Journal of Agrometeorology 18 (1) : 41-47 (June 2016)

Agronomic management options for sustaining chickpea yield under climate change scenario

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ABSTRACT

The impact of future climate change on the chickpea productivity was studied using the sequence analysis tool of DSSAT V 4.5 to simulate fallow-chickpea rotation at four locations viz Anantapur, Kurnool, Kadapa and Prakasam of Andhra Pradesh State. The results indicated that as compared to baseline climate, the climate change to be anticipated by 2069 (Mid –century period) would decrease the yield of chickpea by 4.3 to 18.6 per cent across various locations tested. Yield benefits obtained based on the simulation study from various adaptation options revealed that advancing the sowing window by one fortnight and application of one critical irrigation at 60 DAS found to be beneficial in increasing chickpea yields under climate change scenario.

Key Words : CROPGRO - chickpea, climate change, management options, sequence analysis, sowing window

Chickpea (Cicer arietinum L.) is one among the largest pulse crops grown in India and the second largest food legume in the world. It occupies around 15 per cent of total pulse area globally and is cultivated in almost 52 countries (FAO, 2014). India ranks first in terms of chickpea production and consumption in the world (both at almost 70%). Currently, chickpea covers 35 per cent of total pulse area and constitutes nearly 47 per cent of total pulse production in India (GOI, 2014). Six major States namely Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Karnataka and Andhra Pradesh together contribute more than 90 per cent of total area and production in India . Prakasam, Kurnool, Kadapa and Anantapur are the major chickpea growing districts in Andhra Pradesh. The chickpea productivity enhancement in the recent period was more conspicuous in Andhra Pradesh as compared to other States in India. However there are still several biotic and abiotic factors that prevalent in chickpea growing regions affect yield (Knights and Siddique, 2003). Among abiotic factors, terminal drought, high temperature during reproductive phase and cold sensitivity of the crop during its vegetative phase were the most important abiotic stresses faced by the chickpea crop (Kashiwagi *et al*., 2006; Leport *et al*., 2006). Heat stress at reproductive stage was becoming a major constraint to chickpea production in the country because of large shift in chickpea area from the cooler to warm environments (Gaur *et al*., 2014). The Intergovernmental Panel on Climate Change (IPCC) had reported a likely global temperature increase in the range from 1.4 to 6.4 °C by 2100, with a corresponding increase in atmospheric CO_2 concentration (IPCC, 2007). Given the importance of chickpea as a major pulse crop, it is highly necessary to study and understand the impact of future climate changes on chickpea productivity in major chickpea growing regions of the State

MATERIALS AND METHODS

The study locations (Kurnool, Anantapur, Prakasam and Kadapa districts) represent major chickpea producing areas in Andhra Pradesh. Dominant soils in the study area are vertisols and irrigated alfisols which are most preferred soils for chickpea cultivation. Spatial distribution of potential extractable soil water varied from 164 to 273 mm depth due to variations in soil depth and texture (120-200 cm). Fallow-chickpea is the dominant cropping pattern existing in the study locations and about 75 per cent of the total chickpea production is concentrated in these four selected districts. These districts are characterized by annual rainfall ranged from 550 to 870mm.

The CROPGRO -Chickpea model

CROPGRO -Chickpea growth simulation model which is a part of DSSAT V. 4.5 developed by International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) (Hoogenboom *et al*., 2010) was used to study the impact of climate change on chickpea productivity and also to evaluate various agronomic adaptation options.

Table 1 : Crop management information

Scenario	Anantapur	Kadapa	Kurnool	Prakasam
Sowing window	1st Oct – 15th Oct	16th Oct 30th Oct	1st Oct – 15th Oct	1st Nov 15th Nov
Advance sowing window	16th Sep- 30th Sep	1st Oct—15th Oct	16th Sep- 30th Sep	15th Oct to 1st Nov
Cultivar	JG-11	JG-11	JG-11	JG-11
Plant population (no m^{-2})	40	40	40	45
FYM/Compost(kg ha^{-1})	0	0	0	0
N fertilizers(kg ha^{-1})	40	39	64	98
Irrigation (50 mm/ irrigation)	60 DAS	60 DAS	60 DAS	60 DAS

Weather data

Thirty-years (1980-2009) of observed daily weather data were used in CROPGRO-chickpea simulation model and these data were obtained from Acharya NG Ranga Agricultural University Agromet observatory located at Anantapur, Nandyal and India Meteorological Department (IMD) weather station at Ongole. The baseline weather datasets were inspected for outliers or anomalous values and if found, such values were adjusted and corrected using bias corrected AgMERRA data.

Soil data

Four different soil profiles according to the soil type were used. The study locations were mapped on the Andhra Pradesh soil map as developed by NBSS&LUP, Nagpur and the representative soil profile for each study location point was prepared. Soil physico-chemical properties such as texture, hydraulic parameters, bulk density, organic matter and available N were estimated from each sample based on the existing soil profile data available and also using the expert's knowledge. Additional soil parameters, including the soil albedo, drainage constant, and runoff curve number were also estimated based on the soil texture data from the generic soil database available in the DSSAT-models (Tsuji *et al.*, 1998).

Crop management data

Crop management data for row spacing and plant population were followed as recommended by the local Agricultural University. A model feature called "automatic planting'' was used to obtain the appropriate planting date, with planting condition requirements set to 40 per cent of extractable soil moisture for the top 30 cm of the soil profile. The detailed management practices followed for each district was sourced from representative crop management survey conducted under Standing Panel on Impact Assessment (SPIA) funded project (Bantilan *et al.*, 2014) and the collected information are presented in the Table1. At all the sites, the crop was not irrigated and grown under residual moisture condition after a fallow during rainy season.

Model calibration and determination of genetic coefficients

JG11, a short duration variety (90–100 days) mostly used in the study location was used in the simulations. The variety was calibrated using the crop data sets available in the annual reports of the All India Coordinated Research Project on Pulses (AICRPP, 1999–2011). The multi-location trail data where JG-11 used as a regional check were used to calibrate and evaluate the JG-11 cultivar coefficients. The crop data on sowing dates, days to physiological maturity, yield attributes and yield data from agronomic trials and phenological data from physiology trials were used for generating the genetic coefficients (Singh *et al.*, 2014).

Simulation runs

The sequence analysis tool of DSSAT V4.5 was used to simulate fallow-chickpea rotation in the study regions. This tool allowed the user to conduct simulations of crop rotations or crop sequences and to analyze the results. The main aspect of the sequence analysis was the consideration of experiments that were conducted across the multiple cropping seasons. Simulations were done initially for 30 years using historical baseline weather data (1980-2009). The approach used in this simulation studies was to first determine the set of management options that best suited for chickpea and then evaluated them as the best climate change adaptation practice options for mid-century period under climate change condition. Projections for future climate were obtained by using the Fifth Coupled Model Inter-comparison Project (CMIP5) and the Representative Concentration Pathways (RCP) for carbon emissions used for the IPCC Fifth Assessment Report. Future climate projections were created by utilizing a "delta" approach, in which the mean monthly changes (from baseline) RCP 8.5 for Near, Mid and End Century time slices that was centered around 2030, 2055 and 2080 respectively were applied to

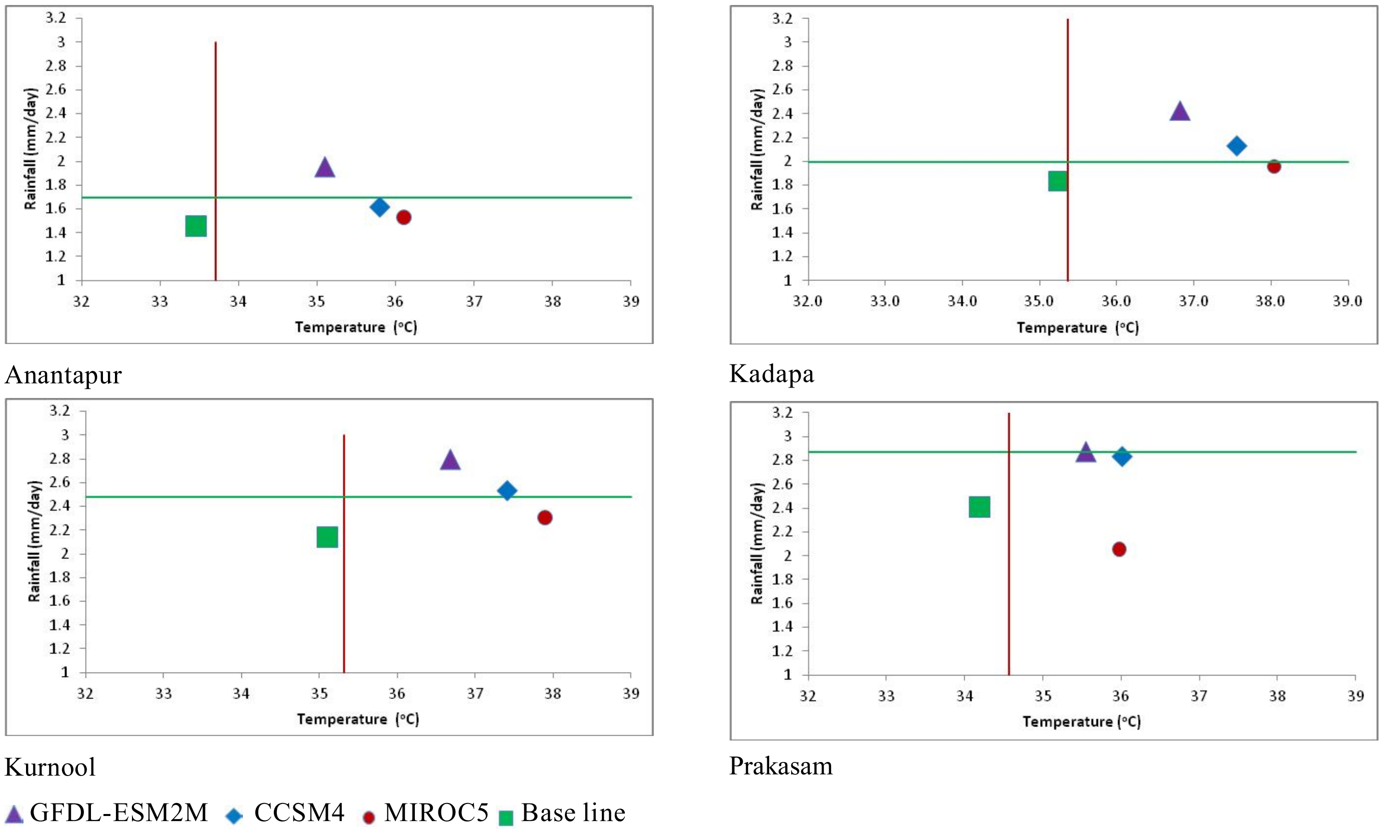

Fig. 1 : Projections for yearly rainfall and mean temperatures under RCP 8.5 midcentury climate conditions in the study area locations. Red and green lines indicate calculated significance thresholds (at the 0.05 level), beyond which the rainfall and temperature changes become significant. The green square indicates the baseline temperature and yearly mean rainfall.

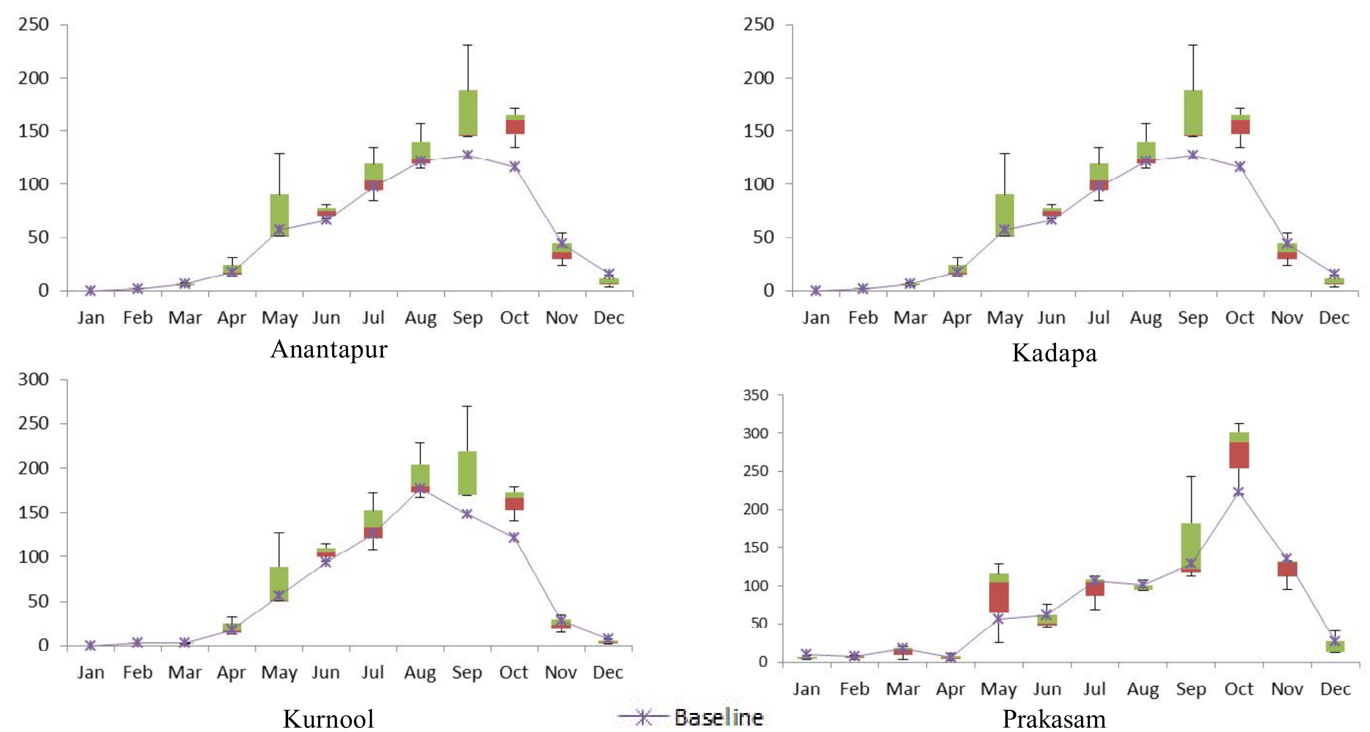

Fig. 2 : Box plots showing projections for monthly rainfall under RCP 8.5 midcentury climate conditions in the study area locations for three GCMs. The line graph indicates base line monthly rainfall.

Table 2 : The summary of climate change impact on chickpea in four districts of Andhra Pradesh during mid-century period (2040-2069)

Region	Base climate (1980-2009)	CCSM4				GFDL-ESM2M				MIROC5				Average of 3 GCMs			
		Without CO_2		*With CO_2		Without CO_2		*With CO_2		Without CO_2		*With CO_2		Without CO_2		*With CO_2	
	yield kg ha^{-1}	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)
Anantapur	611	447	-26.9	499	-18.4	830	35.8	1005	64.5	476	-22.0	542	-11.2	584	-4.3	682	11.6
Kadapa	1812	1358	-25.1	1613	-11.0	1811	0.0	2193	21.0	1257	-30.6	1508	-16.8	1475	-18.6	1771	-2.2
Kurnool	1780	1452	-18.4	1700	-4.5	1680	-5.6	2021	13.6	1408	-20.9	1659	-6.8	1513	-15.0	1794	0.8
Prakasam	2235	1743	-22.0	2077	-5.7	2184	-2.3	2656	20.6	1623	-27.4	1918	-12.9	1850	-17.2	2217	0.7

* CO_2 concentration of 571 ppm was used for RCP8.5 Mid-Century period

the daily baseline weather data series. These monthly changes were imposed on baseline climate series for all selected sites by adding temperature changes to the baseline record and multiplying by a precipitation change factor. The future time scale weather series and the corresponding projected carbon dioxide concentration, according to 8.5, was used in all crop model simulations. This procedure was repeated for each of the three GCMs. The three GCMs used were CCSM4, GFDL-ESM2M, and MIROC5. The simulations were initiated one month before actual start of fallow-chickpea rotation (May 15) and the soil profile was considered to be at the lower limit of soil water availability on that day.

RESULTS AND DISCUSSION

Future climate characteristics relative to baseline

The mean rainfall changes were both highly significant and spatially heterogeneous across the study locations of Andhra Pradesh. Two critical points could be observed from the spatial distribution of the rainfall data. The first, there was an overall increase in crop season rainfall except GCM in Prakasam district (MIROC5). The average rainfall projections of three GCMs relative to baseline data (1980-2009) showed 7.3 to 19.1 per cent increase during mid-season period (2040-69) with RCP 8.5 and MIROC5 showing the least and GFDL-ESM2M exhibited the highest increase in rainfall (Fig 1). The second pattern was increase in September and October rainfall in all the GCMs studied which might have positive impact on early sown post-rainy season crop (Fig 2). The spatial analysis of rainfall data revealed that increased rainfall activity will be observed in all the parts of the chickpea growing districts. The average increase in rainfall as predicted by the three GCMs was the highest at Kurnool district (19%) followed by Kadapa (18.4%), Anantapur (16.7%) and Prakasam district (7.3%).

Similarly, the changes in mean temperatures were also predicted by the GCMs and MIROC5 predicted warming exceeding 1.35 to 2.8 °C by 2069 in the chickpea growing regions while GFDL-ESM2M predicted lesser warming in the study area. Spatial analysis of temperature changes indicated that increase in minimum temperatures was more (1.7 to 2.52 °C) than the maximum temperatures (1.65 to 2.33 °C) in all the regions of the study which would l have direct impact on chickpea yields.

Impact of climate change on chickpea yield

At Anantapur, the simulated pod yield averaged to 611 kg ha^{-1} under baseline climate (Table 2). Changes in

Table 3 : Effect of different management options on mitigating climate change impacts in chickpea

Adaptation options	Base climate (1980-2009)		Climate change (2040-2069) CCSM4		GFDL-ESM2M		MIROC5	
	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)	Yield (kg ha^{-1})	change (%)
Anantapur								
Recommended practices	611		499		1005		542	
Supplemental irrigation	1160	89.9	862	72.8	1471	46.3	916	69.0
Advancing the sowing window	1029	68.5	903	80.9	1789	78.1	1061	95.7
High plant population (44 plants m^{-2})	577	-5.5	467	-6.4	973	-3.2	515	-5.0
Increased N application (40kg N ha^{-1})	608	-0.5	486	-2.5	1005	0.0	524	-3.4
Kadapa								
Recommended practices	1812	-	1613	-	2193	-	1508	-
Supplemental irrigation	2666	47.1	2287	41.8	3118	42.2	2222	47.3
Advancing the sowing window	2347	29.5	1871	16.0	2832	29.2	1951	29.3
High plant population (44 plants m^{-2})	1761	-2.8	1550	-3.9	2153	-1.8	1451	-3.8
Increased N application (40kg N ha^{-1})	1806	-0.3	1599	-0.9	2191	-0.1	1496	-0.8
Kurnool								
Recommended practices	1780	-	1700	-	2021	-	1659	-
Supplemental irrigation	2546	43.0	2259	32.9	2848	40.9	2269	36.7
Advancing the sowing window	2425	36.3	2120	24.7	2824	39.7	2207	33.0
High plant population (44 plants m^{-2})	1746	-1.9	1659	-2.4	1982	-1.9	1618	-2.5
Increased N application (40kg N ha^{-1})	1770	-0.6	1686	-0.9	2013	-0.4	1647	-0.8
Prakasam								
Recommended practices	2235	-	2077	-	2656	-	1918	-
Supplemental irrigation	3140	40.5	2949	42.0	3622	36.4	2807	46.4
Advancing the sowing window	2933	31.2	2875	38.4	3472	30.7	2686	40.1
High plant population (44 plants m^{-2})	2202	-1.5	2028	-2.4	2624	-1.2	1869	-2.5
Increased N application (40kg N ha^{-1})	2200	-1.6	2064	-0.6	2654	-0.1	1903	-0.8

temperature and rainfall by 2069 significantly ($p<0.05$) decreased the pod yield by 4.3 per cent with values ranging from (-)22.2 to 35.8 per cent among the three GCMS tested. The pod yield was found to be increased to 11.6 per cent with CO_2 concentration (T+R+CO_2) and the values were ranging from -18.4 to 64.5 per cent with climate change scenario. In the fallow-chickpea crop rotation, chickpea was grown in post-rainy season under residual moisture condition and rainfall received during October-December was critical for enhancing crop productivity. The positive results in the form of increased yields were observed in these districts. This was due to increased rainfall projections coupled with CO_2 concentration even though there was significant increase in both minimum and maximum temperature.

At Kadapa, the mean simulated pod yield under baseline climate was 1812 kg ha^{-1}. The change in temperature and rainfall significantly ($p<0.05$) decreased the pod yield by 18.6 per cent and with CO_2 it was 2.2 per cent and yield changes were ranging from 0 to (-) 30.6 per cent and 21 to (-)16.8 per cent during the mid-century period without and with CO_2 respectively under different GCMs tested. Higher yields were observed with GCM where increased rainfall projection was given during post -rainy season (GFDL-ESM2M). In spite of projected increase in annual rainfall, the reduction in yield under climate change in fallow-chickpea crop rotation was attributed to the rise in temperature. The effect of T+R+CO_2 on crop yield was found to be positive.

The mean simulated pod yield at Kurnool was 2230 kg ha^{-1} under baseline climate. The rainfall was projected to increase in post-rainy season when all the GCMs were tested at this site. Even though the mean annual temperatures was projected to increase significantly, with increased rainfall activity, the yield reduction was limited to (-)15.0 per cent without CO_2 and a positive value of 0.8 per cent with CO_2 concentration.

The mean simulated chickpea pod yield was 2235 kg ha^{-1} under baseline climate at Prakasam district (Table 2). The changes in temperature and rainfall (T +R) did decrease pod yield to the tune of 17.2 per cent. With the increase in CO_2 concentration (T+R+CO2), the pod yield was increased to 0.7 per cent. These results show that except for the Kadapa, future climate change would have positive effect on the yield (mean of three GCMs) of chickpea despite negative effect from increase in temperature. However, when CO_2 concentration was not considered all the study districts did exhibit decline in yield. Further, substantial increase in rainfall activity (GFDL-ESM2M) had resulted in increased yield at all the regions of chickpea in Andhra Pradesh which skewed the mean yield to positive side even though other two GCMs (MIROC5 & CCSM4) predicted decrease in yield under the climate change.

Adaptation options for enhancing yield

Advancing the sowing window : At Anantapur, the mean pod yield of chickpea under normal sowing window in baseline climate was 611 kg ha^{-1} (Table 3). With climate change during mid-century period, the chickpea yield found decreased by 11.2 to 18.4 per cent as projected by two GCMs (MIROC5 & CCSM4) and increased yields up to 1005 kg ha^{-1} under GFDL-ESM2M GCM. However, advancing the sowing window by one fortnight under climate change scenario significantly ($p<0.05$) increased the pod yield by 78 to 96 per cent under all the GCMs tested., indicating that under future climate, the sowing date of fallow-chickpea needs to be advanced at Anantapur district to take the advantage of increased rainfall activity to be obtained during October month. With projected increase in rainfall in September and October months with climate change at Kadapa, Kurnool and Prakasam districts, the pod yield significantly ($p<0.05$) found increased by 29.3, 33.0 and 40 per cent respectively above the baseline yield level. Advancing the sowing dates under climate change found to be highly beneficial for chickpea growth in these districts. Advancing planting window would be a successful adaptation option under climate change scenario for fallow-chickpea rotation in these districts.

Agronomic practices : Various agronomic adaptation practices were evaluated for chickpea under climate change scenario by using crop growth simulation models. Changing plant population and increasing N application had nonsignificant effect on chickpea yield. These results concluded that optimum plant population of 33 plants m^{-2} was good for the future climate scenario at all the study sites. Since chickpea is a leguminous crop, negligible response to nitrogen application was observed. and this reduces the need for chemical fertilizer application. Providing one supplemental irrigation during pod-filling stage significantly ($p<0.05$) increased the pod yield by 33 per cent across all the study locations. The increase in yield was found ranged between 37and 69 per cent with the highest response observed at Anantapur and the lowest with Kurnool location. Among the two adaptation strategies tested or evaluated, supplemental irrigation at pod-filling stage gave significant improvement in pod yield than advancing the sowing window.

CONCLUSION

The simulation results obtained from this study suggested that the present chickpea yield in Andhra Pradesh would get reduced under future climate change scenario. The results from three GCM scenarios did indicate that yield reduction was up to 16.9 per cent without CO_2, while a positive effect of 2.7 per cent increase in yield was noticed with CO_2. The simulated CO_2 effect counter balanced partially the negative effect from climate change in all the four study locations tested. Simulations study indicated that providing one supplemental irrigation wherever possible either through diverting water from growing high water intensive crops or practicing farm pond technology and advancing the sowing window appeared to be best bet adaptation to reduce the negative impact from future climate change scenario. However, the model results need to be validated through on farm trials for upscaling.

ACKNOWLEDGMENTS

This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI). Funding support for this study was provided by the Global Futures Project funded by the Bill & Melinda Gates Foundation; the CGIAR Research Program on Climate Change, Agricultural and Food Security (CCAFS); CGIAR Research Program on Grain Legumes (GL) and CGIAR Research Program on Policies, Institutions, and Markets.

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Received : August 2015 ; Accepted : March 2016