UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF CLIMATE CHANGE IMPACTS ON SOYBEAN AND SUGAR BEET PRODUCTION IN RELATION TO UNCERTAINTY OF GENERAL CIRCULATION MODELS IN IRAN

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HAMIDREZA AHMADZADEH ARAJI

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Earth is faced with dramatic changes in the weather systems due to global warming, which leads to climate change. Climate change affects water resources and crop production especially soybean and sugar beet yield which are major industrial crops in Iran. This study aims to assess the impact of projected climate change on soybean and sugar beet production considering the uncertainty of General Circulation Models (GCMs). Soybean data were collected from four different varieties treated under three irrigation treatments in the field experiments carried out at Karaj Seed and Plant Improvement Institute in two successive years (2010 and 2011). Sugar beet data were also collected from three different genotypes and irrigation treatments in the field experiments carried out at Karaj Sugar Beet Seed Institute in two successive years (2002 and 2003). These data used for calibration and validation of AquaCrop model to simulate yield and biomass of soybean and sugar beet. On the other hand, five and seven GCMs respectively collected from the Fourth and the Fifth Assessment Reports existed in data distribution centre of IPCC. Emission scenarios including B1, A1B, and A2 for AR4, RCP2.6, and RCP8.5 for AR5 were applied to predict future climate change. LARS-WG was downscaled by observed data then the weighting method of Mean Observed Temperature-Precipitation (MOTP) has been used to determine the uncertainty between climate models. Weighted multi model ensemble means for climate change scenarios related to temperature (ΔT) and precipitation (ΔP) applied to LARS-WG to generate ensemble means of temperature and precipitation for the period of 2020-2039 centered on 2030s. These ensemble means were incorporated into the calibrated AquaCrop model to predict final yield and biomass in the future 2030s. The results of statistical analysis between simulated and observed values of yield and biomass for all soybean varieties and sugar beet genotypes at different irrigation levels did not indicate any significant differences between the observed and simulated values. It has been suggested that AquaCrop is a valid model to predict yield and biomass for the study area in the future. The results of Mann-Kendall trend test for the mean of annual minimum temperature (T-min), maximum temperature (T-max), and precipitation (Pre) during 1985-2014 showed that there is an increasing trend in T-min and T-max, while Pre did not have a significant trend. Furthermore, comparison between historical period (1985-2010) and future climatic variables during soybean growing months (July–October) and sugar beet growing months (May-November) indicated that climatic variables increased by the 2030s. The soybean and sugar beet yield, biomass, water productivity based on evapotranspiration (WP_{ET}) and water productivity based on irrigation (WP_{IR}) increased for all treatments in the 2030s. Qualitative yield of soybean and sugar beet was also predicted for 2030s. The result showed that oil content of soybean increased similarly as yield increased in the future period while protein content decreased inversely with yield. It was also predicted that sugar yield and white sugar yield of sugar beet increased similarly as yield increased in the future. The correlation between climatic variables and soybean averaged yield and biomass of four varieties in three irrigation levels showed that correlation coefficients had positive values. Soybean yield and biomass had most significant correlation with T-max at the 99% confidence level in treatments of without water stress and mild water stress whereas in severe water stress soybean yield and biomass had most significant correlation respectively with Pre and T-max at the 95% confidence level. The correlation between climatic variables and sugar beet averaged yield and biomass of three genotypes in three irrigation levels showed that correlation coefficients had positive values. Sugar beet yield and biomass had most significant correlation respectively with T-max and CO_2 at the 99% confidence level in all irrigation treatments. The findings showed that crops could reach an optimal threshold temperature and take advantage of elevated CO_2 rate, which led to increasing of crop production in the future. This research can contribute to the science of impact assessment of climate change on crops, which is significantly important for irrigation water management, agricultural decision-making, and implementing adaptation approaches in the future.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafiah

PENILAIAN IMPAK PERUBAHAN IKLIM TERHADAP PENGELUARAN SOYA DAN BIT GULA MENGAMBILKIRA KETIDAKPASTIAN MODEL PEREDARAN AM DI IRAN

Oleh

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Bumi berhadapan dengan perubahan sistem cuaca yang drastik akibat pemanasan global. Perubahan iklim menjejaskan sumber air dan pengeluaran tanaman terutamanya hasil pengeluaran kacang soya dan bit gula yang merupakan tanaman industri utama di Negara Iran. Kajian ini bertujuan menilai impak perubahan iklim terhadap pengeluaran kacang soya dan bit gula menerusi ketidakpastian Model Peredaran Am (GCMs). Data dari empat varieti kacang soya dikumpulkan di bawah tiga rawatan pengairan di eksperimen lapangan yang dijalankan di *Karaj Seed and Plant Improvement Institute* dalam tempoh dua tahun berturut-turut (2010 dan 2011). Manakala data bit gula pula dikumpulkan dari tiga jenis genotaip dan tiga rawatan pengairan di eksperimen lapangan yang telah dijalankan di *Karaj Sugar Beet Seed Institute* dalam tempoh dua tahun berturut-turut (2002 dan 2003). Data-data ini digunakan untuk tujuan kalibrasi dan validasi model AquaCrop untuk simulasi hasil pengeluaran dan biomas kacang soya dan bit gula. Di samping itu, lima dan tujuh GCMs masing-masing dikumpulkan dari Laporan Penilaian Keempat dan Kelima yang terdapat dalam pusat pengagihan data IPCC. Senario pelepasan seperti B1, A1B, dan A2 untuk AR4, manakala RCP2.6, dan RCP8.5 untuk AR5 digunapakai untuk meramalkan perubahan iklim pada masa hadapan. LARS-WG dikecilkan pada skala kecil mengikut data pemerhatian dimana kaedah pengukuran "Mean Observed Temperature-Precipation" (MOTP) telah digunapakai untuk menentu ketidakpastian di antara model iklim yang lain. Pelbagai model pemberat ensemble purata bagi senario perubahan iklim yang dikaitkan dengan suhu (ΔT) dan hujan (ΔP) telah digunapakai dalam LARS-WG untuk menghasilkan purata suhu dan taburan hujan bagi tempoh 2020-2039 yang tertumpu pada 2030s. Ensemble purata ini dimasukkan ke dalam model AquaCrop yang telah dikalibrasi untuk meramalkan hasil akhir dan biomas pada tahun 2030 nanti. Hasil dapatan dari analisis statistik untuk nilai pengeluaran dan biomass semua jenis kacang soya dan genotaip bit gula yang disimulasikan dan diperhatikan pada tahap pengairan yang berbeza, tidak menunjukkan sebarang perbezaan

yang signifikan di antara nilai pemerhatian dan simulasi. Dengan ini terbukti bahawa AquaCrop adalah model yang sah untuk meramal hasil dan biomas kacang soya dan bit gula untuk kajian pada masa akan datang. Hasil dapatan dari ujian kecenderungan Mann-Kendall untuk purata suhu tahunan minimum (T-min), suhu maksimum (T-maks), dan taburan hujan (Pre) pada tahun 1985-2014 menunjukkan terdapat peningkatan trend untuk T-min dan T-max, manakala Pre tidak menunjukkan trend yang ketara. Selain itu, perbandingan antara tempoh terdahulu (1985-2010) dan pembolehubah iklim pada masa hadapan semasa tempoh penanaman kacang soya (Julai-Oktober) dan tempoh penanaman bit gula (Mei-November) menunjukkan bahawa pembolehubah iklim akan meningkat pada tahun 2030-an. Hasil pengeluaran kacang soya dan bit gula, biomas, produktiviti air berdasarkan kadar evapotranspirasi (WP_{ET}) dan produktiviti air berdasarkan kadar pengairan (WP_{IR}) menunjukkan peningkatan untuk semua rawatan pada tahun 2030-an. Hasil kualiti kacang soya dan bit gula juga turut diramalkan untuk tempoh 2030-an. Keputusan menunjukkan kandungan minyak kacang soya akan turut meningkat bersama peningkatan hasil pengeluaran pada masa akan datang manakala kandungan protein akan berkurangan. Didapati ramalan hasil pengeluaran gula dan gula putih dari bit gula akan turut meningkat bersamai peningkatan hasil pengeluaran pada masa akan datang. Korelasi diantara pembolehubah iklim dengan purata hasil dan biomas bagi empat varieti kacang soya pada tiga paras pengairan menunjukkan pekali korelasi mempunyai nilai positif. Hasil dan biomas kacang soya mempunyai kolerasi yang paling signifikan dengan T-max pada tahap keyakinan 99% dalam rawatan eksperimen tanpa tekanan kekurangan air dan sederhana tekanan kekurangan air manakala tekanan kekurangan air yang teruk menunjukkan kolerasi yang paling signifikan dengan Pre dan T-max pada tahap keyakinan 95%. Manakala, korelasi diantara pembolehubah iklim dengan purata hasil dan biomas bit gula dari tiga genotaip pada tiga paras pengairan menunjukkan pekali korelasi mempunyai nilai positif. Hasil dan biomas bit gula mempunyai korelasi yang paling signifikan dengan T-max dan CO_2 pada tahap keyakinan 99% dalam semua rawatan pengairan. Penemuan ini menunjukkan bahawa tanaman boleh mencapai suhu optimum dan memanfaatkan kadar CO_2 yang tinggi untuk meningkatkan pengeluaran tanaman pada masa akan datang. Disamping itu, kajian ini dapat menyumbang kepada sains penilaian impak perubahan iklim terhadap tanaman, dimana sangat penting untuk pengurusan pengairan, membantu membuat keputusan dalam aktiviti pertanian, dan pelaksanaan pendekatan yang bersesuaian untuk masa akan datang.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANNs	Artificial neural networks
AMIP	Atmospheric Model Intercomparison Project
AOGCMs	Atmosphere-Ocean General Circulation Models
CCA	Canonical correlation analysis
CGC	Canopy growth coefficient
CDC	Canopy decline coefficient
CCA	Canonical correlation analysis
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project Phase 5
CDF	Cumulative probability distribution function
DDC	Data Distribution Centre
ET	Evapotranspiration
AR5	Fifth Assessment Report
AR4	Fourth Assessment Report
GCMs	General Circulation Models
GHG	Greenhouse Gas
HS	Hargreaves–Samani
HI	Harvest index
IPCC	Intergovernmental Panel on Climate Change
K-S	Kolmogorov-Smirnov
LSAT	Land surface air temperature
LAI	Leaf Area Index
LAM	Limited area model

LARS-WG	Long Ashton Research Station-Weather Generator
MK	Mann-Kendall
MBE	Mean bias error
CCX	Maximum canopy cover
MOTP	Mean Observed Temperature-Precipitation
MS	Molasses sugar
NFRD	National recommended fertilizer dose
NMAT	Night marine air temperature
Obs	Observed
ppb	Part per billion
ppmv	Parts per million by volume
PWP	Permanent wilting point
PM	Penman-Monteith
RCBD	Randomized complete block design
RCMs	Regional Climate Models
RCP	Representative Concentration Pathway
RMSE	Root mean square error
RMSEn	Root mean square error normalized
SED	Semi-empirical distribution
SST	Sea surface temperature
Sim	Simulated
SRES	Special Report on Emission Scenarios
SD	Standard deviation
SDSM	Statistical Down Scaling Model
SC	Sugar content

SY	Sugar yield
TAW	Total available water
UNEP	United Nation Environmental Program
VIP	Vegetation Interface Processes
WP	Water productivity
WUE	Water use efficiency
WGEN	Weather Generator
WSC	White sugar content
WSY	White sugar yield
WMO	World Meteorological Organization
NFRD	National recommended fertilizer dose

LIST OF NOTATIONS

G1	7221 Genotype
Ha	Alternative hypothesis
2030s	Averaged of future years 2020-2039
1985-2005	Baseline
B	Biomass
G2	BP-Mashhad Genotype
C	Calibrated
ΔPi	Climate change scenarios related to precipitation
ΔTi	Climate change scenarios related to temperature
R^2	Coefficient of determination
D	Default
E	Evaporation
ET	Evapotranspiration (actual)
FC	Field capacity
1985-2010	Historical period
Ksat	Hydraulic conductivity at saturation
d	Index of agreement
V1	L17 Variety
V4	M7 Variety
V3	M9 Variety
ETx	Maximum evapotranspiration
T-max	Maximum temperature
Yx	Maximum yield

Ō	Mean observed data from yield or biomass
M	Measured
I2	Mild water stress
S	MK statistic
T-min	Minimum temperature
WP*	Normalized crop water productivity
H0	Null hypothesis
Oi	Observed value of yield or biomass
Pre	Precipitation
Pro	Protein
G3	Rasoul Genotype
ET_O	Reference Evapotranspiration
HI_0	Reference harvest index
SAT	Saturation point
I3	Severe water stress
$P_{GCM,base,i}$	Simulated future average precipitation of given years
$T_{GCM,base,i}$	Simulated future average temperature of given years
$P_{GCM,base,i}$	Simulated historical average precipitation of given years
$T_{GCM,base,i}$	Simulated historical average temperature of given years
Pi	Simulated value of yield or biomass
α	Significance level
θ_{SAT}	Soil water content at saturation
θ_{FC}	Soil water content at field capacity
θ_{PWP}	Soil water content at permanent wilting point
Tr	Transpiration

Var(S)	Variance of S statistic
WP_{ET}	Water productivity per unit of evapotranspiration
WP_{IR}	Water productivity per unit of irrigation
Es	Weighted multi-model ensemble means
Wi	Weight of each climate model in month i
V2	Williams*Hobbit Variety
I1	Without water stress
Y	Yield (actual)
Ys	Yield under stress condition
Yp	Yield without stress condition

CHAPTER 1

INTRODUCTION

1.1 General

One of the most significant changes of our planet earth is variation of weather systems, which is defined by the term climate change. Climate change is the alteration of climatic trends due to internal changes within the climate system or external forcing either by natural factors or anthropogenic changes in the atmospheric compositions and land use (Lavell et al., 2012). According to the report of the IPCC (Intergovernmental Panel on Climate Change) 2007, the concentration of carbon dioxide (CO_2) which substantially caused by anthropogenic activities has increased from 280 ppmv just before the industrial era to 379 ppmv in 2005. The highly growth rate of 1.9 ppmv from 1995 to 2005 demystifies the increase of fossil fuel use. Methane is the next gas in which has a large contribution to global warming. Methane (CH4) concentration has risen from 715 ppb before industrial era to 1774 ppb in 2005. Nitrous oxide (N2O) increased by 270 ppb from pre-industrial era to 319 ppb in 2005. Although this increasing rate is slow, the atmospheric lifetime (150 years) is longer than other gases. The increase of Methane and nitrous oxide emission are mostly caused by anthropogenic activities and agriculture (Mavi and Tupper, 2004; Solomon et al., 2007). It is worth mentioning that evidences of observed global average temperature since the mid-20th century have proven that anthropogenic impacts on greenhouse gas concentrations is more significant. In other words distinguished human influences are extended to other climatic patterns such as continental-average temperatures, temperature extremes, wind patterns and ocean warming (Solomon et al., 2007). Atmosphere-Ocean General Circulation Models (AOGCMs) are reliable to predict future climate change, especially at globally and continental scales. These numerical models can interpret a comprehensive three-dimensional representation of the climate system, illustrating dynamical and physical processes, their interactions, and feedbacks. These models can provide a regional estimation of changes in greenhouse gases and aerosol concentration and their impact on future climate (Randall et al., 2007; Ruosteenoja et al., 2003). The IPCC has published SRES (Special Report on Emission Scenarios) to observe future developments in the global environment with reference to production sources of greenhouse gases and aerosol emissions. Some storylines such as A2, A1B, and B1 are defined respectively as the representatives of high, moderate, and low growth rate of future emission scenarios. These emission scenarios, with different demographic, social, economic, technological, and environmental developments in increasingly unalterable ways (IPCC-TGICA, 2007), depict the relationships between the greenhouse gases particularly annual atmospheric CO2 concentration and forces driving aerosol emissions and its development during the 21st century on a global scale. As the climate models became more sophisticated, the IPCC released the latest generations of General Circulation Models for the Fifth Assessment Report (AR5), which were introduced as the fifth phase of the Coupled Model Intercomparison Project (CMIP5). However, as a result of considering land use changes and external forcing such as solar and volcanic forcing at a finer resolution, models were more sophisticated in CMIP5 (Knutti and Sedláček, 2012). Moreover, the new Representative

Concentration Pathway (RCP) with time- and space-dependent trajectories of concentrations of greenhouse gases and other forcing agents are used in CMIP5 as the following scenarios namely; RCP2.6 (very low forcing level), RCP4.5/RCP6 (medium stabilization scenarios) and RCP8.5 (very high baseline emission scenario) (Van Vuuren et al., 2011).

One of the significant impacts of climate change is undoubtedly on water resources and agricultural sectors including economy, society, and environment (Figure1.1). The climate change phenomenon has different consequences on agricultural sectors including lengthening growing seasons at high latitudes, changing crop water demand and yield trends, and development of pest ranges. Therefore, the study of different aspects of climate change plays an important role in environmental adaptation policies and futuristic decision making in the 21century.

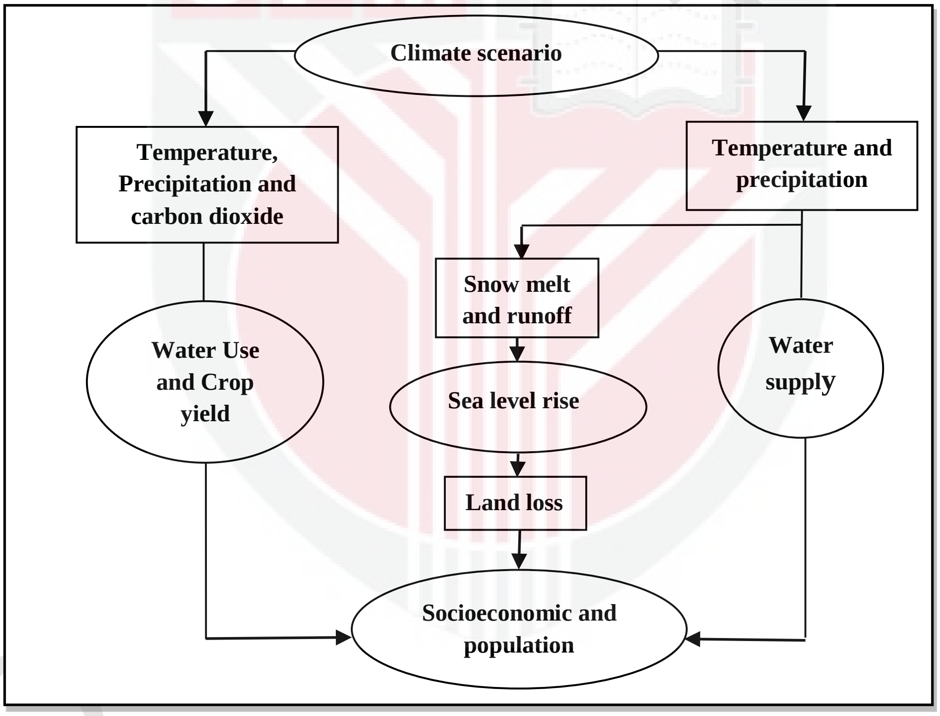

Figure 1.1: Impact of climate change on water resources and agriculture (Mavi and Tupper, 2004)

1.2 Problem statement

Crop yield in Iran like other developing countries is highly vulnerable to climate variability. Soybeans (*Glycine max*) are one of the globally important oil seed crops which are used in feed for livestock and aquaculture, source of protein for the human diet and as a biofuel feedstock (Masuda and Goldsmith, 2009). Sugar beet (*Beta vulgaris*) is an industrial crop with a source sucrose production. Sucrose is a sweet and stable product that can be applied to many foods, drinks, and drugs (Cooke and Scott, 1993). Sugar beet can also be available for feeding to livestock. Therefore, soybean and sugar beet play a pivotal role as industrial crops in the agricultural section of Iran. A research in central India showed that the response of soybean to increase of CO_2 concentrations due to projected climate change is beneficial for yield production due to increased photosynthesis rate. Moreover, a rise in the surface air temperature induces early flowering and shortening the grain fill period (Lal et al., 1999). Elevated CO_2 and temperature induced respectively increase and decrease of root dry mass in sugar beet (Demmers-Derks et al., 1998). However, Impact assessment of climatic variables on crop production differs from region to region. For example, climate change is expected to bring yield increases in northern of Europe with decreases in northern France, Belgium and west/central Poland in the future (2021–2050) (Jones et al., 2003). In current century, the combination of CO_2 enhancement and anticipated thermal stress under different climate change scenarios is in the core of interest for agriculture and industry sectors. Applying crop simulation model is practical method to predict final grain yield and crop biomass (Bannayan et al., 2003). By applying crop models, impacts of climate change on crop are predictable in the future and consequently adaptation approaches with climate change could be implemented. Some approaches such as management of agricultural practices, choosing varieties resistant to water stress, choosing early or late cultivars, changing sowing date, changing irrigation intervals and amount of applied irrigation will mitigate the drawback of climate change impacts on crop production. Moreover, the studies regarding impacts of climate change on soybean and sugar beet yield for different varieties under water deficit conditions are limited. In climate change impacts studies, existing uncertainties should be taken into consideration to produce more accurate outputs. Studies have shown that among different uncertainties, GCM outputs have the most influence on output results (Massah Bavani, 2006; Minville et al., 2008; Prudhomme and Davies, 2007). Notwithstanding the existing studies that have conducted on climate change impacts on different systems along with mitigation and adaptation methods, most studies have concentrated on sensitivity analysis and system vulnerability to one or few climate change scenarios (Alexandrov and Genev, 2003; Brouyère and Dassargues, 2004; Fowler et al., 2004; Gellens and Roulin, 1998; Kamga, 2001; Yates and Strzepek, 1998). Therefore, in climate change studies, the uncertainty sources should be taken into account for better understanding and evaluation of system output. On the other hand, in many studies, the climate models have been selected without considering similarity of GCMs with global pattern of surface temperature. Therefore, not all climate models are suitable enough to apply for impact studies of climate change. In Iran like any other countries impact study of climate change on agricultural sector is still limited. It's also worth mentioning that study of the impacts of climate change on different varieties of soybean and sugar beet by calibration of AquaCrop model and considering uncertainty of AOGCM models in Karaj area has not been studied yet.

In order to decrease uncertainties between climate models, a weighted multi-model ensemble means can apply to GCMs outputs under different emission scenarios such as B1, A1B, A2, RCP2.6, and RCP8.5. Furthermore, although few studies have been done regarding calibration of the AquaCrop model for soybean and sugar beet in some regions, there is a research gap in Iran to predict soybean and sugar beet production by crop modeling specifically for different cultivar reactions under water stress treatments. On the other hand, AquaCrop model has been designed by FAO to simulate quantitative yield response in relation to water supply, but still the model has no capability to simulate qualitative yield. Some linear regression models can be suggested as an additional function to simulate qualitative yield of soybean and sugar beet in the future. Therefore, this study aims to evaluate proposed linear regression models to simulate qualitative yield of soybean and sugar beet and consequently predict their values under projected climate change scenarios. This study also designed for prediction of future changes of other parameters including yield, biomass and water productivity that define soybean and sugar beet production for selected cultivars in the study area for the period 2020-2039 centered on 2030s by considering uncertainty of GCMs outputs.

1.3 Objectives

The main objective of this research is to assess the impact of projected climate change on soybean and sugar beet production considering the uncertainty of General Circulation Models (GCMs). In order to achieve this goal, the following specific objectives are established:

1. To calibrate and validate AquaCrop model for simulation of soybean and sugar beet yield and biomass under experimental plot
2. To generate daily weather data for future period (2020-2039 centered on 2030s) considering uncertainty of GCMs collected from IPCC and downscaled to the local climate
3. To predict soybean and sugar beet yield, biomass, water productivity and their qualitative yields under future climate change scenarios
4. To assess the impact of future climate change on the production of soybean and sugar beet

1.4 Scope of work and limitations

The scope of this study is firstly evaluation of Aquacrop model to simulate yield and biomass of soybean and sugar beet. Secondly, weighted multi-model ensemble means were used to decrease the uncertainty between GCMs. Thirdly, GCM outputs under three emission scenarios (B1, A1B, and A2) and two Representative Concentration Pathways (RCP2.6, and RCP8.5) applied to predict yield and biomass in the future. Finally, the findings of yield, biomass, water productivity, and qualitative yield from the historical (1985-2010) and future period (2030s) compared to investigate the climate change impacts on soybean and sugar beet production.

Due to the lack of information to measure some parameters and input data in the future, for the prediction of crop production, these parameters, and data assumed to be similar to the calibration year. Regardless of weather data, other data related to irrigation, soil, crop parameters, and field management were considered constant in AquaCrop model for prediction of yield and biomass in the future. These limitations may have influence on certainty of final findings. The most important limitation of the AquaCrop model is that pests or diseases are neglected in simulations, which leads to overestimated results of final yield. The model prediction accuracy will be higher if field experimental years could increase. However, authentic data of crop phenology, irrigation, and soil play the most important role in crop modeling therefore this research limited to two years experiments, which were more accurate.

Another limitation in climate change studies is uncertainty between the outputs of GCMs, which in this study weighted multi-model ensemble means method, could minimize uncertainties. Although, using different GCMs and more emission scenarios may represent broad spectra of findings, the technical aspects such as process of GCMs downloading, transforming weather data, downscaling, making scenario files and generation of daily data need super computer and high internet speed for simulation modeling, therefore several GCMs selected from IPCC data center. In climate change studies, there is a limitation to predict climatic variables in each year, which is almost impossible due to the uncertain essence of weather. Moreover, the results of stochastic weather generator (LARS-WG) are reliable on decade periods. Therefore, the average of two decades (2020-2039) was considered in this study.

1.5 Significance of the study

Crop modeling needs to be calibrated for each region in terms of existed microclimate, soil features, irrigation treatments, type of crops and cultivars. In this research, calibration and validation of AquaCrop could fill the gaps in simulation of yield, biomass, and water productivity for two generic crops (soybean and sugar beet) under different varieties and irrigation levels. The results are applicable for irrigation water management and agricultural decision-making in the future.

It is clear that changes in temperature, precipitation, and CO_2 rate in the future will influence crop growth and the final yield. However, studies regarding these variables in Iran are limited, and most investigations have focused on impacts of planting date, drought stress, irrigation regimes, and type of cultivars on growth and yield of crops. In this research the probable impacts of climatic variable during yield formation stages were taken into consideration for yield prediction under projected climate change scenarios.

In this research, weighted multi-model ensemble means, which is a comprehensive method to model the uncertainty of climate models proposed to decrease the uncertainties between GCMs. This method contributes to improve the accuracy of final findings from crop models in impact studies of climate change. Moreover, applying stochastic LARS-WG model for downscaling and making scenario files to generate on daily basis could facilitate daily weather data needed for crop modeling and prediction of crop production under projected climate change scenarios.

In studies regarding the impacts of climate change on crop production the estimation and prediction of qualitative yield is marginalized. On the other hand, AquaCrop model does not cover any function to estimate qualitative yield of crops. In this research based on literature and experimental results, regression models developed in case that crop models suffer from the lack of functions to estimate qualitative yield of crops. However, this method could approximately estimate the values of qualitative yield of crops under projected climate change scenarios in the future.

All in all, this dissertation can be used in impact assessment research and promote to implement some adaptation strategies, which eventually lead to less water consumption, better efficiency in agricultural management and crop productivity enhancement in the future.

1.6 Thesis outline

The thesis is organized in the following manner:
Chapter 1 discussed on general introduction, problem statement, objectives of the study, scope of work and existed limitations, and significance of the study.

Chapter 2 represents a review of climate models, emission scenarios, and downscaling methods. The review has been set on crop modeling, and impacts of climate change on crop production, and uncertainty in climate change studies in different parts of the world, and then focuses on some available related studies in which has already done in Iran.

Chapter 3 introduces the study area, data collection, and available existed data. This chapter describes methods for data analysis and details of models including details and evaluation of AquaCrop model, LARS-WG model, downscaling method, and calculation of uncertainty sources. However, this chapter represents a schematic overview of the flow and integration that follows these methods.

Chapter 4 demystifies the results of calibration and validation of model in experimental years and then discusses the impacts of climate change on crop production (soybean and sugar beet) for the future period for the period 2020-2039 centered on 2030s. Comparison between yield and biomass of soybean and sugar beet for different treatments in the historical period (1985-2010) and predicted future period 2030s under the AR4 and AR5 emission scenarios conducted in this chapter. After that, the values of water productivity and qualitative yield of soybean and sugar beet under historical and future period were discussed. Eventually, impact assessment of climatic variables on soybean and sugar beet production was investigated.

Finally, the summary and conclusions of the thesis, as well as recommendations for the direction of future research are presented in Chapter 5.

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LIST OF PUBLICATION

Ahmadzadeh Araji H, Wayayok A, Khayamim S, Teh CBS, Fikri Abdullah A, Amiri E, Massah Bavani A (2019). Calibration of the AquaCrop model to simulate sugar beet production and water productivity under different treatments. Applied Engineering in Agriculture. (Q4, ISI, IF:0.497)

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International Conference

First International Conference on Water Security (ELSEVIER conference) June17-20, 2018, Toronto, Canada. “Impacts of climate change on evapotranspiration and water productivity of soybean with applying climate models from CMIP3, and CMIP5”.

Fourth World Conference on Climate Change, Conferenceseries, October 19-21, 2017, Rome, Italy. “Impacts of projected climate changes on soybean production in Karaj Region, Iran”.

PAWEES-INWEPF, August 19-21, 2015, Kuala Lumpur, Malaysia. “Simulation of rice yield under water and salinity stress in Rasht area using AquaCrop model”.

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