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Research Paper

Modelling adaptation strategies towards climate smart red gram production in Tamil Nadu

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ABSTRACT

Assessing the pulse of an important legume crop, red gram (*Cajanus cajan L.*) of Tamil Nadu under changing climate and framing adaptation strategies were formulated using the DSSAT model. The assessment was done for the popular variety of red gram, viz., CO(RG)7 with August 1st as sowing date, under constant CO_2 (380ppm) and CO_2 enrichment. The adaptation strategies such as altering the sowing date and 25 per cent increment in nitrogenous fertilizer were carried out with CO_2 enrichment conditions. The yield was found to be adversely affected by the warming scenario of the climate system without CO_2 fertilization. With the incorporation of enriched CO_2 data, the average yield increases until the end of the century, but with temporal and spatial variations. Among the different agro climatic zones of Tamil Nadu, highest yield was recorded in Western Zone and lowest in Southern Zone. There was no response to application of nitrogenous fertilizer. July 15 sowing was identified to be the best sowing for the base as well as future period for CO(RG)7.

Key words: Red gram, Climate change, climate smart agriculture, adaptation, Agroclimatic zones

The variability over the normal weather conditions are perceived all over the world and the projections of climate using high resolution models also confirmed the aggravated changes in the future climate. The studies on changes in the climate have projected the changes to be higher over tropics and sub tropics (Bastin *et al.*, 2019). Redgram is an important C3 pulse crop which is sensitive to rainfall and higher temperature stress (Mishra *et al.,* 2017) especially when coincides with the reproductive stage. The increase in both minimum and maximum temperature as well as rainfall were found to have negative impact on seed yield (Patil *et al.,* 2018). Hence to sustain the yield in the future to ensure food security. There are varieties of varying duration of 105 days to 300 days with hardy nature and drought tolerant capacity. The projected impact of climate change using DSSAT model showed delayed reproductive stages (anthesis, maturity) in short, medium and long duration redgram genotypes which has progressive decreased yield (Yadav *et al.,* 2021). Employing the crop models for assessing the impact of climate change on crop productivity and identifying the ways to sustain by adapting simple adaptation approaches could help in dropping the influences of climate change and its extremes (Singh, 2023). The adaptations that a farmer could consider involves altering the sowing window (Patil *et al.,* 2018), selection of better performing cultivar (Rezaei *et al.,* 2018), irrigation scheduling (Ivanova and Popova, 2021) and nutrient application. Also, being a C_3 crop redgram would respond positively towards the increase in CO_2 in the atmosphere (Sreenivas *et al.,* 2021).

Pigeon pea is a major altruist towards nutritional security in terms of protein requirement. This study has been formulated considering the state's food as well as nutritional security, to

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quantify the impact of the changing climate and develop adaptation option for a widely cultivated medium duration variety, (CO (RG)7) of Tamil Nadu using climate and crop models.

MATERIALS AND METHODS

Study was taken up for the entire state of Tamil Nadu, India which is geographically located in the latitude between $08^{0}00'$ and $13^{0}30'$ N and longitude between $76^{0}15'$ and $80^{0}18'$ E. For this study, the study region's important ruling medium duration variety, CO (RG)7 was selected. The crop was sown during 2016 in five locations that have different climatic conditions, with the different dates of sowing (Fig. 1). The crop was grown under irrigated condition. Biometric observations of the crops were taken at 15 days interval along with the management data. The collected data were used for calibration and validation of CO (RG)7 of redgram. The plant growth parameters (plant height, number of leaves, leaf area index and dry matter production) and yield parameters (pods per plant, seeds per pod, unit grain weight and yield) were observed (Table 1). The minimum set of weather data viz., minimum and maximum temperature, rainfall and solar radiation required for the running of crop simulation model were collected from the agromet observatory as well as automatic weather stations (AWS) installed at the experimental locations by Agro Climate Research Centre, TNAU.

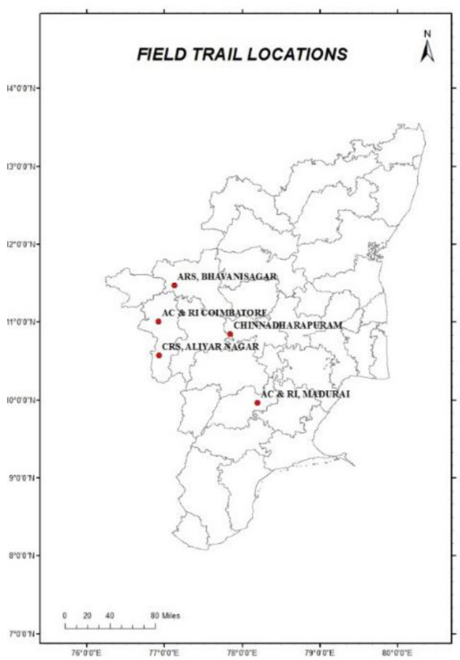

Fig. 1: Penta locational field trial

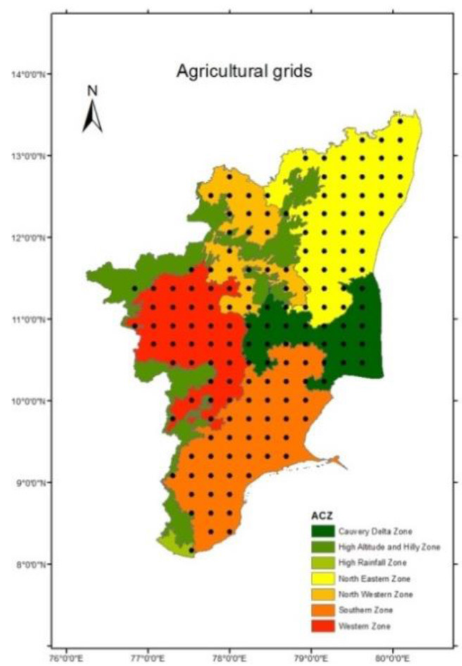

Fig. 2: Agro Climatic Zones & grid points

Calibration and validation

The genetic coefficient parameters that influence the occurrence of phenological stages, growth parameter, yield parameters and yield in the CROPGRO were derived by manipulating the relevant coefficient parameters to achieve the best possible match between the simulated and observed data with the help 'GENCALC' tool available in DSSAT v4.7 model (Table 1). The model was calibrated and validated using the penta-locational field trial.

The performance of the cultivar was determined by the prevailing climate and hence it varies with time and region. Considering this, the yield was aggregated over the five Agro Climatic Zones (ACZs) of Tamil Nadu viz., Cauvery Delta zone (CDZ), Western Zone (WZ), North Western Zone (NWZ), Southern Zone (SZ) and North Eastern Zone (NEZ) excluding the high altitude and hilly zone and the high rainfall zone which were inefficient zones for red gram cultivation (Fig. 2).

Downscaled climate data

Representative Concentration Pathway 4.5 (RCP4.5) is a stabilization scenario under which greenhouse gas concentration stabilizes at about 540 vpm by 2100 which is likely to be expected in case of developing countries like India (Thomson *et al.,* 2011). Hence, this scenario was selected for the study. The data was derived by statistically downscaling the data of Community Climate System Model version 4 (CCSM4), a global Circulation Model (GCM) with RegCM4.4 (Regional Climate Model version 4.4), a Regional Climate Model (RCM) at Agro Climate Research, TNAU.

Climate change impact assessment and adaptation strategies

The climate change impact assessment and framing of adaptation strategies were done by using the downscaled historic base line data for the period 1971-2005 and future projected data (RCP4.5 radiative forcing) for the period 2006-2099. The future period was divided into three time scales such as near century (2011-2040), mid century (2041-2070) and end of century (2071-2099). The climate change impact assessment was done for 160 grid

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

Coefficients	Particulars	CO(RG) 7
ECO#	Code for the ecotype to which this cultivar belongs (see *.eco file)	PP0001
CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for shortday plants) (hour)	12.94
PPSEN	Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour)	0.10
EM-FL	Time between plant emergence and flower appearance (R1)(photothermal days)	37.5
FL-SH	Time between first flower and first pod (R3) (photothermal days)	10.4
FL-SD	Time between first flower and first seed (R5) (photothermal days)	16.5
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)	19.02
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)	20.87
LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO2/m2s-1)	50.1
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm2/g)	400.
SIZLF	Maximum size of full leaf (three leaflets) (cm2)	301.4
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	0.90
WTPSD	Maximum weight per seed (g)	0.24
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	39.6
SDPDV	Average seed per pod under standard growing conditions (#/pod)	2.00
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	10.3
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.	76.2
SDPRO	Fraction protein in seeds (g(protein)/g(seed))	0.224
SDLIP	Fraction oil in seeds (g(oil)/g(seed))	.015

points that were found to be efficient of redgram cultivation.

Climate change simulations not only deals with the simulation of yield using the projected weather parameters, soil, and cultivar data but also increase in CO_2. To know the response of the cultivar for CO_2 enrichment, the impact assessment was done with constant CO_2 concentration (constant 380 vpm) as well as enrichment of CO_2 conditions as suggested by Keeling *et al*., (2001). Adaptation strategies such as identification of the altering the date of sowing i.e., preponing and postponing the sowing date 15 and 30 days from the default sowing of August 1st and supplementing 25 per cent extra dose of nitrogenous fertilizer.

Percentage relative difference (R.D.%)

Percentage relative difference from base year (1971-2005) for red gram productivity was worked out for the time slices of the future century using the following formula.

$$\text{R.D. \%} = \frac{\text{Average predicted productivity (Future period – Base period) x 100}}{\text{Average predicted productivity of base years}}$$

RESULTS AND DISCUSSION

Climate change under RCP 4.5 scenario

The downscaled CCSM projected climate data using the RCM, REGCM4.4 disclose the increase in maximum temperature, minimum temperature and rainfall over Tamil Nadu. The projected increase in maximum temperature when compared with base period are 1.58, 2.01 and 3.64 percentage during the near, mid and end century, respectively. The increase in minimum temperature is much higher compared to maximum temperature and the increase for near, mid and end century are expected to be 3.26, 5.17, 6.59 percentage respectively. There is also an expected increase in rainfall over Tamil Nadu with the amplitude of 202.77 mm (13.1 %), 428.61 mm (27.7 %) and 94.12 mm (6.1 %) during the near, mid and end century, respectively.

Climate change impact assessment- under constant CO_2 (380 vpm)

The simulation with the carbon dioxide concentration as 380 vpm had revealed that the yield over Tamil Nadu to be 1065 kg ha^{-1} during the base period and the yield was found decrease during near century by 9.6 per cent, during mid-century by 17.1 per cent and 5.5 percent during end century (Table 2).

The yield was found to be reduced in all the five ACZs for the future. The reduction in yield was projected to vary from 7.6 to 10, 13.1 to 17.1 and 4.5 to 8.5 per cent at the near, mid and end century, respectively. Among the agro climatic zones, WZ would record the highest yield while NWZ the lowest under future scenario (Table 2).

Redgram (CO(RG)7)- with CO_2 elevation

With the incorporation of CO_2 data, the average yield over Tamil Nadu was found to be 952 kg ha^{-1} during the base period and increased continuously till the end century at the rate of 13,

Table 2: Productivity of redgram (CO (RG) 7) under time slices for ACZs of Tamil Nadu (Constant CO_2 method)

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	1009		1115		834		872		1399		1065	
Near	931	-7.8	1030	-7.6	765	-8.3	801	-8.1	1260	-10.0	970	-9.6
Mid	877	-13.1	965	-13.4	699	-16.2	731	-16.2	1160	-17.1	895	-17
End	962	-4.7	1064	-4.5	795	-4.7	797	-8.5	1309	-6.5	995	-5.5

Table 3: Yield and Relative yield of redgram (CO (RG) 7) over the five Agro Climatic Zones of Tamil Nadu

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	909		987		731		797		1246		952	
Near	1024	12.6	1150	16.5	867	18.6	874	9.7	1402	12.5	1076	13
Mid	1081	18.9	1228	24.5	921	26.0	886	11.3	1466	17.6	1125	18
End	1223	34.4	1387	40.5	1080	47.7	999	25.4	1698	36.3	1286	35

Table 4: Redgram yield over ACZs during base period for different sowing date

Sowing dates	CDZ	NEZ	NWZ	SZ	WZ	State
July 1	1040	1054	757	862	1316	1006
July 15	999	1035	755	851	1313	991
August 1	909	987	731	797	1246	934
August 15	813	907	691	737	1130	856
September 1	714	796	614	650	942	743

18 and 35 per cent during near, mid and end century, respectively. The average yield over Tamil Nadu and the contribution of different ACZs is presented in the Table 3.

Among the different zones, WZ recorded the highest yield followed by NEZ and the lowest in SZ. Even though highest yield was noticed in Western zone, the increment per cent was found to be highest in NWZ during the near century (18.6 %), mid-century (26 %) and end century (47.7%). The increase in yield was observed to take place in more than 99 per cent of grid points when compared with the base period, across the state during the 21st century (near, mid as well as end century).

Redgram yield was found to oscillate but does not follow any regular pattern. The yield during near century underwent a mild decline, reached the lowest during mid-century and then went on a positive change at end century. Similar condition also exists in case of all ACZs. The decline in yield might be due to the temperature impact or the precipitation distribution and intensity in case of mid-century. This crop is sensitive to high temperature; the reduction in yield with higher temperature was reported to be due to the sensitivity of the male (pollen, anthers) and female (stigma-style, ovary) organs, leading to poor seed set and development (Kiran *et al.,* 2018).

The negative effect of increase in temperature was found to be outstripped by the CO_2 enrichment (keeling curve method) in which the yield continuously increased till the end of the century. This might be due to the increase in CO_2 concentration; similar findings were in blackgram (Pradipa *et al.,* 2022). The increase in number of pods, number of seeds and test weight of red gram crop by 97.9%, 119.5% and 7.2% respectively under elevated CO_2 was reported by Vanaja *et al.,* (2010). Similarly an increment of more than 50 per cent was noticed in case of blackgram during the future with RCP 4.5 scenario with the incorporation of CO_2 elevation data as suggested in Keeling curve (Pradipa *et al.,* 2022). Similar results were also reported in case of soybean (Kumagai *et al.,* 2015) and in kidney bean (Prasad *et al.,* 2002).

Among the ACZs, WZ was identified to produce higher yield, which is followed by NEZ, CDZ, NWZ and SZ (Fig. 3). This might be due to the soil profile characteristics and the climatic parameters. The Southern Zone (SZ) is the region in Tamil Nadu, where the frequency of dry spells is more, and moisture stress is the major contributor for the reduction in yield. Redgram being a long duration crop, any moisture stress or rainfall during the flowering stage reduces the yield terrifically. The irregularity in yield deviation might be due to the variation in rainfall quantity and pattern, which varies spatially and temporally (Kabote *et al.*, 2012).

Adaptation strategies

The adaptation strategies selected are altering the date of sowing and application of additional dosage of nitrogenous fertilizer.

Table 5: Redgram yield over ACZs during near, mid and end century for different sowing dates

Sowing dates	CDZ	NEZ	NWZ	SZ	WZ	State
			Near Century			
July 1	1124	1146	828	895	1436	1086
July 15	1097	1165	857	905	1464	1098
August 1	1024	1150	867	874	1402	1063
August 15	927	1062	826	810	1290	983
September 1	806	925	722	706	1077	847
			Mid century			
July 1	1158	1194	876	902	1524	1131
July 15	1140	1214	899	906	1541	1140
August 1	1081	1228	921	886	1466	1116
August 15	992	1163	888	829	1338	1042
September 1	883	1035	805	751	1167	928
			End century			
July 1	1309	1378	1039	1018	1720	1293
July 15	1279	1394	1070	1019	1759	1304
August 1	1223	1387	1080	999	1698	1277
August 15	1158	1334	1048	972	1590	1220
September 1	1059	1234	972	887	1402	1111

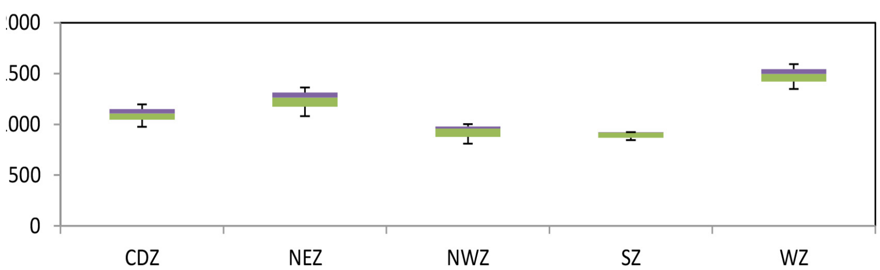

Fig. 3: Redgram (CO(RG)7) yield changes projected for the ACZs of Tamil Nadu (2011-2099)

Altering sowing date for base period: The mean yield of the cultivar CO(RG)7 was 1006 kg ha^{-1} for the base period, when the sowing was taken 15 days earlier. When the sowing was fixed 30 days prior to the default sowing, the mean yield was 1017 kg ha^{-1}. Yield of more than 1500 kg ha^{-1}was noticed in 57 locations, irrespective of the two sowing dates. The mean positive deviation in productivity was 6.3 and 5.2 per cent for July 1st and July 15th sowing, respectively. In case of July 1st sowing the number of grids in which increase in yield was noticed was 127 locations; for July 15th sowing it was 142 out of 160 locations. In some locations yield was found to decrease unto 13.6 per cent whereas increment percent of 35.9 per cent was noticed when sowing was taken on July 1st.

The yield of the crop simulated with July 1st as sowing dates was found to be higher in all the five ACZs. The second highest yield was simulated with July 15th sowing irrespective of the ACZs. Among the ACZs, the highest yield was noticed in WZ followed by NEZ and CDZ, whereas the lowest was noticed in NWZ irrespective of the sowing dates (Table 4).

The crop response to delayed sowing for the base period is found to be on negative side. The decrease in yield is noticed in 96.3 and 98.8 per cent of locations for August 15th and September 1st sowing, respectively when compared to that of August 1st sowing. The mean relative yield difference for August 15th and September 1st are (-) 7.1 and (-) 19.1 per cent, respectively. The range in deviation is between (-) 16.8 and 8.7 per cent for August 15th sowing. For September 1st sowing the range in deviation is between (-) 42.6 and 4.3 per cent.

Altering sowing date for future climate: When the sowing was taken 15 (July 15) and 30 days (July 1) earlier for the redgram cultivar CO(RG)7, the mean yield for the 21st century (2011 to 2099) is simulated to be 1188 and 1174 kg ha^{-1}, respectively (Fig. 3). The yield of more than 2000 kg ha^{-1} was recorded in 36, 38 and 59 locations during the time slots of 2011-2040, 2041-2070 and 2071-2099, respectively, for 30 days advancement in sowing (July 1). When the sowing is shifted 15 days in advance (July 15), positivity in simulated yield is little higher than in case of 30 days in advancement.

The number of locations with yield of more than 2000 kg ha^{-1} is expected in 38, 40 and 60 grids for the near, mid and end century, respectively. That is, in case of July 1st sowing the number of grids in which increase in yield is noticed in 127 locations; for July 15th sowing it is 142 out locations.

For CO(RG)7, delaying the sowing by 15 days (August 15), the yield would increase only in 8.0, 6.2 and 19.1 per cent of locations over Tamil Nadu during near, mid and end century, respectively. Wherein, delaying the sowing by 30 days would result in yield increase in an insignificant number of locations.

Whereas, considering the average yield over the ACZs, the best choice for date of sowing varies. Considering the CDZ, July 1st would the best option followed by July 15th sowing for the near, mid and end century. July 15th sowing would yield more in SZ and WZ during all the three future time slots and during near and end century in NEZ. Whereas For NWZ, August 1st sowing was found to be the best during near, mid and end century (Table 5).

Identification of optimal date of sowing is essential to obtain higher productivity of the crop under changing climate (Tingem and Rivington, 2009). The success of a crop simulated under non-irrigated conditions depends on the onset of sowing window, coincidence of the rainfall with the critical stages of the crop, non-coincidence of rainfall during flowering stage (Kumari and Reddy, 2021) and also non coincidence of temperature stress during flowering stages (Saxena *et al.*, 2018).

CONCLUSION

To sustain the vegetable protein requirement of our nation, it is necessary to have a detailed study on the pulse crop that is reported to be affected seriously by the burning issue of the climate change. The yield of redgram was found to be adversely affected by the warming scenario of the climate system without CO_2 fertilization. The productivity of the selected cultivar of redgram under climate change was found to have beneficial stimulus with the fertilization of CO_2. This is because, redgram being a C_3 crop has responded expressively and positively with increased CO_2. July 1st was found to be the best option for CDZ whereas July 15th sowing for SZ and WZ during all the three future time slots. For NEZ, July 15 sowing was found to yield more during near and end century whereas, August 1st for mid-century. For NWZ, August 1st sowing was found to be the best during near, mid and end century

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