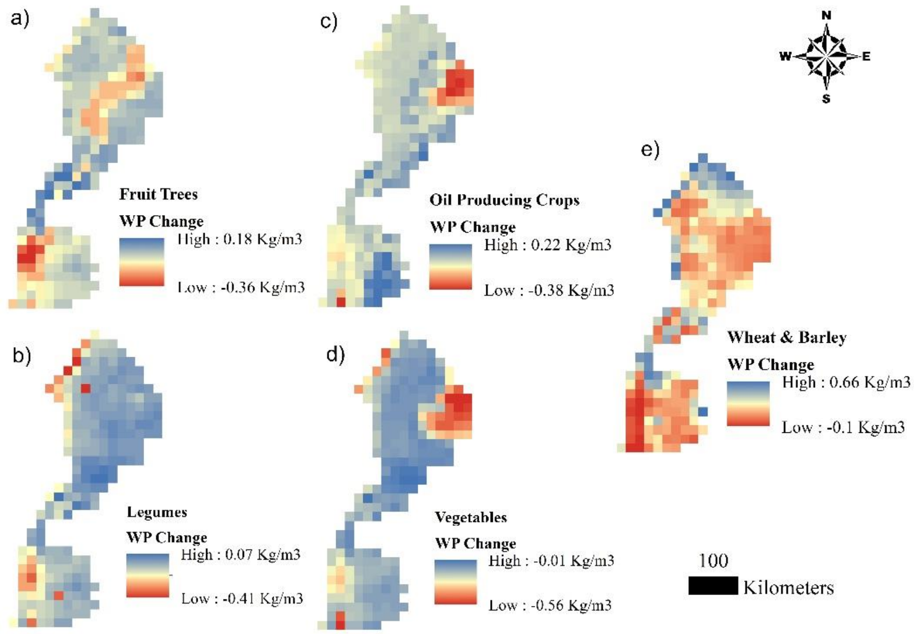

Figure 26. Water productivity change (Kg/m^3) for fruit trees (A), legumes (B), oil producing crops (C), vegetables (D), and wheat & barley (E) in the Jordan, Litani, and Orontes River Basin

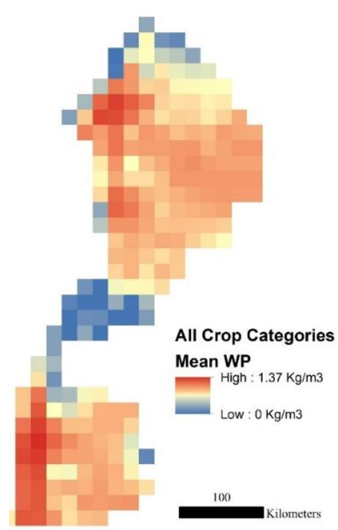

Figure 27. Mean WP for all the crop categories of the current scenario for Orontes, Litani, and Jordan River Basins

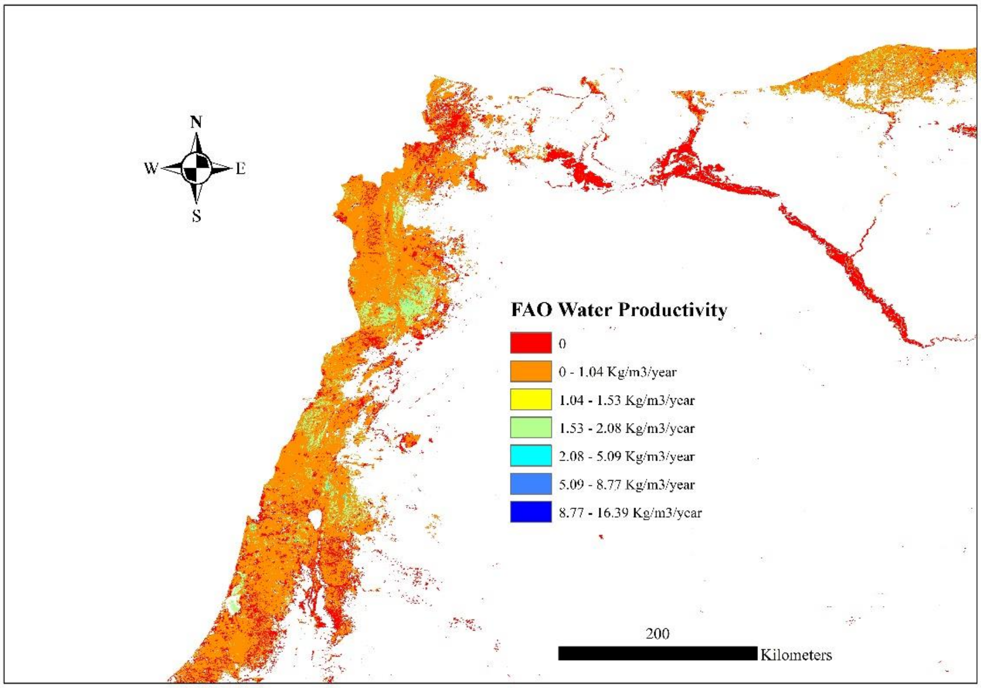

Figure 28. The FAO WP spatial representation for the Orontes, Litani, and Jordan River Basins in the year of 2016

The FAO Water Productivity portal provides spatial data on the current WP. The assumption for these calculations is that areas of transpiration higher than 100 mm are included in their analysis. Figure 28 presents the FAO WP current values and Figure 27 presents the mean simulated WP values for the current scenario; averaged for all the crops. It is noted that the WP values simulated by the AquaCrop model are lower than that of the FAO portal values. The resolution of our data is coarser than that of the FAO portal data, which makes it harder for comparison where uncertainties can occur. However, low WP values for the LRB were simulated by the AquaCrop model (less than 0.4), while higher values of WP (more than 1) were simulated for the ORB and JRB. Note that in the FAO

WP map, there are missing data in the LRB, hence we can assume low values of WP since the data of the FAO doesn't include locations where transpiration is less than 100 mm.

E. Relationship between crop suitability and yield in the JRB, LRB, & ORB

There are two possibilities that can relate yield with crop suitability: (i) either they increase/decrease together, or (ii) one will increase and the second will decrease. In the JRB, LRB & ORB, the two possibilities occur. Legumes and wheat & barley correspond to the second scenario, where their yields are individually projected to increase by 2050 in the three river basins (Tables 11 & 13) while, on the contrary, their suitability will decrease. Therefore, there is no relationship between the suitability and yield of wheat & barley and legumes in the JRB, LRB and ORB. In the AquaCrop model, all the crops were considered irrigated where AquaCrop automatically accounts for an increase in ET (i.e. it assumes that water is not a limiting factor). This increase in ET is directly resulting in an increase in yield. When the evapotranspiration increases, the biomass will increase and hence the yield will increase if no other stresses happen. For fruit trees, oil producing crops, and vegetables, there is a relationship between suitability and yield where they both are projected to decrease by 2050 in the three river basins. The water requirement of these crops is increasing, but it's not being matched by the decreasing annual precipitation in 2050 (Table 4). In this case, there are other factors that may be interfering, including temperature and length of the growing season. It is projected that the temperature will increase by 3 ^{0}C in the Jordan river basin (Table 4). Moreover, the ET and yield were simulated using the same length of the growing season and over the same timeframe. The length (start and end dates) of the growing season is entered into the AquaCrop, which is not considered by EcoCrop. Hence, the productivity period will be shortened by 2050 so that's why there will be a decrease in suitability since the effect of the temperature increase is shortening the length of the growing season of the crop.

The degree of tolerance varies from crop to crop and from one river basin to another; some will be affected, and others will be slightly affected. This is evident in the yield reduction variations among the different crop groups in the JRB, LRB & ORB. The JRB has the lowest mean suitability scores for the benchmark and future (2050) climate emission scenarios, followed by ORB & LRB where the LRB has the highest suitability scores among them Table 7. Similarly to the suitability reduction order, the yields of the fruit trees, oil producing crops, and wheat & barley are the lowest in the JRB, followed by ORB and LRB respectively. This portrays the effect of suitability reduction on decreasing the yields of these crops and hence enforcing the presence of relationship between the yield and suitability.

F. Limitations of the crop models used

In planning of climate and crop interactions, it is critical to have a thorough knowledge on the interaction between the environment and crop plants (Krishnan & Aggarwal, 2018). For that, quantitative representations of ecophysiological operations are used in crop simulation models to prognosticate the effects of crop management and the environment on the development and growth of plants; in the model, crop management and environmental conditions are identified as input data (X. Li, Zhu, Wang, & Yu, 2012). Researchers state that crop models are resorted to for an increasing range of applications, with an increasing number of methods. Thorough formulation of research queries and development of selected and adequate methods and inputs are thus essential (Challinor et al., 2018).

To start with, not all models incorporate all the required inputs. This makes the formulation of models an intricate task where the relations between the inputs themselves are hard and complex to formulate. In fact, some models require less inputs than others, yet they still can perform accurate simulations; which is the case of AquaCrop and EcoCrop models. The original version of the EcoCrop model predicts crop suitability based on monthly temperature and precipitation, without taking into account soil constraints. Piikki et al. (2017) used a digital soil map of Tanzania in simulating the crop suitability of common beans in Tanzania under climate change scenarios. Per se, other factors include diseases and pests which can affect the crop production.

The EcoCrop and AquaCrop are the crop models used in assessment studies. They use meteorological datasets as an input to perform the simulations. All the suitability results generated by the EcoCrop model are based on the assumption that crops are rainfed whereas in the AquaCrop model, they are based on an irrigation component. In the AquaCrop model, the irrigation schedule is automatically generated based on the user selection of the percentage allowable water depletion (set as 50% in this research). The EcoCrop model assumes rainfed conditions where the irrigation component is integrated in the AquaCrop model. Therefore, the results of the AquaCrop model, in which the irrigation component is selected, doesn’t clearly dictate the effects of climate change on crop production where the model applies an irrigation scheduling in case of insufficient water.

On the other hand, the EcoCrop model assumes the precipitation as the only source of water to plant growth and development.

Another limitation of the usage of the two models is that the date of growing season differs between the two models. The EcoCrop model simulates the crop suitability irrespective of the start and end of the growing seasons (check the methodology section for more information on how the model works). On the other hand, the AquaCrop model detains a fixed length and period of the growing season in its simulations. Therefore, the effect of climate change on shortening or expanding the length of the growing season is not taken into consideration. Moreover, the length of the growing season differs from region to region, depending on the eco-physiological factors domination the region. In this research, the length of the growing season is assumed the same over the different river basins, which in turn may affect the simulation results where the growing season for both models differ in the start and end cycles.

CHAPTER V

SUMMARY, CONCLUSIONS, & RECOMMENDATIONS

A. Summary

Spatial meteorological data were used to generate crop suitability indices, evapotranspiration, biomass, yield and water productivity for the benchmark (average years of 1970-2000) and future (2050) climate scenarios for the major crops grown in the Near East at the watershed level of: Litani, Orontes, Jordan, Euphrates-Tigris and Nile River Basins. The study was conducted over two periods: the benchmark (average 1970-2000) and future (2050) periods. The spatial climate data and crop parameters were downloaded from the WorldClim database 1.4 including: mean monthly minimum and maximum temperature, precipitation, solar radiation, wind speed, and vapor pressure from the output of the three GCMs: HadGEM2-ES, CCSM4, and GFDL-CM3 under the high emission scenario (RCP8.5). The major crops (19 crops) grown in this region were categorized into five groups: fruit trees, legumes, oil producing crops, vegetables, and wheat & barley. For this study, the EcoCrop model was used to generate the suitability maps of the major crops for the two periods based on the combination of precipitation and temperature parameters choosing the minimum scores as the aggregation procedure. The simulated suitability maps the crops were summed into the corresponding crop groups using the “Raster Calculator” in ArcGIS at the watershed and croplands level. Moreover, the AquaCrop model was used to simulate and assess the evapotranspiration, biomass, yield and water productivity, also for the same periods, under the two climate scenarios at the watershed level of Litani, Jordan &

Orontes River Basins. The change of the simulated results was calculated using the “Raster Calculator” in ArcGIS by subtracting the future scenario output from the benchmark one. The numerical outputs of the two models were compared after calculating their corresponding watershed’s means using the “Zonal Statistics as Table” tool in ArcGIS. At last, the presence of a relationship between crop yield and suitability in the Jordan, Litani & Orontes River Basins was assessed. The simulation results showed that the suitability of the major crops grown in the Near East region, namely Jordan, Litani, Orontes, Euphrates-Tigris & Nile River Basins, will decrease by 2050 under a high emission scenario RCP8.5. Also, their evapotranspiration will increase in the Jordan, Orontes, and Litani River Basins. The global warming will cause the yields of fruit trees, oil producing crops and vegetables while the legumes, wheat and barley will have an increase in their yields.

B. Conclusions

Climate change has been a contemporary concern due to the continuing escalation in the greenhouse gas emissions. The Near East region is increasingly susceptible to climate change impacts due to the increase in population, decrease in rainfall, and increase in temperature. In this research, the assessment of the potential climate impacts on crop suitability, evapotranspiration, yield and water productivity was performed for the major crops grown in the Near East at the watershed and croplands level. The climate regimes in this region is projected to experience a decline in the mean annual precipitation in the ORB (-16%), JRB (-20%), LRB (-17%) and ETRB (-7%), while the NRB will experience an overall increase in precipitation by 10%. Regarding the temperature regimes, it is predicted that the ORB, LRB & NRB will experience a 3°C increase in temperature while the temperature in the JRB and ETRB rise by 4°C relative to the mean benchmark temperature for each river basin. Also, the results suggest that temperature will be higher in the warm months than in the cold ones in the five river basins, where the highest increase in temperature will be observed in July & August. The derived crop suitability maps were generated using the climate datasets and EcoCrop model for the benchmark (average years of 1970-2000) and future (2050) climate scenarios. Regarding the suitability of strategic crops, the global suitability simulations showed major gains in the suitability of wheat, barley, coffee, rice, cotton and tobacco in Europe while the suitability losses will be spread all over the continents depending on the location and climate. The evaluation of the benchmark and future suitability of the major crops revealed decreases in crop suitability for the five studied river basins. Indeed, fruit trees, wheat & barley, legumes, vegetables, and oil producing crops were simulated to have decreases in suitability by 2050 under climate scenario RCP8.5 in the JRB, LRB & ORB at the watershed and cropland level. In the ETRB and NRB, the oil producing crops were simulated to have increases in their suitability. In addition, AquaCrop model was used to simulate the evapotranspiration, yield & water productivity in the JRB, ORB & LRB. The evapotranspiration of the five crop categories was simulated to increase in the three watersheds by 2050. The yields of fruit trees, oil producing crops and vegetables will decrease in the three river basins due to climate change effects. On the other hand, the yield of legumes, wheat & barley was projected to increase in response to global warming and increasing CO_2 concentration. The decrease in yield of the major crops will be higher in the JRB, followed by ORB and LRB, respectively. Moreover, the water productivity of the five crop categories will decrease by 2050 in response to global warming in JRB, ORB & LRB except for the wheat & barley where their WP will experience some increases. In fact, this research highlights an approach of relating crop suitability to yield. The results suggested a relationship between the yield and suitability of the fruit trees, oil producing crops and vegetables in the JRB, ORB & LRB where their suitability and yield were simulated to decrease, whereas there was no relationship between the yield and suitability of legumes, wheat & barley in the three watersheds.

C. Recommendations

More research should be conducted on the subject covering the relationship between crop suitability and yield not only at the watersheds level, but at the country level. Truly, the EcoCrop model was able to simulate the suitability of crops based on climate datasets (mean monthly precipitation and temperature input data), but other factors including socioeconomic conditions and existing land use of the region were not included in the simulations. These features need to be involved in the model to restrict the suitable areas for locations that are favorable to a specific crop. For instance, the simulated suitable areas need to have favorable conditions (i.e. presence of water source) where the suggested suitable locations will not overlap with an urban or forest areas. Moreover, the AquaCrop model simulates the yield in response to water under climate scenarios without taking into consideration the effects of crop diseases and pests which have potentials to further reduce crop yields. Yield assessment needs further consideration taking into account factors other than the climate factors.

APPENDIX

```
clear all ;
tic
% read the excel file which includes the data
ALL = xlsread('3. 2050_RCP85_Data_V2.xlsx') ;

% chose the section (from the excel file) which needs to be sorted as
% required
Data = ALL(:, 3:end ) ;

[ro co] = size(ALL) ;
[roData coData]  = size(Data) ;
warning('off','MATLAB:xlswrite:AddSheet');

Col_to_sort = 6 ;  %how many col-s are to be sorted under each other
for N_location = 1: ro % run over all locations
    Data_needed = Data(N_location, : ) ;

    ii = 1 ; % months counter

    for jj = 1:Col_to_sort:coData % number of months per lcoation
        Data_for_this_location(ii, 1:Col_to_sort) = Data_needed(jj:jj+Col_to_sort - 1);
        ii = ii+1 ; |
    end

    MONTH = 1:12 ; MONTH = MONTH' ;
    YEAR  = ones(12,1) .* 2016 ;
    FINAL = [ YEAR, MONTH, Data_for_this_location ] ;

    % write to text file
    save(sprintf('data%d.txt',N_location),'FINAL','-ascii')

    % delete the data
    clear Data_for_this_location

end
toc
```

Figure 29. The code written in Mathlab software for the generation of the climate text files with the needed format

Table 14. Suitability scores for the major crops for each category in the Jordan River Basin croplands

Croplands of Jordan River Basin (JRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.151	0.061	-0.090	-59
	Grape	0.184	0.079	-0.106	-57
	Average	0.168	0.070	-0.098	-58
Legumes	Alfalfa	0.304	0.151	-0.152	-50
	Chickpeas	0.405	0.226	-0.179	-44
	Average	0.354	0.189	-0.166	-47
Oil Producing	Cotton	0.135	0.048	-0.086	-64
	Maize	0.221	0.101	-0.120	-54
	Olives	0.245	0.236	-0.009	-4
	Average	0.200	0.129	-0.072	-36
Vegetables	Cabbage	0.470	0.261	-0.210	-45
	Cucumber	0.126	0.051	-0.075	-59
	Eggplant	0.003	0.000	-0.003	-100
	Lettuce	0.000	0.000	0.000	0
	Onion	0.713	0.476	-0.237	-33
	Pepper	0.202	0.094	-0.108	-53
	Potato	0.557	0.345	-0.211	-38
	Sugarbeet	0.176	0.066	-0.111	-63
	Tomato	0.282	0.127	-0.155	-55
	Watermelon	0.358	0.171	-0.188	-52
	Average	0.289	0.159	-0.130	-45
Wheat & Barley	Barley	0.556	0.411	-0.144	-26
	Wheat	0.291	0.152	-0.139	-48
	Average	0.423	0.282	-0.142	-33

Table 15. Suitability scores for the major crops for each category in the Litani River Basin croplands

Croplands of Litani River Basin (LRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability

Fruit Trees	Apple	0.715	0.358	-0.357	-50
	Grape	0.508	0.326	-0.182	-36
	Average	0.612	0.342	-0.270	-44
Legumes	Alfalfa	0.722	0.609	-0.113	-16
	Chickpeas	1.000	0.762	-0.238	-24
	Average	0.861	0.686	-0.175	-20
Oil Producing	Cotton	0.507	0.238	-0.269	-53
	Maize	0.508	0.397	-0.111	-22
	Olives	0.066	0.108	0.042	65
	Average	0.360	0.248	-0.113	-31
Vegetables	Cabbage	0.946	0.666	-0.280	-30
	Cucumber	0.609	0.312	-0.296	-49
	Eggplant	0.103	0.007	-0.095	-93
	Lettuce	0.038	0.000	-0.038	0
	Onion	0.925	0.896	-0.029	-3
	Pepper	1.000	0.454	-0.546	-55
	Potato	0.966	0.676	-0.289	-30
	Sugarbeet	0.944	0.331	-0.612	-65
	Tomato	1.000	0.619	-0.381	-38
	Watermelon	0.945	0.823	-0.122	-13
	Average	0.747	0.478	-0.269	-36
Wheat & Barley	Barley	0.779	0.619	-0.160	-21
	Wheat	0.832	0.521	-0.310	-37
	Average	0.805	0.570	-0.235	-29

Table 16. Suitability scores for the major crops for each category in the Orontes River Basin croplands

Croplands of Orontes River Basin (ORB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.294	0.195	-0.099	-34
	Grape	0.364	0.185	-0.178	-49
	Average	0.329	0.190	-0.139	-42
Legumes	Alfalfa	0.470	0.293	-0.178	-38
	Chickpeas	0.598	0.416	-0.181	-30
	Average	0.534	0.355	-0.179	-34

Oil Producing	Cotton	0.304	0.160	-0.144	-47
	Maize	0.415	0.261	-0.153	-37
	Olives	0.109	0.170	0.061	56
	Average	0.276	0.197	-0.079	-29
Vegetables	Cabbage	0.502	0.353	-0.149	-30
	Cucumber	0.252	0.167	-0.085	-34
	Eggplant	0.024	0.010	-0.014	-60
	Lettuce	0.013	0.004	-0.009	0
	Onion	0.617	0.591	-0.026	-4
	Pepper	0.425	0.248	-0.178	-42
	Potato	0.526	0.390	-0.136	-26
	Sugarbeet	0.297	0.169	-0.128	-43
	Tomato	0.456	0.252	-0.204	-45
	Watermelon	0.558	0.327	-0.231	-41
	Average	0.367	0.251	-0.116	-32
Wheat & Barley	Barley	0.540	0.457	-0.083	-15
	Wheat	0.374	0.253	-0.121	-32
	Average	0.457	0.355	-0.102	-22

Table 17. Suitability scores for the major crops for each category in the Euphrates-Tigris croplands

Croplands of Euphrates-Tigris River Basin (ETRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.139	0.099	-0.039	-28
	Grape	0.155	0.110	-0.045	-29
	Average	0.147	0.105	-0.042	-29
Legumes	Alfalfa	0.291	0.194	-0.097	-33
	Chickpeas	0.403	0.318	-0.085	-21
	Average	0.347	0.256	-0.091	-26
Oil Producing	Cotton	0.125	0.122	-0.003	-2
	Maize	0.183	0.208	0.025	14
	Olives	0.051	0.082	0.031	61
	Average	0.120	0.137	0.018	15
Vegetables	Cabbage	0.289	0.268	-0.020	-7
	Cucumber	0.172	0.126	-0.045	-26

	Eggplant	0.009	0.002	-0.007	-76
	Lettuce	0.002	0.000	-0.002	-85
	Onion	0.170	0.392	0.222	130
	Pepper	0.259	0.154	-0.106	-41
	Potato	0.195	0.279	0.084	43
	Sugarbeet	0.159	0.086	-0.073	-46
	Tomato	0.270	0.184	-0.085	-32
	Watermelon	0.349	0.128	-0.221	-63
	Average	0.187	0.162	-0.025	-14
Wheat & Barley	Barley	0.360	0.320	-0.040	-11
	Wheat	0.222	0.151	-0.071	-32
	Average	0.291	0.236	-0.055	-19

Table 18. Suitability scores for the major crops for each category in the Nile River Basin croplands

Croplands of Nile River Basin (NRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.605	0.616	0.011	2
	Grape	0.483	0.467	-0.016	-3
	Average	0.544	0.542	-0.002	0
Legumes	Alfalfa	0.717	0.704	-0.012	-2
	Chickpeas	0.750	0.702	-0.048	-6
	Average	0.733	0.703	-0.030	-4
Oil Producing	Cotton	0.540	0.603	0.063	12
	Maize	0.750	0.758	0.008	1
	Olives	0.558	0.508	-0.050	-9
	Average	0.616	0.623	0.007	1
Vegetables	Cabbage	0.680	0.534	-0.145	-21
	Cucumber	0.587	0.647	0.060	10
	Eggplant	0.298	0.360	0.062	21
	Lettuce	0.287	0.280	-0.007	0
	Onion	0.623	0.426	-0.196	-32
	Pepper	0.735	0.722	-0.013	-2
	Potato	0.602	0.393	-0.209	-35
	Sugarbeet	0.440	0.349	-0.091	-21

	Tomato	0.754	0.671	-0.083	-11
	Watermelon	0.657	0.639	-0.018	-3
	Average	0.566	0.502	-0.064	-11
Wheat & Barley	Barley	0.655	0.562	-0.093	-14
	Wheat	0.548	0.461	-0.087	-16
	Average	0.601	0.512	-0.090	-15

Table 19. Suitability scores for the major crops for each category in the Jordan River Basin

Jordan River Basin (JRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.085	0.039	-0.046	-55
	Grape	0.096	0.043	-0.053	-55
	Average	0.091	0.041	-0.050	-55
Legumes	Alfalfa	0.172	0.088	-0.083	-49
	Chickpeas	0.241	0.138	-0.104	-43
	Average	0.207	0.113	-0.094	-45
Oil Producing	Cotton	0.068	0.025	-0.043	-63
	Maize	0.117	0.054	-0.062	-53
	Olives	0.172	0.147	-0.025	-15
	Average	0.119	0.075	-0.043	-36
Vegetables	Cabbage	0.283	0.156	-0.126	-45
	Cucumber	0.077	0.037	-0.040	-52
	Eggplant	0.002	0.000	-0.002	-90
	Lettuce	0.000	0.000	0.000	0
	Onion	0.443	0.276	-0.167	-38
	Pepper	0.118	0.066	-0.053	-44
	Potato	0.345	0.208	-0.137	-40
	Sugarbeet	0.103	0.046	-0.058	-56
	Tomato	0.160	0.080	-0.079	-50
	Watermelon	0.196	0.099	-0.097	-50
	Average	0.173	0.097	-0.076	-44
Wheat & Barley	Barley	0.374	0.250	-0.124	-33
	Wheat	0.174	0.092	-0.083	-47
	Average	0.274	0.171	-0.103	-38

Table 20. Suitability scores for the major crops for each category in the Litani River Basin

Litani River Basin (LRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.597	0.386	-0.210	-35
	Grape	0.417	0.311	-0.106	-25
	Average	0.507	0.349	-0.158	-31
Legumes	Alfalfa	0.671	0.585	-0.086	-13
	Chickpeas	0.974	0.815	-0.158	-16
	Average	0.822	0.700	-0.122	-15
Oil Producing	Cotton	0.389	0.218	-0.171	-44
	Maize	0.427	0.384	-0.043	-10
	Olives	0.074	0.137	0.064	86
	Average	0.297	0.246	-0.050	-17
Vegetables	Cabbage	0.927	0.766	-0.160	-17
	Cucumber	0.606	0.406	-0.200	-33
	Eggplant	0.142	0.070	-0.073	-51
	Lettuce	0.117	0.056	-0.061	0
	Onion	0.918	0.903	-0.014	-2
	Pepper	0.956	0.583	-0.373	-39
	Potato	0.924	0.761	-0.163	-18
	Sugarbeet	0.804	0.403	-0.401	-50
	Tomato	0.926	0.654	-0.272	-29
	Watermelon	0.788	0.726	-0.062	-8
	Average	0.711	0.533	-0.178	-25
Wheat & Barley	Barley	0.771	0.656	-0.115	-15
	Wheat	0.762	0.541	-0.221	-29
	Average	0.767	0.599	-0.168	-22

Table 21. Suitability scores for the major crops for each category in the Orontes River Basin

Orontes River Basin (ORB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit	Apple	0.195	0.132	-0.062	-32

Trees	Grape	0.221	0.117	-0.104	-47
	Average	0.208	0.125	-0.083	-40
Legumes	Alfalfa	0.306	0.197	-0.109	-36
	Chickpeas	0.402	0.284	-0.117	-29
	Average	0.354	0.241	-0.113	-32
Oil Producing	Cotton	0.181	0.105	-0.076	-42
	Maize	0.252	0.166	-0.086	-34
	Olives	0.075	0.112	0.037	50
	Average	0.169	0.127	-0.042	-25
Vegetables	Cabbage	0.347	0.247	-0.099	-29
	Cucumber	0.177	0.122	-0.055	-31
	Eggplant	0.022	0.014	-0.009	-39
	Lettuce	0.017	0.010	-0.008	0
	Onion	0.428	0.389	-0.039	-9
	Pepper	0.289	0.175	-0.114	-40
	Potato	0.376	0.272	-0.104	-28
	Sugarbeet	0.206	0.115	-0.091	-44
	Tomato	0.313	0.177	-0.136	-43
	Watermelon	0.360	0.217	-0.143	-40
	Average	0.254	0.174	-0.080	-31
Wheat & Barley	Barley	0.408	0.313	-0.096	-23
	Wheat	0.259	0.169	-0.090	-35
	Average	0.334	0.241	-0.093	-28

Table 22. Suitability scores for the major crops for each category in the Euphrates-Tigris River Basin

Euphrates-Tigris River Basin (ETRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.061	0.067	0.005	8
	Grape	0.065	0.064	-0.001	-1
	Average	0.063	0.065	0.002	4
Legumes	Alfalfa	0.167	0.147	-0.020	-12
	Chickpeas	0.279	0.241	-0.038	-14
	Average	0.223	0.194	-0.029	-13
Oil	Cotton	0.050	0.065	0.015	30

Producing	Maize	0.080	0.105	0.025	32
	Olives	0.044	0.041	-0.003	-8
	Average	0.058	0.070	0.012	21
Vegetables	Cabbage	0.244	0.213	-0.031	-13
	Cucumber	0.120	0.093	-0.026	-22
	Eggplant	0.006	0.002	-0.005	-75
	Lettuce	0.002	0.000	-0.002	-88
	Onion	0.205	0.278	0.073	35
	Pepper	0.173	0.132	-0.040	-23
	Potato	0.211	0.223	0.012	5
	Sugarbeet	0.106	0.080	-0.027	-25
	Tomato	0.189	0.154	-0.035	-19
	Watermelon	0.182	0.142	-0.040	-22
	Average	0.144	0.132	-0.012	-8
Wheat & Barley	Barley	0.263	0.249	-0.014	-5
	Wheat	0.156	0.134	-0.023	-14
	Average	0.210	0.191	-0.018	-9

Table 23. Suitability scores for the major crops for each category in the Nile River Basin

Nile River Basin (NRB)					
Crop Category	Crop	Current Suitability	Future Suitability	Change Suitability	% in Change Suitability
Fruit Trees	Apple	0.362	0.364	0.002	1
	Grape	0.256	0.239	-0.017	-7
	Average	0.309	0.302	-0.007	-2
Legumes	Alfalfa	0.424	0.409	-0.015	-4
	Chickpeas	0.416	0.400	-0.016	-4
	Average	0.420	0.404	-0.016	-4
Oil Producing	Cotton	0.336	0.352	0.016	5
	Maize	0.423	0.428	0.005	1
	Olives	0.295	0.289	-0.006	-2
	Average	0.351	0.356	0.005	1
Vegetables	Cabbage	0.389	0.296	-0.094	-24
	Cucumber	0.368	0.397	0.029	8
	Eggplant	0.209	0.247	0.038	18
	Lettuce	0.180	0.152	-0.028	0

	Onion	0.367	0.236	-0.131	-36
	Pepper	0.413	0.406	-0.007	-2
	Potato	0.347	0.215	-0.132	-38
	Sugarbeet	0.234	0.179	-0.056	-24
	Tomato	0.430	0.378	-0.052	-12
	Watermelon	0.356	0.353	-0.003	-1
	Average	0.329	0.286	-0.044	-13
Wheat & Barley	Barley	0.369	0.328	-0.042	-11
	Wheat	0.299	0.254	-0.044	-15
	Average	0.334	0.291	-0.043	-13

Table 24. Evapotranspiration (mm/season) for the major crops in the Jordan River Basin croplands

Croplands of Jordan River Basin (JRB)					
Crop Category	Crop	Current ET (mm/season)	Future ET (mm/season)	Change ET (mm/season)	% in Change ET
Fruit Trees	Apple	779	817	38	5
	Grape	773	803	30	4
	Average	776	810	34	4
Legumes	Alfalfa	1521	1848	328	22
	Chickpeas	462	485	23	5
	Average	991	1167	175	18
Oil Producing	Cotton	664	703	39	6
	Maize	440	458	18	4
	Olives	1573	1883	310	20
	Average	892	1015	122	14
Vegetables	Cabbage	293	307	13	4
	Cucumber	465	491	26	6
	Eggplant	781	821	40	5
	Lettuce	194	201	7	4
	Onion	1003	1133	130	13
	Pepper	776	821	45	6
	Potato	606	628	22	4
	Sugarbeet	608	628	20	3
	Tomato	627	681	54	9
	Watermelon	527	566	39	7

	Average	588	628	40	7
Wheat & Barley	Barley	468	587	119	25
	Wheat	528	648	120	23
	Average	498	618	120	24

Table 25. Biomass (t/ha) for the major crops in the Jordan River Basin croplands

Croplands of Jordan River Basin (JRB)					
Crop Category	Crop	Current B (t/ha)	Future B (t/ha)	Change B (t/ha)	% in Change B
Fruit Trees	Apple	11.6	11.2	-0.3	-3
	Grape	13.7	11.5	-2.1	-16
	Average	12.6	11.4	-1.2	-10
Legumes	Alfalfa	35.3	37.4	2.1	6
	Chickpeas	8.2	7.0	-1.2	-15
	Average	21.8	22.2	0.5	2
Oil Producing	Cotton	12.1	10.4	-1.7	-14
	Maize	8.8	8.1	-0.8	-9
	Olives	30.0	35.4	5.4	18
	Average	17.0	18.0	1.0	6
Vegetables	Cabbage	5.3	4.6	-0.7	-13
	Cucumber	7.7	6.5	-1.1	-15
	Eggplant	14.1	11.7	-2.5	-17
	Lettuce	3.2	2.8	-0.5	-14
	Onion	21.2	21.0	-0.2	-1
	Pepper	15.0	11.7	-3.3	-22
	Potato	11.6	10.2	-1.4	-12
	Sugarbeet	11.8	10.2	-1.6	-14
	Tomato	11.0	9.4	-1.6	-15
	Watermelon	9.0	7.5	-1.4	-16
	Average	11.0	9.6	-1.4	-13
Wheat & Barley	Barley	8.6	13.6	5.0	58
	Wheat	9.7	14.5	4.8	49
	Average	9.2	14.1	4.9	53

Table 26. Yield (t/ha) for the major crops in the Jordan River Basin croplands

Croplands of Jordan River Basin (JRB)					
Crop Category	Crop	Current Y (t/ha)	Future Y (t/ha)	Change Y (t/ha)	% in Change Y
Fruit Trees	Apple	6.1	5.5	-0.5	-9
	Grape	7.2	5.9	-1.3	-18
	Average	6.7	5.7	-0.9	-14
Legumes	Alfalfa	14.2	15.2	1.0	7
	Chickpeas	4.2	3.5	-0.7	-17
	Average	9.2	9.3	0.1	1
Oil Producing	Cotton	6.2	5.2	-1.1	-17
	Maize	7.5	4.2	-3.3	-44
	Olives	12.1	14.3	2.2	19
	Average	8.6	7.9	-0.7	-8
Vegetables	Cabbage	4.5	3.9	-0.6	-13
	Cucumber	3.9	3.3	-0.7	-17
	Eggplant	12.0	5.8	-6.2	-52
	Lettuce	2.7	2.4	-0.4	-14
	Onion	10.7	11.0	0.3	3
	Pepper	12.7	5.8	-6.9	-54
	Potato	6.2	5.3	-0.9	-14
	Sugarbeet	6.3	5.3	-1.0	-16
	Tomato	5.7	4.6	-1.1	-19
	Watermelon	4.6	3.7	-0.9	-20
	Average	6.9	5.1	-1.8	-26
Wheat & Barley	Barley	4.4	6.9	2.5	56
	Wheat	5.0	7.3	2.3	46
	Average	4.7	7.1	2.4	51

Table 27. Water productivity (Kg/m^3) for the major crops in the Jordan River Basin croplands

Croplands of Jordan River Basin (JRB)					
Crop Category	Crop	Current WP (Kg/m^3)	Future WP (Kg/m^3)	Change WP (Kg/m^3)	% in Change WP
Fruit Trees	Apple	0.78	0.68	-0.10	-13
	Grape	0.93	0.73	-0.20	-21
	Average	0.86	0.71	-0.15	-18

Legumes	Alfalfa	0.96	0.85	-0.11	-12
	Chickpeas	0.91	0.72	-0.19	-21
	Average	0.93	0.78	-0.15	-16
Oil Producing	Cotton	0.94	0.73	-0.21	-22
	Maize	1.71	0.92	-0.78	-46
	Olives	0.79	0.78	-0.01	-1
	Average	1.15	0.81	-0.33	-29
Vegetables	Cabbage	1.54	1.28	-0.25	-16
	Cucumber	0.85	0.67	-0.18	-22
	Eggplant	1.54	0.71	-0.83	-54
	Lettuce	1.41	1.17	-0.24	-17
	Onion	1.08	0.98	-0.10	-9
	Pepper	1.64	0.71	-0.93	-57
	Potato	1.02	0.84	-0.17	-17
	Sugarbeet	1.03	0.84	-0.19	-19
	Tomato	0.92	0.68	-0.23	-25
	Watermelon	0.88	0.66	-0.22	-25
	Average	1.19	0.85	-0.34	-28
Wheat & Barley	Barley	0.94	1.16	0.22	23
	Wheat	0.96	1.12	0.16	16
	Average	0.95	1.14	0.19	20

Table 28. Evapotranspiration (mm/season) for the major crops in the Litani River Basin croplands

Croplands of Litani River Basin (LRB)					
Crop Category	Crop	Current ET (mm/season)	Future ET (mm/season)	Change ET (mm/season)	% in Change ET
Fruit Trees	Apple	752	770	18	2
	Grape	838	855	17	2
	Average	795	813	18	2
Legumes	Alfalfa	1300	1552	252	19
	Chickpeas	452	465	13	3
	Average	876	1009	133	15
Oil Producing	Cotton	645	668	23	4
	Maize	439	478	38	9
	Olives	1362	1597	235	17

	Average	816	914	99	12
Vegetables	Cabbage	281	291	10	3
	Cucumber	454	468	14	3
	Eggplant	745	774	29	4
	Lettuce	187	192	5	3
	Onion	884	1005	121	14
	Pepper	741	774	33	4
	Potato	628	680	52	8
	Sugarbeet	625	680	54	9
	Tomato	600	633	33	5
	Watermelon	510	530	21	4
	Average	566	603	37	7
Wheat & Barley	Barley	423	446	23	5
	Wheat	474	497	23	5
	Average	449	472	23	5

Table 29. Biomass (t/ha) for the major crops in the Litani River Basin croplands

Croplands of Litani River Basin (LRB)					
Crop Category	Crop	Current B (t/ha)	Future B (t/ha)	Change B (t/ha)	% in Change B
Fruit Trees	Apple	11.7	12.2	0.6	5
	Grape	15.9	14.7	-1.1	-7
	Average	13.8	13.5	-0.3	-2
Legumes	Alfalfa	27.6	32.6	4.9	18
	Chickpeas	8.4	7.7	-0.6	-8
	Average	18.0	20.2	2.1	12
Oil Producing	Cotton	12.3	11.4	-0.9	-7
	Maize	9.1	9.8	0.8	9
	Olives	26.0	32.3	6.3	24
	Average	15.8	17.9	2.1	13
Vegetables	Cabbage	5.4	5.2	-0.2	-3
	Cucumber	7.9	7.2	-0.6	-8
	Eggplant	14.0	12.7	-1.3	-9
	Lettuce	3.3	3.1	-0.2	-5
	Onion	17.4	19.5	2.0	12
	Pepper	14.8	12.7	-2.2	-15
	Potato	12.6	13.1	0.6	5

	Sugarbeet	12.7	13.1	0.5	4
	Tomato	11.1	10.2	-0.9	-8
	Watermelon	9.1	8.3	-0.9	-10
	Average	10.8	10.5	-0.3	-3
Wheat & Barley	Barley	2.1	5.2	3.1	144
	Wheat	3.0	6.1	3.1	103
	Average	2.6	5.6	3.1	120

Table 30. Yield (t/ha) for the major crops in the Litani River Basin croplands

Croplands of Litani River Basin (LRB)					
Crop Category	Crop	Current Y (t/ha)	Future Y (t/ha)	Change Y (t/ha)	% in Change Y
Fruit Trees	Apple	6.2	6.3	0.0	0
	Grape	8.2	8.0	-0.2	-2
	Average	7.2	7.1	-0.1	-1
Legumes	Alfalfa	11.5	13.3	1.7	15
	Chickpeas	4.4	3.9	-0.5	-11
	Average	8.0	8.6	0.6	8
Oil Producing	Cotton	6.5	5.8	-0.7	-10
	Maize	7.7	4.9	-2.8	-36
	Olives	10.4	13.0	2.6	25
	Average	8.2	7.9	-0.3	-3
Vegetables	Cabbage	4.6	4.4	-0.1	-3
	Cucumber	4.1	3.7	-0.4	-11
	Eggplant	11.9	6.5	-5.4	-46
	Lettuce	2.8	2.7	-0.1	-5
	Onion	9.1	9.9	0.8	9
	Pepper	12.6	6.5	-6.1	-49
	Potato	6.3	6.7	0.4	6
	Sugarbeet	6.4	6.7	0.4	6
	Tomato	5.8	5.2	-0.6	-11
	Watermelon	4.8	4.2	-0.6	-12
	Average	6.8	5.6	-1.2	-17
Wheat & Barley	Barley	1.0	2.5	1.5	149
	Wheat	1.4	3.0	1.6	112
	Average	1.2	2.8	1.6	127

Table 31. Water productivity (Kg/m^3) for the major crops in the Litani River Basin croplands

Croplands of Litani River Basin (LRB)					
Crop Category	Crop	Current WP (Kg/m^3)	Future WP (Kg/m^3)	Change WP (Kg/m^3)	% in Change WP
Fruit Trees	Apple	0.83	0.81	-0.02	-2
	Grape	0.97	0.93	-0.04	-4
	Average	0.90	0.87	-0.03	-3
Legumes	Alfalfa	0.91	0.88	-0.03	-3
	Chickpeas	0.98	0.85	-0.13	-13
	Average	0.94	0.87	-0.08	-8
Oil Producing	Cotton	1.00	0.87	-0.13	-13
	Maize	1.74	1.03	-0.71	-41
	Olives	0.78	0.84	0.05	7
	Average	1.17	0.91	-0.26	-22
Vegetables	Cabbage	1.62	1.53	-0.10	-6
	Cucumber	0.91	0.79	-0.12	-14
	Eggplant	1.60	0.84	-0.76	-48
	Lettuce	1.51	1.39	-0.11	-8
	Onion	1.03	0.99	-0.04	-4
	Pepper	1.70	0.84	-0.87	-51
	Potato	1.01	0.99	-0.02	-2
	Sugarbeet	1.02	0.99	-0.03	-3
	Tomato	0.97	0.82	-0.15	-16
	Watermelon	0.94	0.79	-0.15	-16
	Average	1.23	1.00	-0.23	-19
Wheat & Barley	Barley	0.22	0.56	0.33	149
	Wheat	0.29	0.60	0.31	108
	Average	0.26	0.58	0.32	126

Table 32. Evapotranspiration (mm/season) for the major crops in the Orontes River Basin croplands

Croplands of Orontes River Basin (ORB)					
Crop Category	Crop	Current ET (mm/season)	Future ET (mm/season)	Change ET (mm/season)	% in Change ET

Fruit Trees	Apple	809	816	7	1
	Grape	850	877	27	3
	Average	829	846	17	2
Legumes	Alfalfa	1450	1702	252	17
	Chickpeas	468	486	18	4
	Average	959	1094	135	14
Oil Producing	Cotton	687	702	15	2
	Maize	473	495	22	5
	Olives	1506	1736	230	15
	Average	888	977	89	10
Vegetables	Cabbage	298	304	6	2
	Cucumber	471	492	20	4
	Eggplant	788	816	28	4
	Lettuce	195	202	7	4
	Onion	980	1096	116	12
	Pepper	784	816	32	4
	Potato	673	689	16	2
	Sugarbeet	672	690	18	3
	Tomato	630	673	42	7
	Watermelon	532	561	29	5
	Average	602	634	32	5
Wheat & Barley	Barley	438	489	51	12
	Wheat	488	547	59	12
	Average	463	518	55	12

Table 33. Biomass (t/ha) for the major crops in the Orontes River Basin croplands

Croplands of Orontes River Basin (ORB)					
Crop Category	Crop	Current B (t/ha)	Future B (t/ha)	Change B (t/ha)	% in Change B
Fruit Trees	Apple	11.6	11.2	-0.4	-3
	Grape	15.0	13.3	-1.8	-12
	Average	13.3	12.2	-1.1	-8
Legumes	Alfalfa	33.8	36.6	2.9	9
	Chickpeas	7.7	6.8	-1.0	-12
	Average	20.8	21.7	1.0	5
Oil Producing	Cotton	12.0	10.3	-1.8	-15
	Maize	10.1	9.7	-0.4	-4

	Olives	29.2	35.1	5.8	20
	Average	17.1	18.4	1.2	7
Vegetables	Cabbage	5.4	4.8	-0.6	-12
	Cucumber	7.2	6.3	-0.9	-12
	Eggplant	13.7	11.6	-2.1	-16
	Lettuce	3.2	2.8	-0.3	-10
	Onion	20.4	21.1	0.7	3
	Pepper	14.5	11.6	-2.9	-20
	Potato	13.3	12.1	-1.2	-9
	Sugarbeet	13.5	12.1	-1.4	-10
	Tomato	10.5	9.2	-1.3	-12
	Watermelon	8.4	7.3	-1.1	-13
	Average	11.0	9.9	-1.1	-10
Wheat & Barley	Barley	6.8	10.6	3.8	55
	Wheat	7.9	11.6	3.6	46
	Average	7.4	11.1	3.7	50

Table 34. Yield (t/ha) for the major crops in the Orontes River Basin croplands

Croplands of Orontes River Basin (ORB)					
Crop Category	Crop	Current Y (t/ha)	Future Y (t/ha)	Change Y (t/ha)	% in Change Y
Fruit Trees	Apple	6.0	5.5	-0.5	-9
	Grape	8.0	7.1	-0.9	-12
	Average	7.0	6.3	-0.7	-10
Legumes	Alfalfa	13.7	14.6	0.9	7
	Chickpeas	4.0	3.4	-0.6	-14
	Average	8.8	9.0	0.2	2
Oil Producing	Cotton	6.2	5.1	-1.0	-17
	Maize	8.6	5.0	-3.6	-42
	Olives	11.8	14.0	2.3	19
	Average	8.8	8.1	-0.8	-9
Vegetables	Cabbage	4.6	4.1	-0.5	-12
	Cucumber	3.7	3.2	-0.5	-14
	Eggplant	11.7	5.7	-5.9	-51
	Lettuce	2.7	2.4	-0.3	-10
	Onion	10.4	10.8	0.4	4
	Pepper	12.3	5.7	-6.6	-54

	Potato	6.9	6.4	-0.5	-7
	Sugarbeet	7.0	6.4	-0.6	-8
	Tomato	5.4	4.5	-0.8	-15
	Watermelon	4.3	3.6	-0.7	-17
	Average	6.9	5.3	-1.6	-23
Wheat & Barley	Barley	3.5	5.5	2.0	56
	Wheat	4.2	6.0	1.9	44
	Average	3.9	5.8	1.9	50

Table 35. Water productivity (Kg/m^3) for the major crops in the Orontes River Basin croplands

Croplands of Orontes River Basin (ORB)					
Crop Category	Crop	Current WP (Kg/m^3)	Future WP (Kg/m^3)	Change WP (Kg/m^3)	% in Change WP
Fruit Trees	Apple	0.74	0.67	-0.07	-9
	Grape	0.95	0.81	-0.14	-15
	Average	0.84	0.74	-0.10	-12
Legumes	Alfalfa	0.96	0.88	-0.08	-9
	Chickpeas	0.85	0.70	-0.15	-18
	Average	0.91	0.79	-0.12	-13
Oil Producing	Cotton	0.90	0.73	-0.17	-19
	Maize	1.81	1.01	-0.80	-44
	Olives	0.80	0.82	0.03	3
	Average	1.17	0.85	-0.32	-27
Vegetables	Cabbage	1.55	1.34	-0.21	-14
	Cucumber	0.79	0.65	-0.14	-18
	Eggplant	1.48	0.70	-0.78	-53
	Lettuce	1.39	1.20	-0.19	-14
	Onion	1.07	0.99	-0.07	-7
	Pepper	1.58	0.70	-0.88	-56
	Potato	1.02	0.93	-0.10	-9
	Sugarbeet	1.04	0.93	-0.11	-11
	Tomato	0.85	0.67	-0.18	-21
	Watermelon	0.80	0.64	-0.17	-21
	Average	1.16	0.87	-0.28	-24
Wheat &	Barley	0.80	1.13	0.33	41

Barley	Wheat	0.85	1.10	0.25	30
	Average	0.82	1.11	0.29	35

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