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Full Research Article

Application of CSM-CERES-Maize Model to Define a Sowing Window and Nitrogen Rates for Rainfed Maize in Semi-arid Environment

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Abstract

Growing period or planting window concept is a useful approach in identifying suitable planting time to ensure crop success under rainfed conditions. CERES-Maize model was validated with experimental data collected during 2009 and 2010 to ensure its fitness in the region in order to simulate the growth and development of hybrid maize under semiarid environment of Hyderabad and to determine the impact of various sowing windows and N application rates on grain yield of maize crop. Validation of CERES-Maize model confirmed that the model can be used as a research tool in the variable agro-environments of Andhra Pradesh to suggest suitable sowing window and optimum nitrogen rate. Seasonal analysis tool of DSAAT model was used to optimize sowing date and nitrogen rate, using 30 years historical daily weather data from 1981 to 2010 for 154 different scenarios (treatment combinations; 14 sowing dates×11 nitrogen levels) starting from 01 June to 31 August at weekly interval and nitrogen levels ranging from zero (0) to 500 kg ha^{-1} at 50 kg incremental increase. The simulation scenarios showed that under rainfed conditions, 15 June sown crop predicted the highest average grain yield of 5449 kg ha^{-1} and it was on par up to 29 June sown crop. The median yield decreased consistently with each delay in time of sowing. Based on seasonal analysis the optimum sowing window for rainfed maize would be from 8 June to 29 June. The response to nitrogen was up to 150 kg N ha,$^{-1}$ and there was no response to any added N beyond 150 kg N ha^{-1}.

1. Introduction

Maize (*Zea mays* L.) is the world's widely grown highland cereal and primary staple food crop in many developing countries. It is the third most important cereal after rice and wheat for human food, contributing almost nine percent to India's food basket and five percent to world's dietary energy supply. Because of its wider adaptability and high yield potential, it is finding place in cropping systems.

In India, its production has increased more than 12 times from a mere 1.73 mt in 1950-51 to 21.73 mt in 2010-11. Presently, it occupies 8.55 mha area with the mean yield of 2.54 t ha^{-1} (Anonymous. 2011). In Andhra Pradesh, maize occupies an area of 7.80 lakh ha with a production of 27.60 lakh ton and an average productivity of 3527 kg ha^{-1} (FAOSTAT, 2011), where the biophysical and socio-economic conditions are favourable, significant shifts was observed from rice monoculture and rice- pulse system to more profitable rice-maize systems.

Successful maize cultivation requires an understanding of various management practices as well as environmental conditions that affect crop production (Eckert, 1995). Corn grain yields are influenced by a number of factors, including N fertility, growing season, water availability and soil conditions. Sowing time is probably the most important non monitory input subjected to variation between the seasons because of the difference in weather conditions at sowing time prevailed. Under rainfed condition, adequate moisture is an important factor to ensure the success of crop production. A suitable planting time with sufficient soil moisture during the planting season should be available before planting. According to Forsthofer et al. (2006), properly selecting sowing date does not affect production cost, but certainly will affect yield and consequently, farm´s profit.

Planting window concept has been proven to be a very useful approach to ensure sufficient moisture availability in the soil. This concept sometimes called as the growing period concept and was first introduced by Cocheme and Franquin (1967). The concept was defined as the period in a year where agriculture can be practiced due to adequate soil moisture and absence of temperature limitations. The concept was later modified by FAO and defined, as a continuous period in one year where precipitation is greater than half-potential evaporation with a number of days required for evaporation (Kowal, 1978). According to Andrade et al. (2009), in general, there are interactions between various factors that affect crop growth, development and yield, whose individual effect is difficult to quantify. Modeling can be a useful tool for studying this kind of problem. The application of systems analysis that combines both experimental field research and crop modeling to determine optimum farming practices in different countries has become common. Razak et al. (2000) used CERESMaize model to identify the suitable planting time under rainfed conditions of Malaysia and found that most of the zones have double planting windows except for two zones (1 and 26), which have a single planting window. In view of this, an experiment was conducted to identify the planting window and optimum nitrogen for maize under irrigated conditions, whereby actual crop growth was taken into account during the simulation process.

The CERES-Maize, one of the models of the Decision Support System for Agrotechnology Transfer, DSSAT (Hoogenboom et al., 2010), can be used to simulate crop growth and development under scenarios of varying climatic conditions and to evaluate management strategies like nitrogen management to improve crop yield. In this study validity of the model was also taken into consideration. In addition to validation the present study aimed to use DSSAT seasonal tool to set a sowing window and nitrogen level by using 30 years historical daily weather data from 1981 to 2010 for rainfed maize crop at farm level.

2. Materials and Methods

The study was divided into three phases. In the first phase the genetic coefficients for maize hybrid Dekalb Super 900M were derived. In the second phase, the model predictive capability was verified with experimental data from a farm located at Agricultural Research Institute, Acharya N G Ranga Agricultural University, Rajendranagar, Hyderabad during *Kharif* seasons of 2009 and 2010 under irrigated conditions. In the third phase, model´s seasonal module was used to simulate scenarios of sowing dates and different nitrogen levels in order to define the best sowing window and nitrogen level for rainfed maize production at that farm.

2.1. Model parameterization

The investigations were carried out during *Kharif* 2009 and 2010 at Agricultural Research Institute, Rajendranagar, Hyderabad situated at an altitude of 542.3 m above mean sea level at 17°19’ N latitude and 78°23’ E longitude. It is in the Southern Telangana agro-climatic zone of Andhra Pradesh. The cultivar was managed under optimum conditions to allow it to express its genetic potential under current weather conditions. Data collection and maize genetic coefficients adjustments were done according to procedures described by Hunt and Boote (1998). Derived genetic coefficients for the hybrid were added to DSSAT´s genotype file to be used in other simulations.

2.2. Model predictive capability

In this second phase of the study, the model’s predictive capability was verified by comparing simulated grain yield with observed maize grain yield which obtained from experimental data. Validation of CERES-Maize model confirmed that the model can be used as a research tool in the variable agro-environments of Andhra Pradesh to suggest suitable sowing window and optimum nitrogen rate

2.3. Maize yield seasonal and temporal variability analysis

If the calibrated models stand the test of validation with independent data sets, they can be potentially used as tools for operational, tactical, and strategic decision support in on-farm crop management (Mathews et al., 2002). The third step of this study consist of applying the CERES-Maize model seasonal tool to evaluate the various levels of nitrogen and sowing date effects on maize grain yield under rainfed conditions. The model was set to simulate 154 different scenarios (treatment combinations; 14 sowing dates×11 nitrogen levels) starting from 01 June to 31 August at weekly interval and nitrogen levels ranging from zero (0) to 500 kg ha^{-1} at 50 kg incremental increase under rainfed conditions of semiarid environment for 30 years using historical daily weather data from 1981 to 2010. Thirty years of records was used with model´s seasonal tool to generate 30 values of simulated grain yield for each one of the 14 sowing weeks and 11 nitrogen levels, which were plotted as a box plot frequency distribution and as average yield values versus variance.

The data were analyzed statistically applying one way analysis of variance technique using SAS. The significance was tested by ‘F’ test (Snedecor and Cochron, 1967). Critical difference for examining treatment means for their significance was calculated at 5 percent level of probability (p=0.05). In order to analyse the pattern of difference between means Fisher’s least significant difference test (t test) was employed (Hayter, 1986).

3. Results and Discussion

3.1. Optimum planting window under rainfed conditions

Seasonal analysis for identifying the optimum planting date and nitrogen levels for maize production using crop simulations was conducted. Selecting a suitable sowing window and optimum nitrogen level is a crop management strategy that is costless to the farmer but, under varying climate conditions, it allows improvement on yield stability.

The simulation scenarios showed that under rainfed conditions, 15 June sown crop predicted the highest average grain yield (5449 kg ha^{-1}) and it was on par up to 29 June sown crop (Table 1). The median yield decreased consistently with each delay in time of sowing.

However, the data depicted in Figure 1 showed that, 31 August sown crop was considerably less variable than all other dates and consequently, smaller variance was associated to its average yield. Low variance was not always associated to high yields, however, a group of sowing dates, which clearly provided greater yield with intermediate variances. This information could assist in defining a sowing window, which in that case, would be from 8 June to 29 June. Khaliq (2008) also reported that, the CERES-Maize simulated maize grain yield between the 0th and 25th percentiles at 40 days delay in current planting date showed an increase in the risk of obtaining very low yields for the late planting dates.

Table 1: t Test (LSD) for mean grain yield (kg ha^{-1}) of maize under rainfed situations under different dates of sowing

Rainfed				
Date of sowing	Grain yield (kg ha^{-1})	t Grouping		
15-Jun	5449	A		
8-Jun	5276	A	B	
22-Jun	5272	A	B	
29-Jun	5135	A	B	
1-Jun	5132		B	
13-Jul	5030		B	C
6-Jul	5016		B	C
27-Jul	4764			C
20-Jul	4727			C
3-Aug	4332			D
10-Aug	3774			E
17-Aug	3057			F
24-Aug	2686			G
31-Aug	2187			H

With regard to nitrogen uptake by grain and biomass also showed the similar trend (Figure 2). The median uptake increases consistently with each delay in time of sowing up to 29 June, however, the box plots showed that, 15 June sown crop had considerably less variability than all other and consequently, smaller variance was associated to its average nitrogen uptake. Further, irrespective of planting time, all sowing dates showed the decreasing trend of nitrogen uptake with less variance (Figure 3).

Simulation results (Figure 4) of nitrogen leaching at different planting dates, showed that the median nitrogen leached value decreased consistently from 6 July onwards with each delay in time of sowing up 27 July, there after increased at decreasing trend with more downside risk (risk of more leaching).

3.2. Optimum nitrogen level under rainfed conditions

Simulation results of different levels of nitrogen under rainfed

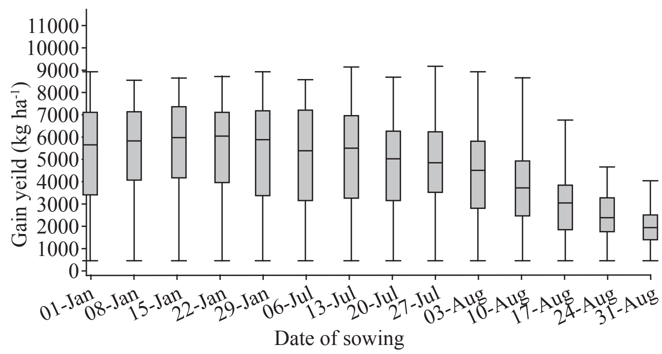

Figure 1: Simulated grain yield of maize under different dates of sowing in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values.

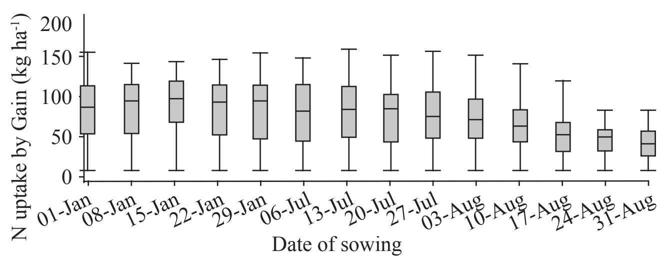

Figure 2: Simulated N uptake by maize grain under different dates of sowing in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values.

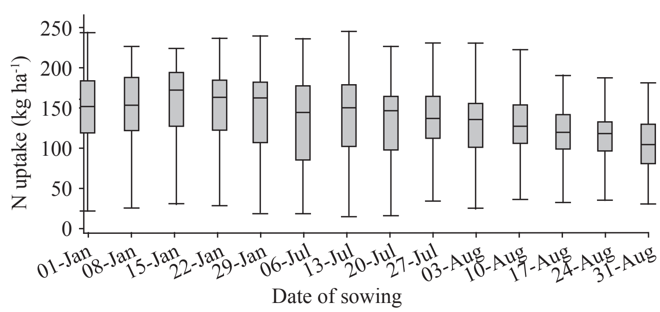

Figure 3: Simulated N uptake by maize under different dates of sowing in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values.

Table 2: t Tests (LSD) for mean grain yield (kg ha^{-1}) of maize under irrigated and rainfed situations at different levels of nitrogen

Rainfed		
Nitrogen (kg ha^{-1})	Grain yield (kg ha^{-1})	t Grouping
250	4999	A
200	4999	A
300	4963	A
450	4943	A
350	4937	A
400	4930	A
500	4906	A
100	4577	B
50	3366	C
0	1020	D

Note : Means with the same letter are not significantly different

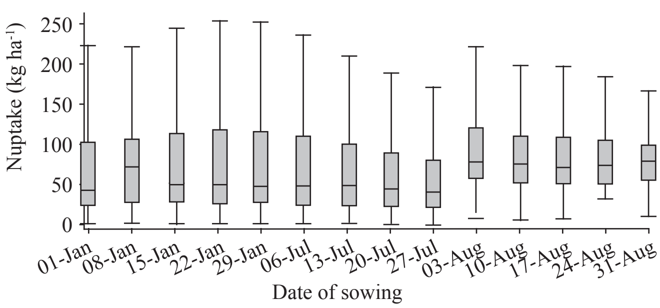

Figure 4: Simulated N leaching under different dates of sowing in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values

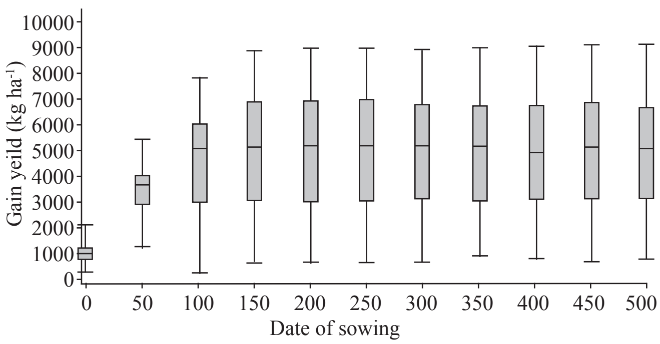

Figure 5: Simulated grain yield of maize under variable nitrogen rates in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values

conditions analyzed statistically and presented in the Table 2.

The response to nitrogen is a classic response curve where yield increased rapidly in response to the first 50 kg N ha^{-1} with diminishing trend to each additional 50 kg N ha^{-1} up to 150 kg N ha^{-1} where there was no response to any added N (Figure 5). The response to N added beyond 150 kg N ha^{-1} was not economically beneficial (Table 2). The spread of the whiskers on the box plots indicates that yield variability increased with each added increment of N application. Similar trend was observed as grain yield simulation for nitrogen uptake by grain as well as biomass also (Figure 6 and 7).

Simulation results showed that, leaching (Figure 8) losses increased consistently with increased levels of nitrogen upto 500 kg N ha^{-1}. High variance was associated with higher levels of nitrogen as upper whiskers continued to increase up to 500 kg N ha^{-1}, this added risk was upside risk (risk of maximum

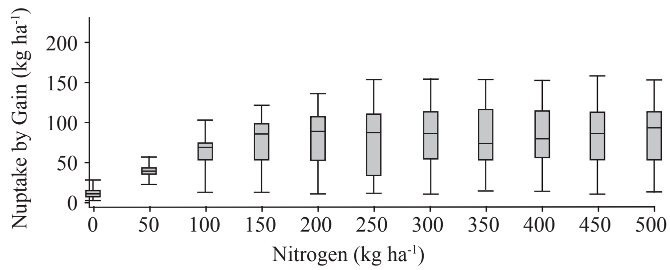

Figure 6: Simulated N uptake by maize grain under variable nitrogen rates in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values.

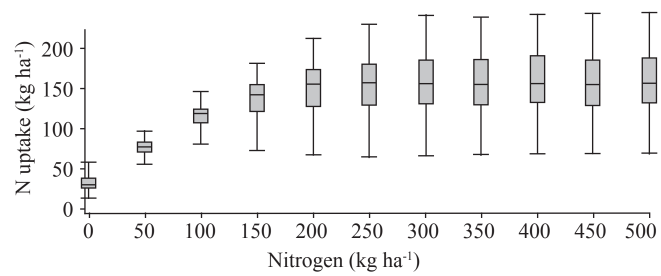

Figure 7: Simulated N uptake by maize under variable nitrogen rates in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values.

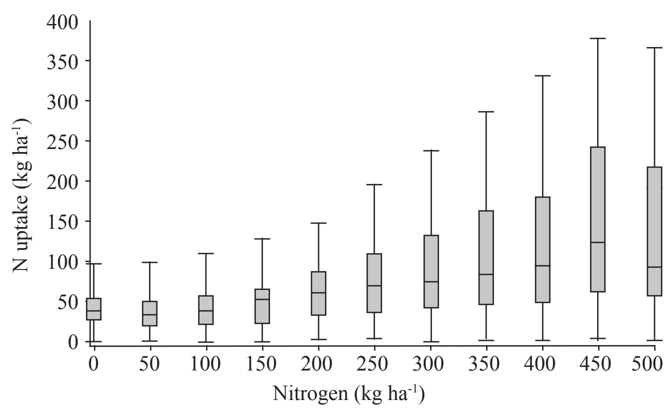

Figure 8: Simulated N leaching under variable nitrogen rates in rainfed conditions. Box limits represent the 25th and 75th percentiles, box central line represents the median, and outliers represent the minimum and maximum values

leaching). Low variance was observed with 150 kg N ha^{-1}.

5. Conclusion

This study showed the potential of the CERES-Maize model to serve as a tool for determining the best sowing time and nitrogen levels for growing maize under rainfed conditions of semiarid environment of Hyderabad. Based on seasonal analysis, optimum sowing window for rainfed maize was from 8 June to 29 June and optimum nitrogen dose was 150 kg ha^{-1}. Therefore, we can conclude that the CERES-maize model could potentially assist resource-poor farmers in Andhra Pradesh by providing them with alternate management options.

However, we suggest that in order to identify the optimum management practices for a specific region and for a specific crop, a few years of actual field experiments should be conducted for model evaluation and that long-term historical weather records are used for management scenario analysis.

6. References

Andrade, C.L.T., Amaral, T.A., Silva, D.F., Garcia, A.G.Y., Hoogenboom, G.,guimaraes, D.P., 2009. Utilização do modelo CERES-maize como ferramenta na definição de estratégias de semeadura de milho: 2 sistema de produção irrigado. In: CONGRESSO BRASILEIRO DE AGROMETEOROLOGIA, 6., Belo Horizonte. Mudanças climaticas, recursos hídricos e energia para uma agricultura sustentavel. Resumos... Belo Horizonte: SBA; Viçosa, MG: UFV; Sete Lagoas: Embrapa Milho e Sorgo.

Cocheme, J., Franquin, P., 1967. An agroclimatological survey of a semi-arid area in Africa, south of the Sahara. World Meteorological Organization 86 (210), TP 110.

Eckert, D., 1995. Corn production in Ohio. Available from http://ohioline.uso.edu/b472/html.

Forsthofer, E.L., Silva, P.R.F., Strieder, M.L., Minetto, T., Rambo, l., Argenta, G., 2006. Desempenho agronômico e econômico do milho em diferentes níveis de manejo e épocas de semeadura. Pesquisa Agropecuaria Brasileira, Brasilia 41(3), 399-407.

Hayter, A.J., 1986. The maximum familywise error rate of fisher's least significant difference test. Journal of the American Statistical Association 81(396), 1000-1004.

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Boote, K.J., Hunt, L.A., 2010. Decision support system for agrotechnology transfer (dssat) version 4.5. Honolulu: University of Hawaii,. 1 CD-ROM.

Hunt, L.A., Boote, K.J., 1998. Data for model operation, calibration and evaluation. In: Tsuji, G.Y., Hoogenboom, G and Thornton, P.K. (Eds.), Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands, 9-39.

Jaliya, M.M., Falaki, A.M., Mahmud, M., Sani, M.Y., 2008. Effect of sowing date and NPK fertilizer rate on yield and yield components of quality protein maize (*Zea mays* L.). Journal of Agricultural and Biological Science 3(2), 23-29.

Khaliq, T., 2008. Modelling the impact of climate change on maize (*Zea mays* L.) Productivity in the Punjab. Ph.D Thesis. University of Agriculture, Faisalabad, Pakistan.

Kowal, J., 1978. Agro-ecological zoning for the assessment of land potentialities for agriculture. Land Evaluation Standards for Rainfed Agriculture. FAO World Soil Resources Report 49, FAO, Rome.

Mathews, R., Stephens, W., Hess, T., Middleton, T., Graves, A., 2002. Applications of crop/soil simulation models in tropical agricultural systems. Advances in Agronomy. 76, 31-124.

Razak, H.A., Aminuddin, B.Y., Fauzj, R.M., 2000. CERES-Maize Simulation Model: Establishment of Planting Windows for Grains Maize under Rainfed Conditions. Journal of Tropical Agriculture Science 23(2), 75-81.

Snedecor, G.W., Cochron, W.G., 1967. Statistical Methods. Oxford and IBH Publishing company 17, Parklane, Calcutta, 172-177.