

Assessment of climate change impact and adaptation strategies for rainfed maize (*Zea mays L.*)

ABSTRACT

The study was performed to assess the impact of climate change on spatiotemporal changes in rainfed maize yield. Climate projections data of MIROC-ESM-CHEM model from CMIP6 was used for future climatic scenarios in the maize growing areas of Dindigul and Perambalur districts of Tamil Nadu. The DSSAT model was used to simulate maize yield and evaluate adaptation strategies for base period (1991-2020), the mid (2040-2069) and end centuries (2070-2099) under SSP245 and SSP585 scenarios. The simulation finding shows that, in all scenarios maize yield declined in both Dindigul (7 to 9% and 11 to 12%) and Perambalur (6 to 9% and 11 to 13%) during mid and end centuries respectively from the base period (1991-2020). Following the adaptation strategies such as delayed sowing, the yield was increased in both Dindigul (5 to 6% and 4 to 5%) and Perambalur (4 to 5% and 5 to 6%) with respect to normal sowing date. The results of this study would help in developing adaptation strategies for minimizing the adverse effects of the projected climate in maize-growing districts of Tamil Nadu.

Key words: SSP 245, SSP 585, Climate change, Impact, Adaptation

1. INTRODUCTION

Maize (*Zea mays L.*) is the third most important crop grown next to rice and wheat in India. Globally maize (dry grain) is primarily used as feed, between 2020 and 2021, cereal production has grown by 64 million tonnes driven by 4.1 per cent increases in maize production [1]. The leading producers are USA (32.61%), followed by China (22.91%), Brazil (9.42%), European Union (8.41%), Argentina (5.41%) and India (4.1%) [2]. At the global level, maize (dry grain) is primarily used as feed (56% of production) [1]. In India the area under cultivation of maize is raised to 9.38 million hectares, yielding 28.752 million metric tonnes [3]. Maize grain contains approximately 72% starch, 10% protein, 4% fat and 365 Kcal/100g energy, whereas green fodder contains 10-12% of crude protein and 25-30% crude fibre. It is a day neutral plant with C4 type of photosynthesis and has very efficient utilization of solar radiation which is known as the "Queen of Cereals" due to its photo-thermo insensitive nature and the highest genetic potential for yield [4].

By 2050 the global population is projected to reach around 10 billion and global cereal equivalent food demand is expected to rise by around 10,094 million tonnes in 2030 and 14,886 million tonnes in 2050 [5]. Maize production is expected to approach around 50 million metric tonnes by 2025 to cope with the growing population [6]. Earlier studies in India generally confirm the trend of agricultural fall owing to climate change [7,8,9,10].

The Coupled Model Inter-comparison Project (CMIP) is the multi-model experimental framework by IPCC (Intergovernmental Panel on Climate Change) for bringing out information on changing climate. The IPCC sixth assessment report (AR6) featured a new state of CMIP6 models with has a new set of emissions scenarios driven by various Shared Socioeconomic Pathways. With current land use, projections indicate a loss of 4-5 million tonnes

production for every 1°C increase in temperature during the growing season [10]. Rainfall influences maize growth during monsoon season by influencing soil moisture availability. Impact of elevated temperature is negated by increase in rainfall. Rainfall increases of 20% and 30% are expected to reimburse for the yield loss brought about by 1°C and 2°C temperature increases, respectively [11].

Climate change's impact on crop production has been extensively researched using statistical models and process-based crop models. The Decision Support System for Agrotechnology Transfer (DSSAT) is windows based user friendly version that uses a variety of input variables, including crop, soil, and weather data that can simulate multi-year outcomes of crop management strategies for different crops [12]. Autonomous adaptation such as delayed date of sowing can be put forward for changing environment in order to meet the demands for future. This study was conducted to know the impact of climate change on maize production under normal and delayed date of sowing.

2. MATERIALS AND METHODOLOGY

2.1 Study area

The most efficient cropping zones for maize are Theni, Perambalur, Dindigul, Salem, Trichy, Ariyalur, Erode and Tiruppur [13,14] in which Perambalur and Dindigul have been chosen as study areas (Figures 1). Perambalur district spread between 11° 13' 59.99" N and 78° 52' 59.99" E has a total geographical area of 175736 ha and a net sown area of 2,16,422 ha. The soil is primarily red loamy and black. Average rainfall is 908 mm in which 52%, 34% and 14% of annual rainfall is contributed by northeast monsoon, southwest monsoon, and the winter hot weather period accounts respectively. The area and production of Perambalur is 67183 ha and 601209 tonnes respectively in 2021-2022 [15]

Dindigul district lies between 10° 22' 2.3232" N and 77° 58' 49.0476" E with a total geographical area is 626664 ha, and the net sown area is 253541 ha, accounting for nearly 40% of the total geographical area. The district is dominated by red and black soil, followed by red sandy soil. The average rainfall is 836.0 mm among which northeast monsoon, southwest monsoon, summer and winter period accounts for 50%, 26%, 18% and 5% of annual rainfall, respectively. The area and production of Dindigul is 27649 ha and 223741 tonnes respectively in 2021-2022 [15]

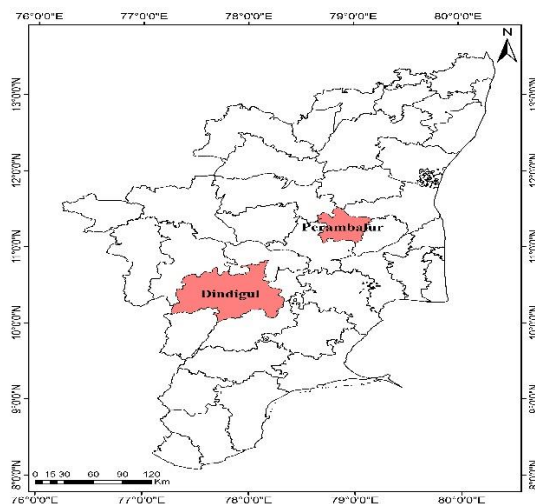


Figure.1 Study area map

2.2 Methodology

For base period (1991-2020) maximum temperature, minimum temperature and precipitation data were taken from India Meteorological Department (IMD) and for future two climatic scenarios SSP245 and SSP585 of MIROC-ESM-CHEM model with the parameters of Tmax, Tmin, precipitation and solar radiation was taken for Dindigul and Perambalur district. The future climate projection was done for two-time period mid (2040-2069) and end centuries (2070-2099). This data was taken as an input to run the DSSAT model. CERES maize module of DSSAT performed well around the Asian conditions [16] was chosen to run maize COHM6 under normal date of sowing (30th June) and delayed date of sowing as adaptation strategy (15th July) to project the future yield for both mid and end centuries in SSP245 and SSP585 scenarios in rainfed condition.

2.3 Weather Data

For the base period 1991-2020, data on daily maximum and minimum temperatures at $1^\circ \times 1^\circ$ resolution and daily rainfall at $0.25^\circ \times 0.25^\circ$ resolutions were obtained from the National Data Centre (NDC), India Meteorological Department (IMD), Pune.

The IPCC is the United Nations (UN) intergovernmental body empowered with regularly assessing the science of the Earth's changing climate and determining the state of insights into climate change. The World Climate Research Programme (WCRP) organised the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6). CMIP is evolving into an integrated framework for organising a number of individual Model Intercomparison Projects (MIPs). MIPs are bundles of experiments and simulations deployed to test and compare specific aspects of climate models. These climate projections will be moulded by a new set of emissions and land use scenarios [17] designed around new societal development future pathways, the Shared Socioeconomic Pathways (SSPs) and RCPs. CMIP 6 global climate model data was collected from NASA Earth Exchange Global Daily Downscaled Projections at a resolution of $0.25^\circ \times 0.25^\circ$ for maximum temperature, minimum temperature and rainfall. Among the General Circulation Model (GCMs) MIROC-ESM-CHEM model was best for precipitation and temperature projections [18] is chosen for this study. The daily weather data on maximum temperature ($^\circ\text{C}$), minimum temperature ($^\circ\text{C}$), solar radiation ($\text{MJ}/\text{m}^2/\text{day}$), and rainfall (mm) for SSP254 and SSP585 scenarios were converted into DSSAT weather file format using the Weatherman tool available in DSSAT for running CERES- Maize. In DSSAT CERES maize module performed well in Asian conditions [16].

2.4 Soil Data

District wise soil data was obtained from the database incorporates soil characteristic parameters of 623 Indian districts gleaned from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) soil database/map [19]. From the 27 Generic Soil Profiles presented by [20], compatible soil profiles for each district were allocated based on soil texture, rooting depth, and organic carbon content (proxy of fertility). HC27 soil profiles have been widely employed in crop modelling studies at the regional and global levels [21,22,23,24] this soil profile was used as an input database file in 'S Build' to create a soil file in DSSAT.

2.5 Crop Data

Maize COHM6 which is 110 days crop of parentage UMI 1200 x UMI 1230. It is grown in both rainfed and irrigated condition. Crop management information such as sowing date, spacing, planting depth, planting population fertilizer dosage and irrigation schedule is referred from crop production guide 2020. The crop management file (X-File) allows the inputs to the models to be simulated for each experiment to replicate the field situation with an assumption of pest and disease free condition.

2.6 Adaptation Strategies

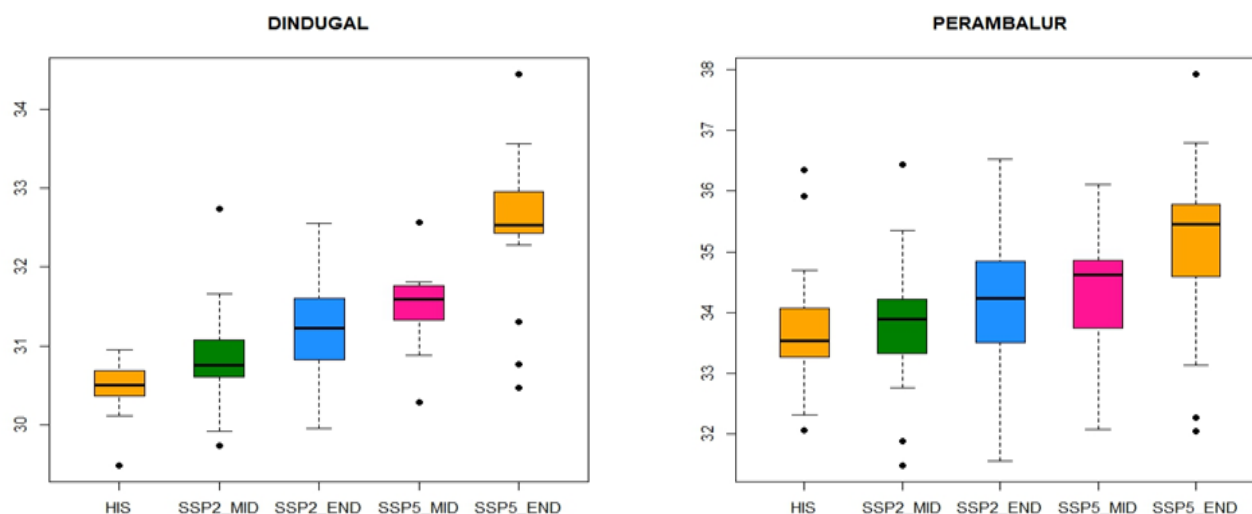
In previous studies different adaptation strategies had been adopted to minimize the impact of future climate change. The adaptation strategies include different dates of sowing [11,25,26,27,28], increase in fertilizer dosage [29,30] and irrigation scheduling [31,32,30]. In this study changes in the sowing data was adopted, the normal date of sowing (30th June) was fixed from the information gathered by the farmers and late date of sowing (15th July).

3. RESULT AND DISCUSSION

The average yield of Dindigul for the base period is 4553 Kg/ha, the yield reduction was ranged from 7 to 9% for future scenarios of SSP245 (mid & end centuries) and 11 to 12% for SSP585 (mid & end centuries). For Perambalur district the yield reduction from the base yield (4031kg/ha) range from 6 to 9% and 11 to 13% for both centuries in SSP245 and SSP585 respectively. In Dindigul district the projected mean Tmax (32°C) and Tmin (24°C) was increased from the baseline Tmax (30°C) and Tmin (22°C) whereas in Perambalur district the projected mean Tmax (35°C) and Tmin (26°C) was increased from the baseline Tmax (34°C) and Tmin (26°C). Under rainfed conditions, a 1°C increase in both Tmax and Tmin reduces crop yield by 1.55% and 0.88%, respectively [33]. Fig. 2&3 depicts the projected changes in mean Tmax ($^\circ\text{C}$) and Tmin ($^\circ\text{C}$) for normal and delayed sowing dates in the mid and end of the century under SSP245 and SSP585 in comparison to the baseline during the crop growth period.

With respect to the normal date of planting, the yield for SSP245 and SSP585 increased from 5 to 6% and 4 to 5% in Dindigul, and from 4 to 5% and 5 to 6% in Perambalur in delayed sowing. In both the district the Tmax and Tmin doesn't have any significant deviation during the crop growth period for normal and delayed sowing but there was an increase in average rainfall for the crop growth period (9 to 15% and 10 to 12% in Dindigul for SSP245 and SSP 585 respectively) (13 to 22% and 15 to 17% in Perambalur for SSP245 and SSP 585 respectively). Fig. 4 & 5 shows the projected changes in mean Rainfall (mm) and rainy days (days) in the mid and end of the century for (a) normal and (b) delayed sowing dates under SSP245 and SSP585 in comparison to the baseline during crop growth period. The reason for increase in projected rainfall is due to increase in rainy days 2 to 4 days in Dindigul and 4 to 5 days in Perambalur for both the scenarios. Previous studies conducted by [34] showed that delaying the planting date could increase the yield. Crop may benefit over delayed sowing by avoiding heat and drought stress during the early growth stage [35] and water stress during flowering time [36]. [37] stated that planting date at July is a good adaptation practice to protect maize yield in future.

(a) Normal date of sowing



(b) Delayed date of sowing

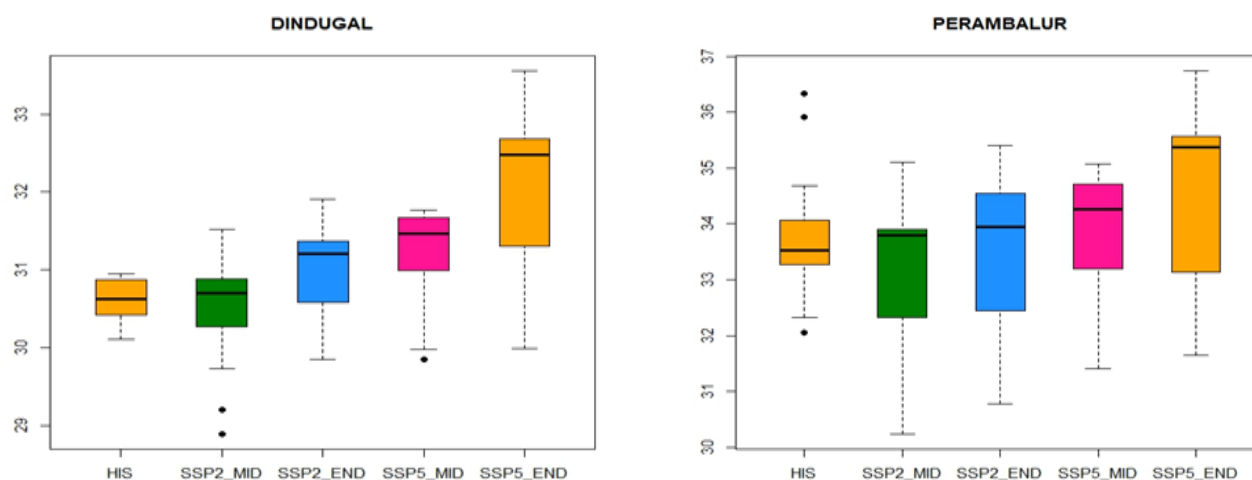
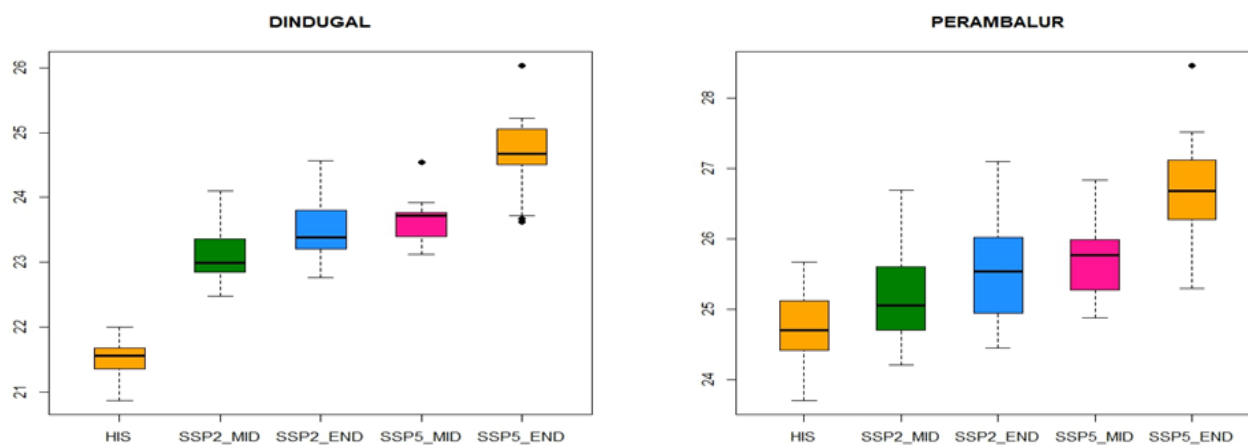


Fig. 2 depicts the projected changes in mean Tmax (°C) for (a) normal date of sowing and (b) delayed sowing dates in the mid and end of the century under SSP245 and SSP585 in comparison to the baseline during the crop growth period

(a) Normal date of sowing



(b) Delayed date of sowing

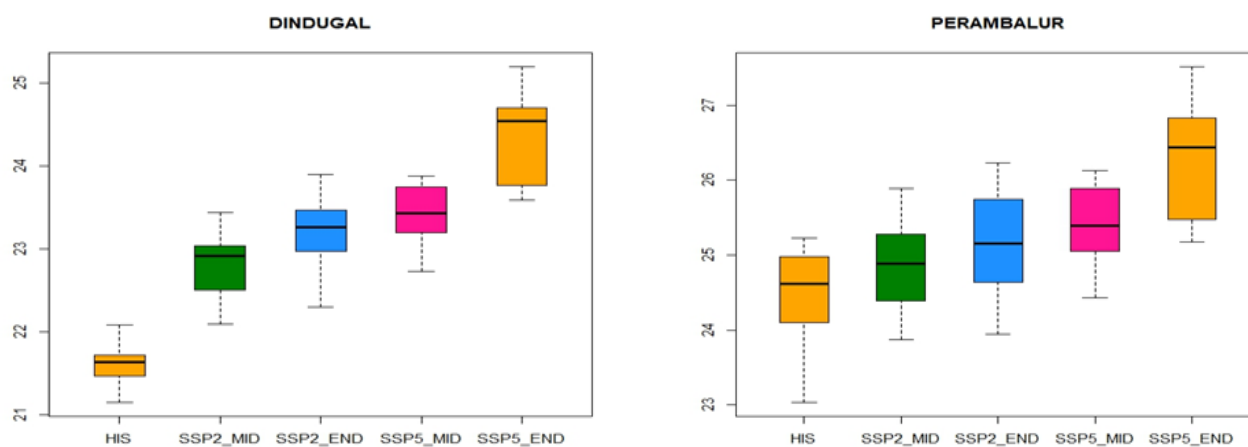
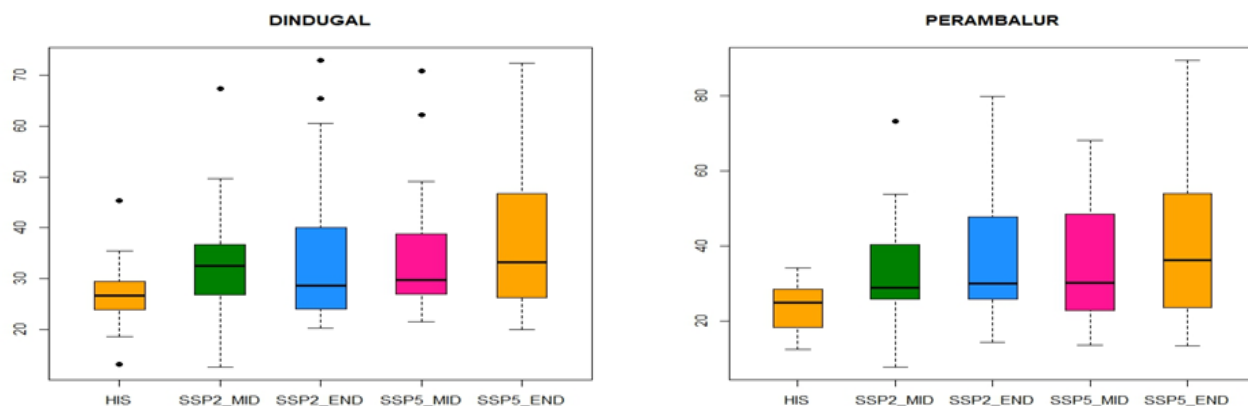


Fig. 3 depicts the projected changes in mean Tmin (°C) for (a) normal date of sowing and (b) delayed sowing dates in the mid and end of the century under SSP245 and SSP585 in comparison to the baseline during the crop growth period

(a) Normal date of sowing



(b)Delayed date of sowing

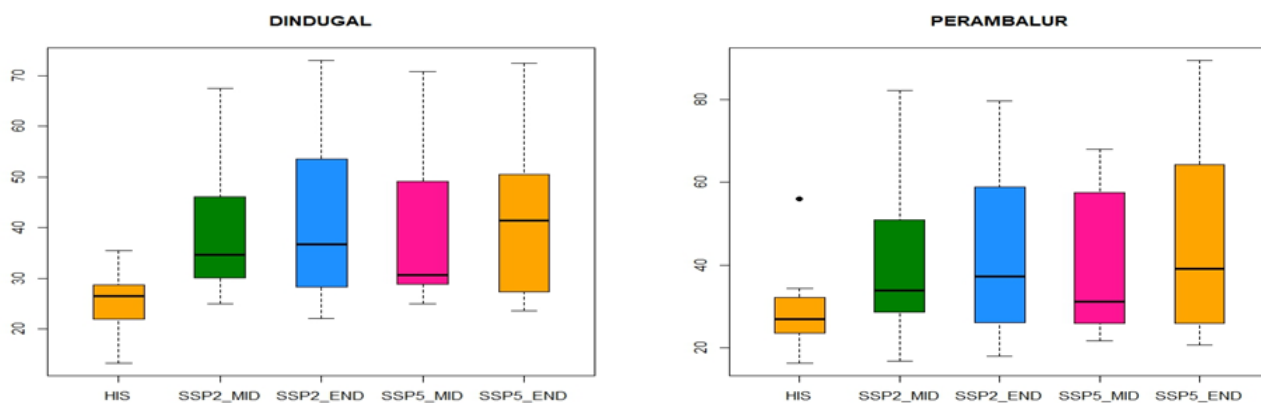
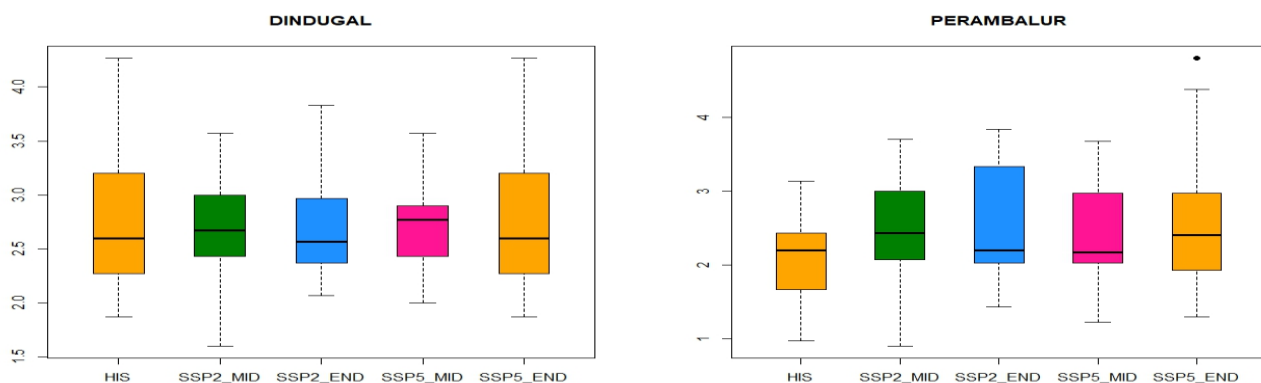


Fig. 4 shows the projected changes in mean Rainfall (mm) in the mid and end of the century for (a)normal and (b)delayed sowing dates under SSP245 and SSP585 in comparison to the baseline during crop growth period.

(a)Normal date of sowing



(b)Delayed date of sowing

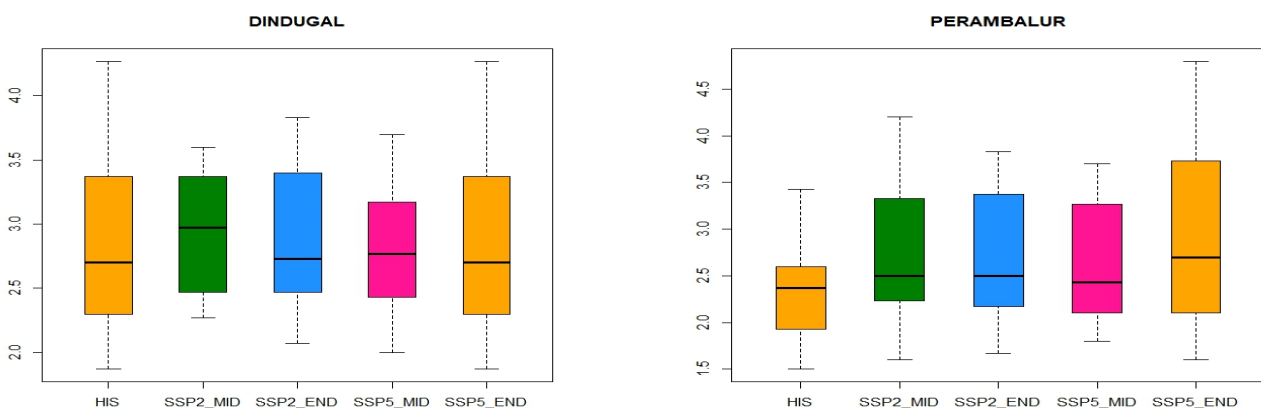


Fig. 5 shows the projected changes in mean Rainy days (days) in the mid and end of the century for (a)normal and (b)delayed sowing dates under SSP245 and SSP585 in comparison to the baseline during crop growth period.

4. CONCLUSION

The maize yield for future scenarios (SSP245 and SSP585) in efficient cropping districts of Dindigul and Perambalur was estimated using the DSSAT crop simulation model. Delayed date of sowing as an adaptation strategy was evaluated for mid and end centuries. The mean Tmax, Tmin, rainfall and total rainy days was consistent increase in the study areas for both the future scenarios. Without adaptation strategies the maize yield was reduced in future. It was found that in delayed date of sowing both the district shows higher yield than normal date of sowing. This study could quantify future spatiotemporal changes in maize yield as well as adaptation strategies to mitigate the adverse impact of climate change.

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