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Assessing the future yield and water use efficiency of tomato crop: Statistical downscaling approach

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Abstract
A Field experiment was carried out at Ponnaniyar dam, Mugavanur village, Vaiyampatti block of Thiruchirapalli district, Tamil Nadu during the season of November 2016 - April 2017 to assess the impact of climate change on tomato yield over Thiruchirapalli using AquaCrop model. Seasonal maximum and minimum temperatures over Thiruchirapalli are projected to increase in the mid-century under both RCP4.5 and RCP8.5 scenarios. Maximum temperature is expected to increase up to 1.7°C/2.5 °C in SWM and 1.9 °C/2.9°C in NEM by the mid of century as projected through stabilization (RCP 4.5) and overshoot emission (RCP 8.5) pathways. Minimum temperature is expected to increase up to 1.6°C/2.2 °C in SWM and 1.6 °C/2.1°C in NEM by the mid of century as projected through stabilization (RCP 4.5) and overshoot emission (RCP 8.5) pathways. Seasonal rainfall over Thiruchirapalli is expected to decrease with RCP4.5 and RCP8.5scenarios with different magnitude. Rainfall is expected to change to the tune of -1 to -11 per cent in SWM and -2 to -14 per cent in NEM by the mid of century as projected through stabilization of RCP 4.5 and overshoot emission of RCP 8.5 pathways. Tomato yield is expected to decline with the mean decrease of 13 per cent by mid of the century from the current yield levels due to climate change.

Keywords: Climate change, SWM, NEM, RCP

Introduction
Tomato (*Lycopersicum esculentum*, L.) is one of the most important vegetable plants in the world. Global production estimated at 163.96 million metric tons, with China and India as the leading producers in 2013 (Faostat, 2016) [4]. In India, tomato occupies fourth position in area and second position in production. It occupies an area of about 865 hectares under production of 16826 MT and productivity of 19.50 MT. The major producing states are Bihar, Karnataka, Uttar Pradesh, Orissa, Andhra Pradesh, Maharashtra, Madhya Pradesh and Assam. The tomato plant requires significant quantities of water, but not in excess, since tomato roots will not function under waterlogged conditions (Benton, 2008) [1]. Tomato plants are sensitive to water stress and show high correlation between evapotranspiration (ET) and crop yield (Nuruddin *et al.*, 2003) [8]. AquaCrop is a menu-driven program with a well-developed user interface. Algorithms and calculation procedures to model the infiltration of water, the outflow drainage of the root zone, the canopy and root zone development, the evaporation and transpiration rate, the biomass production, and the yield formation are presented (Steduto *et al.* 2009) [11]. The primary objective of this study is to determine quantitatively the expected changes of Tomato yield and water use efficiency in the Thiruchirapalli district of Tamil Nadu for future climate scenarios using AquaCrop model and statistical downscaling technique.

Materials and methods
Location
Field experiment was carried out at Ponnaniyar dam, Mugavanur village, Vaiyampatti block of Thiruchirapalli district, Tamil Nadu during the season of November 2016 - April 2017.

Input requirement for setting up AquaCrop
AquaCrop model uses a relative small number of explicit parameters and largely intuitive input variables, either widely used or requiring simple methods for their determination. Input consists of weather data, crop and soil characteristics, and management practices that define the environment in which the crop will developed.

Impact of current climate variability on water productivity of Tomato
To understand the impact of current variability of climate on water productivity of Tomato weather data at daily time steps for a period from 1980 to 2010 was obtained from the

observatory located at Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Thiruchirapalli. Climate data file was generated with entire dataset of rainfall, maximum temperature, minimum temperature, sunshine hours, wind speed and relative humidity in AquaCrop model. The simulation was performed for 31 years and extracted the required data (fruit yield, ET) from the output file and assessed the impact of climate variability on crop water productivity of Tomato.

Climate projection approach

Future climate projections were created by utilizing "mean and variability" approach, in which the mean monthly changes as well as the magnitude of variability (from baseline) under RCP 4.5, RCP 8.5 for Mid Century time slices, centered around 2055 was applied to the daily baseline weather. These scenarios of future projections were referred to as "mean and variability change scenarios". This procedure was repeated for each of the 29 global climate models (GCMs) listed in table 1.

For the impact analysis, the ensemble (29 climate models data on future climate were ensembled to reduce the uncertainty in projecting the future climate) future climate data was used for the mid-century (2040-2069) time slice based on RCP4.5 and 8.5 scenarios. AquaCrop model forced with the future climatic data and other input files were used similarly which were used with current climatic runs. In the model, the data on the CO_2 concentration respective to RCP4.5 and RCP8.5 are available in the file name of RCP4-5.CO_2 and RCP8-5.CO_2. In .CO_2 file the CO_2 concentration is given based on IPCC data from 1902 to 2100. In the model, defined the CO_2 concentration for future scenarios by choosing CO_2 files corresponding to RCP4.5 and RCP8.5 scenarios. The data were extracted from the model simulations and analysed for evaluating the impact of climate change on water productivity in tomato.

Table 1: Climate models used for future climate projection

Notation		GCMs	Notation		GCMs
A	:	ACCESS1-0	P	:	MIROC-ESM
B	:	bcc-csm1-1	Q	:	MPI-ESM-LR
C	:	BNU-ESM	R	:	MPI-ESM-MR
D	:	CanESM2	S	:	MRI-CGCM3
E	:	CCSM4	T	:	NorESM1-M
F	:	CESM1-BGC	U	:	FGOALS-g2
G	:	CSIRO-Mk3-6-0	V	:	CMCC-CM
H	:	GFDL-ESM2	W	:	CMCC-CMS
I	:	GGFDL-ESM2M	X	:	CNRM-CM5
J	:	HadGEM2-CC	Y	:	HadGEM2-AO
K	:	HadGEM2-ES	Z	:	IPSL-CM5B-LR
L	:	inmcm4	1	:	GFDL-CM3
M	:	IPSL-CM5A-LR	2	:	GISS-E2-R
N	:	IPSL-CM5A-MR	3	:	GISS-E2-H
O	:	MIROC5			

Results and Discussion

Temperature

Maximum and minimum temperature of was projected to increase by the model studied. Though variation in magnitude exist between the scenarios (RCP4.5 and RCP8.5), both projected an increment for maximum and minimum temperatures during mid century time scale, probably due to increased concentration of green house gases in the atmosphere as indicated by IPCC (2014) [5].

Both, the stabilization scenario RCP 4.5 as well as the overshoot scenario RCP 8.5, projected an increase in temperature. Among the monsoons, increase in SWM is (RCP 4.5:1.7°C and RCP 8.5: 2.5°C) maximum temperature, which is comparatively lesser than that of NEM (RCP 4.5: 1.9 °C and RCP 8.5: 2.9°C) for projections through both the scenarios. For minimum temperature, the range of increase projected for SWM (RCP 4.5:1.6°C and RCP 8.5: 2.2°C), which is comparatively higher than that of temperature projections for NEM (RCP 4.5: 1.6°C and RCP 8.5: 2.1°C). A similar higher range of increase during SWM period was also reported by Kothawale and Rupakumar (2005) [7]; Rupakumar *et al.* (2006) [10] over parts of India.

The appreciable difference in the temperature projection between the monsoon seasons could also be attributed to the seasonal wind shifts during monsoon period and the nature of orography in Tamil Nadu (Jegankumar *et al.,* 2012) [6]. Relative change in the magnitude of maximum and minimum temperature was compared. Interestingly, both the RCP scenario has projected a higher range of increase for maximum temperature than that of minimum temperature over Thiruchirapalli during mid-century.

Rainfall

Monsoon rainfall projection over Thiruchirapalli was studied as it plays vital role in rainfed agriculture of Tamil Nadu. Among the monsoons, irrespective of the scenarios, SWM is projected to have a decrease (RCP 4.5: -1 % and RCP 8.5: -11 %) and NEM is also projected to receive a decreased rainfall of 2 (RCP 4.5) and 14 per cent (RCP 8.5). The appreciable difference in the rainfall projection between the monsoon seasons could be attributed to the seasonal wind shifts during monsoon period and the nature of orography in Tamil Nadu (Jegankumar *et al.*, 2012) [6].

Assessing the impact of current climate variability and future climate projection on water use efficiency of tomato

Tomato and WUE was varied over 30 years. Tomato yield varied between -10.3 to 20.5 per cent and WUE varied between -13.6 and 16.8 per cent. Different climatic conditions prevailed during cropping between the years might have influenced yield and WUE of tomato. Climate variability has been principal source of fluctuations in Indian food production. Even though there is no long-term trend, inter - annual variability of Indian monsoon rainfall leading to frequent droughts and floods has profound influence on agriculture (Rajeevan and Pie, 2006) [9].

Results showed that future climate would negatively impact the tomato productivity and WUE. As per RCP 8.5 scenario, tomato yield is expected to decrease in the range of 12.6 to 19.4 per cent with the mean decrease of 13 per cent. WUE is expected to decrease between 3.3 and 15.1 with the mean of 14.3 per cent. In the future WUE reduced might be due to higher crop water requirement (ET) with fewer yields under warming conditions. These results are in harmony with the finding of Weiguang *et al.* (2012) [12]. Doll (2002) [3] found increases in evaporative demands lead to increase the need for irrigation worldwide, with relative changes in total, about +5 to –8 per cent by 2070. Studies undertaken by Chattopadhyay and Hulme (1997) [2] for Indian sub-continent indicated likely increase of potential evapotranspiration for future warming.

The current investigation indicates that extreme rainfall situations such as deficit and excess conditions are affecting the tomato yield and water productivity. Optimization of irrigation through analyzing the response of tomato to deficit and excess rainfall conditions could improve the yield and WUE of tomato.

Impact of climate change on tomato and water use efficiency (WUE)

Results showed that future climate would negatively impact the *Rabi* tomato productivity as well as WUE and the impact is expected to be more with RCP8.5 while negligible changes is expected with RCP4.5 (Fig.1). Tomato yield is expected to decrease in the range of 12.6 to 19.4 per cent with the mean decrease of 13 per cent. WUE is expected to decrease between 3.3 and 15.1 with the mean of 14.3 per cent.

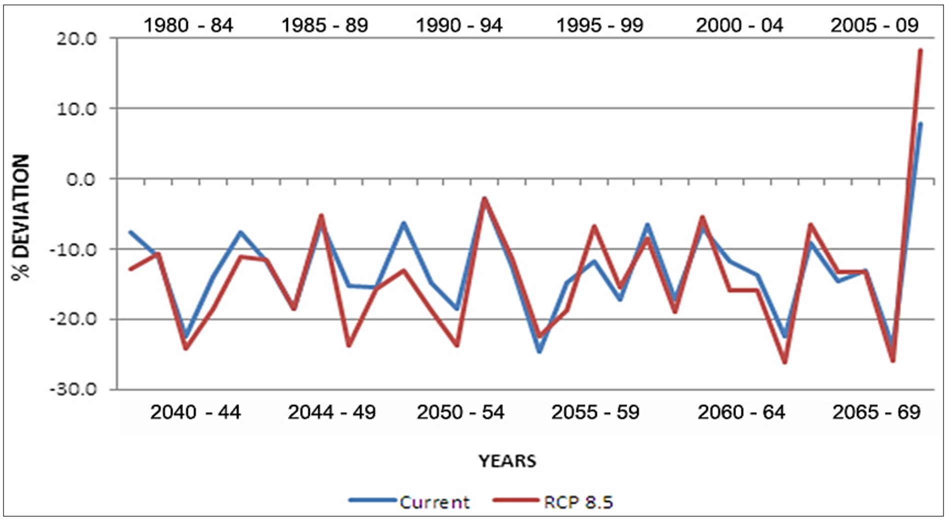

Fig 1: Deviation of tomato yield under Current and RCP 8.5 future scenario

From the study, it could be understood that varied climatic condition (deficit and excess) affects the tomato yield and WUE considerably. Study proved that optimizing the irrigation through the investigation of occurrence of water stress and adopting suitable irrigation schedule with sufficient amount of water would increase the tomato yield and WUE.

Conclusion

Tomato productivity is expected to decline in the range of 12.6 to 19.4 per cent with the mean decrease of 13 per cent by mid of the century from the current yield levels due to climate change. In future, under warming conditions the WUE is expected to decrease between 3.3 and 15.1 with the mean of 14.3 per cent. The irrigation water requirement (IWR) is expected to shoot up under future warmer climatic conditions at the rate of 4 to 8.1 per cent and 4.5 to 14.7 per cent in the mid and end century respectively.

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