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Research Paper

Sowing window adjustments in rice (*Oryza sativa*), groundnut (*Arachis hypogaea*) and sugarcane (*Saccharum* species) as an adaptation strategy to changing climate scenario: A simulation study in Tamil Nadu

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ABSTRACT

Evaluation of climate-change impacts on crop yield for the north-east agroclimatic region of Tamil Nadu, was assessed during 2014, using DSSAT4.5 model under IPCC, RCP4.5 emission trajectory. Results showed that, the yields of the major crops, viz. rice (*Oryza sativa* L.), groundnut (*Arachis hypogaea* L.) and sugarcane (*Saccharum* sp.), tend to decrease towards the end of 21st century. In this purview, this study was an endeavour to investigate the easiest agronomic adaptation options, i.e. sowing-date adjustment to offset the projected climate-change impacts on yield. Advancing or delaying sowing dates were found to be giving better yield under climate change scenario. Results for rice showed that, adjusting the sowing dates can have better yield rates in future. Experimental outcomes showed that rice crop sown on 1st November led to a yield increase of 2.18%, and this would be the most appropriate response to offset the impacts. The groundnut sown on 10th December and 1 January were performing well, with a yield increment of 7.51 and 7.50%, respectively, by the end of century. For sugarcane, planting season extends to 6 months in the study area. The results revealed that, planting on 15th March can increase the yield by 3.5% in the near century period under RCP 4.5. The overall agreement between simulated and observed rice yields was 74% with an R^2 and (RMSE) values of 0.92 and 807 kg/ha respectively. The overall agreement between simulated and observed groundnut yield was 82% with R^2, root mean square error **(**RMSE) values of 0.71 and 408.98 kg/ha respectively. The agreement between simulated and observed sugarcane yields was 76% with 0.76 and 25.82 tonnes/ha as R^2 and RMSE values respectively. The challenge is to disseminate this information for the benefit of the farmers as part of awareness creation, preparedness and capacity building. Therefore, researchers and agriculturists have a major role to play in taking forward, scientific findings for the benefit of the stakeholders.

Key words: Agronomic adaptation, Crop simulation, Climate change impacts, DSSAT, Groundnut, Planned adaptation, Rice, Sugarcane

There is a growing concern that climate change may have multidimensional impacts on Indian agriculture. Accelerated warming due to a rise in greenhouse gases may intensify the negative consequences in an agrarian economy and affects unreasonably the regions like India, endangering crop and livestock production, and fisheries (Challinor *et al*., 2014; FAO, 2014). The United Nations Agenda of 2030 recognizes that, progress towards the eradication of poverty (SDG2) and the response to climate change (SDG13) will depend on the extent to which food insecurity and malnutrition are effectively addressed and sustainable agriculture is promoted locally and regionally (IPCC, 2013). It is reported that foodgrain production has to be doubled by 2050 to meet the demand and offset the negative impacts of high temperature and unevenly distributed rainfall have on crop productivity all over the world (Deryng *et al.,* 2014). There are large uncertainties in the assessment of climate-warming effects on global crop production. Reducing the uncertainty will greatly benefit the development of strategy for innovation in crop-production technology and policy-making for coping with climate changes. Disaster-risk reduction and climate-change adaptations in crop management is a practice for prevention, mitigation, preparedness and recovery from various climatic hazards (Aixing Denga *et al.,* 2017).

Increasing agricultural productivity and ensuring livelihood security have been critical for Indian agriculture, as this sector accounts for 18% of our gross domestic product (GDP) and provides employment to more than 50%

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working population of the country. Presently, there is a growing recognition that with the rising temperature, possible alterations in the hydrological cycles may pose serious risks to Indian agriculture sector which is largely the monsoon driven. It is essential to build resilience to the farming community to withstand internal and external stresses from environmental, social, economic, and political changes (Bana *et al.,* 2022).

There are variety of risks related to climate and agriculture (Fig. 1). The major among them is hydro climatic disasters. Report issued by the National Institute of Disaster Management (NIDM) shows that hydro-meteorological disaster has 78.4% rise for the past 100 years (NIDM, 2012). India also stands as the one of the most vulnerable countries with 22.67 climate risk index score and 0.146% losses per unit GDP as per 2017 levels by Report on Global Climate Risk Index (CRI, 2019). Risk duration arises not only from the susceptibility of crops failures during different stages of crop development, from emergence to maturity, but pre-sowing to post-harvest as well.

Social dimension to resilience is a thrust area to be studied more. Even when a region is under high risk due to climate-related stresses in the form of increased dry spells, droughts, flash floods, offseason rainfall gusty winds etc create havoc in the agriculture sector, sensitivity and farmers' capacity to cope with the changes will play a major role in rebuilding and recovering from the loss and damages (Muller *et al.,* 2015; Ramachandran *et al*., 2015). The study area that falls under the state of Tamil Nadu has a drought recurrence frequency of every 2.5 years and has got high sensitivity since it has got almost 45% of its cultivable area under dryland agriculture. Research studies using De Martonne Aridity index indicate that, the index values tend to be further decreased from 13.7 to 16.4 mm/°C, characterizing this area to be more semi-arid in nature with anticipated future warming under RCP 4.5 of IPCC (Bemal *et al.,* 2013; Ramachandran *et al*., 2015).

The India Meteorological Department is providing weekly and seasonal forecasts and crop-weather advisories

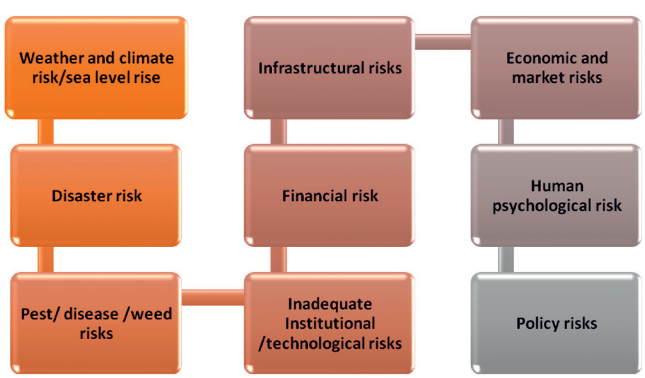

Fig. 1. Types of risks associated with agriculture sector

to manage the risks in our country. Model-based simulation studies have come up to enhance the capacities and projecting the likely productivity of the major crops in these areas. The crop-simulation model, the Decision Support System for Agrotechnology Transfer (DSSAT) 4.5, was used to understand the plausible impacts on the major crop yields of rice (*Oryza sativa* L.), groundnut (*Arachis hypogaea* L.), and sugarcane (*Saccharum* sp.) under the RCP 4.5 trajectory. The findings revealed that, under the RCP 4.5 scenario there will be decrease in the major C3 and C4 crop yields in the study area (Kumar *et al.,* 2013; Krishnan *et al.,* 2016). It is stated that changing in the farm management will play a crucial role in minimizing agriculture risks (Bana *et al*., 2022). Since no simulation studies have been undertaken to evaluate optimum planting dates with respect to higher yield, under rice, groundnut and sugarcane crops for north-east agroecological zones of Tamil Nadu, a study was carried on these crops.

MATERIALS AND METHODS

Data collection

Field observations were collected during 2014, to understand the real-time situations of agronomical practices and management details for the major crops growing in the study area Kancheepuram district, North Tamil Nadu. Information on crop production, phenology, major ruling varieties and experimental trial were collected from the Tirur Rice Agricultural Research Station, the Groundnut Research Station, Tindivanam; and the Sugarcane Research and Breeding Centre, Puducherry, Tamil Nadu. Department of Agricultural Economics and Statistics, Chennai, was the source for collecting data on crop area coverage, crop production and crop yield etc.

Model-based crop yield impact assessment

Agronomical adjustments have the potential to exert positive impacts on agriculture production which faces multidimensional climate-change risks of delay in onset dates, dry spells, acute water, soil-moisture stresses, disease and pest outbreaks on crops and livestock (Dass *et al.,* 2012; Boote *et al.,* 2013). In this regard, this study tries to understand how agronomical adaptations with respect to adjustments in sowing dates can minimize the risk of crop yield losses due to likely climate change. For climate-change projections, the dynamically downscaled data from Regional Climate Model-RegCM 4.4 rc22 and HadGEM 2-ES lateral boundary conditions were used in this study. The downscaled output was collected from the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, India. Climate data grid points covering the entire study area were extracted for analysis purposes. The daily data outputs of Reg CM4.4 were processed to get mean changes for the 30-year time slices.

Crop Simulation Models (CSM), Decision Support System for Agro technology Transfer (DSSAT-V4.5) (Hoogenboom *et al*., 2012) (Fig. 2). CERES-RICE under cereals, CROP-GRO under legumes, CANE-GRO under sugar/energy modules were selected to simulate the future yield variations based on sowing adjustments. Simulated daily weather files, soil files and crop- management files were created for the purpose. The weather input files were generated for 4 districts in the study area using weathermen in DSSAT covering the study area. Along with the latitude/longitude information, the daily weather data on maximum temperature (°C), minimum temperature (°C), solar radiation (MJ/m^2/day) and rainfall (mm) for the baseline period was processed**.** The input of soil files was generated using 'S' build IN DSSAT. Soil types such as red sandy loam and clay loam predominate this area. An inbuilt program called GENCALC in DSSAT was used to calculate the genetic coefficients of crop varieties. The X build module of the DSSAT was used to generate crop-management files.

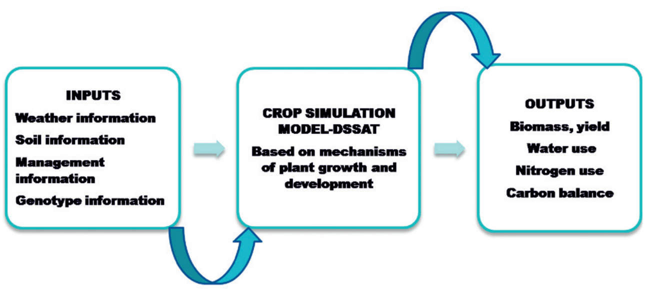

Fig. 2. Processes in DSSAT crop simulation

The CERES-Rice Plant Growth Model was used by Geethalakshmi *et al.,* (2011). The output was validated and mentioned that CERES-Rice performed reasonably well in the regions of south India. Anticipated yield changes in the crops like soybean (*Glycine max* (L.) Merr.], peanut, dry bean (*Phaseolus vulgaris* L.), chickpea (*Cicer arietinum* L.), cowpea [*Vigna unguiculata* (L.) Walp.] was simulated using CROPGRO plant-growth module in India. The CANEGRO Plant Growth Module has been widely used to simulate the yield changes under changing climate and management conditions. The CSMs was used as a suitable tool to assist with this complex task of yield predictions. The daily values of the simulated outputs were converted into monthly values and then aggregated into 30 years mean period starting from baseline 1971 to 2000, and near century (2010 to 2040), mid-century (2041 to 2070), and end century (2071 to 2100). The simulated yields were validated against observed yields using degree of errors in terms R^2 and RMSE.

The relative yield change was calculated as:

$$\textit{Relative Yield Difference} = \left(\frac{\textit{Simulated Yield} - \textit{Observed yield}}{\text{Observed Yield}}\right) * 100$$

Sowing-date adaptation assessment using DSSAT

With the understanding from the impact assessment, it was clear that the yields of the major crops tended to decrease towards the end of 21st century. In this purview this study also took an endeavour to investigate the easiest management-adaptation option, i.e. sowing-date adjustment, to offset the projected climate-change impacts on yield. The crop calendars gathered during the field visits and literature review were used to identify different sowing windows for the selected

RESULTS AND DISCUSSION

Crop production in the study area

The study area comes under the north-east agroclimatic zones of Tamil Nadu, South India, where rice is cultivated mainly in 3 major seasons such as *Sornavari* (April to July), *Samba* (August–November), 'Navarai' (December–January). During *Sornavari* and *Navarai* seasons short-duration varieties are grown. Major ruling varieties of rice grown in the study are 'ADT 37', 'ADT 47', 'Mdu 5, 'ADT®-45' (105–110 Days), during *Samba,* medium- and long duration varieties such as 'IWP', 'ADT 44', 'ADT 43', 'CR 1009', 'ADT 38', 'TRY 1-2' (135–150 days) are grown.

Groundnut cultivation in the study area is pertaining to 3 major seasons such as winter season/*margali pattam* (December–January) with verities, viz. 'TMV 7', 'VRI 2', 'ALR 3', 'CO (gn); *Masi Pattam* (February–March) with 'TMV 7', 'CO 2', 'VRI 2' and summer/*chithirai pattam* (April–May) with 'Co 2', 'Co 3', 'VRI 2' varieties. Sugarcane crop is cultivated mainly in the seasons such as primary during December–January months, with varieties 'CO 658', 'CO 62174', 'CO 62198'. As a mid-season crop, it is cultivated in February–March with varieties 'COC 85019', 'COC 99061', 'CO 86032' and as a end season crop during the months of April/May with varieties such as 'COC 93076', 'COC 85019' and 'COC 9906'1. The genetic coefficient of major ruling varieties 'ADT ® 45' of rice, 'TMV 7' variety of groundnut and 'Co 86032' variety of sugarcane was used for simulation.

Projected impacts of future climate change on crop yield across study area

Previously published research outcomes reveal that, the study area may experience a rise in day time and night time temperature of 2.3 and 2.4°C for RCP 4.5 by mid-century (Fig. 3). There are research publications revealing that sea level of Chennai coast may by 0.92 m above mean sea-level rise under moderately strong emission reduction scenario of IPCC AR5 under RCP 4.5. It shows the necessity

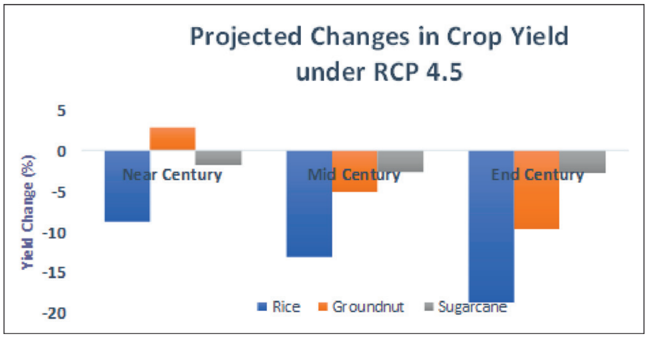

Fig. 3. Projected changes in crop yield under RCP 4.5

to have aggressive cuts in the carbon pollution, through energy efficient ways (Ramachandran *et al.,* 2017).

The simulated mean yields of rice in the study area were 3,472 to 4,520 kg/ha as compared to the observed yields of 2,680 to 3731 kg/ha. The overall agreement between simulated and observed rice yields was 74%, with the average errors of 0.92 and 807 kg/ha for R^2 and RMSE respectively. The predicted yields of groundnut in the study area were 1,831 to 2,537 kg/ha as compared to the observed yields of 1345 to 3119 kg/ha. The overall agreement between simulated and observed yield was 82% with the average errors of 0.71 and 408.98 kg/ha for R^2 and RMSE respectively. The simulated yields of sugarcane in the study area were 74.72 to 86.98 tonnes/ha as compared to the observed yields of 93.02 to 118.85 kg/ha. The overall agreement between simulated and observed yields was 76%, with the average errors of 0.76 and 25.82/ha for R^2 and RMSE respectively.

The crop calendars gathered during the field visits and literature review were used to identify and test different sowing windows for the selected crops. Advancing or delaying sowing dates were found to be giving better yield under the projected scenario of climate change. The simulation results for rice showed that, adjusting the sowing dates can have better yield rates in future. Different sowing dates windows were chosen for rice crop. The experimental sowing dates were 1st September, 15th September, 1st October, 15th October and 1st November.

Experimental outcomes showed that rice crop sown on 1st November showed a yield increase of 2.18%, and this would be the most appropriate response to offset the impacts. Even then during the end century there was no benefit from the sowing-date adjustment and the yield loss was by –18.06% (Fig. 4). This was still much better than other sowing dates. Rice crops sown on 15th October were showing –25.89% yield decrement. Rice crops sown on 1st September and 15th September recorded the maximum yield loss by –34.5 to –33.4%.

Five different sowing windows tried for groundnut yield adaptation simulation were, 1st December, 10th December,

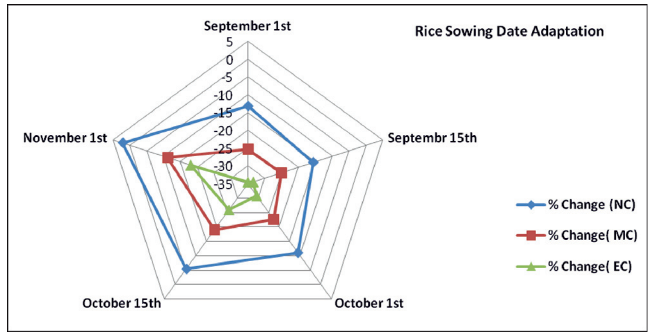

Fig. 4. Percentage change in the rice yield with sowing date adaptation in near, mid and end of 21st Century

20th December, 1st January and 10th January (Fig. 5). The groundnut that was sown on 10th December and 1st January were performing well during near century with a yield increment of 7.51 and 7.50% respectively. But during the end century, the 20th December sown crop revealed 1.9% increase in yield. The adaptation experiment of crop sown on 10th January showed a yield decrement by –0.495% during end century.

Simulation studies conducted with changes in sowing dates and cultivars are found to support increased yield and better coping capacity (Jalota *et al*., 2012). In contrary to this, the studies conducted by many researchers have shown that more than sowing dates, the genotype adaptation was found to be more effective to offset the undesirable impacts (Shamim *et al.,* 2012). It is imperative to understand thoroughly the historical and current context in which the farming system is operating at a particular place, based on which future assessment can be built. It is always a combination of factors that affect the productivity of crops (Singh *et al.,* (2015) and Nayaka *et al*., (2022). But majority of the studies ignore the importance of evaluating farmer's experiences in the context of agricultural adaptations (Jami *et al.,* 2014). Understanding farmers' responses to the weather vagaries locally is crucial in anticipating the impacts of changing climate patterns, as only when a problem is perceived well, the appropriate steps can be taken to adapt to it.

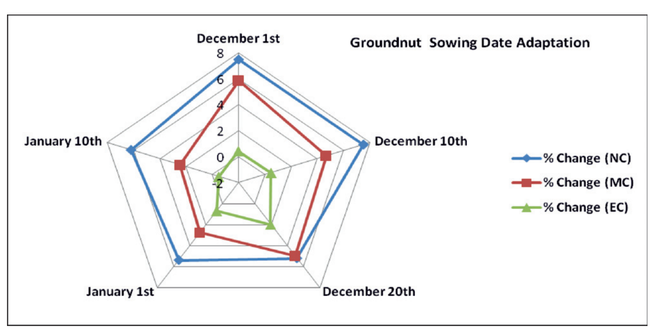

Fig. 5. Percentage change in the groundnut yield with sowing date adaptation in near, mid and end of 21st Century

As sowing date adaptations in sugarcane crops are concerned, planting season extend to 6 months in the study area (Fig. 6). Thus, wide span of sowing windows is employed for the experimental simulation and covered sowing dates from the month of December to May. The findings showed that planting on 15th March can increase the yield rates by 3.5% in the near-century period and under the future climate pathway under RCP 4.5. However, sugarcane planted on 15th March showed higher yield rates by 5.1 and 6.9% in the mid-and end century, respectively, compared to the other dates.

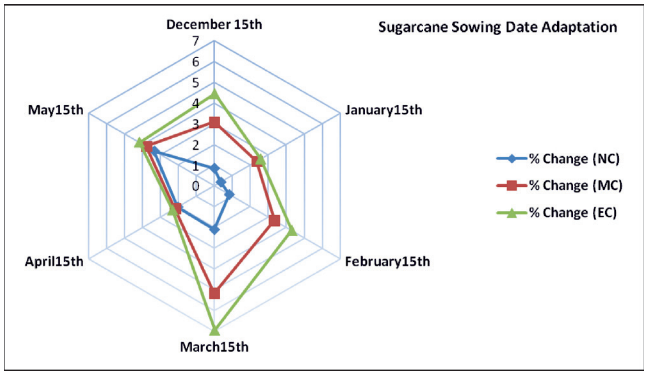

Fig. 6. Percentage change in the sugarcane yield with sowing date adaptation in near, mid and end of 21st Century

It is necessary to enhance research and developments in agriculture as proactive changes in the farm practices can have profound effects in minimizing climate risks. The best outcomes from the simulation output can be used for experimentation at field-level assessments and further farm-level implementation. The main challenge is to disseminate this information for the benefit of the farmers during their farming operations.

Adoption of planned adaptation lies in the hands of the stakeholders. Farmers should be willing to adopt and take advantages of the support provided through agro-advisories Krishiwani by the IMD or state agricultural universities etc. Scientific and technological research advancements should be capable of disseminating reliable advisories to the grassroot level. For this our research, institutional and technological capacities need to be increased further. From the research and development perspective, there is growing need to provide smart cultivars/ seeds which are drought, salt, flood-tolerant crops which can grow successfully in poor salt-affected soils of our coastal wetlands. Even after realizing the terrible situation of water shortages, poor and marginal farmers in our country are neither willing nor capable of adopting planned adaptations.

There should be a climate leader at each vulnerable district in our country to in-still a climate lens to each and every developmental activity that happens in the district. Sensitizing the local youth in rural areas, inviting more participation from NGOs. Self-help groups may also help in wider acceptance of smart and sustainable adaptation options to reduce risks. The success stories of post-disaster resilience created by the social media networks during the devastating floods (2019) in Kerala are a remarkable example for community-owned adaptations. Social media groups through Face Book or WhatsApp were doing excellent reactive or responsive adaptations in smart ways to revive the farmers from loss and damage due to unprecedented floods, landslides and crop loss. Lessons on adaptation should be learnt from success stories.

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