

Impact of global warming (1.5°C) on the productivity of selected C3 and C4 crops across Tamil Nadu.

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ABSTRACT

Over the last century, mean annual temperatures increased by ~1°C. UNFCCC has proposed to limit warming below 1.5°C relative to pre-industrial levels. A study was conducted on rice (C3 pathway) and maize (C4 pathway) over Tamil Nadu using DSSAT to understand the climate change impacts with projected temperature increase of 1.5°C. The future climate under RCP 4.5 and RCP 8.5 indicated 1.5°C increase in temperature to happen by 2053 and 2035, respectively over Tamil Nadu. Annual rainfall deviations in RCP4.5 showed drier than current condition and RCP8.5 projected wetter SWM and drier NEM (90 % of current rainfall). Impact of 1.5°C warming on crop phenology indicated 8 days reduction in duration for rice and maize. The WUE of rice would decrease by 17 per cent at current CO₂ whereas, enrichment (430 ppm) would reduce by 12 per cent and rice yield is reduced by 21 per cent with 360 ppm CO₂ and 430 ppm reduced by 17 per cent. There is no considerable variation (- 5 to 1 %) in maize productivity with 1.5 °C warming. The above results indicated that 1.5 °C warming has more negative impacts on plants with C3 compared to C4 pathway.

Key words : 1.5 °C warming, global warming, climate change, IPCC

Crops are sensitive to temperature changes, variations in precipitation and to increased CO₂ concentration in the atmosphere (Bal and Minhas, 2017; Rosenzweig *et al.*, 2014; Wheeler and Braun, 2013). Most climate models forecast temperature increases with certainty, but patterns of changes related to precipitation are considerably more uncertain (Porter and Gawith, 1999; Ottman *et al.*, 2012). Meteorological records show that mean annual temperatures have risen by ~1°C in the past century and are anticipated to increase continuously by 2 to 5 °C in the future towards 2100, with higher greenhouse gas emissions (Gourdji *et al.*, 2013; Liu and Allan, 2013).

It is necessary to keep the temperature increase within a tolerable limit to prevent the greater negative effects of changing climate. With this endeavour, the EU (Environment Council), as per the IPCC Second Assessment Report, has proposed a global mean temperature rise of 2°C above pre-industrial levels as a target not to be surpassed. But this 2 °C cannot be guaranteed as a safe limit since substantial impacts are already occurring at the current temperature rise level and further increase will only result in severe irreversible impacts. Consequently, at COP15, UNFCCC suggested that the heating be held below 1.5 °C compared to pre-industrial

rates, since a difference of 0.5 °C might significantly reduce the impacts (Hare *et al.*, 2011; UNFCCC, 2009).

Tamil Nadu, an agrarian state, falls in the tropical climate zone and 1.5°C rise in global temperature could have serious effects on crop growth and yield. The state has 5.9 million hectares of cultivable area grown mainly with crops that has either C3 or C4 photosynthetic pathways, which is influenced differently by temperature increase. Hence, to study the impact of 1.5°C warming on crops viz. rice (C3) and maize (C4) has been selected as representative crops (Nelson *et al.*, 2010). Most scientists demonstrated the effect of increasing temperature on farming from historical records of climate and crop production (Lobellet *et al.*, 2011; Tao *et al.*, 2012; Tao *et al.*, 2014), or using crop simulation model experiments (Jalota *et al.*, 2013; Porter *et al.*, 2014; Yadav *et al.*, 2015; Aravindkumar *et al.*, 2017; Biswas *et al.*, 2018), or experiments performed under temperature controlled chambers (Ottman *et al.*, 2012; Chen *et al.*, 2016) and sowing date based experiments (Dari *et al.*, 2017). Scheleussner *et al.*, (2016) reported that maize yield loss in topical areas is doubled by a temperature increase of 2 °C compared to the loss due to a 1.5 °C increase.

IPCC (2014) demonstrated the negative impact of

temperature rise on crops in terms of shortening of crop duration and reduction in growth and productivity. It is therefore important to measure the effect of 1.5°C temperature rise on crop growth as well as yield parameters, taking into account of the spatial variations, for developing targeted adaptive tactics for ensuring the food safety over Tamil Nadu.

MATERIALS AND METHODS

Current climate analysis

The study was conducted for Tamil Nadu, India and crops selected were rice and maize to represent the C3 and C4 photosynthetic pathways, respectively. For the baseline analysis, gridded daily rainfall data of 0.25x0.25 degree provided by India Meteorological Department (IMD) from 1980 to 2013 was used. Maximum and minimum temperatures data generated by IMD at 0.5 x 0.5 degree was downscaled to match the rainfall grids. Further, solar radiation data generated by means of temperature was used for creating weather file.

Future climate projection

Future climate data for solar radiation (Wm^{-2}), maximum and minimum temperatures (°C) and rainfall (mm) were created for RCP4.5 and RCP 8.5, using 29 climate models proposed in the fifth IPCC assessment report by mean change and variability method. Ensemble of all the 29 models was done and the model that is closely representing the ensemble was selected for the future climate projection. For both RCP 4.5 and RCP 8.5 scenarios, the model selected was GFDL-ESM2 and the future climate was generated from 2011 to 2099. The projected data was further averaged to get the pentad values (5-year mean) to identify the time of attainment of 1.5 °C increase in temperature. In addition to this, to study the relationship between magnitudes of increase in temperature with change in rainfall, scatter plots were drawn at annual and seasonal scales. Further, GIS maps of annual and seasonal rainfall were generated to understand the spatial variability over Tamil Nadu.

Impacts of elevated temperature (1.5 °C) on crops

Effect of 1.5 °C increase in temperature on rice and maize crops over Tamil Nadu was studied by employing well calibrated and validated rice and maize crop simulation models (DSSAT). The model was setup with the 30 years climate data (1981-2010) and simulated the crops yield for various districts of Tamil Nadu. Crop yields were averaged over 30 years and arrived at current yield in each district of Tamil

Nadu. Environmental modifications were made in the model to study the influence of 1.5 °C elevated temperature on crops coupled with changes in rainfall based on the above climate analysis and assumed CO₂ concentration with the following treatments.

- T1 : Current climate
- T2 : Temperature increase of 1.5 °C +360ppm CO₂
- T3 : Temperature increase of 1.5 °C +430 ppm CO₂
- T4 : Temperature increase of 1.5 °C +430 ppm CO₂ +10% Rainfall
- T5 : Temperature increase of 1.5 °C +430 ppm CO₂ -10% Rainfall
- T6 : Temperature increase of 1.5 °C +430 ppm CO₂ +20% Rainfall
- T7 : Temperature increase of 1.5 °C +430 ppm CO₂ -20% Rainfall

Impact of different treatments on the phenology of the crop was recorded by observing the duration taken for anthesis as well as number of days required for attaining maturity. Biomass and yield changes were also assessed through DSSAT model simulations. (Is the same procedure followed for the projected climates also? Actually the projected values are already incorporated with emissions).

RESULTS AND DISCUSSION

Baseline climate of Tamil Nadu

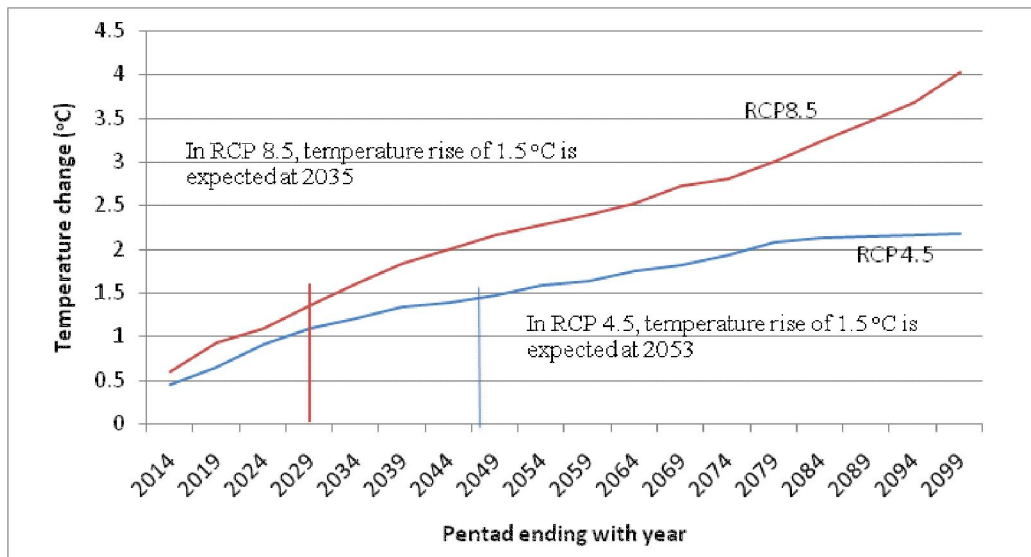
Observed annual and seasonal climatic variability in maximum temperature, minimum temperature, rainfall and rainy days over Tamil Nadu are presented in Table 1.

Normal annual maximum temperature of Tamil Nadu was found to be 32.5°C with a range from a minimum of 29.0°C to a maximum of 33.9°C. Standard deviation derived for the 30 years of study period is 1.5°C. Among the seasons, hot weather period (HWP) had the highest mean temperature of 35.2°C (ranging from 32.1 to 37°C) followed by southwest monsoon (SWM) with 33.2°C (27.5 to 35.3°C) and cold weather period (CWP) with 30.9°C (29.3 to 32.1°C) and the lowest temperature 30.0°C (27.7 to 31.2°C) was observed during northeast monsoon (NEM) season. The standard deviation for maximum temperature was the highest with SWM (2.5°C) followed by HWP (1.4°C), NEM (1.1°C) and the least were recorded with CWP (0.7°C).

Mean annual minimum temperature of Tamil Nadu was found to be 22.7°C and it varies from a minimum of 18.8°C to a maximum of 24.4 °C, with a standard deviation

Table 1: Climatic normal with its range over Tamil Nadu

Parameters	Statistics	Annual	CWP	HWP	SWM	NEM
Maximum	Mean	32.5	30.9	35.2	33.2	30
	Maximum	33.9	32.1	37	35.3	31.2
	Minimum	29	29.3	32.1	27.5	27.7
	SD	1.5	0.7	1.4	2.5	1.1
Minimum	Mean	22.7	19.9	24.1	24	21.5
	Maximum	24.4	22.1	25.7	25.8	23.2
	Minimum	18.8	16.5	20.2	19.6	18
	SD	1.7	1.7	1.7	1.9	1.6
Rainfall	Mean	930	32	117	322	460
	Maximum	1647	209	343	703	992
	Minimum	276	0	18	67	99
	SD	322	51	76	154	214

**Fig. 1:** Projected mean temperature changes (°C) from the baseline (mean of 1980-2009) over Tamil Nadu - cutting down the 1.5 °C rise

of 1.7°C. Among the seasons, HWP had the highest minimum temperature of 24.1°C (20.2 to 25.7°C) followed by SWM 24.0°C (19.6 to 25.8°C) and NEM 21.5°C (18.0 to 23.2°C) and the lowest of 19.9°C (16.5 to 22.1°C) was observed during CWP. The standard deviation for the minimum temperature was also the highest with SWM (1.9°C) followed by both HWP and CWP (1.7°C) and the least with NEM (1.6°C). Comparing both the temperatures, minimum temperature had the highest standard deviation in all the seasons except for SWM related to maximum temperature.

Mean annual rainfall of Tamil Nadu was found to be 930 mm; it varies with a minimum of 276 mm to a maximum of 1647 mm with a standard deviation of 322 mm. Among the

seasons, NEM had highest amount of rainfall (460 mm) followed by SWM (322 mm), HWP (117 mm) and the least was observed during CWP (32 mm). Over 30 years' period, rainfall recorded during CWP varied from 0 mm to 209 mm while HWP varied from 18 mm to 343 mm. Among the monsoons, SWM rainfall ranged from 67 mm to 703 mm while NEM varied from 99 to 992 mm. Standard deviation was the highest for NEM followed by SWM, HWP and CWP with 214 mm, 154 mm, 76 mm and 51 mm, respectively.

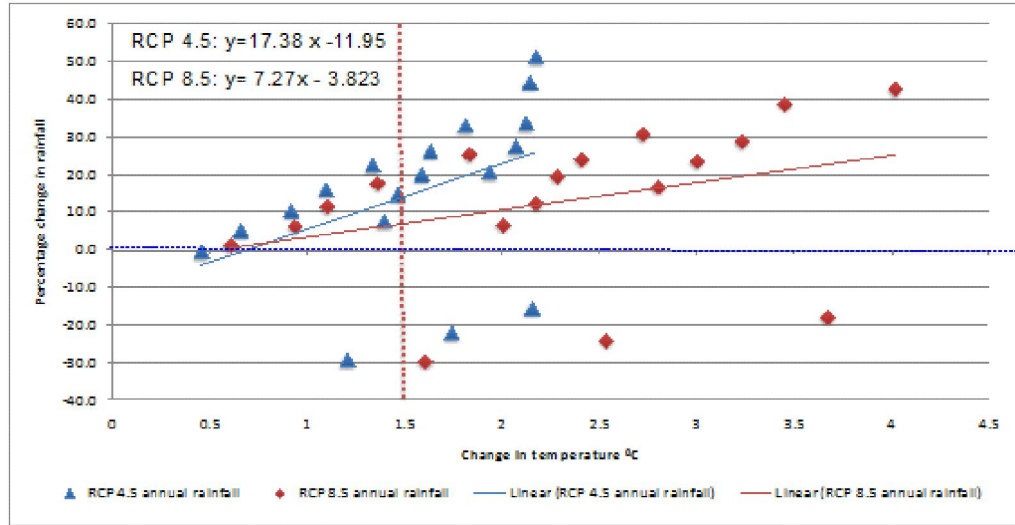
Future climate projection with a temperature rise of 1.5°C

Future climate was projected using GFDL-ESM2 model for a period from 2011 to 2099 and the values were

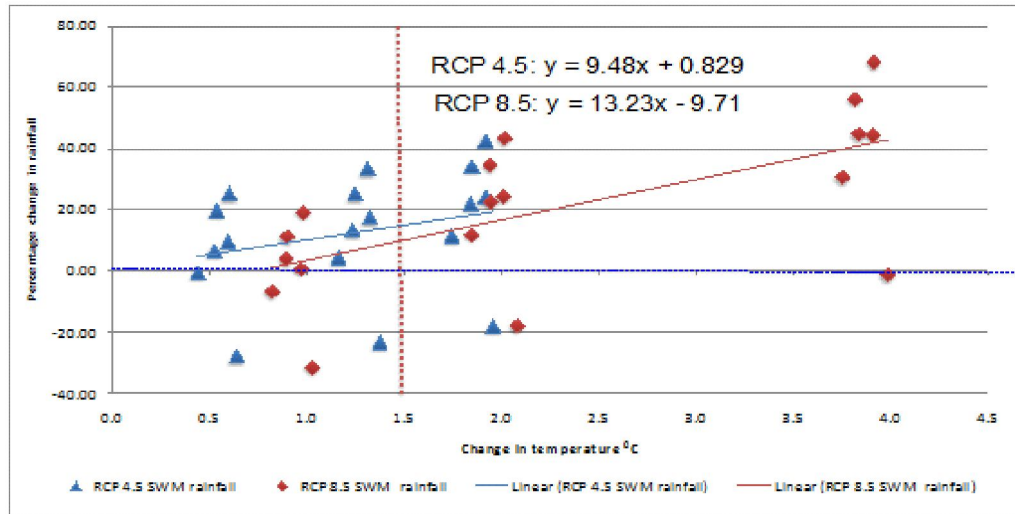
Table 2: Days taken for anthesis and maturity in the current climatic condition and with 1.5 °C elevated temperature

Districts	Days taken for Anthesis				Days taken for maturity			
	Rice		Maize		Rice		Maize	
	Current condition	With 1.5°C	Current condition	With 1.5°C	Current condition	With 1.5°C	Current condition	With 1.5°C
Ariyalur	81	-5	59	-3	109	-7	107	-7
Chennai	82	-5	59	-3	112	-7	107	-7
Coimbatore	95	-7	69	-6	130	-11	132	-11
Cuddalore	98	-8	59	-3	134	-12	109	-7
Dharmapuri	88	-6	61	-4	120	-9	113	-8
Dindigul	85	-6	62	-4	115	-8	114	-8
Erode	91	-7	61	-4	124	-10	114	-8
Kancheepuram	82	-5	60	-4	112	-7	112	-8
Kanniyakumari	81	-4	62	-4	108	-7	116	-9
Karur	80	-5	59	-3	109	-7	110	-8
Krishnakiri	90	-6	59	-4	124	-10	109	-8
Madurai	84	-5	58	-4	114	-8	109	-8
Nagapattinam	80	-5	59	-4	109	-7	109	-7
Namakkal	84	-5	70	-6	114	-8	130	-10
Nilgiris	97	-8	68	-5	134	-12	128	-10
Perambalur	81	-5	59	-3	109	-7	109	-8
Pudukkottai	80	-5	58	-3	108	-7	109	-7
Ramanathapuram	82	-5	61	-4	111	-7	115	-8
Salem	86	-6	58	-3	117	-8	109	-7
Sivaganga	82	-5	59	-4	111	-7	110	-8
Thanjavur	80	-5	67	-5	109	-7	125	-10
Theni	98	-8	62	-4	134	-12	117	-8
Tiruppur	82	-5	72	-6	113	-8	134	-11
Tirunelveli	80	-5	63	-4	108	-7	121	-9
Thiruvarur	81	-5	59	-4	111	-7	110	-8
Thothukkudi	81	-5	65	-4	109	-7	125	-10
Tiruchirappalli	81	-4	59	-3	109	-7	111	-8
Thiruvallur	80	-5	61	-4	108	-7	117	-9
Tiruvannamalai	93	-7	60	-4	127	-10	113	-8
Vellore	85	-6	59	-4	116	-8	113	-8
Villupuram	81	-5	61	-4	109	-7	115	-8
Virudhunagar	85	-5	70	-5	114	-8	133	-11
Tamilnadu	85	-5	62	-4	115	-8	116	-8
Maximum	98	-4	72	-3	134	-7	134	-7
Minimum	80	-8	58	-6	108	-12	107	-11

a. Annual rainfall



b. Southwest monsoon rainfall



c. Northeast monsoon rainfall

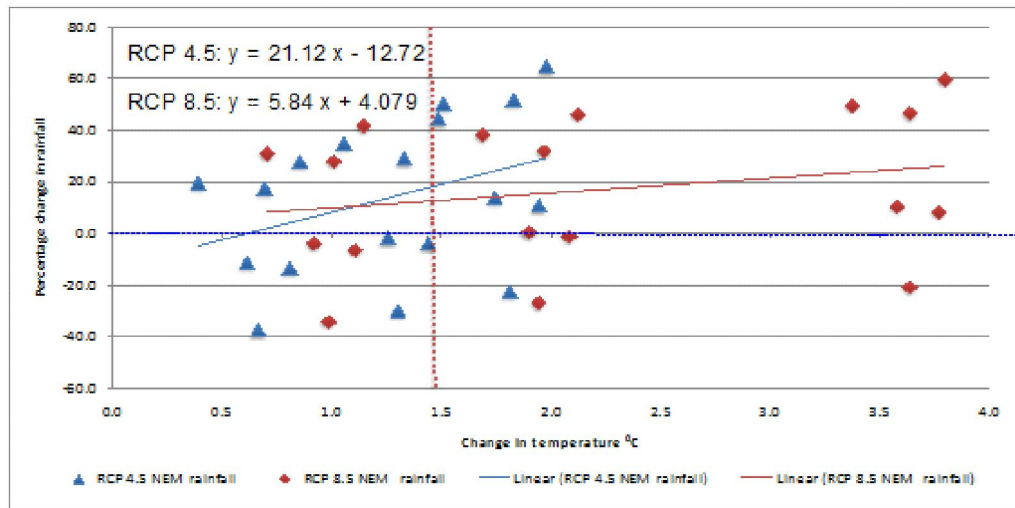


Fig. 2: Projected change rainfall in relation to future temperature changes

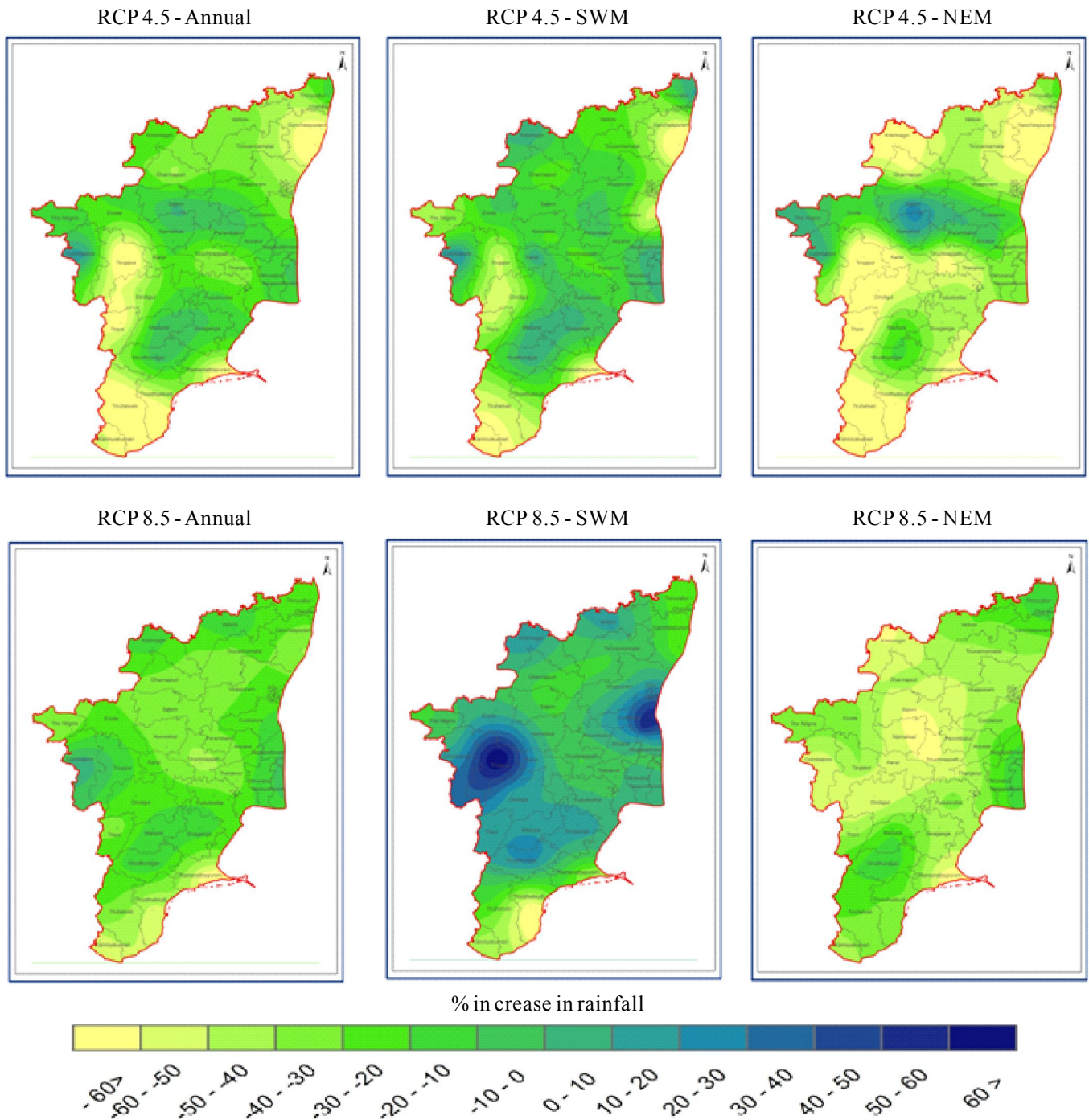


Fig. 3: Projected spatial variability with RCP 4.5 and RCP 8.5 in annual and seasonal rainfall at 1.5°C warming

averaged for every five years. The pentad mean for RCP 4.5 and RCP 8.5 is presented in Fig. 1. Based on the pentad analysis, both the RCPs projection showed an increase in temperature with progress of time for Tamil Nadu. RCP4.5 projected an increase ranging from 0.45 to 2.17 °C by the end of the century while RCP 8.5 projected an increase ranging from 0.60 to 4.02 °C. The difference in magnitude expresses the pathways of the scenarios. From the graph, it is evident that 1.5°C increase in temperature is expected to

reach around 2035 with RCP 8.5, while in the projections through RCP 4.5, the same rise in temperature would happen around 2053.

Scatter plots drawn for comparing the changes in rainfall for the corresponding temperature change at annual and seasonal scales are presented in Fig.2. Based on GFDL-ESM2 estimates, as Per RCP 4.5, expected variation in annual rainfall ranged from -30.1 to +51.6 per cent and with RCP 8.5, from -29.9 to +41.2 per cent. SWM has-27.5 to

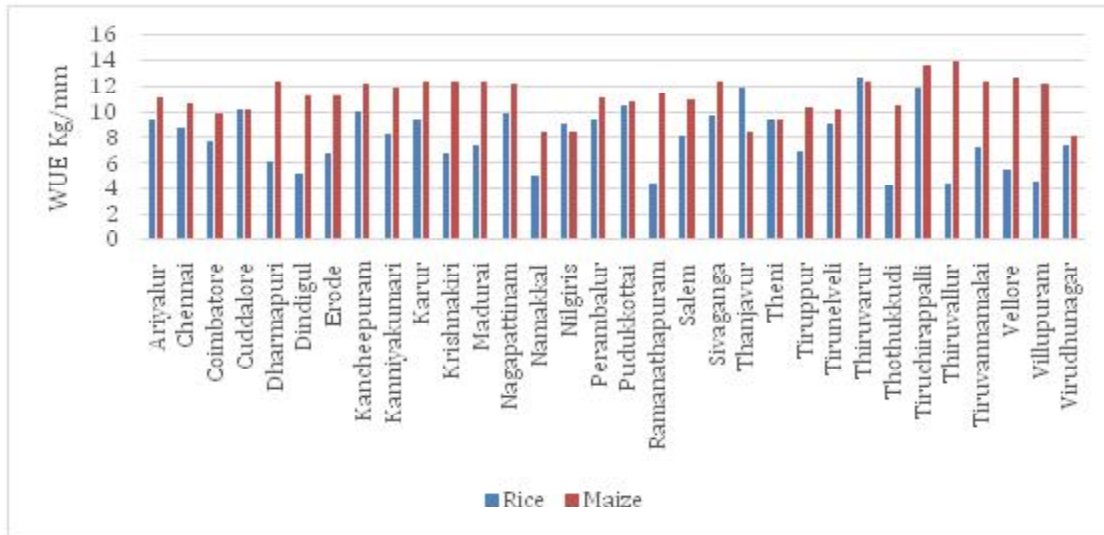
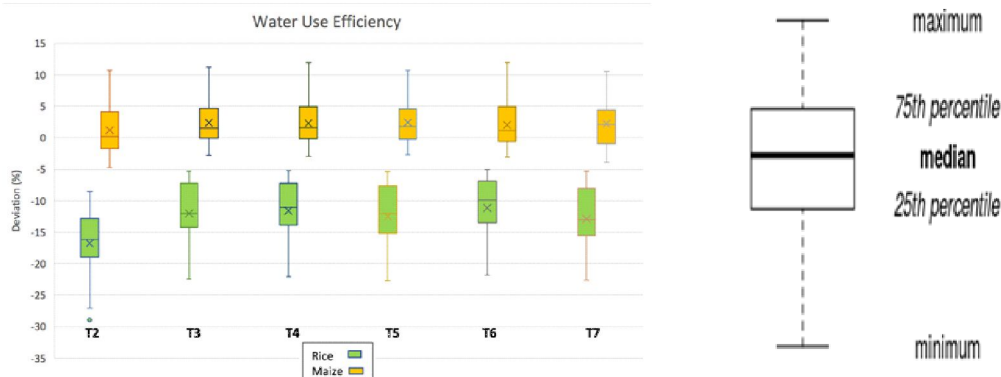


Fig. 4: WUE of rice and maize crops under current climatic condition



T : Temperature. R : Rainfall

T2 : T (+ 1.5 °C) + CO₂ (360ppm)

T3 : T (+ 1.5 °C) + CO₂ (430ppm)

T4 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 10 %)

T5 : T (+ 1.5 °C) + CO₂ (430ppm)+R (-10 %)

T6 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 20 %)

T7 : T (+ 1.5 °C) + CO₂ (430ppm)+R (- 20 %)

Fig. 5: Deviation in WUE of rice and Maize crops with 1.5 °C increase in temperature, change in rainfall and CO₂ enrichment

+42.7 percent change for RCP 4.5 and -31.2 to 68.3 per cent variation for RCP 8.5. During NEM, variation of -37.1 to 65.1 percent and -33.8 to 60.0 per cent is anticipated through RCP4.5 and 8.5, respectively. There is increase in rainfall with increase in temperature in most of the grid points up to 1.5 °C. Above the ceiling of 1.5 °C even the steady increase of temperature results in decrease in rainfall for about 10 to 15 per cent of the points. The annual and seasonal trend lines indicate that increase in temperature has positively increased the rainfall and the magnitude of increase through RCP 4.5 is higher than that of RCP 8.5 for annual rainfall. Seasonal changes in rainfall had variation between the monsoons. SWM had higher increase in rainfall through

RCP 8.5 than RCP 4.5, in contrast, for NEM, increase in rainfall is higher through RCP 4.5 than in RCP 8.5.

Spatial variability in projected annual and seasonal rainfall at 1.5 °C warming over Tamil Nadu is given in Fig.3. For 1.5 °C warming, annual rainfall deviations in RCP 4.5 scenario shows drier than the current condition in most part of Tamil Nadu. More drying is expected in southern most part of Tamil Nadu. Western districts in the plains and northernmost costal districts are also showing drier condition for 1.5 °C warming. As far as agriculture is concerned, seasonal rainfall has more relevance. Compared to SWM, more dryness is expected in NEM which is the major rainy

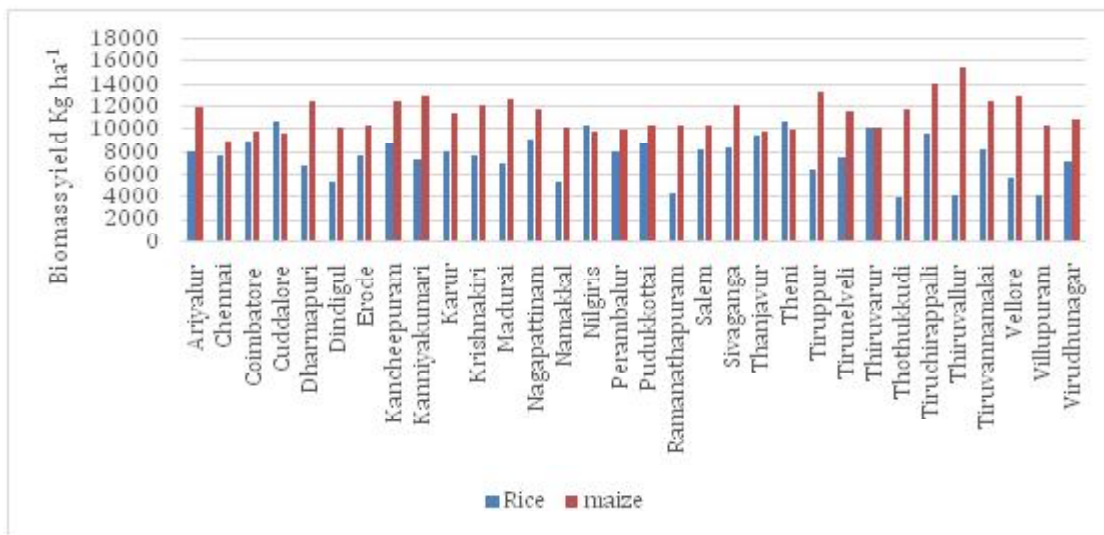
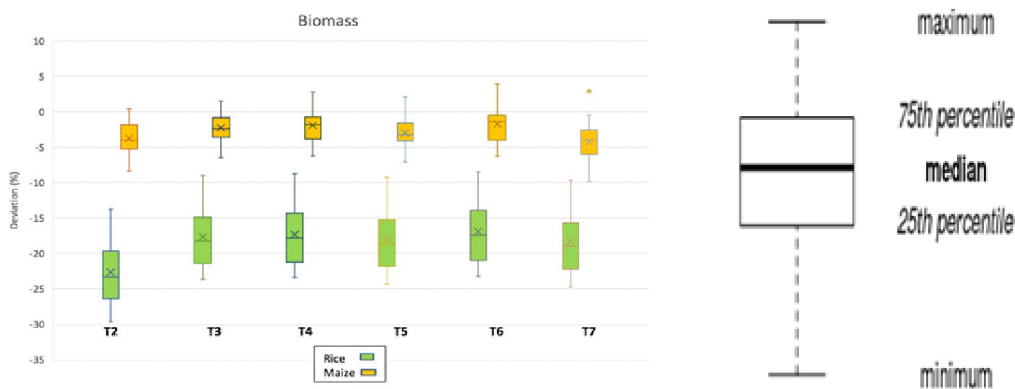


Fig.6: Biomass productivity (Kg ha⁻¹) of rice and maize crops under current climatic condition



T: Temperature R: Rainfall

T2 : T (+ 1.5 °C) + CO₂ (360ppm)

T3 : T (+ 1.5 °C) + CO₂ (430ppm)

T4 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 10 %)

T5 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (-10 %)

T6 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 20 %)

T7 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (- 20 %)

Fig.7: Deviation (%) in Biomass productivity of rice and Maize with 1.5 °C increase in temperature, change in rainfall and CO₂ enrichment

season of Tamil Nadu. Except Cauvery Delta, hilly zone and part of north western zone, other areas are expected to receive only around 60 per cent of the current rainfall. With respect to RCP8.5 scenario, the SWM will have wetter conditions in most part of Tamil Nadu and NEM is expected to receive around 90 per cent of the current rainfall.

Impacts of elevated temperature (1.5 °C) on crops

Change in crop phenology

The results for rice and maize crops for the days taken to anthesis and number of days taken for maturity are presented in Table 2. As temperature is the main determining factor for phenological changes in crops, difference in days

to attain anthesis and physiological maturity between control (T1) and all the other treatments with 1.5 °C (T2 through T7) were same. On an average, for Tamil Nadu, days taken to anthesis of paddy crop are 85 days (including 21 days nursery period) and for maize, it is 62 days. Among the districts, the variation for anthesis ranges from 80 to 98 days for paddy and for maize, it ranged from 58 to 72 days depending upon the climatic conditions prevailed during the crop growing season. For 1.5 °C warming, the anthesis days get advanced by 5 and 4 days for rice and maize crops respectively. The days taken for maturity of paddy crop is 115 days and for maize, it is 116 days. Among the districts, the variation for maturity ranges from 108 to 134 days for

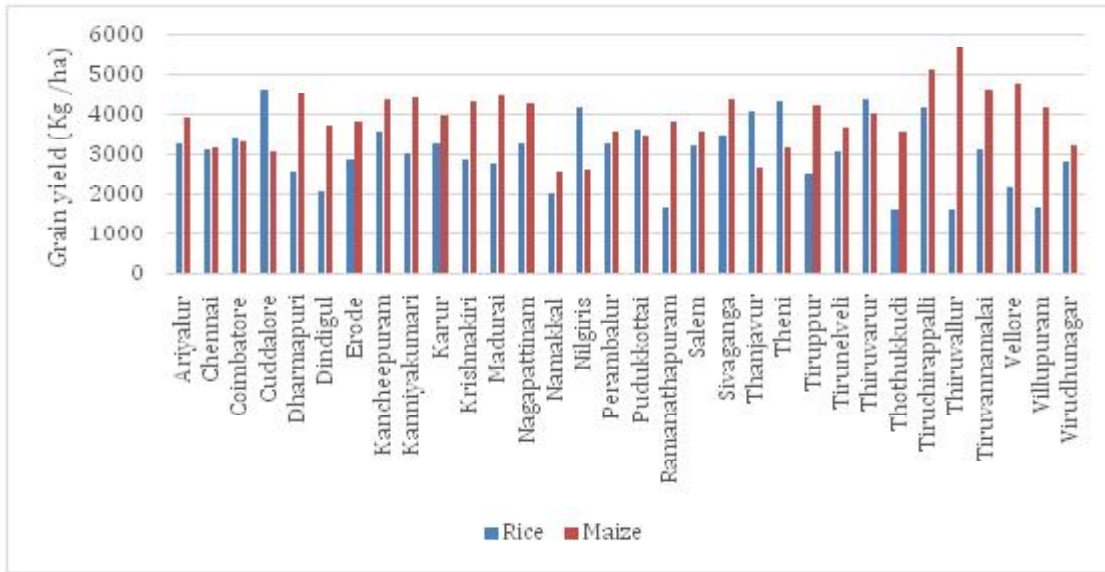
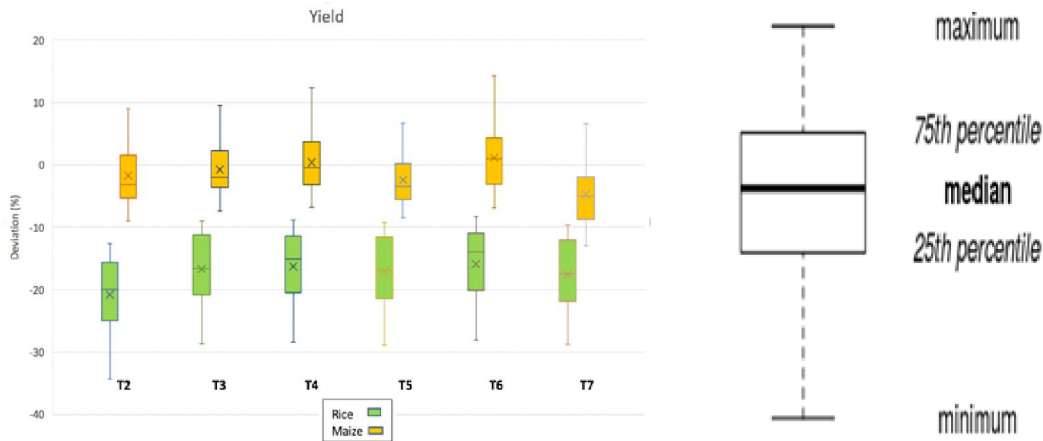


Fig. 8: Grain yield (Kg ha⁻¹) of rice and maize under current climatic condition



T: Temperature. R: Rainfall

T2 : T (+ 1.5 °C) + CO₂ (360ppm)

T3 : T (+ 1.5 °C) + CO₂ (430ppm)

T4 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 10 %)

T5 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (-10 %)

T6 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (+ 20 %)

T7 : T (+ 1.5 °C) + CO₂ (430ppm)+ R (- 20 %)

Fig. 9: Deviation (%) in Biomass productivity of rice and Maize with 1.5 °C increase in temperature, change in rainfall and CO₂ enrichment

paddy and for maize, it ranged from 107 to 134 days. For 1.5 °C warming, the days to maturity get advanced by 8 days for both rice and maize crops.

Influence on water use efficiency

Water use efficiency (WUE) of rice and maize under the current climate condition is presented in Fig. 4. The WUE ranged from 4.6 (Ramanathapuram) to 12.8 kg mm⁻¹ (Thiruvavur) in different districts for rice with average WUE of 8 kgmm⁻¹. In maize WUE ranges from 8 to 14 kg mm⁻¹ with

an average of 11 kg mm⁻¹.

Impact of climate change on water use efficiency of rice and maize are presented in Fig. 5. In the 1.5 °C warming scenario with current CO₂ concentration (360 ppm), WUE got reduced by 17 per cent, whereas, CO₂ enrichment (430 ppm) decreased the negative effect of warming condition and lead to a reduction in WUE only by 12%. Increase and decrease in rainfall along with CO₂ enrichment showed minimal impact on WUE (up to + 1%). WUE of maize shows

less changes (on an average 1 to 2 %) for 1.5 °C warming over Tamil Nadu (Fig.5).

Influence on biomass productivity

Biomass productivity of rice and maize under the current climate condition is presented in Fig.6. Rice biomass ranged from 3915 to 10645 kg ha⁻¹ with an average of 7584 kg ha⁻¹ over Tamil Nadu, while maize biomass ranged from 8856 to 15573 kg ha⁻¹ with an average of 11343 kg ha⁻¹.

Impact of climate change on biomass productivity of rice and maize are presented in Fig.7. Biomass of rice gets affected due to 1.5 °C warming by 23 per cent with current CO₂ concentration (360 ppm), while the biomass reduction is compensated with CO₂ fertilization (430 ppm) to certain extent and the reduction in biomass was by 18 per cent. Increase or decrease in rainfall from 10 to 20 per cent have little change on biomass with current as well as elevated CO₂ concentrations with increase in temperature by 1.5 °C. The magnitude of 1.5 °C warming effect is less (up to -4 %) on maize biomass compared to rice over Tamil Nadu.

Influence on grain yield

Grain yield of rice and maize under the current climate condition is presented in Fig. 8. Rice yield ranged from 1594 to 4631 kg ha⁻¹ with an average of 3062 kg ha⁻¹ over Tamil Nadu and maize yield ranged from a minimum of 2585 to a maximum of 5689 kg ha⁻¹ with an average of 3898 kg ha⁻¹.

Impact of climate change on grain yield of rice and maize are presented in Fig.9. Rice yield reduces by 21 per cent with 360 ppm CO₂ concentration under 1.5 °C warming scenario. Yield advantage due to CO₂ enrichment (430 ppm) reduces the negative effect of 1.5 °C warming by 4 per cent. Rice yield varied up to ± 1 percent for the rainfall changes (±10 and ±20 %) coupled CO₂ enrichment under 1.5 °C warming compared to CO₂ enrichment alone. There is no considerable variation (-5 to 1 %) in maize productivity with 1.5 °C warming.

CONCLUSION

In Tamil Nadu, with warming of 1.5 °C, annual rainfall deviations in RCP 4.5 scenario shows drier than current condition and with RCP 8.5 scenario, the SWM will have wetter conditions and NEM is expected to have deficit rainfall by 10 per cent from the current rainfall. The results of the crop simulation models indicated that the days to maturity get advanced by 8 days for both rice and maize crops in Tamil Nadu under projected warming of 1.5 °C. The WUE of rice would decrease by 17 per cent, whereas, less

change is expected for maize (on an average 1 to 2 %) for 1.5 °C warming. The present study clearly indicates that the crops which fall under C3 photosynthetic pathway are not tolerant to the projected temperature rise as the yield is reduced by around 21 per cent and the increase in CO₂ also will not help the C3 plants as the yield compensation due to CO₂ is of only four per cent.

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