Climate change impacts on crop water balance of maize (*Zea mays* L.) in lower Krishna River Basin of South India

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Maize (*Zea mays* L.) is predominantly grown as a commercial crop in river basins of lower Krishna, Telangana, South India. A long-term crop water balance analysis for maize in two sowing windows (normal sowing: 20 June; late sowing: 25 July) was done for A1b climate change scenario using the downscaled climate data from the GCM model ECHAM5. The crop water balance parameters such as rainfall, effective rainfall, crop evapotranspiration (ET) and irrigation requirements of maize during the two sowing windows were estimated using the CROPWAT model for the base period (1961–90) and long-term period (2011–50; mid-century). In the normal sowing window of maize, there was significant variation in the decadal crop ET (24% to 28%) and irrigation requirements (–7% to 26%) having increasing trend during 2011–2050 over base period. The amount of average decadal rainfall and effective rainfall decreased during 2011–2050 in the range 6% to –23% and 10% to –7% respectively, over the base period. The decadal average rainfall and effective rainfall showed increasing trends of 147–151% and 96–110% respectively, over base period in late sowing window. Also, the crop ET and irrigation requirements exhibited a decreasing trend. The study indicates a shift in the seasonal rainfall in normal sowing window during June to July and it extends up to October and November after the season, indicating more rainfall in late sowing window of maize and scope for rainwater harvesting in the lower Krishna river basin for sustaining maize production.

Keywords: Climate change, crop evapotranspiration, effective rainfall, irrigation water requirement, maize.

CLIMATE change in the semi-arid regions will affect agricultural production and productivity, posing a serious threat to food security world-wide[1–3]. It is projected that by the end of century, the average temperature is likely to increase by +2°C to 4.5°C in the Southern region[4]. It is also predicted through modelling approach that temperature in the southern Telangana region will increase by 0.5°C and seasonal rainfall will decrease by 11.4% by 2060 (ref. 5). The southern Telangana region consists of Rangareddy, Nalgonda and Mehboobnagar districts in the lower Krishna river basin. Nalgonda district is characterized by low rainfall, frequent droughts and almost 60% of the land is cultivated under rainfed conditions. Therefore, it is necessary to understand crop water balance under the climate change scenario in the lower Krishna river basin for effective planning, development and utilization of water resources for agricultural production.

There are many models to estimate the crop water balance of different crops and irrigation scheduling in the literature. However, the CROPWAT model developed by FAO, Rome is simple, robust and accurate, and been extensively used for estimating crop water balance[6]. Hence CROPWAT was used to understand the impacts of climate change on crop water balance of maize in two sowing windows adopted in Nalgonda district.

Maize (*Zea mays* L.) is the most widely cultivated cereal crop in the world resulting in more than 960 Mt production in 2013–14 (ref. 7). Maize cultivation in India contributes 9% of total foodgrain production. The annual growth was from 7.14% with 14 Mt in 2004–05 to 23 Mt in 2013–14 (ref. 7). The maximum area (4.5 lakh ha) of maize is grown in Telangana during *kharif* (rainy season) under rainfed conditions. Nalgonda district had an average area of 5000 ha under *kharif* during 1998–2011 with a productivity of 2.5 t ha^{-1}. In rainfed conditions, maize is grown in two sowing windows – June followed by delayed sowing in July if the onset of monsoon is delayed. Two sowing windows were selected for maize as practised by the farmers in the selected region of Nalgonda district.

Nalgonda district, also known as Neelagiri (Blue Hill) is located in a lower Krishna river basin in the southern part of Telangana (Figure 1) between 16°25′N–17°50′N lat. and 78°40′E–80°05′E long.

One third of the study area is under agricultural production, of which half the area is rainfed. The average annual rainfall of the district is 753 mm with 46 rainy

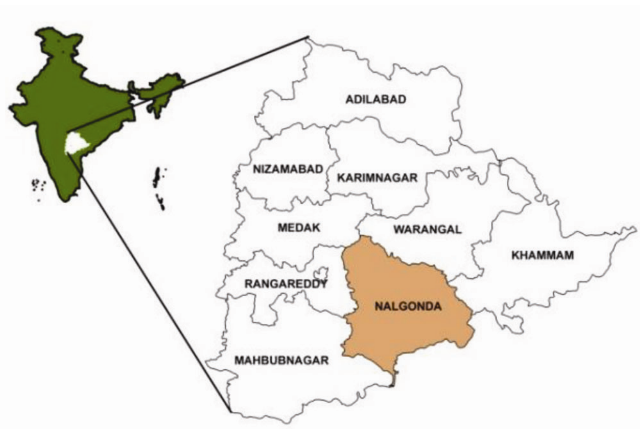

Figure 1. Location map of the study area.

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days. The predominant soil types in the district are red loamy soil (91%) and black soil (9%). Over 90% of the farmers in the district belong to the small and marginal farming category. Maize cultivation starts with the onset of monsoon around 20 June in the normal sowing window and extends up to 25 July in the late sowing window. The normal crop growth period is 120 days.

The daily climatic data of rainfall, minimum and maximum temperature, and average solar radiation were obtained from MarkSim™ DSSAT weather file generator (http://gismap.ciat.cgiar.org/MarkSimGCM/) for A1b climate change scenario for the period of 2011–2050 (mid-century). The downscaled GCM data of ECHAM5 model were utilized due to their prominent use in Indian agriculture[8,9]. The crop sowing dates and soil information were obtained from the literature[10]. The base data for the period 1961–1990 were also downloaded from MarkSim website for estimating the crop water balance of maize for comparison with decadal changes up to mid century. The major crops in Nalgonda district include rice, cotton, castor, pulses and groundnut. Traditionally, jowar and bajra were cultivated as important staple food crops along with rice. In due course of time, however, the cultivation of jowar and bajra was replaced by non-food crop, i.e. cotton crop, which has affected the food security in the district. The decadal changes in crop acreage along with changes in the traditional crops were recorded and analysed using the long-run cropping system data (1972–2013) obtained from the Directorate of Economics and Statistics, Government of India.

The CROPWAT v8.0 model was developed by FAO to calculate the crop water requirements, and planning and managing irrigation water resources. The input data of the CROPWAT model include crop and climate data, i.e. maximum and minimum temperature, wind speed, sunshine hours, maximum and minimum relative humidity, and rainfall. These data were used to estimate PET using Penman and Monteith methods. The effective rainfall and crop parameters were estimated according to the USDA-SCS method (Table 1).

CROPWAT takes daily rainfall of growing period of maize in each sowing window for both base period (1961–1990) and projected period (2011–2050). The model calculates decadal rainfall for estimating effective rainfall, crop evapotranspiration (ET) and irrigation requirements.

The USDA-SCS method was utilized to estimate the decadal effective rainfall using the following equations[11]

$$P_{\mathrm{eff(dec)}} = \frac{P_{\mathrm{dec}} * (125 - 0.6 * P_{\mathrm{dec}})}{125}, \text{ if } P_{\mathrm{dec}} \le \left(\frac{250}{3}\right) \text{mm}, \quad (1)$$

$$P_{\mathrm{eff(dec)}} = \left(\frac{125}{3}\right) + 0.1 * P_{\mathrm{dec}}, \text{if } P_{\mathrm{dec}} > \left(\frac{250}{3}\right) \text{mm}, \quad (2)$$

where $P_{\mathrm{eff(dec)}}$ represents 10 days of effective rainfall (mm) and P_{dec} represents 10 days of rainfall (mm).

The CROPWAT model uses the FAO-56 Penman–Monteith method for calculation of reference evapotranspiration (ET_0, in mm day^{-1}) as described below[11].

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/(T+273))U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)}, \quad (3)$$

where R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G the soil heat flux density (MJ m^{-2} day^{-1}), T the mean daily air temperature at 2 m height (°C), U_2 the wind speed at 2 m height (m s^{-1}), e_s the Saturation vapour pressure (kPa), e_a the actual vapour pressure (kPa), $e_s - e_a$ the saturation vapour pressure deficit (kPa), Δ the slope vapour pressure curve (kPa °C^{-1}) and γ is the psychrometric constant (kPa °C^{-1}).

Thus reference evapotranspiration was further multiplied with crop coefficients (K_c) for determining the crop evapotranspiration (ET_c). The crop coefficients of maize for different growth stages were adopted from FAO-56 (Table 1). The crop coefficient largely depends on the type of crop, soil and climatic parameters.

The irrigation requirement was estimated as the difference between reference crop evapotranspiration and effective rainfall.

The long-term differences in estimation of crop water balance were tested for their significance using Mann–Kendall test[12], cumulative sum (CUSUM) test and Student's *t*-test methods. CUSUM test was used to identify the step change in crop water balance parameters during the period 2011–2050. Student's *t*-test was used to compare the means of different periods of step change in crop water balance.

The cropping system prevailing in the district was analysed for decadal changes (Table 2). Rice is the predominant food crop in Nalgonda district and is cultivated in both irrigated as well as rainfed areas. Jowar and bajra were additional food crops cultivated in large areas in the past to substantiate the staple food production in rainfed areas. However, there has been a shift in the cropping pattern in which traditional jowar and bajra are replaced

Table 1. Crop parameters at different stages

	Season				
Parameter	Initial	Development	Mid	Late	Harvest
K_c value	0.3		1.2		0.85
Stage (days)	20	35	40	25	
Rooting depth (m)	0.3			1	
Crop height (m)			2		

Adopted from FAO-CROPWAT, 2008.

Table 2. Long-term changes of cropping pattern area (ha) in Nalgonda district, Telangana

Year	Rice	Jowar	Bajra	Maize	Groundnut	Pulses
1973–74	136,017	101,860	137,090	1201	37,240	53,881
1982–83	148,797	72,302	112,607	2426	34,974	147,202
1992–93	181,851	21,306	25,875	1309	41,523	60,629
2002–03	131,665	28,008	15,097	3300	26,938	73,536
2012–13	117,000	3000	2000	5000	22,000	72,000

1972–73 data were not considered since it was drought year in which 51% departure from normal rainfall was observed. Source: Directorate of Economics and Statistics, Government of India.

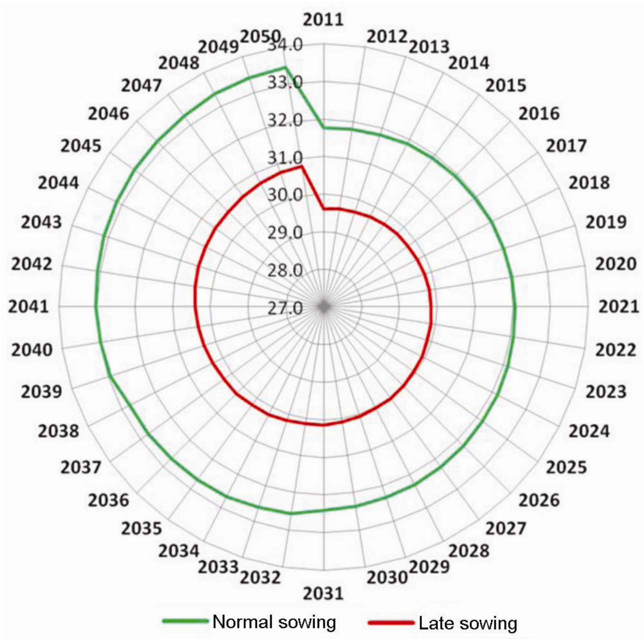

Figure 2. Changes of mean temperature in the growing period of maize under normal and late sowing windows over the period 2011–2050.

by a non-food crop, i.e. cotton. Now there is concern regarding self-sufficiency in foodgrain production in the region to achieve food security in the district. Besides cotton, the staple food and commercial crop of maize has emerged as an alternative to traditional crops. By introduction of maize in the district, the problem associated with the shifting in cultivable area of food crop to non-food crop can be reduced and food production can be sustained in the long term with profitability.

The mean temperature trends over the period 2011–2050 are presented in Figure 2 for both normal and late sowing windows. It can be observed that there is an increasing trend in the long-term mean temperature with gradient increase of 1.7°C and 1.2°C for normal and late sowing windows respectively, which basically influences crop ET and irrigation requirements. The trend analysis of mean temperature for both normal and late sowing window shows the significantly increasing trend at $P \leq 0.01$ by Mann–Kendall method. CUSUM test shows that the shift in mean temperature happens in the year 2029, which indicates that the major increase in temperature will occur during the period 2030–2050. Similar results are indicated by Student's *t*-test as the means of temperature are significant in normal sowing window of maize (Table 3). However, the mean temperature also varies significantly over the two shift periods (2011–2030, 2031–2050) in the late sowing window as tested by Student's *t*-test (Table 3). This indicates that climate change may influence the crop water requirement of maize in both the sowing windows.

The rainfall received during normal and late sowing windows has been analysed over base period from 2011 to 2050 (Figure 3 *a*). In normal sowing window, it is observed that rainfall decreases significantly at $P \leq 0.01$ with a major shift in the year 2031, as indicated by Mann–Kendall and CUSUM tests respectively. Student's *t*-test indicates that the means of rainfall during 2011–2030 and 2031–2050 are significantly different ($P < 0.01$; Table 2). In normal sowing window, 33% decrease in rainfall during growth period of maize is noticed over the period 2011–2050. However, in late sowing window, there is an advantage of increase in rainfall to 658 mm during 2011–2050, though variation is not significant as indicated by CUSUM test (Table 3). This indicates that late sowing window is advantageous in the event of climate change due to increase in rainfall during the growth period of maize.

The percentage changes in decadal rainfall over the base period (1961–1990) were calculated (Table 4). The decadal average rainfall is represented by their mid years as 2015 (2011–2020), 2025 (2021–2030), 2035 (2031–2040) and 2045 (2041–2050). Though average rainfall in the first decade is surplus over base period in normal sowing window, it decreases towards mid century with maximum percentage change of 23 (Table 4), indicating deficit rainfall over the base period. However, in late sowing window of maize the percentage changes are found to vary from 147 to 151 in all decades over the base period, which indicates an advantage of surplus rainfall over the base period. This surplus rainfall could be effectively harvested and efficiently utilized for maize production in the lower Krishna River Basin. The effective rainfall estimated using USDA-SCS method indicates that in the normal sowing window, it exhibits decreasing trend over the period 2011–2050 (Figure 3 *b*) with

Table 3. Statistical analysis of crop water balance under normal and late sowing windows of maize during the period 2011–2050

Statistical parameters	Normal sowing window: Estimated statistic (Z)	Normal: Critical values (Z) a = 0.01	Normal: Critical values (Z) a = 0.05	Normal: Result	Late sowing window: Estimated statistic (Z)	Late: Critical values (Z) a = 0.01	Late: Critical values (Z) a = 0.05	Late: Result
Mean temperature								
Mann–Kendall	8.7	2.6	2.0	S	8.3	2.6	1.9	S
CUSUM	20.0	10.4	8.7	S	21.0	10.4	8.7	S
Student's t	–3.1	2.7	2.0	S	–5.2	2.7	2.0	S
Rainfall								
Mann–Kendall	–7.5	2.6	1.9	S	0.3	2.6	1.9	NS
CUSUM	15.0	10.3	8.6	S	6.0	10.3	8.6	NS
Student's t	5.2	2.7	2.0	S	–0.2	2.7	2.0	NS
Effective rainfall								
Mann–Kendall	–6.4	2.6	1.9	S	3.3	2.6	1.9	S
CUSUM	15.0	10.3	8.6	S	11.0	10.3	8.6	S
Student's t	4.8	2.7	2.0	S	–3.2	2.7	2.0	S
Crop evapotranspiration								
Mann–Kendall	8.3	2.6	1.9	S	0.8	2.6	1.9	NS
CUSUM	20.0	10.3	8.6	S	9.0	10.3	8.6	NS
Student's t	–5.2	2.7	2.0	S	–1.6	2.7	2.0	NS
Irrigation requirement								
Mann–Kendall	7.1	2.6	1.9	S	–3.7	2.6	1.9	S
CUSUM	17.0	10.3	8.6	S	11.0	10.3	8.6	S
Student's t	–5.1	2.7	2.0	S	3.1	2.7	2.0	S

S, Significant; NS, non-significant.

significant variation ($P \leq 0.01$) and shift in the effective rainfall in 2030. There is a 17% reduction in effective rainfall in normal sowing window. In late sowing window, the effective rainfall varies from 381 nm to 424 mm with significantly ($P \leq 0.01$) increasing trend and shift in 2020 (Table 4), as there is an increase in rainfall during the late sowing window.

Table 4 presents the percentage change of effective rainfall for different decades over the base period. The effective rainfall decreases towards mid century with maximum negative deviation of 6.6% in the normal sowing window. However, during the first to third decades, effective rainfall is found to be surplus with decreasing trend of 9.6%, 4.5% and 1.0% in 2015, 2025 and 2035 respectively. In late sowing window, the decadal percentage change in effective rainfall over the base period varies from 96% to 110% with positive deviation, indicating that there is good amount of green water available in the root zone during late sowing window for better growth and productivity.

Figure 3 *c* shows the estimated ET_c for both normal and late sowing windows. In normal sowing window, ET_c has an increasing trend varying from 510 nm to 530 mm over the period 2011–2050. However, there is less increase in ET_c during 2011–2030 (variation of 10 mm) as compared to the period 2031–2050 (10–30 mm variation). CUSUM test has shown a significant shift in ET_c during 2030 (Table 3). In late sowing window, ET_c is uniform with almost no changes during the growing period 2011–2050. Student's *t*-test has shown that the mean of ET_c in 2011–2030 and 2031–2050 is significantly different for normal sowing, in contrast to non-significant in late sowing window. Overall, crop ET increases by 5% in normal sowing window and there is no change in late sowing window from 2011 to 2050. The climate change impacts for A1b scenario indicate that the reduction in ET_c for growing maize crop in lower Krishna River Basin is advantageous in late sowing window towards the mid century.

While comparing the percentage change of crop ET of maize in normal sowing window over the base period, maximum positive deviation (28%) is observed in the fourth decade over the base period. The percentage change in the decadal crop ET varies from 24% to 28%, with increasing deviation. This is due to the fact that the temperature in the normal sowing window has an increasing trend over the base period by 2°C to 4°C over the decades in mean temperature. In late sowing window of maize, the percentage change of crop ET over base period has negative deviations with maximum reduction of 0.2% towards mid century (2045), which may benefit maize production in the lower Krishna River Basin. This is due to reduction in mean temperature in late sowing window in different decades over the base period varying from 2°C to 3°C.

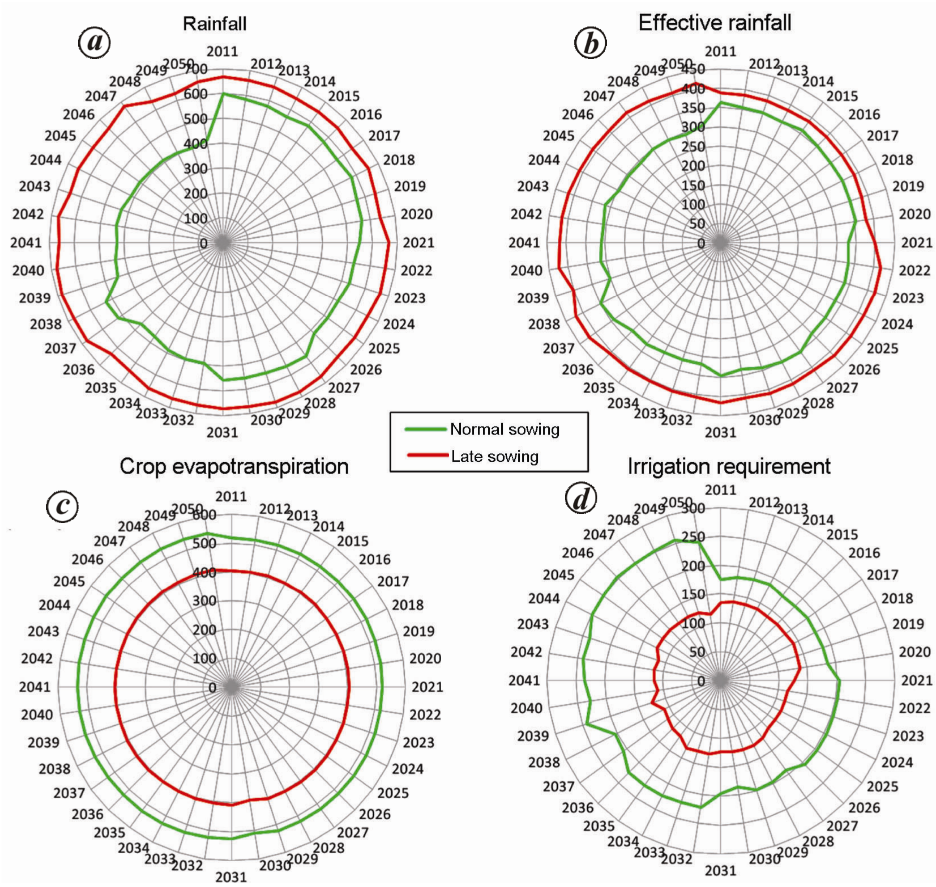

Figure 3 *a–d*. Changes in crop water balance in the growing period of maize under normal and late sowing windows over the period 2011–50.

Table 4. Climate change impacts on CWB of maize in different decades during 2011–2050 over the base period (1961–1990)

	Decadal Mean T (°C)	% Change	Decadal mean R (mm)	% Change	Decadal mean ER (mm)	% Change	Decadal mean ET_c, (mm)	% Change	Decadal mean IR (mm)	% Change
Normal sowing window										
Base period (1961–90)	29.1		542.9		322.8		419.3		196.3	
2015	31.9	9.5	575.7	6.0	353.9	9.6	518.6	23.7	182.8	–6.9
2025	32.2	10.5	540.8	–0.4	337.4	4.5	519.4	23.9	199.9	1.8
2035	32.7	12.2	490.5	–9.7	326.1	1.0	528.0	25.9	219.3	11.7
2045	33.2	14.0	416.5	–23.3	301.4	–6.6	536.5	28.0	247.0	25.8
Late sowing window										
Base period (1961–90)	27.4		264.3		196.6		407.4		261.0	
2015	29.7	8.3	652.3	146.8	385.7	96.16	405.3	–0.53	137.6	–47.3
2025	30.0	9.2	664.1	151.3	412.1	109.6	403.9	–0.85	120.5	–53.8
2035	30.2	10.2	664.5	151.4	411.2	109.1	404.6	–0.7	120.4	–53.9
2045	30.6	11.5	653.8	147.4	413.0	110.1	406.6	–0.19	120.0	–54.0

T, Temperature; R, Rainfall; ER, Effective rainfall; ET_c, Crop evapotranspiration; IR, Irrigation requirements.

The long-term irrigation requirements are presented in Figure 3 *d* over the period 2011–2050. In normal sowing window, IR show increasing trend varying significantly from 176 to 257 mm with significant shift in the year 2031. Increase of 46% can be observed in IR towards mid century (2050), as the growing period is short of rainfall and corresponding effective rainfall (Figure 3 *a* and *b*). In late sowing window, IR are reduced by 15% over the period 2011–2050, varying from 110 to 141 mm. The reduction in IR is significant with shift in their trend in the year 2021 (Table 4). The climate change for A1b scenario indicates that the shift in rainfall in late sowing period provides scope for adaption of proper rainwater harvesting and efficient utilization as an adaptation strategy.

The percentage change in IR of maize in normal sowing window varies from 2 to 26 with maximum increase in mid century, i.e. 2045. An increase in ET_c and reduction in effective rainfall in the normal sowing window in all decades over the base period was observed. However, in late sowing window, decadal IR decreased from 47% to 54% over the base period due to increased effective rainfall and reduction in ET_c.

In the semi-arid region of lower Krishna River Basin, crop water balance of maize was estimated using downscaled projected climatic data of GCM model ECHAM5 (A1b scenario) for two sowing windows. Statistical analysis indicated significant variations in all the crop water balance parameters, namely rainfall, effective rainfall, ET_c and IR during 2011–2050. The climate change impact analysis indicated that the normal sowing window (June 20) is disadvantageous for maize crop. Though the percentage change in the crop water balance parameters is less during the first three decades, there is a sharp increase in these parameters in the fourth decade in normal sowing window. However, the analysis indicates that late sowing window of maize (starting 25 July) with 120 days growing period is advantageous as there is shift in rainfall with increasing trend of effective rainfall and reduction in ET_c and IR. Overall, the study indicates that there is ample scope for rainwater harvesting and efficient utilization as an adaptation strategy to counter climate change impacts in the lower Krishna River Basin in late sowing window of maize towards the mid-century period.

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