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Exploring application of seasonal climate forecast using viable management options in sorghum at Akola, Maharashtra, India.

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ABSTRACT

In India, about two thirds of the cropped areas is rainfed, although the yield from these areas account for only 45% of the total crop production. The objective of this study is to explore application of seasonal climate forecast using viable management options for rainfed sorghum at Akola, Maharshtra. Rainfall hindcast were made on seasonal/sub-seasonal scale using five General Circulation Models (GCMs) viz. CCM, COLA, ECHAM, GSFC and NCEP. Based on correlation studies, hindcast from ECHAM model gave better results than other GCMs. Correlation between observed and hincast rainfall was highest 0.34 for the period July, August and September (JAS) and on the individual month basis was 0.44 for the month of September, coinciding with reproductive phase of sorghum crop. Sorghum yield simulations were made with observed and hindcast weather for different combination of management practices viz. seed rate, row spacing and N-fertilizer applications. The management option with better match between the yields simulated with observed and hindcast weather was taken as viable management practices, which was close to farmers' choice in the region. The optimum planting dates were found as 25 and 30 June based on cumulative probability function of observed yield.

Key words : GCMs, seasonal forecast, crop models, sorghum

Predictability of climate fluctuations at a seasonal time scale offers opportunity to improve agricultural risk management, but if only, forecasts are translated into probabilistic estimates of production and economic outcome of management alternatives. Substantial advances in the efforts to model planetary weather systems, resulting in improvements in the General Circulation Models (GCMs), have led to better predictability of the climate scale, especially by 1 to 6 months in advance (Delecluse et al. 1998). The science of predictability enables us in planning future operations in advance and always provides us enough leeway for making profits out of it. The modeling of crop behavior from weather and management practices is an example of this kind of scientific endeavor. The advantage of crop modeling has been illustrated in the works of Nix (1976) and de Wit (1978).

There is growing interest in linking seasonal climate forecasts based on GCMs with biophysical simulation models to provide crop management strategies. Stone et al. (2000) demonstrated statistical methodologies to generate climate forecasts of rainfall probabilities from GCM-derived SOI phases as useful input for simulation to arrive at agricultural management decision options. Methodologies for linking output of ECHAM general circulation model with crop models have been described recently by Hansen and Indeje (2004). Their work demonstrates model output statistical (MOS) downscaling method to predict seasonal rainfall and field-scale maize yield in Kenya. Generally seasonal rainfall forecast data is available as a seasonal total or sub-seasonal (monthly) total, and most crop models require data on a daily time step. Hence some form of disaggregation (Hansen, 2000) of the forecast variable (rainfall) is needed to be able to use as input by any crop model that simulates crop growth process on a daily basis.

Several researchers in the international arena had demonstrated capabilities of crop simulation models to identify cropping systems and management options for different regions based on varying seasonal rainfall probabilities. Rainfed agriculture is mainly governed by the total seasonal rainfall and its distribution. Information about rainfall a season in advance helps in strategic management decision like planting time, seed density for a given soil system. This study is planned with the aim to explore the viable management options based on seasonal climate forecast for Akola location, Maharashtra.

MATERIALS AND METHOD

Study area and data

Akola is located in Vidarbha meteorological sub-division of Maharashtra state, India, with latitude/longitude 20.7 N/ 77.0 E and altitude of 282 m AMSL. District falls in assured rain fall zone, hence receives monsoon rains during June to September. The mean maximum and minimum temperature of the district is 41 ^{0}C and 21 ^{0}C respectively. Historical weather data for the study area were considered from the Agromet observatory located at Dr. Panjabrao Deshmuhk Krishi Vidaypeeth, Akola. These records included daily rainfall, maximum and minimum temperatures and bright sunshine hours.

The soil colour ranges from black to red. Types of the soil are vertisols, entisols and inceptisols. Soil pH ranges from 7 to 7.5.

The total geographical area of the district is 5,431 sq. km. Sorghum and cotton are the predominant crops grown in the district. Sorghum occupied 33% of gross cropped area. The cropping intensity of Akola district is nearly 120%. Growing kharif sorghum as a single crop during the year has been in practice by the farmers of the region. Sowing window considered by farmers is around 25 June to 10th July, based on the onset of monsoon. Cultivar considered under study for sorghum is CSH-5. This cultivar is of medium duration (90-105 days) and is commonly grown by the farmers of Akola.

Methodology

The methodology employed to generate historical crop yield forecasts associated with a range of management strategies involved downscaling the seasonal rainfall forecasts from dynamic climate model to an appropriate suitable scale in both, space and time (month) using MOS technique, disaggregation of sub-seasonal (month) rainfall hindcast using weather generator into daily weather data for application in crop model, and preparation of other inputs for the crop model such as soil, crop genetic coefficients and different management strategies.

Rainfall hindcast were made from five dynamic climate models viz. CCM, COLA, ECHAM, GSFC and NCEP for the period 1971-1998 at Akola using MOS downscaling technique. The linear statistical relation to estimate the seasonal/sub-seasonal rainfall hindcast for Akola is given by the equation

$$Y = a+b_1*X_1 +b_2*X_2 \ldots (1)$$

where, Y is the rainfall hindcast for the location under study, a, b_1 and b_2 are regression coefficients, estimated by using least square theory. X_1 and X_2 are principal components, representing a predicator field with high spatial resolution and spatial coherence. Values of a, b_1 and b_2 are influenced by the interseasonal and intraseasonal variability in the observed rainfall, over a location/region at seasonal/ sub-seasonal scale. Thus, observed rainfall values for a given month/season give unique values of a, b_1 and b_2 which are replaced in equation-1 given above so as to get hindcast values of rainfall, for the corresponding period.

After the estimation of rainfall hindcast, the correlation is estimated between the observed and hindcast rainfall to show the matched variances between the two time series. The monthly rainfall hindcast estimated from ECHAM model was disaggregated into daily values with stochastic weather generator, to produce 30 realizations to obtain daily values for using as weather input to the crop model for yield simulation.

Crop model selection and simulations methodology

Well-validated crop models are valuable tools for synthesizing our understanding of physiological processes, hypothesizing genetic improvement, and evaluating crop and soil management strategies (Boote et al., 1996). The CERES-Sorghum v3.5 crop model (Ritchie and Algarswamy, 1989) included in DSSAT v3.5 was used in the present study to simulate the sorghum yield. This model was validated under semi arid environment at Pune in India for its various subroutines viz.; phenology, growth, water-balance and nitrogen balance by Varshneya (1999).

Management options considered

The genetic coefficients for the *cv*.

Table 1: Genetic coefficients of *cv.* CSH-5 used in the CERES-Sorghum model

Name	Description	Genetic coefficients
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of $8^{O}C$)	415.0
P2O	Longest day length (in hours) at which development occurs at a maximum rate.	13.50
P2R	Extent to which phasic development leading to panicle initiation (in degree days) is delayed for each hour increase in photoperiod above P2O.	40.5
P5	Thermal time (degree days) from beginning of grain filling to physiological maturity.	525.0
G1	Scaler for relative leaf size.	10.0
G2	Scaler for partitioning of assimilates to the panicle.	5.5
PHINT	Phylochron interval.	49.00

Table 2 : Correlation coefficients between observed and hindcast rainfall using different climate models for Akola

	ECHAM	COLA	CCM	NCEP	GSCF
June	-0.27	-0.13	0.22	0.02	-0.00
July	-0.30	-0.22	-0.28	-0.26	-0.03
August	-0.34	-0.25	-0.28	-0.39	-0.46
September	0.44	0.44	0.13	0.20	0.17
October	0.24	0.28	-0.00	0.04	0.17
June-July	-0.51	-0.61	0.24	-0.07	0.06
July-August	-0.43	-0.23	-0.10	-0.15	-0.18
August-September	0.26	0.17	0.01	0.22	0.05
Jun-Jul-Aug	-0.58	-0.64	0.18	-0.13	-0.21
Jul-Aug-Sept	0.34	0.23	-0.20	0.03	0.01
Jun-Jul-Aug-Sept	0.00	-0.07	-0.06	-0.08	-0.36

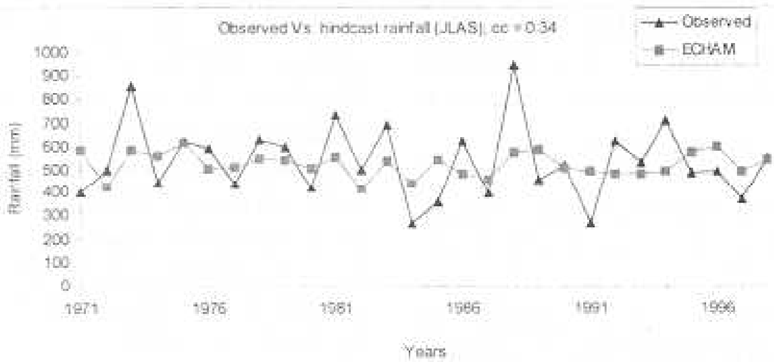

Fig. 1: Observed and hindcast rainfall using ECHAM model for JLAS.

CSH-5, calculated by Varshenya et al. (1999) are used (Table 1) in the present study.

Sowing options considered were broadly of two types :

1. ***Conditional sowing*** : sowing if and when soil moisture conditions were met, within the planting window. The planting window was taken from 1 June to 7August with lower (70% of TASW) and upper (100% of TASW) threshold values of soil water in top 30 cm to decide the time of planting.

2. ***Forced sowing*** : sowing forced on the specified dates i.e. 20 June, 25 June, 30 June, 5 July and 10 July.

Treatments: Different treatments regarding seed rate, row spacing and fertilizers application under rainfed condition are given below.

Seed rate (plants m^{-2})	16	18	20
Row spacing (cm.)	45	60	
N-fertilizer (kg ha^{-1})	60	80	100

Based on yield simulations made with different combination of managements, parameters of viable management option were taken as seed rate 20 plants m^{-2}, row spacing of 45 cm and N-fertilizer as100 kg ha^{-1}.

RESULTS AND DISCUSSION

Rainfall hindcast

Time series data of predictor fields X_1 and X_2 for all five GCMs were provided by International Research Institute for Climate Prediction, to make rainfall hindcast for the period 1971 to 1998 using equation 1. Rainfall hindcast were made not only for the season but for the individual months and also for combination of months, keeping in view the farmers' preference for extended range forecast. The correlation coefficients for season/sub-season and months (June, July, August, September and October) were presented in Table 2. Based on the correlation studies, ECHAM model is found relatively more promising than other GCMs. Observed and hindcast rainfall for the period July, August and September (JAS) with ECHAM model is presented in Fig. 1 and for the month of September in Fig. 2. The month of September, more or less, coincides with reproductive phase of sorghum crop under study.

Sorghum yield simulation with actual and hindcast weather

Simulation runs were carried out to get the yield for different management options with observed weather and hindcast from ECHAM model. In case of hindcast, the simulation was made with 30 stochastic realizations of rainfall, mean temperature and solar irradiance conditioned on occurrence or non-occurrence of rainfall. Further, average of yield from 30 realizations for each year was worked out. The simulated grain yield comparisons between observed and hindcast weather for the sorghum crop were carried out for a range of management combination and the most suitable combination has been presented in the Fig.

The purpose is to explore, based on rainfall hindcast, the management option

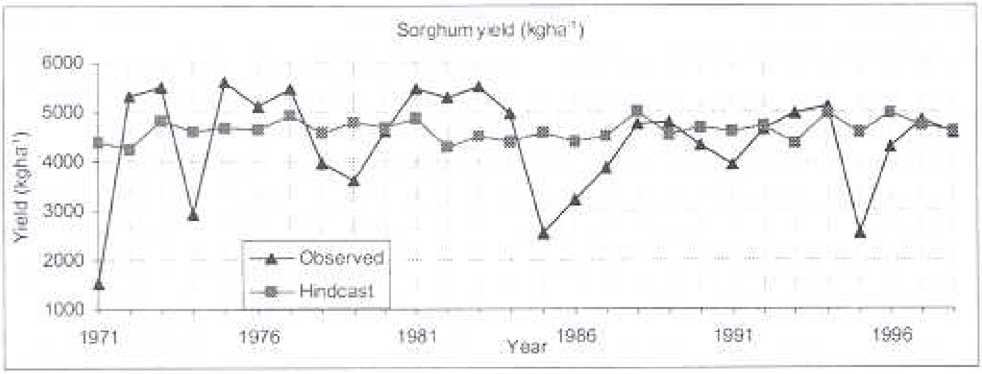

Fig. 2: Observed and hindcast rainfall using ECHAM model for September month

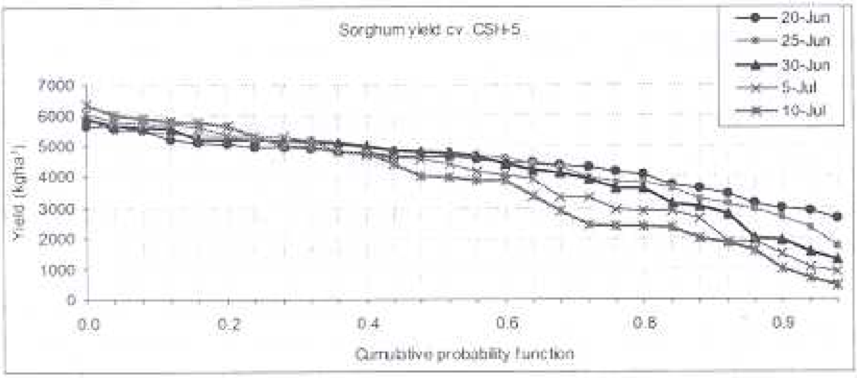

Fig. 3 : Comparison of simulated yield with observed and hindcast weather.

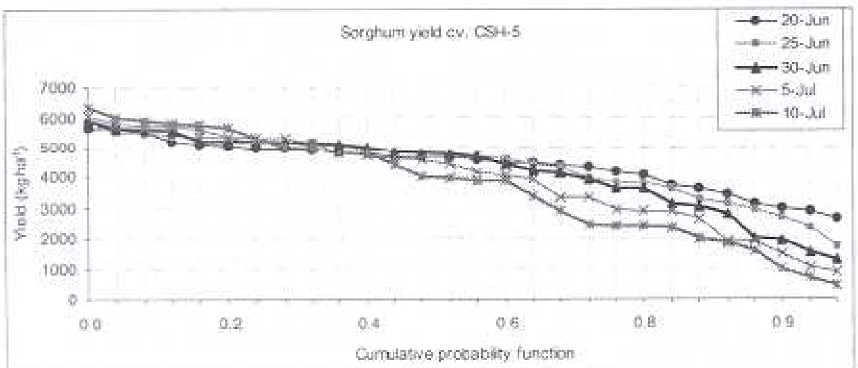

Fig. 4 : Cumulative probability function distribution of yield for different dates of planting.

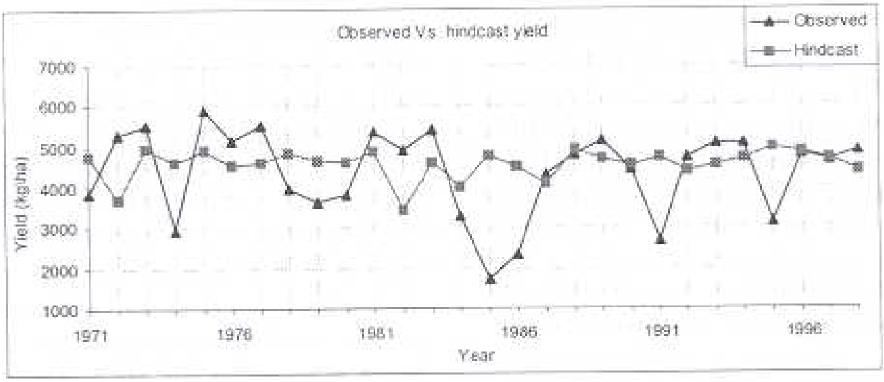

Fig. 5: Comparison of simulated yield (crop sown on 25 June) with the observed and hindcast weather

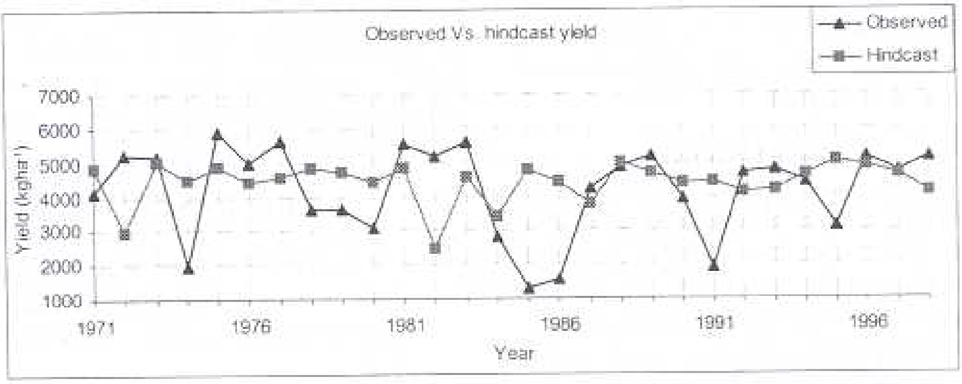

Fig. 6 : Comparison of simulated yield (crop sown on 30 June) with observed and hindcast weather.

which is closer to the farmer's choice. Based on yield simulations made with different range of management under study, parameters of viable management option were taken as seed rate 20 plants m^{-2}, row spacing of 45 cm and N-fertilizer as100 kg ha^{-1}. Correlation coefficient between observed and hindcast yields is 0.24.

With the management scenario, explored in previous section, yield simulations were made with forced sowing on five different dates viz. 20 June, 25 June, 30 June, 5 July and 10 July. The cumulative probability function distributions of yield for 5 different dates of planting are given in Fig. 4. The curve indicates that for a given probability level (at 70% or higher), simulated yield of sorghum planted on 25 and 30 June was higher than all other dates with the same management practices. Thus, 25 and 30 June, were considered as the optimum planting dates for further study.

Simulation runs were made with two fixed dates of sowing viz. 25 and 30 June with above decided management combination. The crop planted on 25 June gives the same trend for yield simulated with ECHAM hindcast excepting in a few years i.e.1972, 1985, 1986, 1991 and 1995 (Fig.5).

The crop sown on 30 June exhibited the same trend between observed and hindcast weather up to 1984 but there is sharp change in trend in the years 1985, 1986, 1991 and 1995 (Fig. 6), which may be attributed to the prolonged dry spell between floral initiations to grain filling stage. These stages were in between end of July to mid August.

CONCLUSION

Rainfall hindcast results revealed that among the models tried ECHAM model gives relatively better correlation for the period JLAS and September month. A long term simulation of sorghum yield under rainfed condition of Akola region indicates that 25 and 30 June may be considered as suitable dates for sowing with preferred management options. The yield simulated with ECHAM hindcast weather data and the trend was found nearer to the simulated observed weather except for a few years. With the use of crop models, decision makers can provide scientifically estimated production outcomes along with different management options.

Limitations

Improved skill of statistical forecasts are constrained by the accuracy of statistical models primarily governed by the length and quality of the historical weather observations and by the dynamic and chaotic nature of the climate system. GCMs on the other hand, are dynamic climate models based on physical laws but are constrained by their inability to resolve all temporal and spatial scale problems. The crop model does not include the nutrient factor i.e. phosphorus, potassium and other essential plant nutrients. These nutrient factors are assumed as in abundant supply in the soil and hence do not cause any stress on crop. Similarly, loss due to weed, pests and diseases are also not included in the model. Under congenial weather conditions, the pests and diseases may cause loss to the crop, which cannot be simulated by the crop model.

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