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Research Paper

Potential impact of future climate change on spatial variability of blackgram yield over Tamil Nadu

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ABSTRACT

Climate change is no longer a distinct prognosis but become a reality and also proved to have its impacts on crop production. Blackgram, a C3 short duration pulse crop was considered in this study to identify the adaptability with respect to changing climate. Dynamically downscaled data (CCSM4 data using REGCM4.4 model) for 1971 to 2099 (RCP 4.5 scenario) was used for the study. The popular Blackgram cultivars CO6 and VBN6 were considered for the study after calibration and validation using DSSAT model. The impact assessment was carried out with August 1st as sowing date. The yield of Blackgram was found to have beneficial stimulus towards the changing climate under enriched CO_2. Considering cultivars, difference was noticed spatially and temporally. The average yield of VBN6 was less than CO6 during base and near century, but it got reverse with time.

Keywords: *Blackgram, climate change, CO_2, dssat, impact, varietal difference*

Globally, changes in long term averages and patterns of weather parameters are being sensed and reported (Konapala *et al*., 2020). The brunt of environmental changes is expected to be substantial in the semi-arid dryland agriculture, in which pulses cultivation forms an integral part. Several studies have reported the negative impact of increase in temperature over the growth and productivity of pulse crops (Kumar *et al*., 2017; Mishra et al., 2017; Partheeban 2017; Devasirvatham and Tan, 2018; Sritharan et al., 2018; Basu et al., 2019; Jincy et al., 2019; Rakavi and Sritharan, 2019; Pavithra et al., 2021). There exists a controversial statement too, that these crops are climate smart since they can adapt as well as mitigate the impact of climate change (Mayes *et al*., 2019)

Blackgram is an important but underutilized short duration pulse crop (65-75 days) which is integrated into the farming system under rainfed conditions (Shukla & Mishra, 2020). Singh *et al*., (2016) reported that the pulses production needs to be stepped up to 26.50 Mt by 2050 to meet the growing food and nutrition demand. Also, with growing water scarcity, crop with higher water use efficiency is the need of the hour and the pulses use just one-fifth of the water as compared to cereals (Praharaj *et al*., 2016).

There exist a pressure on the rainfed crops regarding crop failure due to dependence on rainfall and predictions proves that this might be worsen in future due to changing climate. Hence, it is vital to simulate anticipated impacts to ensure food and nutritional security. Impact assessments are done using calibrated and validated process-based crop models to predict crop yields under both current and future climate conditions (Bhuvaneswari *et al*., 2014). This study is formulated considering the state's food and nutritional security, to quantify the impact of changing climate on blackgram of TamilNadu by using modelling technique.

MATERIALS AND METHODS

The simulation is done for the state of Tamil Nadu, India using the Decision Support System for Agrotechnology Transfer (DSSAT)-CROPGRO module**.** The model is calibrated and validated using field trials data for the two ruling varieties CO6 and VBN6 of blackgram using GENCALC tool (Table 1).

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Table 1: Genetic coefficients used in the model (CROPGRO) characterize the growth and development of blackgram

Coefficients	Particulars	CO 6	VBG6
VAR#	Identification code or number for a specific cultivar.	BG001	BG002
EXPNO	Number of experiments used to estimate cultivar parameters	CP0411	CP0411
ECO#	Code for the ecotype to which this cultivar belongs	11.90	7.140
CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for shortday plants) (hour)	0.394	0.0700
PPSEN	Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour)	15.23	13.90
EM-FL	Time between plant emergence and flower appearance (R1)(photothermal days)	3.000	2.50
FL-SH	Time between first flower and first pod (R3) (photothermal days)	7.046	6.00
FL-SD	Time between first flower and first seed (R5) (photothermal days)	21.84	15.03
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)	7.073	4.00
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)	90.09	8.938
LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 vpm (volume per million) CO_2, and high light (mg CO_2/m^2s^{-1})	565.8	320.0
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)	300.0	300.0
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)	0.980	1.000
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	0.037	.0295
WTPSD	Maximum weight per seed (g)	2.788	5.099
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	3.702	2.00
SDPDV	Average seed per pod under standard growing conditions (#/pod)	1.478	3.5
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	82.00	82.0
THRSH	Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity. Causes seeds to stop growing as their dry weight increases until shells are filled in a cohort.	0.300	.300
SDPRO	Fraction protein in seeds (g(protein)/g(seed))	0.065	.065

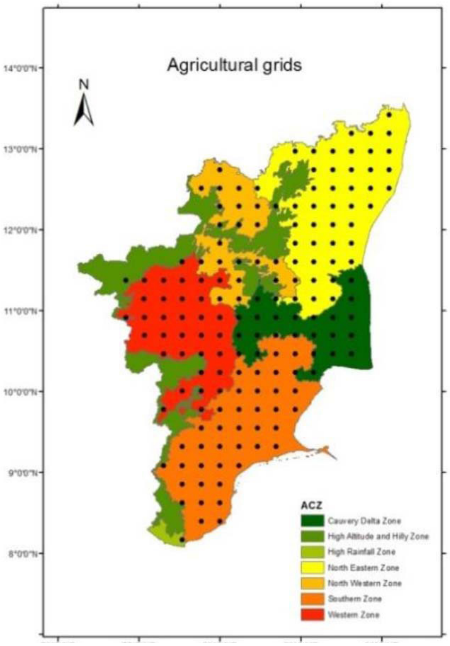


Fig. 1: Agricultural grids and the Agro Climatic Zones of Tamil Nadu

Climate and soil data

The climate data used was obtained using the Global Circulation Model (GCM), Community Climate System Model version 4 (CCSM4) and the dynamical downscaling was performed by employing Regional Climate Model (RCM), Regional Climate Model version 4.4 (RegCM4.4). A historical run was carried out with the above-mentioned model for obtaining base period data for the period of 1971-2005 and the future data for the period 2006-2099 under Representative Concentration Pathway 4.5 (RCP 4.5) scenario. The period from 2011 to 2099 has been considered to be future for the purpose of dividing the whole set into three tri-decadal period, since 30 years average is need for climate studies. Because of this reason three time scales such as near century (2011-2040), mid-century (2041-2070) and end of century (2071-2099) is considered and compared with the base period data. Soil database maintained at Department of Remote Sensing and GIS, TNAU was used for the simulations.

Carbon di oxide data

The effect of CO_2 fertilization was included in the study as recommended by the Coupled Model Inter comparison Project 5 (CMIP5) protocol by keeping two environmental modification

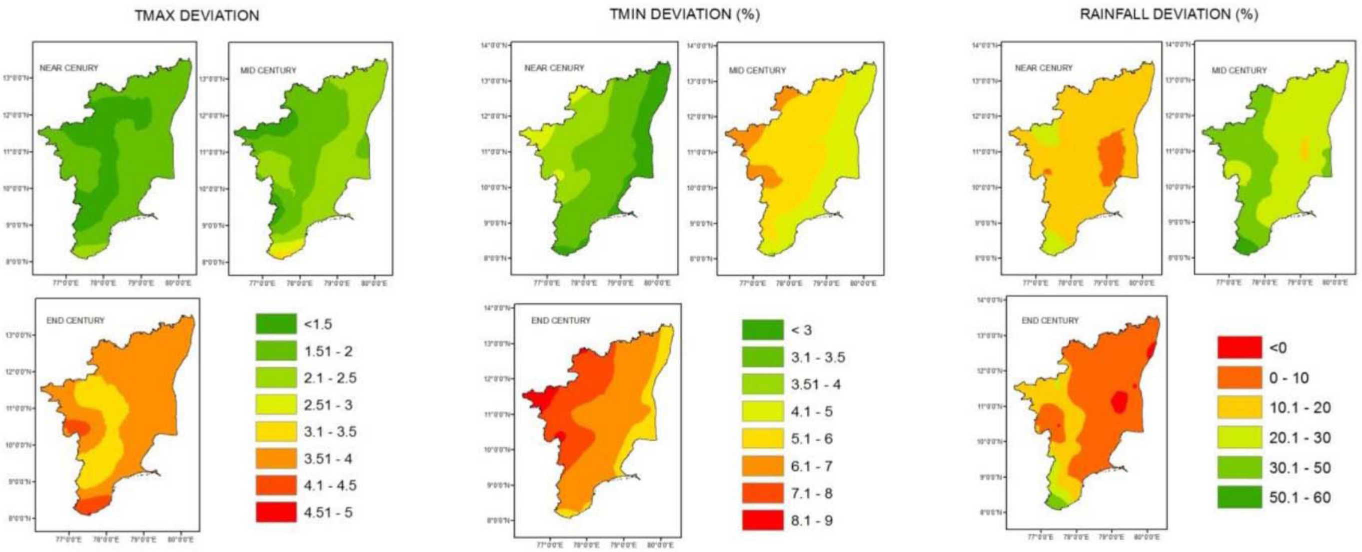


Fig. 2: Relative deviation (R.D.) (%) in maximum temperature, minimum temperature and rainfall compared with the base period.

Table 2: Yield (kg ha^{-1}) and relative deviation (R.D) (%) in yield of blackgram (CO 6) in different Agro Climatic Zones of Tamil Nadu under default CO$_2$-380 vpm

Time period	CDZ		NEZ		NWZ		SZ		WZ		TN	
	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D
BASE	795		909		666		629		1012		800	
NEAR	832	4.6	928	2.1	681	2.2	607	-3.5	977	-3.4	805	0.66
MID	755	-5.1	902	-0.8	631	-5.4	567	-9.8	945	-6.7	762	-4.73
END	828	4.1	939	3.3	691	3.7	612	-2.7	1016	0.4	818	2.28

Table 3: Yield (kg ha^{-1}) and relative deviation (R.D) (%) in yield of blackgram (VBN 6) in different Agro Climatic Zones of Tamil Nadu under default CO$_2$

Time period	CDZ		NEZ		NWZ		SZ		WZ		TN	
	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D
BASE	757		687		517		753		974		752	
NEAR	666	-12.0	598	-12.9	440	-14.9	665	-11.6	850	-12.8	660	-12.2
MID	619	-18.2	547	-20.4	404	-21.9	590	-21.6	795	-18.4	604	-19.6
END	700	-7.5	650	-5.5	465	-10.0	655	-12.9	890	-8.7	686	-8.8

Table 4: Yield (kg ha^{-1}) and relative deviation (R.D) (%) in yield of blackgram (CO 6) in different Agro Climatic Zones of Tamil Nadu under CO$_2$ enrichment

Time period	CDZ		NEZ		NWZ		SZ		WZ		TN	
	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D
BASE	731		841		607		579		932		739	
NEAR	905	24	998	19	744	23	668	16	1053	13	874	18.2
MID	892	22	1023	22	746	23	691	19	1117	20	894	20.9
END	1031	41	1088	29	852	41	751	30	1228	32	986	33.3

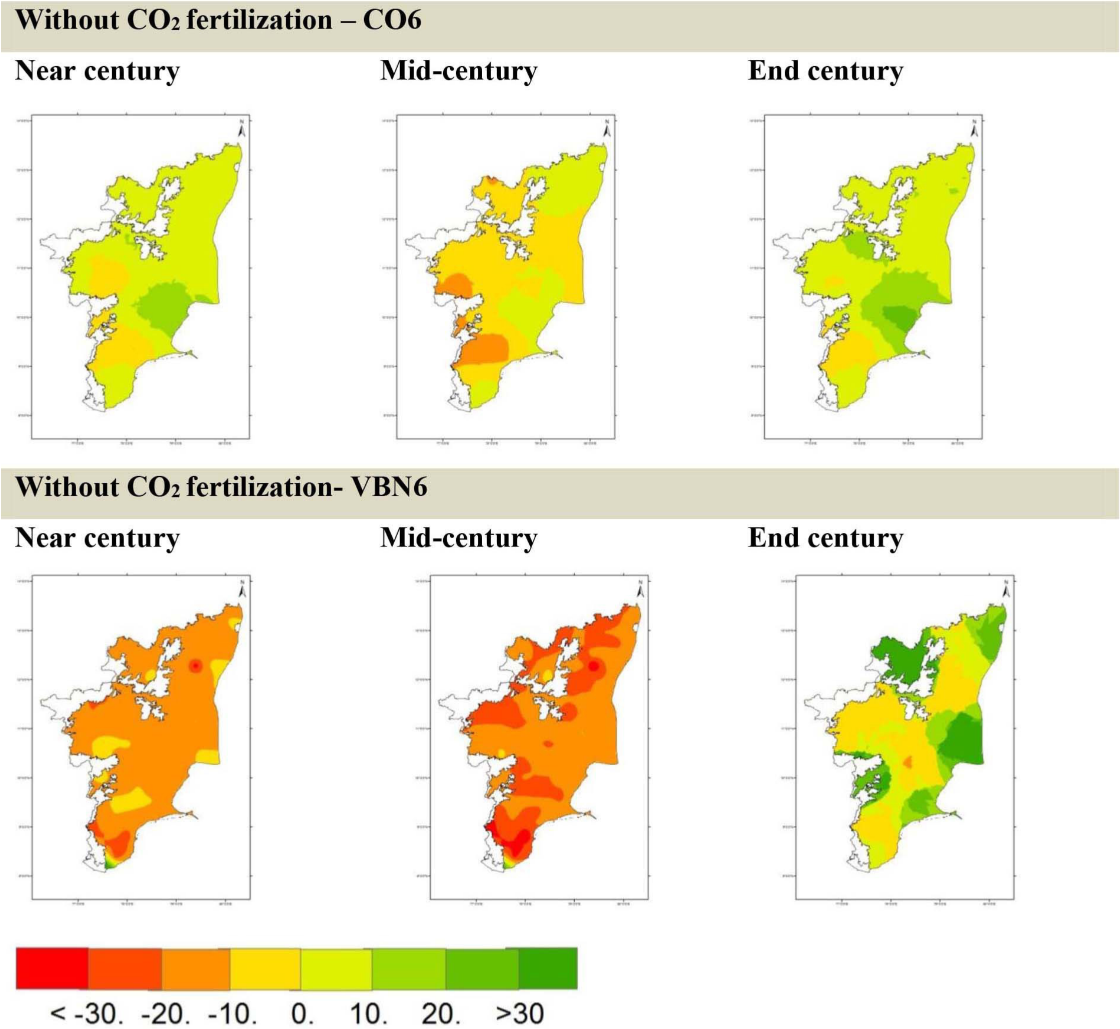


Fig. 3: Relative deviation (R.D) in yield of CO6 and VBN6 in comparison with the base period under default CO_2 concentration

Table 5: Yield (kg ha^{-1}) and relative deviation (R.D) (%) in yield of blackgram (VBN 6) in different Agro Climatic Zones of Tamil Nadu under CO_2 enrichment

Time period	CDZ		NEZ		NWZ		SZ		WZ		TN	
	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D	Yield	R.D
BASE	629		563		424		671		806		633	
NEAR	780	24	731	30	536	26	738	10	1014	26	777	22.7
MID	897	42	835	48	619	46	758	13	1175	46	869	37.2
END	1066	69	1053	87	761	80	873	30	1407	74	1044	64.9

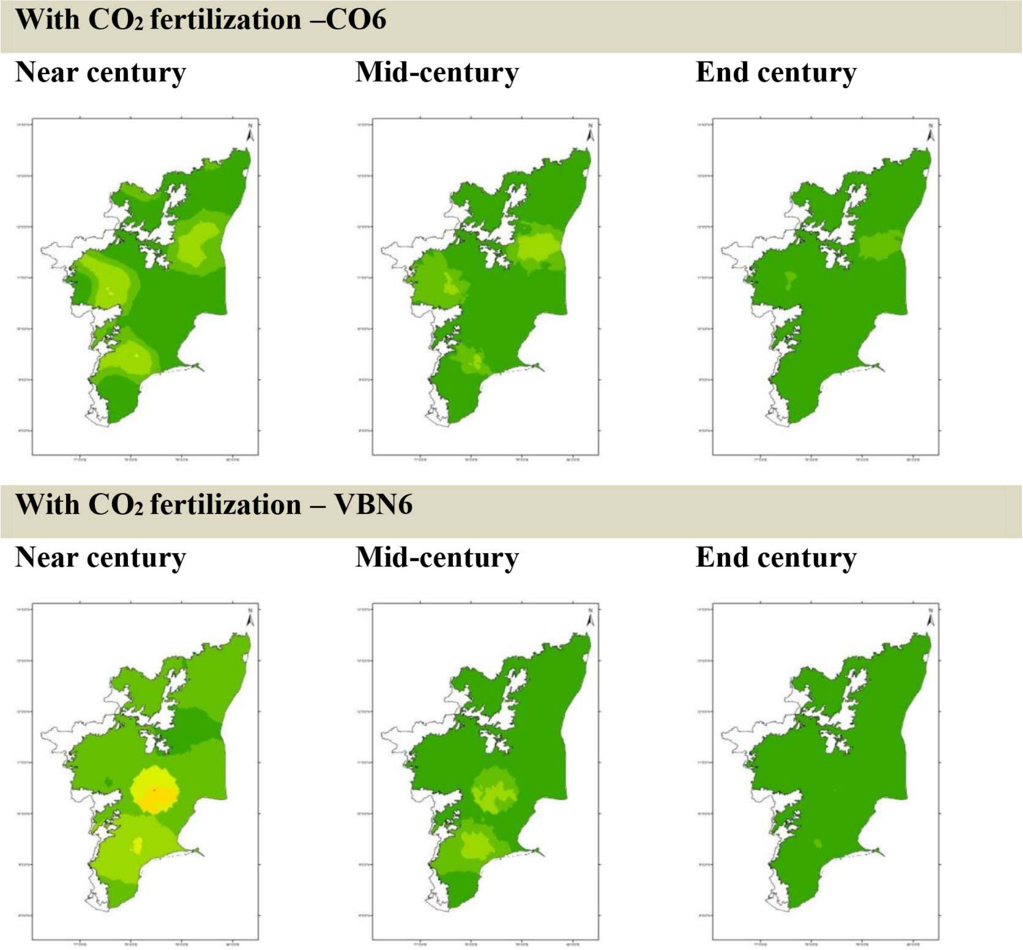
Table 6: Trend equation and correlation coefficient of blackgram cultivars under constant CO_2 concentration and interactive CO_2 (Keeling curve method).

Cultivars	Without CO_2 enrichment (constant 380 ppm)		With CO_2 enrichment (Keeling curve method)	
CO6	$y = 1.5435x + 785.92$	$R^2 = 0.02$	$y = 24.273x + 695.84$	$R^2 = 0.84$
VBN6	$y = -7.1763x + 728.14$	$R^2 = 0.23$	$y = 40.917x + 535.89$	$R^2 = 0.94$

treatments as ‘with CO_2 enrichment’ (Keeling *et al.,* 2001) and ‘without CO_2 enrichment’ (constant 380 vpm).

Grid points and mapping

The 162 Agriculturally important grids (atleast 50 % of area under agriculture) were extracted using land use with Geographical Information System (GIS) provided by Department of Remote Sensing and GIS, TNAU. The climate change impact assessment was done for 160 grid points **(Fig. 1)** by eliminating the two grids that were found to be in the inefficient zones for the cultivation of Blackgram. The spatial impact has been presented for



With CO_2 fertilization –CO6

Near century Mid-century End century

With CO_2 fertilization – VBN6

Near century Mid-century End century

Fig. 4: Relative deviation (R.D) (%) in yield of CO6 and VBN6 in comparison with the base period under enriched CO_2 concentration

the seven Agro Climatic Zones (ACZ) of Tamil Nadu.

RESULTS AND DISCUSSION

Climate change

Elevation in maximum temperature (RCP 4.5), is identified to be about 0.51, 0.65 and 1.18°C during the near, mid and end century, respectively. Also the increase in the minimum temperature during the near, mid and end century are 0.67, 1.07 and 1.36 °C when compared with the base period respectively. The relative increase in the maximum temperature, minimum temperature and rainfall are given in the figure 2.

With default CO_2 (380 vpm)- CO6 & VNB6

The deviation in productivity of CO6 cultivar over Tamil Nadu under default CO_2 is 0.66, (-) 4.73 and 2.28 per cent during near, mid and end century, respectively. But, the yield of VBN6 was found to decrease by 12.16 per cent (near century), 19.63 per cent (mid-century) and 8.79 per cent (end century). Comparing with yield of CO6, greater decline in yield of VBN6 is noticed in VBN6 (Fig. 3).

Temporal and Regional analysis has disclosed an increase in yield of CO6 for near century in Cauvery Delta Zone (CDZ), North Western Zone (NWZ) and North Eastern Zone (NEZ) and negative in Southern Zone (SZ) and Western Zone (WZ) (Table 2.). The yield of VBN6 during the base period was higher in WZ followed by CDZ, SZ, NEZ and the least yield was simulated in NWZ (Table 3).

For the mid-century, the yield of CO6 is observed to reduce irrespective of the zones, ranging between (-) 0.8 and (-) 9.8 per cent. The yield is expected to increase at the end of century in all the Zones except SZ when compared with the base period. The step-down in blackgram (CO6) yield is found to be more in SZ during near, mid and end century. The step-down in VBN6 yield is found to be more in NWZ during near and mid-century, while during the end century it is more in SZ.

Among the ACZs, the difference in yield might be due to the prevalence of favourable conditions like climatic factors, soil and cultivar suitability. The temporal variation among the yield of ACZs might be purely due to the variations in the climatic parameters especially precipitation and temperature.

The increase in productivity of CO6 is noticed in 60.6 per cent, 64.4 per cent and 71.25 per cent grids during near, mid and end century, respectively. The productivity increase is relatively higher in near future, declines toward mid-century and then increases in end century**.** Comparison with base period, decline in yield of VBN6 is likely to happen in 99.4 per cent of grids during near and mid-century, while in end century it is 75.9 per cent grids**.** The relative yield difference of VBN6 is on the negative side for all the three future time slices, but the negativity was more pronounced during the mid-century**.**

The temporal decrease in yield might be due to the impact of the increase in temperature in absence of CO_2 fertilization effect. Raise in temperature accelerates the plant developmental stages (Craufurd and Wheeler, 2009) and hence shorten the phenological stages based on the thermal time (Kiran and Chimmad, 2018). Blackgram being a short duration crop, further reduction in crop cycle duration lowers the total biomass production (Basu *et al.*, 2016) and also yield per unit area due to lesser time available for photosynthate accumulation. Similar kind of reduction in yield of Redgram is reported by Rao *et al*., (2013).

The relative deviation in mean annual rainfall projection over Tamil Nadu for the mid-century was found to be 27.7 per cent. Blackgram being simulated under rainfed condition, precipitation might be the major contribution towards yield deviation; similar finding was reported by Vanaja *et al.*, (2006). In specific, higher decrease in yield during the mid-century might be due to increase in extreme rainfall events during crop season or coincidence of extreme temperature event at the reproductive stage of the crop leading to reduction in pollen production and fertility which in turn reduces the yield (Mondal *et al.,* 2013).

With CO_2 elevation (Keeling curve)

With incorporation of CO_2 data (Keeling *et al*., 2001) the productivity over Tamil Nadu (VBN6 & CO6) is found to increase but with year to year variation. Increment in yield was found to be higher in VNB6 (Fig. 4).

The yield increase of CO6 during near century is 18.18 per cent; 20.93 per cent in mid-century and 33.34 per cent during end century (Table 4). The relative increment percentage of VNB6 is found to be 22.7, 37.2 and 64.9 per cent during the near, mid and end century, respectively (Table 5).

Yield increment of CO6 is recorded in more than 98 per cent of grid points during all tri-decadal time-slices. A relative Deviation (R.D) in yield of more than 20 per cent is anticipated in 51.2, 61.7 and 85.8 per cent of location across Tamil Nadu for near, mid and end century, respectively**.** Across the state, relative increase in productivity of VBN6 is noticed in more than 98 per cent of locations at all time periods. The increment percentage of more than 50 per cent is noticed in 0.62, 43.2 and 88.9 per cent of grid points showing a drastic yield increase (VBN6) towards the end century**.**

For both the cultivars, the yield simulated with CO_2 enrichment, excelled until the last decade of 21st century. The trend equation and correlation coefficient are given in the Table 6. Keeling *et al.*, (2001) suggested that the CO_2 concentration increases and reaches 538.15 vpm during the end of the century under RCP 4.5 scenario. The concentration of CO_2 concentration reached 380 vpm during September 2005 in case of keeling curve. This is the reason for overlapping of yield graphs at 2001-2010 decade. This shows significance of CO_2 on blackgram yield.

The utmost yield for both the cultivars is simulated in WZ irrespective of the time slice. The high-pitched increment in yield is simulated in CDZ, NWZ and CDZ as well as NWZ during near, mid and end century, respectively. In case of VBN6 maximum increment is noticed in NEZ during all the time-slices.

The elevation in maximum and minimum temperature is not so high which this crop could not adapt. Since Blackgram is a C3 crop, the impact of this mild heat stress might be counteracted by CO_2 increment (Vanaja *et al.*, 2006). The increase in CO_2 concentration favours growth, physiology and biochemical processes (Ziska and Ebi, 2021) including increase in net photosynthesis (Rao *et al.*, 2015). Similarly, Vanaja *et al.* (2007) also reported that the blackgram grown in controlled chamber at 550 ppm CO_2 reported 86.8 percent increase in pod weight and Jyothi lakshmi *et al.* (2013) reported an average increase in seed yield by 23.75 percentage. In case of long duration Pigeon Pea, increase in yield was notice under all the four scenarios Viz., RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5 (Yadav *et al*., 2021).

In case of CO6 simulated with carbon dioxide fertilization, SZ had recorded the lowest yield (Table 7), since it the most drought prone area of Tamil Nadu and this cultivar is not meant for drought tolerance. In contrast, VBN6 recorded a higher yield in SZ (Table 8). This difference in response might be due to cultivar characteristics. Also VBN6 is found to have comparatively higher response for $CO_{2.}$ The response of the cultivar to temperature is demonstrated as the function of genetic trait (Nguyen *et al.*, 2013). Derazmahalleh *et al.,* (2019) have indicated varietal variation for heat stress response in cowpea. VBN6 is a variety released by National Pulses Research Centre**,** Vamban, Pudukottai district, Southern Zone, Tamil Nadu. Also this variety was reported suit best for dry tracks of Tamil Nadu with drought tolerance. VBN6 have been reported to have higher pollen tube germination percentage, pollen viability, sustained pollen tube germination, higher fertility coefficient, along with higher number of pods per plant even at a temperature of 44/25 ºC. Among the six varieties studied by Partheeban, (2014), VBN6 was branded as a heat tolerant variety due of its genetic superiority. The cultivar CO6 is found to be susceptible to yellow mosaic disease and had higher reduction in yield during summer season, where temperature influenced the yield (Partheeban *et al.*, 2018).

CONCLUSION

In general, Blackgram accessions have come from the areas with high temperature and persistant droughts. The yield of blackgram was found to be vulnerable to the future change in climate in absence of CO_2 enrichment (default CO_2 conc. 380 vpm). However, this effect would be counteracted to certain extent by the simultaneous increase in the carbon dioxide, since it is a C3 crop. Till mid-century performance of CO6 is better than VBN6 and after mid-century it is vice vera. From this it is clear that this crop would be certified as a climate smart and utilized for climate resilient agriculture.

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