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Uncertainties in future climate projections and consequential impact on maize productivity

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सार – भविष्य की जलवायु को प्रक्षेपण करने और फसल की पैदावार पर उसके प्रभाव का आकलन करने में बड़ी अनिश्चितता मौजूद है। दक्षिणी भारत में तमिलनाडु पर भविष्य की जलवायु को प्रक्षेपित करने की समस्या का समाधान करने के लिए आईपीसीसी के युग्मित मॉडल अंतर तुलना परियोजना (सीएमआईपी 5) के तहत परिभाषित 29 ग्लोबल सर्कुलेशन मॉडल को वर्तमान स्थिति से भविष्य की जलवायु में विचलन की सीमा को समझने के लिए नियोजित किया गया। मध्य शताब्दी में इसके प्रभाव मूल्यांकन के लिए प्रतिनिधि सघन मार्ग (आरसीपी) 4.5 और 8.5 परिदृश्यों के उत्पादों को संसाधित किया गया। तमिलनाडु में मक्का उत्पादकता में स्थानिक परिवर्तनशीलता पर प्रभाव का आकलन करने के लिए चयनित मॉडल उत्पाद को गतिशील फसल सिमुलेशन मॉडल (डीएसएसएटी) में लाया गया और संभावित अनुकूलन विकल्पों के प्रभावों को कम करने के लिए तैयार किया गया । मध्य शताब्दी में पूर्वोत्तर मानसून (एनईएम) के दौरान आरसीपी 4.5 के लिए अधिकतम तापमान 2.0 डिग्री सेल्सियस और आरसीपी 8.5 के लिए 3.0 डिग्री सेल्सियस बढ़ने की उम्मीद है जबकि न्यूनतम तापमान में आरसीपी 4.5 के लिए 1.8 डिग्री और आरसीपी 8.5 के लिये 2.4 डिग्री सेल्सियस बढ़ने की उम्मीद है। वर्षा आरसीपी 4.5 के लिए -22.8 से 21.1% और आरसीपी 8.5 के लिए -31.3 से 32.6% के बीच होने का अनुमान है। उपज में गिरावट 4.5 (10.6%) के परिदृश्य में आरसीपी 8.5 (30.7%) से अधिक होगी। आरसीपी 4.5 और आरसीपी 8.5 परिदृश्यों के तहत 15 सितंबर (सामान्य बुवाई) के मुकाबले बुवाई की तारीख को बदलकर 1 सितंबर (जल्दी बुवाई) करने से भविष्य के जलवायु परिवर्तन के प्रभावों को कम किया जा सकता है। उर्वरक की (25%) अतिरिक्त खुराक ने सकारात्मक प्रतिक्रिया दी और भविष्य की जलवायविक परिस्थितियों में उपज में 15% तक की वृद्धि हुई।

ABSTRACT. There exist a huge uncertainty cascade in projecting the future climate and in-turn using the same in assessing the impact on crop yields. To address the problem of projecting the future climate over Tamil Nadu in Southern India, 29 Global Circulation Models defined under coupled model inter comparison project (CMIP5) of IPCC were employed for understanding the range of deviations in future climate from current condition. Outputs of representative concentration pathway (RCP) 4.5 and 8.5 scenarios for mid-century were processed for impact assessment. Selected models output was forced in dynamic crop simulation model DSSAT for assessing the impact on spatial variability in maize productivity over Tamil Nadu and possible adaptation options were tailored for reducing impacts. During the Northeast Monsoon (NEM), the maximum temperature is expected to rise by 2.0 °C for RCP 4.5 and 3.0 °C for RCP 8.5, while the minimum temperature is expected to rise by 1.8 °C for RCP 4.5 and 2.4 °C for RCP 8.5 in the mid-century. Rainfall is anticipated to vary from -22.8 to 21.1% for RCP 4.5 and -31.3 to 32.6% for RCP 8.5. The magnitude of decline in yield would be more in RCP 8.5 (30.7%) over RCP 4.5 (10.6%) scenario. Impacts of future climate change could be reduced by altering the date of sowing (early sowing) to September 1st against September 15th (normal sowing) under RCP 4.5 and RCP 8.5 scenarios. Additional dose of (25%) fertilizer had positive response with yield increase up to 15% under future climatic conditions.

Key words – Climate models, Future climate, Uncertainty, Maize productivity.

1. Introduction

Climate change has become one of the most important issues around the globe in recent times and it has become a more complex issue than before. Though changing climate is a global issue, its effects are experienced by the people at a scale of regional to local (IPCC, 2007). Developing and executing adaptation actions for reducing the impacts of climate change is complicated due to its diverse and multi-dimensional nature (Barnett *et al*., 2005; Vergara *et al*., 2007). Hence, there is a need to identify the past observed trends and project the future changes in the climate. To forecast the future climate, several institutes around the globe have developed both global climate models (GCMs) and regional climate models (RCMs). However, the projected changes in future climate widely vary among the models based on the model physics causing greater uncertainty, which is a serious concern and need to be addressed. Realistic assumptions about the future atmospheric concentrations of the greenhouse gasses are made, known as climate scenarios. The recent emission scenarios, representative concentration pathways (RCPs) indicated range of scenarios based on socio-economic and technological developments. Future climates projected through the scenarios are utilized in sectorial impact assessments.

Agriculture is highly vulnerable to environment and is one of the most vulnerable sectors affected by climate change (Reilly, 1995; Smith and Skinner, 2002). Impacts of climate change on crop growth and productivity are simulated by employing climate model coupled with a mechanism-based crop growth model. Crop simulation models relate the dynamics of weather-soil-crop interactions to predict the crop growth and productivity.

As a coastal state, Tamil Nadu is highly vulnerable to seasonal fluctuations in rainfall, temperature, relative humidity, wind speed, etc., resulting in instability in agricultural output. Studies on climate projections over Tamil Nadu confirm the higher probability for the occurrence of climate related hazards with increased frequency and intensity and its resultant negative impact on agriculture (TNSAPCC, 2014). Maize (*Zea mays* L.), called 'Queen of the Cereals' is grown widely in Tamil Nadu, during *kharif* season with supplemental irrigation and in *Rabi* season as rainfed crop. Due to high rainfall variability, maize crop productivity is highly fluctuating during the Rabi season and is projected to be more risky in the future warmer climate (Stone *et al*., 2009). Hence, its impact needs to be assessed for changing climatic conditions and adaptation strategies tailored for sustaining food security. The current study was undertaken with the objectives of assessing the uncertainty in future climate projections over

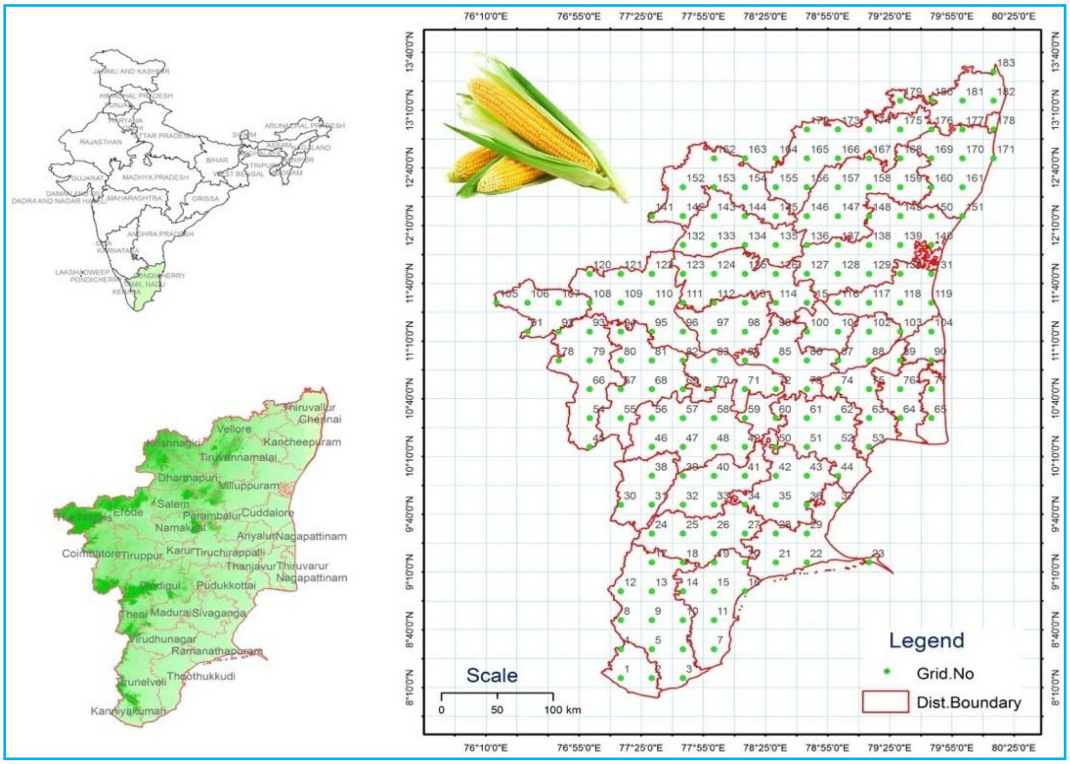


Fig. 1. Study area and choice of crop

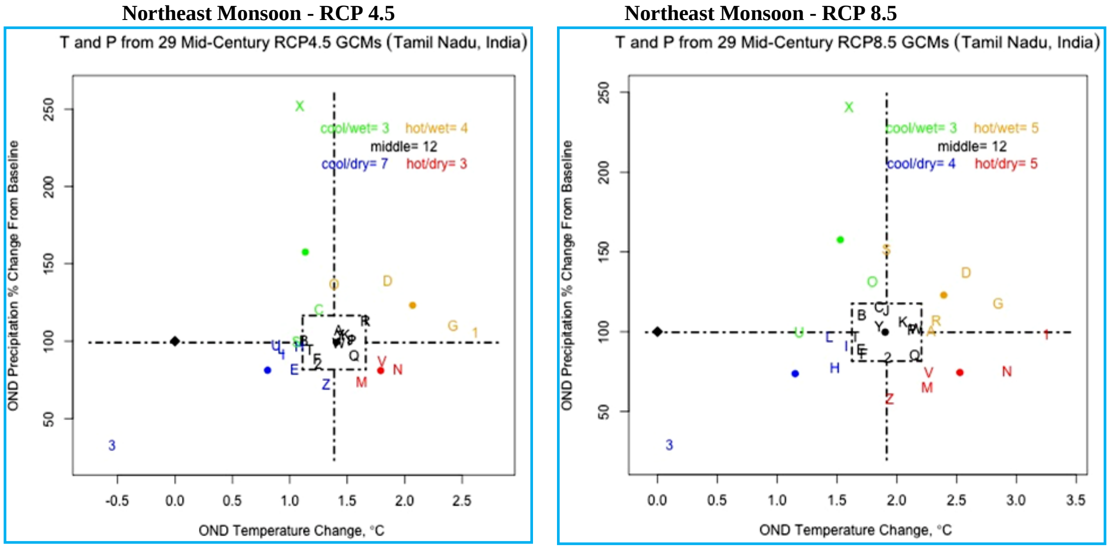


Fig. 2. Scatter plot of representative grid in central Tamil Nadu - Change in precipitation and temperature

TABLE 1

Climate models used for future climate projection

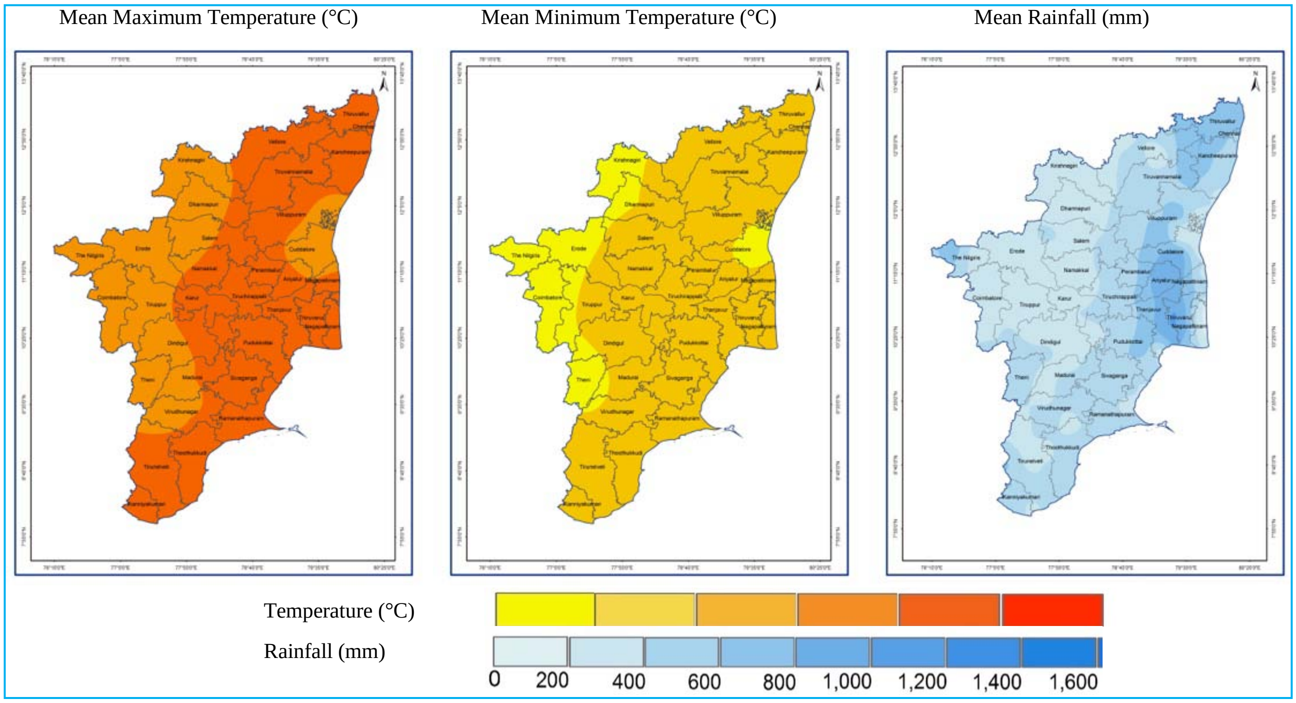
Notation	GCMs	Notation	GCMs	Notation	GCMs
A	ACCESS1-0	K	HadGEM2-ES	U	FGOALS-g2
B	bcc-csm1-1	L	inmcm4	V	CMCC-CM
C	BNU-ESM	M	IPSL-CM5A-LR	W	CMCC-CMS
D	CanESM2	N	IPSL-CM5A-MR	X	CNRM-CM5
E	CCSM4	O	MIROC5	Y	HadGEM2-AO
F	CESM1-BGC	P	MIROC-ESM	Z	IPSL-CM5B-LR
G	CSIRO-Mk3-6-0	Q	MPI-ESM-LR	1	GFDL-CM3
H	GFDL-ESM2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

Tamil Nadu state in India and its associated influence on rainfed maize productivity, besides developing adaptation options to reduce the impacts of changing climate.

2. Materials and method

Tamil Nadu state, located in the southernmost part of India, lying between 8°05' and 13°35' N latitude and 76°15' and 80°20' E longitude, was considered for investigation. The climate and impact analysis was made at 0.25 × 0.25 degree grid resolution as represented in the Fig. 1.Maize hybrid CO 6 which is the main cultivar in the study region was considered for impact assessment. To recognize the current climate variability over the state of Tamil Nadu, 0.25 × 0.25 degree gridded reanalysis rainfall data developed by India Meteorological Department (IMD) was used. District level daily maximum and minimum temperature data of IMD was downscaled to match with the rainfall grid points. Solar radiation data were generated by the weather generator tool embedded in DSSAT model for each grid using maximum and minimum temperatures. All the data were accumulated for a uniform time period of 30 years from 1981 to 2010 for the current climate analysis.

Future climate projections were created employing 29 global climate models (GCMs) listed in Table 1, by utilizing "mean and variability" approach as described by



Mean Maximum Temperature (°C)

Mean Minimum Temperature (°C)

Mean Rainfall (mm)

Fig. 3. Spatial distribution of baseline weather parameters over Tamil Nadu during maize growing (NEM) season

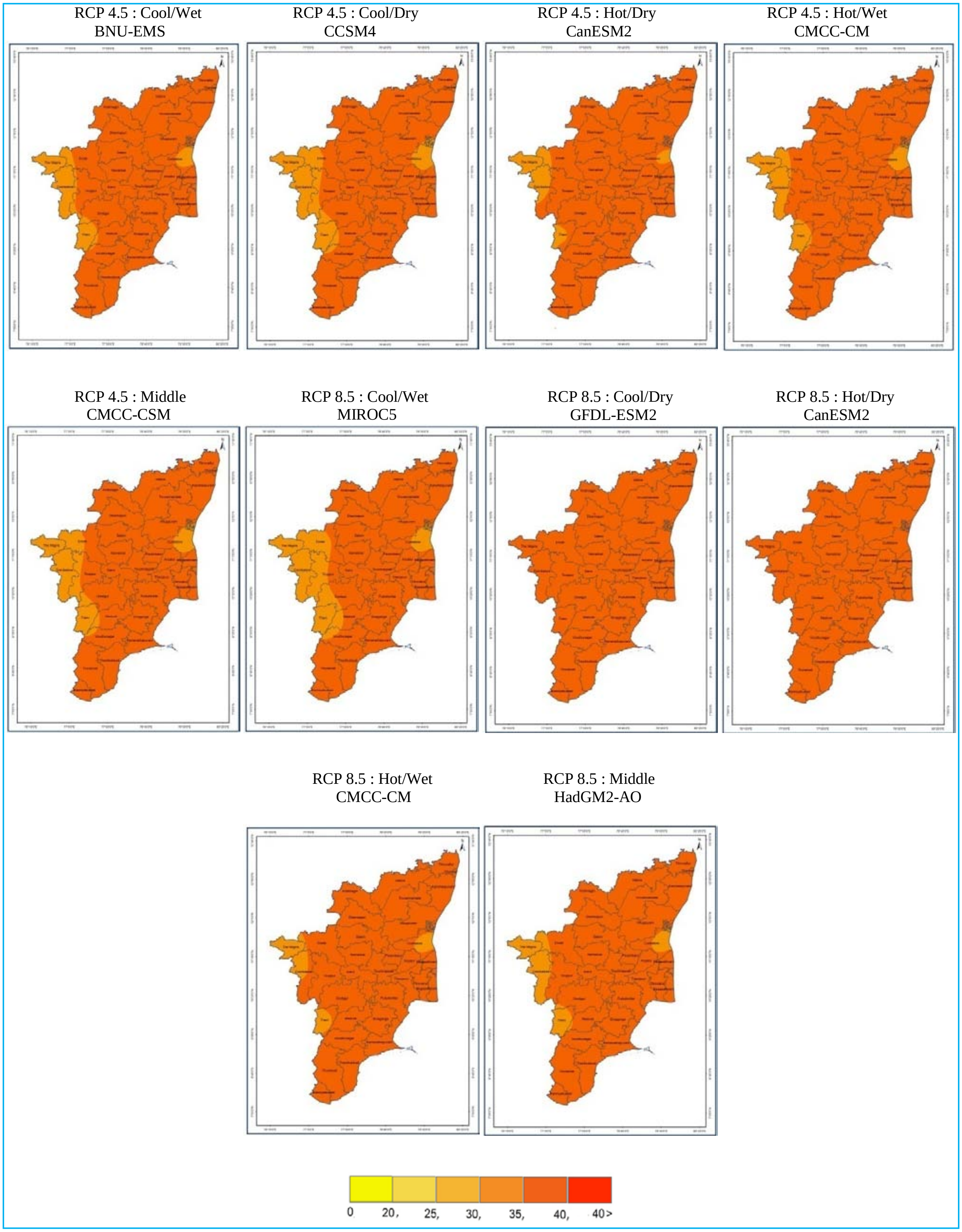
Villegas and Jarvis (2010). Mean monthly changes along with its magnitude of variability projected under RCP 4.5 and RCP 8.5 for the mid-century period (2040-2069) centred around 2055 were integrated with the daily baseline weather series to develop future climate files.

A scatter plot was created to represent climate models with their magnitude of future change in temperature in horizontal axis and rainfall in vertical axis (Fig. 2). With regard to rainfall on the *y*-axis, the value of 100% does not indicate any change in future rainfall, 80 percentage indicates a 20 percentage reduction in rainfall and 120 percentage indicates a 20 percentage increase in future rainfall compared to the baseline. The variations in the temperature in the *x*-axis represent the actual difference between the expected temperature and the baseline.

One standard deviation for all the 29 GCM points representing projected rainfall and temperature was calculated to create a central box within the scatter plot. Cutting across the middle of the central box in vertical and horizontal directions, other four boxes were formed similar to 2×2 matrix.

Among the 29 models, the models that project increased precipitation with lesser magnitude of increase in temperature fall in the top left corner box and are labelled as cool/wet. Similarly, top right corner box as hot/wet, bottom left projects cool/dry and the bottom right signifies hot/dry future climatic conditions. The models that fall in the central box represents mean change in future rainfall and temperature from the current condition. A prominent dot represented the ensemble values of all the models in each of the boxes, while individual models were either indicated as an alphabets or numerals. One model that is close to the ensemble point in each of the five boxes were selected to represent possible five different future circumstances.

For Tamil Nadu, five climate models that stood out commonly for the Northeast monsoon (NEM) period in which the rainfed maize is mainly grown was selected to perform the integrated assessment (IA) by interlinking its outputs with DSSAT, dynamic crop simulation model. The future climate projections of five climate models for RCP 4.5 scenario are: BNU-EMS (Cool/Wet scenario); CCSM4 (Cool/Dry); CMCC-CSM (Middle); CanESM2 (Hot/Wet) and CMCC-CM (Hot/Dry) and for RCP 8.5 scenarios are: MIROC5 (Cool/Wet scenario); GFDL-ESM2 (Cool/Dry); HadGM2-AO (Middle); CanESM2 (Hot/Wet) and CMCC-CM (Hot/Dry). The DSSAT model simulated the crop yields to understand the uncertainty cascaded as a result of projected climate. Specific adaptation strategies such as changing the sowing window, adding an additional 25 percent dose of nitrogen



RCP 4.5 : Cool/Wet
BNU-EMS

RCP 4.5 : Cool/Dry
CCSM4

RCP 4.5 : Hot/Dry
CanESM2

RCP 4.5 : Hot/Wet
CMCC-CM

RCP 4.5 : Middle
CMCC-CSM

RCP 8.5 : Cool/Wet
MIROC5

RCP 8.5 : Cool/Dry
GFDL-ESM2

RCP 8.5 : Hot/Dry
CanESM2

RCP 8.5 : Hot/Wet
CMCC-CM

RCP 8.5 : Middle
HadGM2-AO

Fig. 4. Projected NEM (Oct-Dec) maximum temperature (°C) for RCP 4.5 and RCP 8.5 scenarios

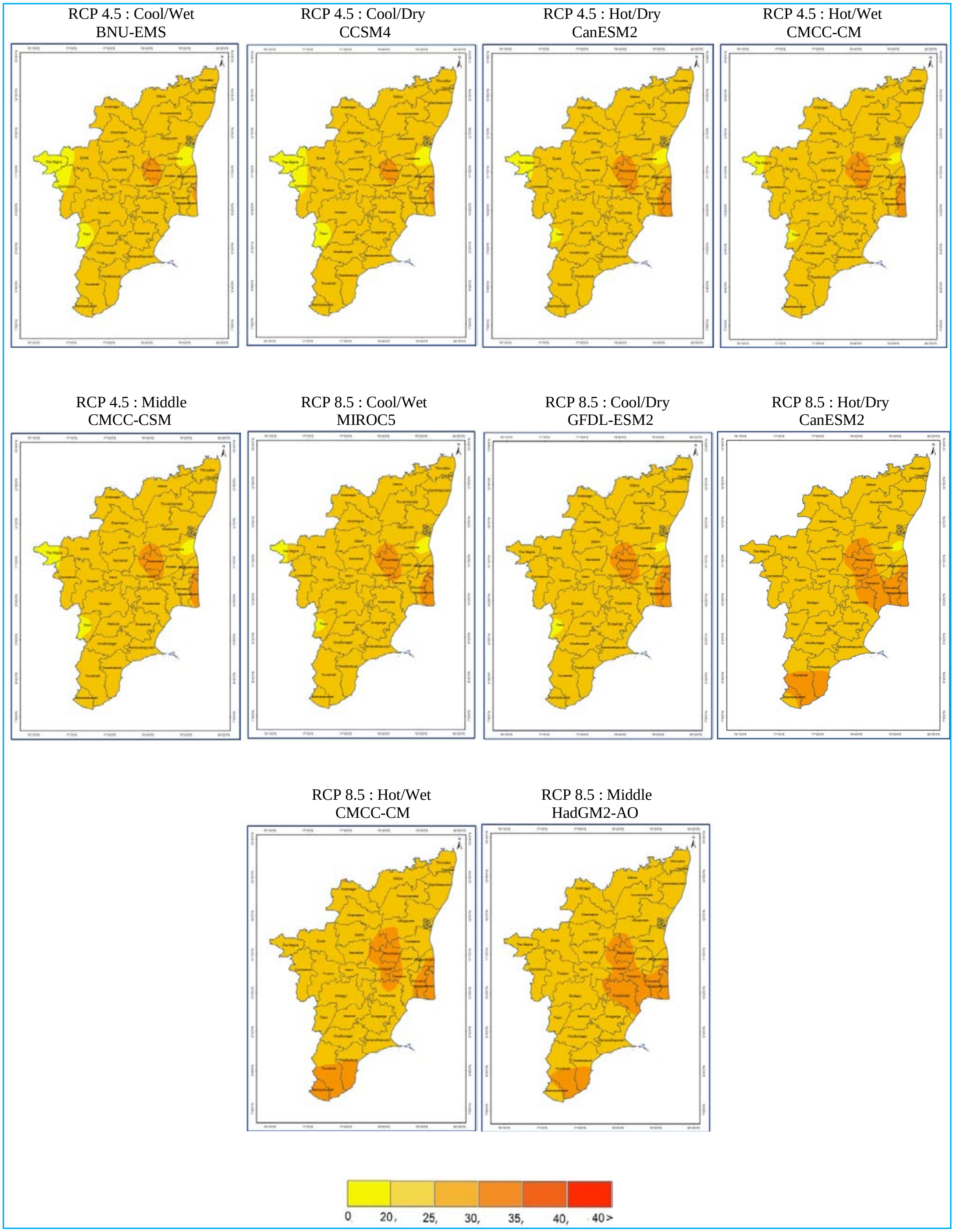


Fig. 5. Projected NEM (Oct-Dec) minimum temperature (°C) for RCP 4.5 and RCP 8.5 scenarios

TABLE 2

Baseline climate over Tamil Nadu during rainfed maize growing (NEM) season

Parameters	Mean	Maximum	Minimum	Standard Deviation
Maximum temperature (°C)	30.0	31.2	27.7	1.1
Minimum temperature (°C)	21.5	23.2	18.0	1.6
Rainfall (mm)	460	992	99	214
Rainy days (Days)	25	43	8	8

fertilizer and supplementing irrigation (50 mm) during the flowering stage were also tested for its suitability in the future situation.

3. Results and discussion

3.1. *Baseline climate of Tamil Nadu*

Tamil Nadu's observed climate and variability were analyzed for maximum temperature, minimum temperature, rainfall and rainy days during the northeast monsoon season during which the rainfed maize is grown. Tamil Nadu's maximum temperature ranged from 27.7 °C to 31.2 °C during the northeast monsoon season with a standard deviation of 1.1 °C. The minimum temperature with a standard deviation of 1.6 °C ranged from 18.0 °C to 23.2 °C. Minimum temperature had the highest standard deviation as compared with maximum temperatures. Rainfall from all the grid points was averaged for 30 years of study period (1981 to 2010). Tamil Nadu's mean rainfall was found to be 460 mm during NEM, ranging from a minimum of 99 mm to a maximum of 992 mm with a standard deviation of 214 mm. Mean number of rainy days during NEM was 25 (Table 2).

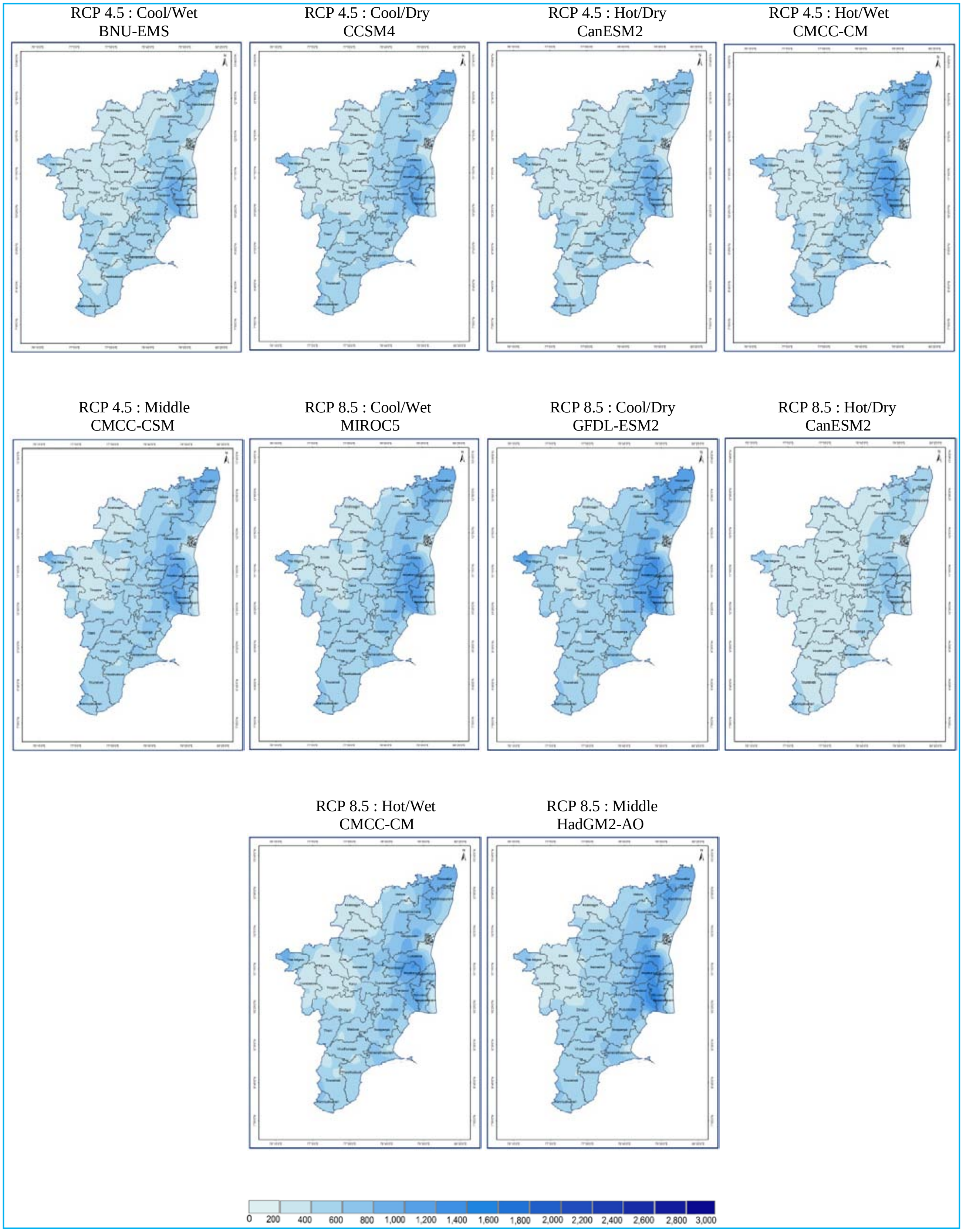
Spatial variation in temperature and rainfall is also observed over Tamil Nadu (Fig. 3). Higher temperatures are recorded along the east coast region, central and southern Tamil Nadu. The East Coast region receives more rainfall and the quantity of rainfall is decreasing towards the inland region. Grid-wise rainfall analysis revealed that 43.7 per cent of the grids (80 grids) receive a rainfall between 201 and 400 mm followed by 37.2 per cent (68 grids) had 401 to 600 mm of rainfall with CV ranging from 36 to 74 and 33 to 67 per cent respectively. Around 14.2 per cent of the grids (26 grids) receive 601 to 800 mm of rainfall with CV varying between 29 and 57 per cent. Less than 4.9 per cent of grids (9 grids) receive 801 to 1000 mm of rainfall with a CV of 28 to 43 per cent.

3.2. *Future climate projections over Tamil Nadu*

Climate projections from five selected GCMs for NEM season over the mid-century time period was compared at grid to grid level to extract the projected change for understanding the spatial variability. All the five models studied for RCP 4.5 scenario, *viz*., BNU-ESM, CanESM2, CCSM4, CMCC-CM, CMCC-CMS for the five different future scenarios over all the locations of Tamil Nadu was projected to increase for the maximum temperature (Fig. 4) ranging between 0.1 °C (CCSM4) and 4.7 °C (CMCC-CM) increase. The lowest increase was projected over north-eastern parts of Tamil Nadu while highest increase was noticed over north-western parts. The five climate models chosen in scenario RCP 8.5, *viz*., GFDL-ESM2, MIROC5, HadGEM2-AO, CanESM2 and CMCC-CM revealed an increase of 0.7 °C (GFDL-ESM2) to 4.7 °C (CanESM2), with the lowest increase over north-eastern parts and highest increase over north-western parts of Tamil Nadu.

Minimum NEM temperature (Fig. 5) was projected to rise from 0.5 °C (BNU-ESM) to 4.9 °C (CMCC-CM) in the RCP 4.5 scenario and from 1.3 °C (MIROC 5) to 5.5 °C (CMCC-CM) in the RCP 8.5 scenario with the lowest increase over the northeast and Cauvery delta zone while the highest increase was projected over the northwest zone of Tamil Nadu. Rajiv Kumar *et al*. (2012) have reported similar findings of temperature increase with differing magnitude under stabilization scenario (RCP 4.5) as well as the overshoot scenario (RCP 8.5). Higher level of temperature increase under RCP 8.5 scenario could be due to increased atmospheric concentration of greenhouse gases that would trap more heat (IPCC, 2014).

Among the models segregated under the five bins, the Hot-Dry (CanESM2) and Hot-Wet (CMCC-CM) had projected the higher range of increase in temperature under both RCP scenarios. Similarly, the Cool-Wet (BNU-ESM and MIROC5) or the Cool-Dry (CCSM4 and GFDL-ESM2) models projected the lower range of increase in maximum and minimum temperatures. The parameters considered by individual models and the disparity in model physics could have led to variation of the temperature projection range by different climate models (Diallo *et al*., 2012).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RCP 4.5 : Hot/Wet
CMCC-CM

RCP 4.5 : Middle
CMCC-CSM

RCP 8.5 : Cool/Wet
MIROC5

RCP 8.5 : Cool/Dry
GFDL-ESM2

RCP 8.5 : Hot/Dry
CanESM2

RCP 8.5 : Hot/Wet
CMCC-CM

RCP 8.5 : Middle
HadGM2-AO

Fig. 6. Projected NEM (Oct-Dec) rainfall (mm) for RCP 4.5 and RCP 8.5 scenarios over Tamil Nadu

TABLE 3

Variation in rainfall projected over Tamil Nadu across scenarios

% Change in rainfall with RCP 4.5				% Change in rainfall with RCP 8.5			
Bins	Models	Highest	Lowest	Bins	Models	Highest	Lowest
Cool/Dry	CCSM4	14.0	-11.8	Cool/Dry	GFDL-ESM2	60.2	6.0
Cool/Wet	BNU-ESM	33.8	-28.4	Cool/Wet	MIROC 5	28.6	-4.1
Hot/Wet	CMCC-CM	57.5	-19.5	Hot/Wet	CMCC-CM	52.0	-10.5
Hot/Dry	CanESM2	21.5	-22.5	Hot/Dry	CanESM2	32.2	-31.6
Middle	CMCC-CMS	44.4	-3.6	Middle	HadGEM2-AO	42.1	-2.7

TABLE 4

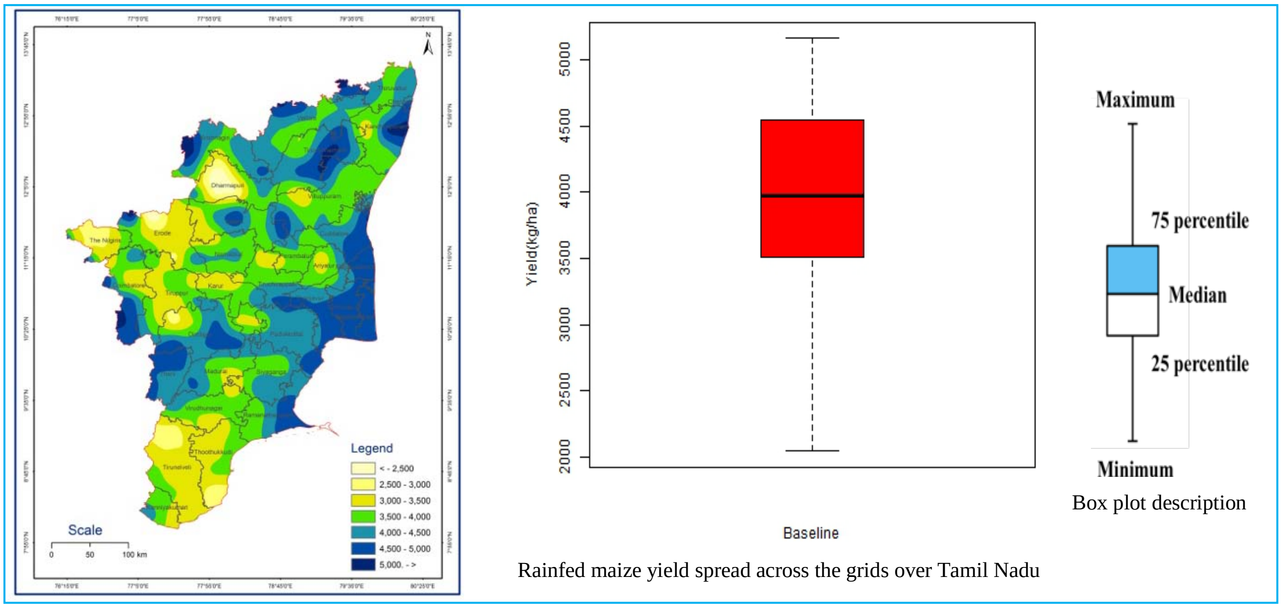
Spatial variability of baseline maize yield (mean of 1981-2010) over Tamil Nadu

Yield class (kg/ha)	Frequency (No. of grids)	% of grids	Mean yield(kg/ha)	SD(kg/ha)	CV(%)
< 2500	3	1.6	2249	224.0	10.0
2500 - 3000	6	3.3	2789	131.8	4.7
3001 - 3500	36	19.8	3249	143.0	4.4
3501 - 4000	51	28.0	3769	144.1	3.8
4001 - 4500	38	20.9	4208	141.0	3.4
4501 - 5000	43	23.6	4707	138.8	2.9
>5001	5	2.7	5062	69.6	1.4
Total	182	100	3958	635.2	16.0

Rainfall during NEM (Table 3 and Fig. 6) was projected to differ from -28.4% (BNU-ESM) to + 57.5% (CMCC-CM) as per the RCP 4.5 scenario and RCP 8.5 projected a variance between -31.6% (CanESM2) and + 60.2% (GFDL-ESM2). The spatial distribution of NEM rainfall predicted by RCP 4.5 showed that all models with the exception of CanESM2 and BNU-ESM had estimated increase in rainfall in large numbers of grids. According to RCP 4.5 scenario up to 20 per cent decrease in rainfall is expected for 93, 85, 35 and 8 per cent of grids in Tamil Nadu under Hot-Dry (CanESM2), Cool-Dry (CCSM4), Hot-Wet (CMCC-CM) and Cool-Wet (BNU-ESM) scenarios for the mid-century slice of time respectively. In contrast, upto 20 per cent increase in rainfall is projected for 92, 86, 58, 13 and 6 per cent of the grids under Cool-Wet, Mean change (CMCC-CMS), Hot-Wet, Cool-Dry and Hot-Dry scenarios respectively. Higher increase in precipitation of 21-40 per cent is projected in Tamil Nadu under mean change condition and Hot-Wet condition for 11 and 7 per cent of the grids respectively.

In RCP 8.5, all representative models estimated rainfall increases for maximum number of grids (> 97%) in Tamil Nadu with the exception of CanESM2, representing Hot-Dry condition that projected reduction in rainfall upto 20 per cent over 98 per cent of the grids under consideration. Out of 98 per cent, 60 per cent for grids had a decrease of 0 to 20 per cent while 38 per cent of grids were expected to have 21 to 40 per cent decline. Cool-Wet condition represented by MIROC5 model projected rainfall increase in all the 100 percent of grids. Increase in rainfall was higher in RCP 8.5 scenario, projecting 20 and 40 percent increase in 63 and 11 percent of grids. This was followed by Hot-Wet (CMCC-CM) and Mean change (CMCC-CMS) conditions which projected moderately wetter condition in 64 per cent of the grids.

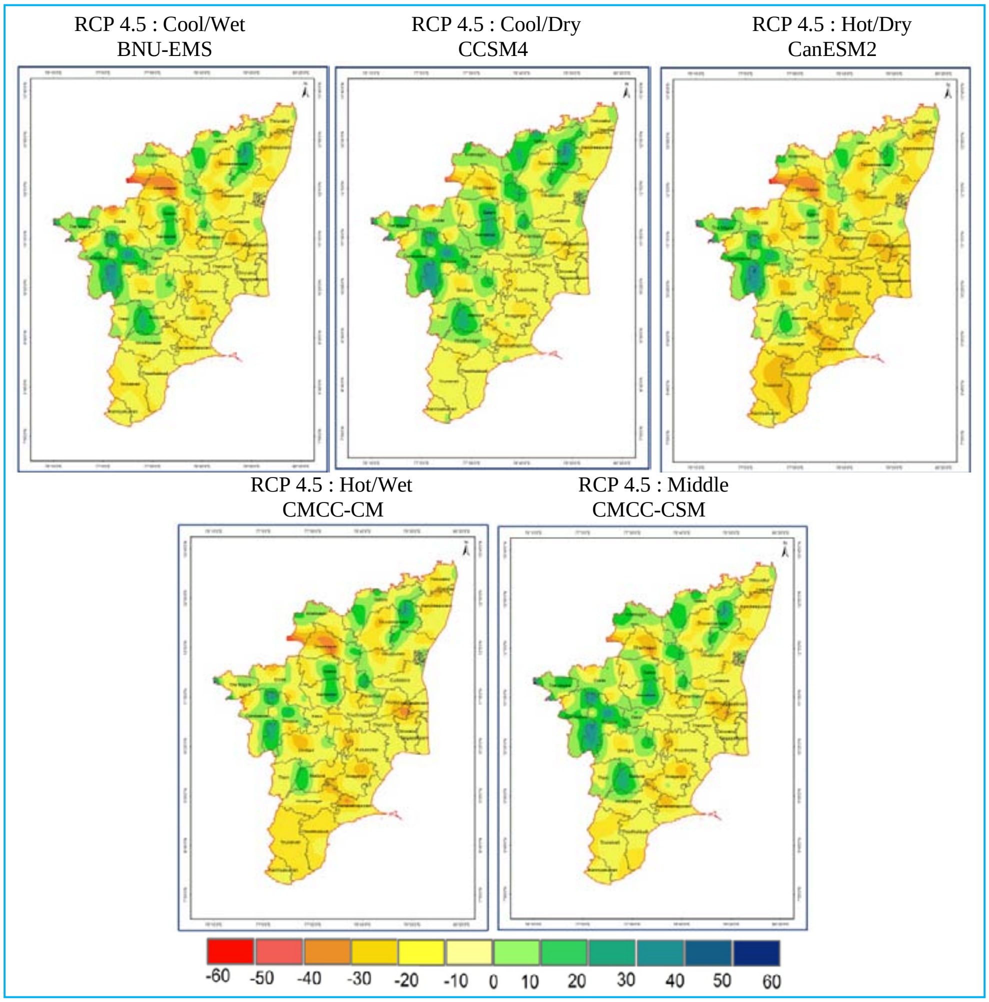
Rainfall increase under hot-wet (CMCC-CM) model through RCP 8.5 might be attributed to the enhanced hydrological activity as a result of increase in temperature. Expected variations in spatial rainfall over Tamil Nadu could be due to the orography with the existence of western ghats and the bordering east coast, which could witness increased cyclonic activity and changes in the circulation of the monsoon, which are expected to increase the supply of moisture over Bay of Bengal, which becomes conducive to deep convection and increased precipitation, as also mentioned by Ashfaq *et al.* (2009). Ramanathan *et al.* (2001)



Rainfed maize yield spread across the grids over Tamil Nadu

Box plot description

Fig. 7. Spatial variation in rainfed maize productivity over Tamil Nadu for the current climate (mean productivity of 1981-2010)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RCP 4.5 : Middle
CMCC-CSM

Fig. 8. Simulated deviation (%) in rainfed maize productivity with RCP 4.5 scenario for mid century time scale

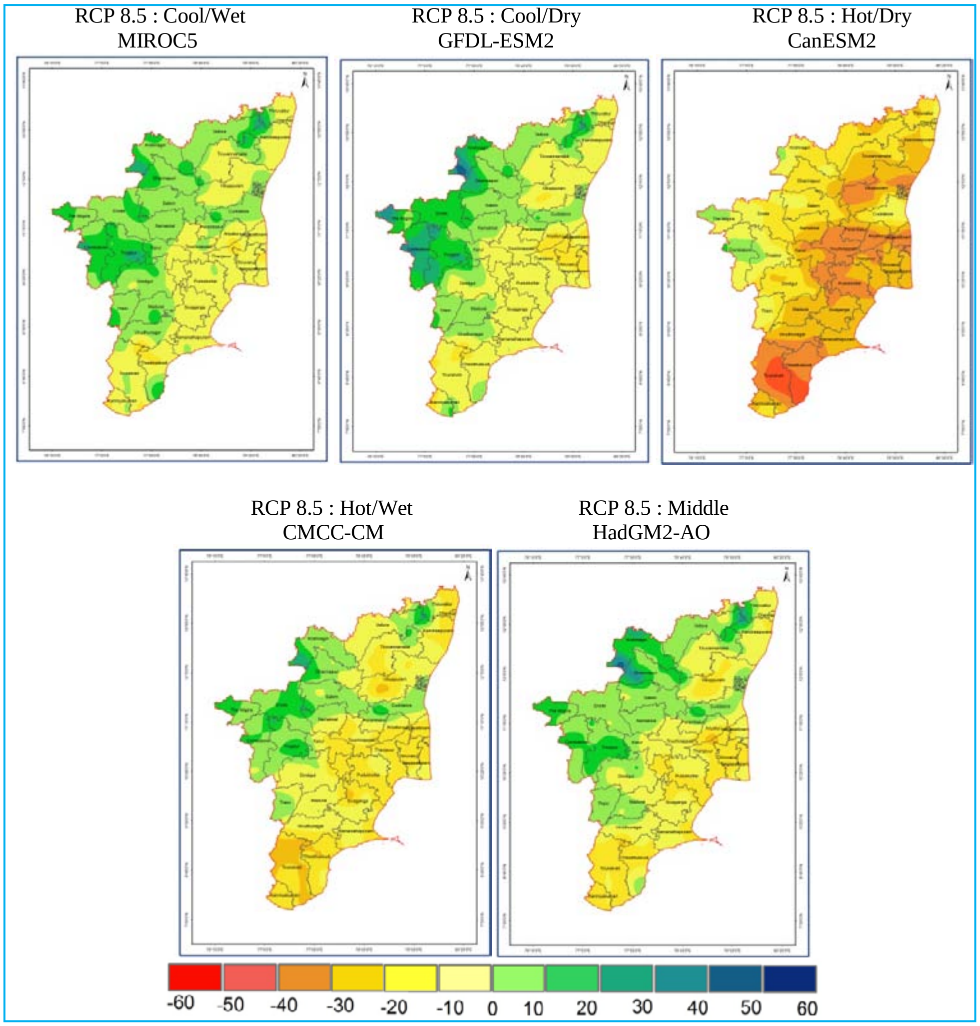

Fig. 9. Simulated deviation (%) in rainfed maize productivity with RCP 8.5 scenario for mid-century time scale

said that the spatial variability in higher temperatures would intensify the hydrological cycle, resulting in increased evaporation.

3.3. *Spatial response of maize productivity to current climate variability*

Using DSSAT model, the productivity of rainfed maize simulated for current climate (mean productivity from 1981-2010) over Tamil Nadu (Table 4 and Fig. 7) indicated high spatial variability from 5161 to 2046 kg ha^{-1} with a mean of 3958 kg ha^{-1} and at 25th and 75th percentiles, the productivity was 3514 and 4541 kg ha^{-1} respectively. The mean productivity of more than 5000 kg ha^{-1} was reported in five grid points distributed near western ghats and coastal region, 4000 to 5000 kg ha^{-1} in 81 grids along the east coast and in southern region, 3500 to 4000 kg ha^{-1} in 51 grids over the north eastern and north western region and 3000 to 3500 kg ha^{-1} in 36 grids over western and southern region. Lower yield of less than 3000 kg ha^{-1} was noticed in nine grids spread in different parts of the state. Reduction in maize growth and yield can be attributed to the negative impact of increased temperature with expected change in the pattern of rainfall (Kumar Panda *et al*., 2012)

3.4. *Spatial response of maize to future climate*

Future climate data generated for mid-century scenarios by five GCMs to reflect Cool-Wet, Cool-Dry, Mean Change, Hot-Wet and Hot-Dry conditions under RCP 4.5 and 8.5 were used to understand the impact on maize productivity across Tamil Nadu through DSSAT model (Table 5). Under RCP 4.5 scenario, increases and decreases in maize yields of varying magnitude is expected for different future climatic conditions (Fig. 8).

TABLE 5

Spatial variability of future maize yield (mean of 2040-2069) over Tamil Nadu for five selected climate models representing five scenarios

% Deviation in maize yield - class	Cool/Dry CCSM4		Cool/Wet BNU-ESM		Hot/Wet CMCC-CM		Hot/Dry CanESM2		Middle CMCC-CMS	
	Grids	%	Grids	%	Grids	%	Grids	%	Grids	%
RCP 4.5										
-60 to -50.01	0	0.0	1	0.6	0	0.0	1	0.6	0	0.0
-51 to -40.01	1	0.6	0	0.0	1	0.6	0	0.0	0	0.0
-40 to -30.01	0	0.0	4	2.2	5	2.8	7	3.9	3	1.7
-30 to -20.01	7	3.9	14	7.8	14	7.8	19	10.6	13	7.3
-20 to -10.01	19	10.6	24	13.4	35	19.6	64	35.8	22	12.3
- 10 to 0	78	43.6	84	46.9	82	45.8	48	26.8	79	44.1
0 to 10.0	45	25.1	27	15.1	22	12.3	21	11.7	31	17.3
10.01 to 20	12	6.7	15	8.4	12	6.7	11	6.1	18	10.1
20.01 to 30	9	5.0	3	1.7	4	2.2	3	1.7	5	2.8
30.01 to 40	6	3.4	6	3.4	3	1.7	2	1.1	4	2.2
40.01 to 50	1	0.6	1	0.6	0	0.0	2	1.1	2	1.1
50.01 to 60	1	0.6	0	0.0	1	0.6	1	0.6	0	0.0

% Deviation in maize yield - class	Cool/Dry GFDL-ESM2		Cool/Wet MIROC 5		Hot/Wet CMCC-CM		Hot/Dry CanESM2		Middle HadGEM2 -AO	
	Grids	%	Grids	%	Grids	%	Grids	%	Grids	%
RCP 8.5										
-60 to -50.01	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
-51 to -40.01	0	0.0	0	0.0	0	0.0	5	2.8	0	0.0
-40 to -30.01	0	0.0	0	0.0	0	0.0	38	21.2	0	0.0
-30 to -20.01	1	0.6	1	0.6	12	6.7	55	30.7	2	1.1
-20 to -10.01	12	6.7	6	3.4	49	27.4	43	24.0	35	19.6
- 10 to 0	76	42.5	69	38.5	57	31.8	29	16.2	65	36.3
0 to 10.0	55	30.7	71	39.7	43	24.0	7	3.9	49	27.4
10.01 to 20	22	12.3	26	14.5	15	8.4	1	0.6	23	12.8
20.01 to 30	10	5.6	4	2.2	3	1.7	0	0.0	3	1.7
30.01 to 40	3	1.7	1	0.6	0	0.0	0	0.0	2	1.1
40.01 to 50	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
50.01 to 60	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Among all the five GCMs, CanESM2 (Hot/dry) showed higher magnitude of negative impact followed by CMCC-CM (Hot/wet). In contrast, DSSAT forced with CCSM4 (cool/dry) climate simulated comparatively positive deviation in maize productivity for most of the grids over Tamil Nadu. Forcing BNU-ESM (Cool/Wet) and CCSM4 (cool/dry) condition with DSSAT indicated a deviation of (-) 51 to (+) 50 per cent and (-) 41 to (+) 53 per cent in maize productivity at various locations respectively. The CMCC-CSM (Middle) forcing showed (-) 38 to (+) 60 per cent deviation in maize yield. The deviation was (-) 50 to (+) 55 with CanESM2 (Hot/dry)

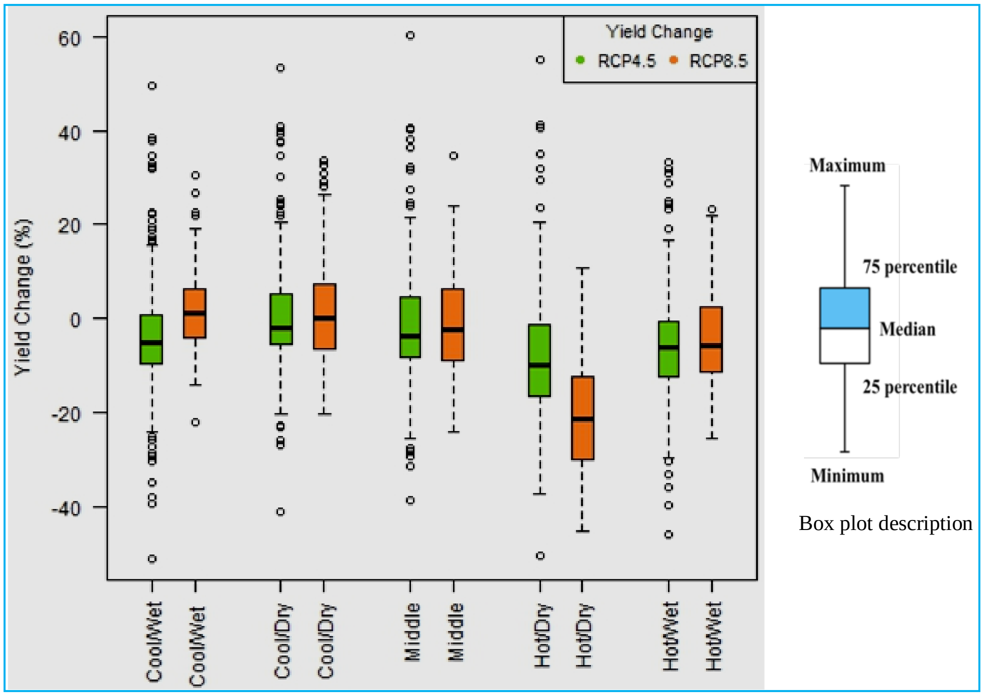

Fig. 10. Deviation (%) in rainfed maize yield under RCP 4.5 and 8.5

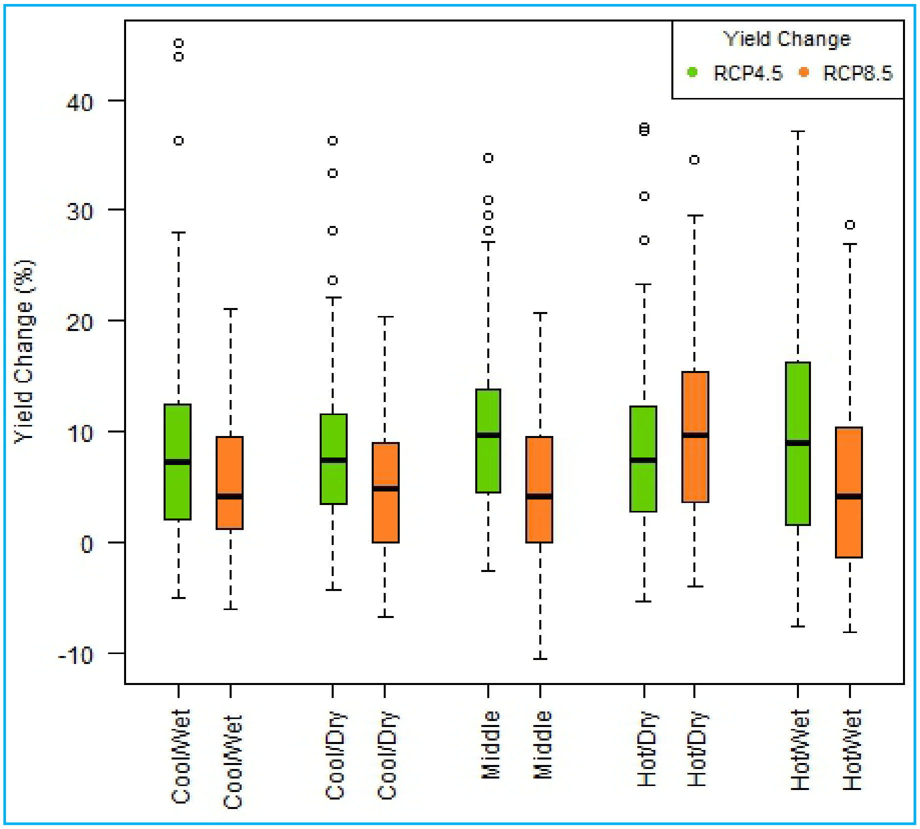

Fig. 11. Relative benefits of 15 days early sowing in future climatic condition

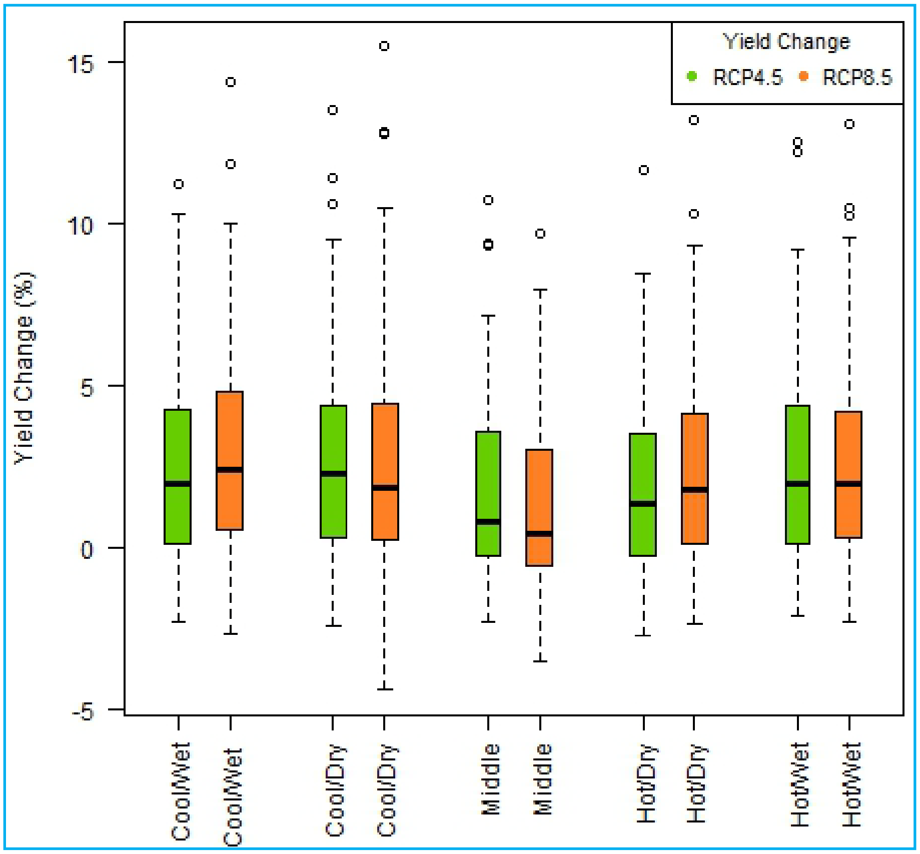

Fig. 12. Relative benefits of 25 % additional N dose in future climatic condition

and (-) 46 to (+) 54 with CMCC-CM (Hot/wet). Though, there is also positive deviation for CanESM2 (Hot/Dry) and CMCC-CM (Hot/Wet), in most of places of Tamil Nadu except few areas maize productivity is expected to get affected negatively.

The response of maize crop for the future climate generated based on the RCP 8.5 scenario is illustrated in Fig. 9. Maize yield is expected to increase in entire western zone, north western zone and parts of southern zone in Tamil Nadu during mid century for MIROC5 (Cool/Wet scenario) as well as for GFDL-ESM2 (Cool/Dry) projections. The increase could also be observed in some places with the future climate projections of HadGEM2-AO (Middle) and CMCC-CM (Hot/wet) conditions.

Predicted rate of decrease is higher in many places under RCP 8.5 for CanESM2 (Hot/dry) and CMCC-CM (Hot/wet) compared to RCP 4.5. Forcing the future climate generated from MIROC5 (Cool/Wet), GFDL-ESM2 (Cool/Dry), HadGEM2-AO (Middle), CanESM2 (Hot/Dry) and CMCC-CM (Hot/Wet) with DSSAT model showed a deviation in maize productivity by (-) 22 to (+) 31, (-) 20 to (+) 34, (-) 24 to (+) 35, (-)11 to (+) 45 and (-) 26 to (+) 23 per cent respectively. Both negative and positive effects are likely to be more with RCP 8.5 scenario compared to RCP4.5 over Tamil Nadu (Fig. 10).

3.4. *Adaptation strategies for changing climate*

Effect of changing climate on crops could be minimized through devising the potential adaptation strategies. In the present investigation the efficacy of selected adaptation strategies was evaluated under future climate conditions

Early sowing : DSSAT simulation for RCP 4.5 under Cool/Wet (BNU-ESM) condition showed an increase of 0.1 to 45.0 per cent across 81.6 per cent of the grids (146 grids) and rest of the grid is expected to have zero to -5.0 per cent change in yield. Hot/dry (CanESM2) condition had the yield change of 0.3 to 37.5 per cent over 157 grids (87.7%) and remaining grids had zero to -5.3 per cent change in yield. The yield is predicted to rise by 0.1 to 36.3 per cent over 163 grids (91.1%) under CCSM4 (Cool/Dry) condition while yield would go down in the range of -0.7 to -4.3 per cent in rest of the grids. Under

Hot/Wet (CMCC-CM) 79.3 per cent of grids produced higher yield (0.2 to 42%) and other grids produced lower yield (0 to -7.7%). DSSAT forced with CMCC-CSM (Middle) climate simulated the yield increase from 0.2 to 34.8 per cent in 93.3 per cent of grids and the rest showed an yield decrease of -0.5 to -2.5 per cent (Fig. 11).

DSSAT simulation for RCP 8.5 under CanESM2 (Hot/Dry) condition showed an increase of 0.3 to 34.5 per cent across 91.1 per cent of the grids (163 grids) and rest of the grid (8.9%) is expected to have zero to -4.0 per cent change in yield. GFDL-ESM2 (Cool/Dry) condition had the yield change of 0.1 to 20.3 per cent over 135 grids (75.4%) and remaining grids had zero to -6.8 per cent change in yield. The yield is expected to increase by 0.1 to 321.0 per cent over 142 grids (79.3%) under MIROC5 (Cool/Wet) climate while yield would go down in the range of zero to -6.0 per cent in rests of the grids. Under Hot/Wet (CMCC-CM) 68.2 per cent of grids produced higher yield (0.1 to 28.6%) and other grids produced lower yield (-0.1 to -8.2%). DSSAT forced with HadGEM2-AO (Middle) climate simulated the yield increase varied from 0.1 to 20.7 per cent in 74.3 per cent of grids and yield decrease ranged from zero to -10.6 per cent in 25.7 per cent of grids.

Late sowing : Delayed sowing in future warmer climate will result in a decrease in rainfed maize yield and may therefore not be recommended as an adaptation strategy under both the RCP scenarios. Altering the sowing window to match the crop growth with the favorable climatic condition and helping the crop to escape from heat stress during its crucial growth stages is one of the adaptation strategies for changing climate. Advancing the planting date by 15 days (1st September against 15th September) showed a steady increase in yield with all the models and the average yield benefit for RCP 4.5 and RCP 8.5 was 15 and 10 per cent respectively.

Fertilizer : Adding additional fertilizer resulted in differential responses under varied future climatic conditions. DSSAT showed increases in the fertilizer adaptation efficacy in most of the places of Tamil Nadu for all the climatic conditions in future for RCP 4.5 and RCP 8.5 scenarios and increased the rainfed maize yield up to 13 per cent. The places with yield decrease are more with CanESM2 (Hot/Dry) and CMCC-CM (Hot/Wet) compared to other future climatic conditions under both the RCP scenarios (Fig. 12). The DSSAT simulation indicated that additional (25%) fertilizer dose had positive response with yield increase up to 15 per cent in the future climatic conditions. This might be due to the compensating effect of losses of applied N fertilizer that has resulted in yield increment in the future warmer climate (Sonali McDermid *et al*., 2016).

4. Conclusions

Uncertainty in future climate projection could be addressed by employing multiple models and creating plausible scenarios of future climate is needed for impact assessment in various sectors including agriculture. In the current study, the maximum and minimum temperatures over Tamil Nadu are projected to increase irrespective of the models and scenarios studied. Among the two climate scenarios, the magnitude of decline in yield was more in RCP 8.5 over RCP 4.5. Earlier sowing window and increased application of fertilizer have minimized the undesirable impacts of changing climate on maize yield. It is recommended that location specific adaptation strategies need to be developed and practiced to reduce the negative effects of climate change on crop production.

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References

Ashfaq, M. S., Ying, T., Wen-wen Trapp, R. J., Xueijie, G., Pal, J. S. and Diffenbaugh, N. S., 2009, “Suppression of South Asian summer monsoon precipitation in the 21st century”, *Geophys. Res. Lett.*, **36**, L01704.

Barnett, T. P., Adam, J. C. and Lettenmaier, D. P., 2005, “Potential impacts of a warming climate on water availability in snow-dominated regions”, *Nature*, **438**, 303-309.

Diallo, I., Sylla, M. B., Giorgi, F., Gaye, A. T. and Camara, M., 2012, “Multi model GCM-RCM Ensemble-based projections of temperature and precipitation over West Africa for the early 21st Century”, *Intl. J. Geophys*., **2012**, 1-20. doi : 10.1155/ 2012/972896

Intergovernmental Panel on Climate Change (IPCC), 2007, “Climate Change 2017: Impacts, adaptation and vulnerability, in Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change”, Ed. Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J. and Hanson, C.E., Cambridge University Press, Cambridge, UK. 976.

Intergovernmental Panel on Climate Change (IPCC), 2014, “Climate Change 2014: Impacts, Adaptation and Vulnerability”, In : Field, C., Barros, V., Mach, K. and Mastrandrea, M., (Eds.), "Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge : University Press, Cambridge, United Kingdom and New York, USA

Kumar Panda, R., Alam, J. and Nandgude, S., 2012, "Effect of climate variability on maize yield and evaluation of coping strategies using the crop growth model", *Intl. J. Climate Change Impact Res.*, **3**, 2, 71-94.

Rajiv Kumar, C., Joshi, J., Jayaraman, M., Bala, G. and Ravindranath, N. H., 2012, "Multi-model climate change projections for India under representative concentration Pathways", *Current Sci.*, **103**, 791-802.

Ramanathan, V., Crutzen, P. J., Kiehl, J. T. and Rosenfeld, D., 2001, "Aerosols, climate and the hydrological cycle", *Science*, **294**, 2119-2124.

Reilly, J., 1995, "Climate change and global agriculture: Recent findings and issues", *Amer. J. Agric. Econ.*, **77**, 727-733.

Smit, B. and Skinner, M. W., 2002, "Adaptation options in agriculture to climate change : Atypology", *Mitigat. Adapt. Strat. Global Change*, **7**, 85-114.

Sonali, M., Gowtham, R., Bhuvaneswari, K., Geethalakshmi, V. and Lakshmanan, A., 2016, "The impacts of climate change on Tamil Nadu rainfed maize production : A multi-model approach to identify sensitivities and uncertainties", *Curr. Sci.*, **110**, 7, 1257-1271.

Stone, D. A., Allen, M. R., Stott, P. A., Pall, P., Min, S. K., Nozawa, T. and Yukimoto, S., 2009, "The detection and attribution of human influence on climate", *Annu. Rev. Env. Resour.*, **34**, 1-16. doi : 10. 1146/annurev.environ.040308.101032.

Tamil Nadu State Action Plan on Climate Change (TNSAPCC), 2014, Towards Balanced Growth and Resilience, DoA, Government of Tamil Nadu.

Vergara, W., Deeb, A. M., Valencia, A. M., Bradley, R. S., Francou, B., Zarzar, A., Grunwaldt, A. and Haeussling, S. M., 2007, "Economic impacts of rapid glacier retreat in the andes", *EOS Transact.*, **8**, 25, 261- 264.

Villegas, J. R. and Jarvis, A., 2010, "Downscaling global circulation model outputs: the delta method decision and policy analysis working paper No. 1. Agricultura Eco-efficiente para Reducir la Pobreza", *International Centre for Tropical Agriculture*, Columbia, 18.