Research Article

Response of Contemporary Maize Hybrids to Future Climate Change for Tamil Nadu, India

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Abstract
In Tamil Nadu, maize occupies an important place among the cereals produced for its commercial use. To sustain maize production, various adaptation options have been recommended in literature. Among the adaptation options, choice of cultivar stands out as one of the better and cost effective option. Thus three contemporary maize hybrids of Tamil Nadu were evaluated for its response to the changing climate. The maize hybrids used in this study were CMH08-282, NK 6240 and 900M Gold. All these hybrids were pre-calibrated and the genetic coefficients were utilized in the study. Weather data from climate models PRECIS and RegCM4 were used to drive the crop model. Results of the simulation revealed that, CMH08-282 had higher levels of yield for both control and CO_2 enrichment also for both the models PRECIS and RegCM4. Even though the rate of reduction was higher for CMH08-282, the yield level was considerably higher than other two hybrids. Response to CO_2 enrichment was outstanding for NK 6240 than other two hybrids with a 66.2 and 66.2 per cent increase over control for both PRECIS and RegCM4 respectively followed by CMH08-282 and the least response is from 900M Gold. Trend analysis infers a lesser rate of reduction for 900 M Gold over the century followed by NK 6240 and CMH08-282. It is evident that 900M Gold has comparatively stable yields over the century while NK 6240 had the highest response for CO_2 enrichment. Overall, the yield level of CMH08-282 outweighs and proves to be sustaining than the other two hybrids.

Keywords: Climate change, CO2 enrichment, DSSAT, Maize hybrids, Impacts

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Introduction

Maize is the major cereal crop after wheat and rice and often referred as "the king of grain crops" [1]. Maize is produced on nearly 100 million hectares, with almost 70 % of the total maize production coming from developing world with low and lower middle income countries. The ongoing climate change is projected to affect dramatically the development, water cycle and productivity of the staple crops in broad regions of the world [2, 3]. The ability of farmers to sustain cultivating maize in the future using current production practices is uncertain, for the given climate change projections. The long-term challenge of avoiding a perpetual food crisis under conditions of global warming is serious. Adaptation is a key factor that will shape the future severity of climate change impacts on food production [3, 4] and has recently received increasing attention.

Adaptation decisions occur on a range of temporal and spatial scales, from the crop management choices of smallholder agriculturalists, to the policy decisions made by governments and regional authorities [5, 6]. Research in developing countries indicate that, in principle, climate change impacts on agriculture can be reduced through human adaptations such as; adjusting sowing dates, changing cropping patterns [7-9] or adopting higher-yielding and heat resistant cultivars, and improved extension services [10, 11]. Among these options choice of cultivar is known to play a critical role and thus the present study was framed in such a way to address and identify the contemporary cultivars that have potential to adapt and sustain future change in climate.

Materials and Methods
Scenario selection

For this study A1B scenario was selected for both the regional climate models (PRECIS and RegCM3). The A1B emission scenario falls under A1 storyline that describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies and this assumes that energy flow is balanced across all sources which takes into account fossil and non-fossil energy.

Climate Model
PRECIS

The Tamil Nadu Agricultural University in agreement with Hadley Centre, UK Met Office, received the PRECIS model. It is a regional climate model that can be run over any area of the globe, which is easy-to-use and is designed to provide detailed climate scenarios. The Hadley Centre, under contract from the UK government departments DEFRA and DFID and from the UNDP, has developed PRECIS regional climate modeling system to assess the vulnerability due to climate change by non- Annex I Parties to make their own predictions. The model was run at a horizontal resolution of 0.22° (~25km).

RegCM4

RegCM4 is a Regional Climate Model (RCM), which was developed by the Abdus Salam International Centre for Theoretical Physics (ICTP) in Italy and has been mostly applied to studies of regional climate and seasonal predictability around the world. It is an open source RCM that can be used for climate simulation over different areas of interest. The model was run at a horizontal resolution of 0.22° (~25km).

Study period

PRECIS was run for 139 years from 1961 to 2099 and RegCM3 was run for 141 years from 1970-2100. For this study data from 1971-2099 for PRECIS and 1971-2100 for RegCM3 was considered. Data were retrieved to analyze the climate change over Tamilnadu and for crop modeling using DSSAT.

Crop Simulation Model

The data retrieved from climate models were exported as weather files in the DSSAT 4.5 crop simulation model for further processing. The Decision Support System for Agrotechnology Transfer (DSSAT) is a software package integrating the effects of soil, crop phenotype, weather and management options that allows users to simulate results by conducting experiments. The DSSAT requires soil file (S Build), Management file (X Build), Weather file (Weatherman) for crop simulation and these files were prepared as per the DSSAT requirements.

Calibrated Genetic Co-efficients

The maize hybrids CMH08-282, NK 6240 and 900M Gold were pre calibrated and the genetic coefficients were utilized **Table 1**.

Table 1 Genetic Coefficients used for calibrating the CERES-Maize model

Maize Hybrids	P1 (^{0}C d)	P2 (d)	P5 (^{0}C d)	G2 (number)	G3 (mg d^{-1})	PHINT (^{0}C d)
CMH 08-282	260.00	0.64	850.00	544.00	8.50	45.00
NK - 6240	330.00	0.68	800.00	612.00	8.50	60.00
900 M Gold	300.00	0.70	770.00	513.00	8.50	60.00

- **P-1:** Thermal time from seedling emergence to the end of the juvenile phase (expressed in growing degree days above a base temperature of 8^{0}C) during which plant is not responsive to changes in photoperiod.
- **P-2:** Extent to which development (expressed as days) is delayed for each hour increase in photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).
- **P-5:** Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8^{0}C).
- **G-2:** Maximum possible number of kernels plant^{-1}.
- **G-3:** Kernel filling rate during the linear grain filling stage under optimum condition (mg day^{-1}).
- **PHINT:** Phyllochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

Assumption made in DSSAT runs

For the present study the following assumption were made in simulating the potential crop yields

- The chemical fertilizers and water was considered as not limiting
- There was no major pest and disease attacked the crop
- CO_2 was fixed as default (Keeling Curve)

CO_2 Enrichment

The effect of CO_2 fertilization was included in the study by keeping two environmental modification treatments as with and without CO_2 enrichment (**Table 2**).

Table 2 Carbon dioxide reduced/augmented over 380ppm as per A1B scenario for yield simulations

Decades	**1971-80**	**1981-90**	**1991-00**	**2001-10**	**2011-20**	**2021-30**	**2031-40**
CO_2 projected (ppm)	337	353	369	391	420	454	491
CO_2 reduced/ Augmented (ppm)	-43	-27	-11	11	40	74	111
Decades	**2041-50**	**2051-60**	**2061-70**	**2071-80**	**2081-90**	**2091-2100**	
CO_2 projected (ppm)	532	572	611	649	685	717	
CO_2 reduced/ Augmented (ppm)	152	192	231	269	305	337	

The control (CTL) treatment simulations were made with default value of 380 ppm CO_2 for all years (1971 to 2100). The CO_2 augmented over the study period is presented in Table 2. The treatments were fixed as per the atmospheric CO_2 concentration projection given by ISAM carbon cycle models used in IPCC's Third Assessment Report [12].

Adaptation options

In the present study, choice of cultivar was considered as adaptation option. Three contemporary maize hybrids CMH 08-282, NK 6240 and 900 M Gold were selected and simulated through DSSAT crop simulation model. Except the cultivar, all the other options and model files were kept constant in the simulations.

Results and Discussion

Yield impact of CMH08-282

The hybrid CMH08-282 (**Table 3**) witnessed a decreasing trend for simulations through both PRECIS and RegCM4 regional climate models also for control and CO_2 enriched simulations. It is evident from the yields that climate change will certainly have a negative impact on crop yields (-15.5 to -40.4 per cent reduction for PRECIS and -12.8 to -29.3 per cent reduction for RegCM4) including control and CO_2 enrichment. But the yield reduction varies in magnitude based on the weather data injected.

Percentage deviation between control and CO_2 enrichment was worked out to understand the magnitude of increase due to CO_2. In case of both PRECIS and RegCM4, CO_2 enrichment had a steep increase. By 2100 an increase of 40 per cent was achieved than control for PRECIS and 23.5 per cent for RegCM4. Between the models PRECIS had considerably higher yield levels than RegCM4 in all the decades.

Yield impact of 900M Gold

The hybrid 900M Gold (**Table 4**) also witnessed a decreasing trend for simulations through both PRECIS and RegCM4 regional climate models similar to that of CMH08-282. It is evident from the yield of both control and CO_2 enrichment that climate change will have a negative impact on yield (-12.4 to -22.0 per cent reduction for PRECIS and -10.9 to -22.8 per cent reduction for RegCM4).

Percentage deviation between control and CO_2 enrichment was worked out to realize the degree of increase due to CO_2. In case of both PRECIS and RegCM4 CO_2 enrichment had a steep increase like other hybrids. By 2100 an increase of 10.6 per cent was achieved than control for PRECIS and 15.5 per cent for RegCM4. Between the models, there was no considerable variation in their yield levels.

Table 3 Future yield of maize simulated for CMH08 282

Decades	PRECIS		RegCM4		PRECIS	RegCM4
	CTL	CO_2	CTL	CO_2	PD	PD
1971-1980	4031	3982	3584	3584	-1.2	0.0
1981-1990	4070	3998	3702	3668	-1.8	-0.9
1991-2000	3868	3918	3315	3504	1.3	5.7
2001-2010	3736	3869	3380	3484	3.6	3.1
2011-2020	3577	3859	3335	3507	7.9	5.2
2021-2030	3590	3834	3165	3397	6.8	7.3
2031-2040	3447	3819	3186	3428	10.8	7.6
2041-2050	3159	3729	3041	3355	18.0	10.3
2051-2060	3185	3758	3022	3265	18.0	8.0
2061-2070	2876	3541	2856	3296	23.1	15.4
2071-2080	2505	3415	2686	3293	36.3	22.6
2081-2090	2543	3366	2672	3196	32.4	19.6
2091-2100	2404	3365	2533	3127	40.0	23.5
DV	-40.4	-15.5	-29.3	-12.8		

Table 4 Future yield of maize simulated for 900 M Gold

Decades	PRECIS		RegCM4		PRECIS	RegCM4
	CTL	CO_2	CTL	CO_2	PD over CTL	PD over CTL
1971-1980	3238	3191	2880	2879	-1.5	0.0
1981-1990	3271	3150	2944	2889	-3.7	-1.9
1991-2000	3288	3198	2831	2837	-2.7	0.2
2001-2010	3012	3086	2819	2837	2.5	0.6
2011-2020	3329	3197	2783	2865	-4.0	2.9
2021-2030	2964	3088	2593	2770	4.2	6.8
2031-2040	2798	3005	2545	2715	7.4	6.7
2041-2050	3111	3051	2518	2751	-1.9	9.3
2051-2060	2868	3005	2523	2669	4.8	5.8
2061-2070	2835	2952	2342	2652	4.1	13.2
2071-2080	2508	2785	2527	2784	11.0	10.2
2081-2090	2638	2891	2212	2599	9.6	17.5
2091-2100	2526	2794	2222	2566	10.6	15.5
DV	-22.0	-12.4	-22.8	-10.9		

Yield impact of NK 6240

The hybrid NK 6240 (**Table 5**) also witnessed a decreasing trend for simulations through both PRECIS and RegCM4 regional climate models like the other two hybrids. It is evident from the yield of both control and CO_2 enrichment that climate change will have a negative impact on yield (-13.2 to -35.9 per cent reduction for PRECIS and -12.3 to -38.4 per cent reduction for RegCM4). The magnitude of reduction varied for control and CO_2 enrichment and also varied based on the weather data injected.

Percentage deviation between control and CO_2 enrichment for PRECIS and RegCM4 had a steep increase. By the end of decade 2100 an increase of 66.2 per cent was achieved than control for PRECIS and 66.1 per cent for RegCM4. Interestingly both the models predicted a same increase in their yield levels. The differential response of hybrids employed here might be attributed to the inherent capacity of hybrids. Such variation over different regions of India was also pointed out [13].

Table 5 Future yield of maize simulated for NK 6240

Decades	PRECIS		RegCM4		PRECIS	RegCM4
	CTL	CO_2	CTL	CO_2	PD over CTL	PD over CTL
1971-1980	3275	4016	3007	3508	22.6	16.7
1981-1990	3067	3852	3019	3546	25.6	17.5
1991-2000	3080	3913	2795	3421	27.0	22.4
2001-2010	3033	3878	2464	3397	27.9	37.9
2011-2020	2753	3639	2883	3367	32.2	16.8
2021-2030	2844	3814	2771	3366	34.1	21.5
2031-2040	2760	3725	2774	3320	35.0	19.7
2041-2050	2656	3716	2225	3328	39.9	49.6
2051-2060	2590	3683	2224	3424	42.2	54.0
2061-2070	2398	3560	2564	3193	48.5	24.5
2071-2080	2350	3559	2134	3342	51.4	56.6
2081-2090	2299	3540	1979	3053	54.0	54.3
2091-2100	2098	3486	1853	3078	66.2	66.1
D V	-35.9	-13.2	-38.4	-12.3		

Trend analysis

To understand the trend and rate of change over the years and between the hybrids, linear trend analysis was done using Microsoft Excel (**Table 6**). From the decadal trend slope values were extracted for both control and CO_2 enrichment also for both PRECIS and RegCM4.

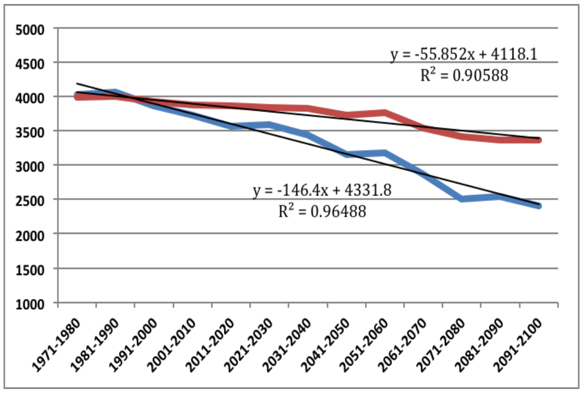
Table 6 Slope of decadal maize yield

Varieties	PRECIS				RegCM4			
	CTL		CO_2		CTL		CO_2	
	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
CMH08 282	-146.4	0.96	-55.8	0.9	-89.5	0.95	-38.6	0.92
900 M Gold	-65.1	0.78	-33.8	0.84	-59.6	0.9	-24.7	0.79
NK 6240	-89.2	0.96	-39.1	0.86	-89.7	0.77	-32.4	0.73

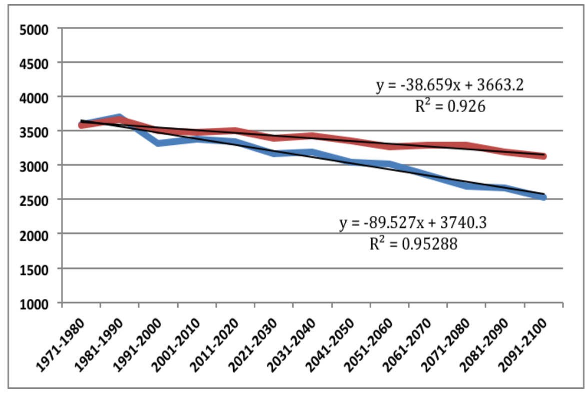
For control simulations, slope (**Figure 1** a, b) of CMH08-282 had higher rate of reduction (-146.4) for PRECIS and in case of RegCM4 both CMH08-282 (-89.5) and NK 6240 (-89.7) had similar rates of reduction. Interestingly In both PRECIS and RegCM4 simulations 900M Gold holds good with a slope of -65.1 and -59.6 respectively for control. In case of CO_2 enrichment a similar trend was noticed and 900M Gold had the least rate of reduction. All the trends had significant R^2 value. Overall the control yields were less than that of CO_2 enrichment in all the combinations. This reduction in yield for control might be attributed to the temperature increase as predicted by the models. This response might be due to the reason that in C4 plants, elevated CO_2 frequently decreases photosynthetic thermo tolerance, at near-optimal growing temperature as well as supra-optimal growing temperature [14, 15].

Inter comparison of the Hybrids

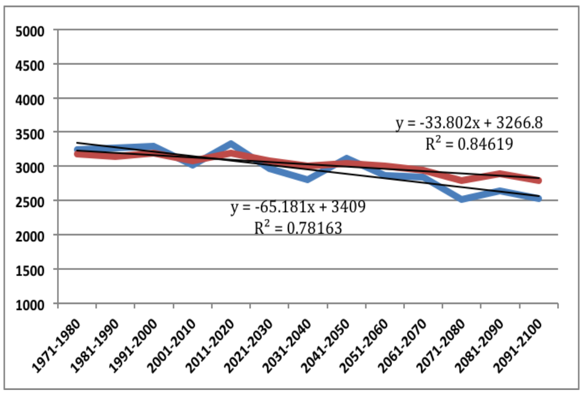
To compare the overall performance of all the hybrids, we first consider the yield levels. CMH08-282 had higher levels of yield for both control and CO_2 enrichment also for PRECIS and RegCM4. Even though the percentage deviation between the first (1971-1980) and last decade (2091 -2100) was higher for CMH08-282 than other two hybrids the yield level was considerably high. Secondly, while considering the response to CO_2 enrichment NK 6240 (Figure 1 e, f) outstands other two hybrids with a 66.2 and 66.2 per cent increase over control for both PRECIS and RegCM4 respectively followed by CMH08-282 and the least response is from 900M Gold. Trend analysis infers a lesser rate of reduction for 900 M Gold (Figure 1 c, d) over the century followed by NK 6240 and CMH08-282. It is evident from these analyses that 900M Gold have comparatively stable yields over the century while NK 6240 had the highest response for CO_2 enrichment. But the yield level of CMH08-282 outweighs and proves to be sustaining than the other two hybrids. The yield variation for control and CO_2 enrichment over Tamil Nadu showed that the yield reduction and the relative contributions of adaptation options (cultivar choice) varies depending on the climate and varietal properties, suggesting the optimal adaptation options should be region specific [16].



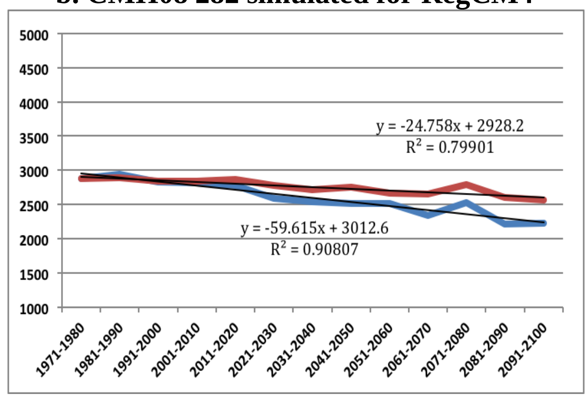
a. CMH08 282 simulated for PRECIS



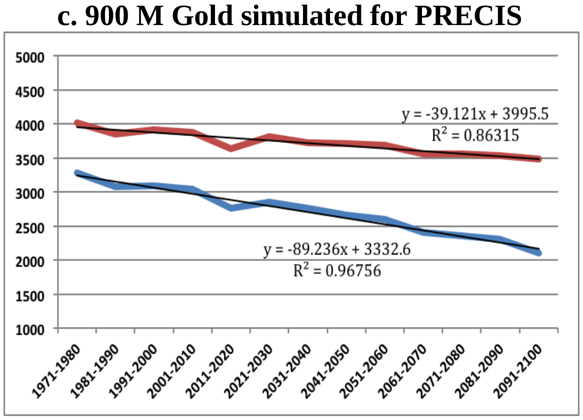
b. CMH08 282 simulated for RegCM4



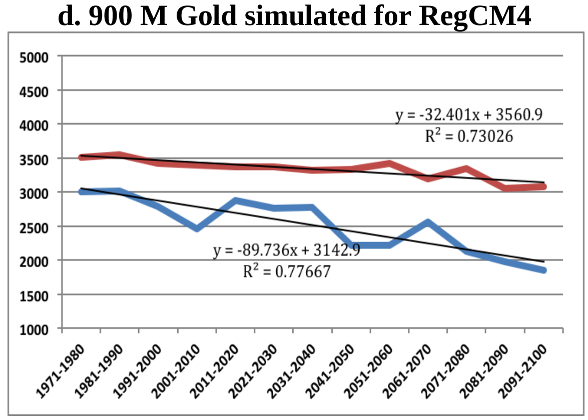
c. 900 M Gold simulated for PRECIS



d. 900 M Gold simulated for RegCM4



e. NK 6240 simulated for PRECIS



f. NK 6240 simulated for RegCM4

Figure 1 Decadal yield trend of maize hybrids

Conclusion

From the study it is clear that climate change will have a negative impact on maize yields over Tamil Nadu. However, CO_2 enrichment considerably offsets the effects of temperature increase. The response to CO_2 enrichment varies among the hybrids. Between the models PRECIS had positive response with all the hybrids than RegCM4. Overall, CMH08-282 responds well under changing climate and along with the hybrids other adaptation options should be tried in combination to improve the yield levels.

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