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Original Research Paper

Use of dssat ceres maize model as a tool of identifying potential zones for maize production in Nigeria

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Iyanda, R.A., Pranuthi , G., Dubey, S.K., and Tripathi*, S.K.

Department of Water Resources Development and Management
Indian Institute of Technology
Roorkee, Roorkee – 247 667
(Uttarakhand),India.

*Corresponding Author
Email: sankufwt@iitr.ernet.in

Maize is an important part of the human diet and it accounts for 20% of the total staple food consumed in Nigeria. However maize yield in Nigeria is about 1.7t/ha which is very low compared to global productivity of 4.9t/ha. This study analyzed potential zones for maize production in Nigeria using DSSAT CERES-Maize model. Six sites were selected and a common hybrid maize variety *Oba Super 2* grown in Nigeria was used for the study. Weather data for ten (10) years from 2001 to 2010 and soil data collected from previous studies were used. The data were used to run CROPWAT model to generate the irrigation schedules at four (4) levels of soil moisture depletion. The levels chosen were, 40%, 50%, 60% and 70% of critical soil moisture depletion. The irrigation schedules where incorporated into the DSSAT CERES-Maize model to simulate the yield at each level of moisture depletion. The yield was also simulated without irrigation. This was carried out for both the rainy and dry seasons. The results showed that Zaria (North West) and Ibadan (South West) have the highest potentials for maize production while Owerri (South East) has the lowest potential during rainy season and Maiduguri (North East) during the dry season.

Key words: CERES-Maize, CROPWAT, maize, Nigeria, irrigation scheduling.

INTRODUCTION

Maize is an important cereal crop grown across the world. According to FAO 1992, maize is ranked the 3rd most important cereal crop after rice and wheat. It serves as a source of nutrients for humans and animals and as raw materials for various industries. In developed worlds, it is mostly used as animal feed while it is used majorly as food in the developing world. Maize has high adaptability to various climatic conditions hence it is widely cultivated around the world. According to Varheye 2010, maize is presently grown in more than 100 counties and it has served as a diversification from the traditional root crops in the local diets.

In Africa, maize is an important staple food and it is widely cultivated across the continent. In sub-Saharan Africa, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories (Offori, 2009). Maize yield in Africa is estimated to be about 1.7t/ha. This is very low compared to the average world yield of 4.9t/ha. According to Kirpich et al. (1999), water scarcity and poor irrigation practices are among the factors considered to cause low yield of crops in Sub-Saharan Africa hence shortage of food supply.

Maize is an important part of the daily diet in Nigeria and it is consumed in different forms such as boiled, roasted and as porridges in all parts of the country. According to a survey conducted by Maziya-Dixon et al. (2006), maize is estimated to account for 20% of the total staple food consumption. About 55 % of maize produced is used as food, 31% as feed and 2% is processed (Cadoni, 2013) in industries. In Nigeria, maize is one of the two major crops occupying 40% of the total cropped area and accounts for 43% of the maize grown in West Africa (Bamire et al., 2010). Although, Nigeria is ranked the10th largest producer of maize in the world, and the largest maize producer in Africa (USAID, 2010; FAOSTAT, 2012), the total production is still among the lowest in the world.

Maize yield in Nigeria is about 1.7t/ha (FAOSTAT, 2012) which is one of the lowest in the world. However, FAO

Table 1. Ten years average yield of various location for rainy and dry seasons for the study sites

Location	Yield (t/ha) Rainy Season	Yield (t/ha) Dry Season
Zaria	4014[a]	2287[b]
Ibadan	3692[a]	2842[a]
Maiduguri	2918[b]	592[d]
Ilorin	2765[b]	1591[c]
Calabar	2350[c]	682[d]
Owerri	1063[d]	1639[c]

Note: Means with the same letter are not significantly different from each other

(2009) noted that under irrigation system, a good commercial maize variety yield is 6 to 9t/ha. From various studies (Nagy 2003; Nagy 2010; Muyiwa and Mikkah 2012) irrigation has been identified as a practice which can increase the yield of maize considerably. Babatunde et al. (2008) noted that production of maize in Nigeria is mainly under the rain-fed system and has been insufficient in meeting the demand of the increasing population particularly during the dry season. Nigeria has a great potential for the production of high value cereals during dry season (Babatunde et al., 2008) as well as rainy season. Irrigation system is aimed at increasing and improving agricultural yield, particularly in semi-arid and arid environment (Ezekiel et al., 2012). However, for an efficient irrigation, the amount of water applied must be controlled to prevent wastage of the available water resources while improving the crop yield. This can be achieved by using various crop growth modeling tools to determine the appropriate amount of water needed for optimum yield. In this study therefore, the objectives of this study were to use CROPWAT model to generate irrigation schedules and the Decision Support System for Agro-technology Transfer (DSSAT) CERES-maize model to determine the potential yield of maize in Nigeria in the rainy and dry seasons under different irrigation schedules generated by the CROPWAT model.

MATERIALS AND METHODS

Description of the study area

Nigeria is classified under five (5) major agro-climatic zones (NIMET, 2012) based on rainfall pattern. The arable area which is 40.1% of the total land receives an annual precipitation of 1150mm. The agro-climatic zones are; Sahel Savannah with average seasonal rainfall of 300-800mm, Sudan Savannah with 800-1100mm of rainfall, Guinea Savannah with average seasonal rainfall of 900-1700mm, Swamp forest with 1200- 2700mm of rainfall and tropical rain forest with 1200-2700mm of rainfall.

For this study, six locations were selected from all agro-climatic zones. Maiduguri was selected as a representative site for Sahel Savannah, Zaria for Sudan Savannah, Ilorin and Ibadan for Guinea Savannah, Calabar for Swamp forest and Owerri for Tropical rain forest climate(Table 1).

Description of the model

The DSSAT is a crop model ensemble that predicts growth, development and yield for various crops. The DSSAT was originally developed by an international network of scientists, cooperating in the International Benchmark Site Network for Agro-technology Transfer project (IBSNAT 1993; Jones et al., 2003). The DSSAT model consists of various sub models which include CERES- cereal model for maize, rice, sorghum, wheat, CROPGRO model for peanut, soybean and phaseolus bean, SUBSTOR model for cassava and potato and CROPSIM model for crops such as tomatoes (Tsuji et al., 1994; Jones et al., 2003). The main data required for running the DSSAT model are: - soil, weather and crop management data which are to be incorporated into X build, S build and Weatherman.

CERES-maize model is a sole crop maize model that predicts growth, development and yield. This model was originally developed by an interdisciplinary team of scientists at the ARS-USDA Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. The model was later adopted and modified by the IBSNAT project (Ritchie et al., 1989). CERES-Maize model has been tested extensively against field data across the world. Panti and Mathauda (2004) validated Ceres-Maize model under different planting dates and moisture regimes. Their result showed that the model can adequately simulate the grain yield of maize crop. Similarly, Razak et al. (2000) and Jagtap et al. (1993) conclude from their studies that CERES-Maize model could be satisfactorily used as a tool to estimate yield potential, growth and development of maize crop.

On the other hand, the CROPWAT model is a decision support system developed by the land and water development division of FAO (1992) for planning and management of irrigation schedules. The model calculates crop water requirements and irrigation requirements based on soil, climate and crop data. The model also develops irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. The model allows the

Table 2. Monthly weather data – maximum and minimum temperatures, sunshine hours and rainfall for the study sites

	Owerri				Zaria			
Month	**Tmax(°C)**	**Tmin(°C)**	**SSH(Hrs)**	**Rain(mm)**	**Tmax(°C)**	**Tmin(°C)**	**SSH(Hrs)**	**Rain (mm)**
Jan	23.1	33.5	6.2	26.6	30.9	15.6	8.6	0
Feb	24.6	35.2	6.3	47.2	33.6	18.1	8.9	0
Mar	24.9	34.7	5.9	103.4	36.2	21.4	8.7	3.3
Apr	24.5	33.5	5.4	173.3	35.7	23.1	7.8	39.7
May	23.9	32.5	5.1	297.7	33.3	22.3	7	105.3
Jun	23.5	31	4.4	325.1	30.3	20.8	6.2	149.2
Jul	23.3	29.8	3.6	382.1	28.9	20.6	5.2	218
Aug	23.2	29.5	3.5	327.3	28.3	20.3	5	300.7
Sep	23.2	30.3	4	373.5	30	20.2	6.1	209.8
Oct	23.5	31.1	4.4	276.6	31.2	19.6	6.9	42.7
Nov	24.1	32.8	5.1	42.3	33	16.7	9.1	0
Dec	23	33.4	6.1	7.6	32	15	9.3	0
	Maiduguri				**Calabar**			
Jan	12.7	31.5	10.1	0	23.2	32.3	5.4	35.2
Feb	15.8	34.5	10.3	0	24.1	33.7	5.9	60.3
Mar	19.5	38.4	10.6	0	24.3	32.8	5.1	184.3
Apr	25.4	41.3	9.5	4.4	23.8	31.9	5	233.5
May	26.8	40.2	8.3	31.9	23.7	31.3	4.6	346.5
Jun	25.2	36.6	7.3	112.8	23.2	29.8	3.9	384.5
Jul	23.7	33.4	6.3	166.9	23	28.8	3.2	452.9
Aug	22.8	31.8	5.6	216	22.9	28	2.6	464.4
Sep	22.9	33.6	6.5	127.1	23	29.1	3.4	358.2
Oct	21.4	36.1	8.5	22.9	23.2	30.1	4	256.5
Nov	16.8	35.9	10.3	0	23.6	31.2	4.5	174.7
Dec	13.6	33.1	10.4	0.4	23.3	31.9	5.2	25.5
	Ilorin				**Ibadan**			
Jan	20.2	34.2	8	2.1	22.2	33.3	8	7.7
Feb	22.8	36.4	7.9	1.9	23.8	35	7.8	29
Mar	24	36.5	7.4	33.1	24.2	34.9	7.4	79.3
Apr	23.7	34.6	6.5	101.7	23.7	33.1	6.3	127.2
May	23	32.5	5.8	137.1	23.3	31.9	5.6	170.4
Jun	22.2	30.9	5.3	190.8	22.6	30.1	4.8	228.9
Jul	21.9	29.3	4.4	177.9	22	28.5	4	181.5
Aug	21.6	28.6	4	139	21.6	27.8	3.8	147.9
Sep	21.6	29.8	4.8	231.3	22	29.3	4.9	249.5
Oct	21.7	31.4	5.7	149.1	22.4	30.5	5.6	183.8
Nov	21.2	34	7.4	5.4	23.4	32.6	6.4	29.5
Dec	19.6	34.5	8.4	2.9	22.8	33.1	7.3	4

recommendation of improved irrigation practices and planning of irrigation schedules under various water supply conditions. The CROPWAT model is a tool for testing the efficiency of different irrigation strategies such as irrigation scheduling and irrigation efficiency under climate change. This model has been used in various studies to evaluate crop production under rain-fed conditions, drought effect and efficiency of irrigation practice. Cavero et al. (2000) used CROPWAT to simulate maize yield under water stress. Thimme et al. (2013) used the CROPWAT model to study Water Requirement of maize in Karnataka. Nazeer (2009) also used the model to simulate maize yield under rain-fed and irrigated conditions. The input data required to run the CROPWAT model are: - soil, climate, crop data and irrigation schedule criteria. In this study,the CERES-Maize and CROPWAT models were used. The latter is a sole maize crop model that predicts growth, development and yield of maize crop.

Data collection

Daily data for precipitation and minimum and maximum air temperature were collected from 6 NIMET weather stations across Nigeria for the period 2001–2010 (Table 2). The collected data were evaluated for errors and missing values through a concise data check. Solar radiation was calculated from the minimum and maximum temperature data using the Hargreaves equation (Hargreaves and Samani, 1982).The humidity and wind speed data were collected from NASA Power Larc (http://power.larc.nasa.gov /cgi

Table 3. Some important properties of the soil at the study locations used as input in CERES-Maize and CROPWAT models

Site	Soil type	Sand	Silt	Clay	OC	TN	pH	Source
				(%)				
Owerri	Sandy soil	58	5	37	1.7	0.04	4.9	Uzoho&Oti 2005; Uzoho 2012.
Ibadan	Loamy sand	88	8	4	0.79	0.08	6.8	Adeoye et al.,2010
Zaria	Sandy Loam	57	25	18	0.47	0.06	6	Ibrahim et al., 2012
Maiduguri	Clay Soil	33.7	45	21.3	0.82	0.7	6.8	Kamara et al. 2011
Ilorin	Loamy Sand	82	10	8	0.07	1.1	7.4	LNRBDA 2012
Calabar	Loamy Sand	84	11	5	0.17	0.4	3.2	Iwara et al 2011

bin/cgiwrap/solar/agro.cgi?email= agroclim @larc .nasa.gov) and the soil data for different locations were collected from previous works (Table 3). The data was arranged in a format acceptable for running the models. The daily data was converted to monthly average to run the CROPWAT model. The data on genetic coefficients of the maize variety used in the simulation pre-existed within the DSSAT CERE-Maize model hence the model was used to generate the data on the growth and development parameters without specifying it in the input data.

Simulation of the parameters

The study was conducted by simulating the yield of maize in six locations, one from each geopolitical zone in Nigeria by scheduling irrigation at various soil moisture depletion levels using CROPWAT and CERES-Maize models. Irrigation scheduling was simulated by running the CROPWAT model using ten years monthly average weather data. This was done at four levels of moisture depletion: - 40%, 50%, 60% and 70%. The values obtained from the CROPWAT model were used in the CERES-Maize model to simulate maize yield for the six locations. The maize yield was also simulated without irrigation and the exercise was done for dry and rainy seasons.

Scheduling of irrigation

Monthly weather data for 10 (2001 -10) years was taken as an average and the irrigation schedules under varying soil water depletions conditions for rainy and dry seasons were simulated using CROPWAT model. For running the model, climate (cli.) file containing monthly maximum and minimum temperatures (°C), relative humidity (%), solar radiation (MJ/m^2/day) and the file for wind speed (km/day) was prepared. In addition, the file with monthly rainfall data (mm) and the file with various soil characteristics data were prepared. Crop file was created by using the sowing and harvesting dates and the Kc values suggested by Allen et al. (1998) for maize crop were adapted for running the CROPWAT model. This database was used to simulate the irrigation schedules for each site.

Simulation of maize yield

The irrigation schedule generated by CROPWAT model was incorporated into the DSSAT CERES-Maize model to simulate maize yield in each level of depletion. The maize yield was also simulated for each location without irrigation in dry and rainy seasons. Oba super 2 was used as an experimental unit because of its popularity and potentials in Nigeria. The planting dates were based on the climatic condition and the onset of rainfall in each location following the recommendations of Iken and Amusa (2004) and USAID, (2010). For the Ilorin, Owerri and Ibadan sites the planting date was 15th April, for Calabar it was 20th March, 1st June for Zaria and 5th June for Maiduguri. In dry season simulation, the planting date was 15th November for all sites. The plant spacing was 75 cm by 25 cm which gave a plant population of 6 plants per m^2. Nitrogen was applied in form of urea by banding 5cm deep at 92kg ha^{-1} two weeks after planting as top dressing and the second application was 46kg ha^{-1} four weeks after planting. Hence, a total dose of 138kg N ha^{-1} was applied. Flooding method was used for the application of irrigation. The harvesting date was simulated for when the crop was at 50% maturity.

Statistical analysis

The data obtained were statistically analyzed using SPSS 16 for the Analysis of Variance (ANOVA) and the Tukey Post HOC method was used to test the differences in mean of maize yield in different sites.

RESULTS

The results obtained from the study are presented in Figure 1 and 2. The results for the differences in mean are summarized in Table 1.

DISCUSSION

Rainy season analysis

The result showed that maize yield was highest (4.0 t/ha) in Zaria followed by Ibadan (3.6 t/ha) and the least yield (1.0 t/ha) was obtained in Owerri (Figure1). Similar maize yield in Zaria was reported by Yusuf, (2010). This shows that maize thrives well in a well-drained loamy sand soil

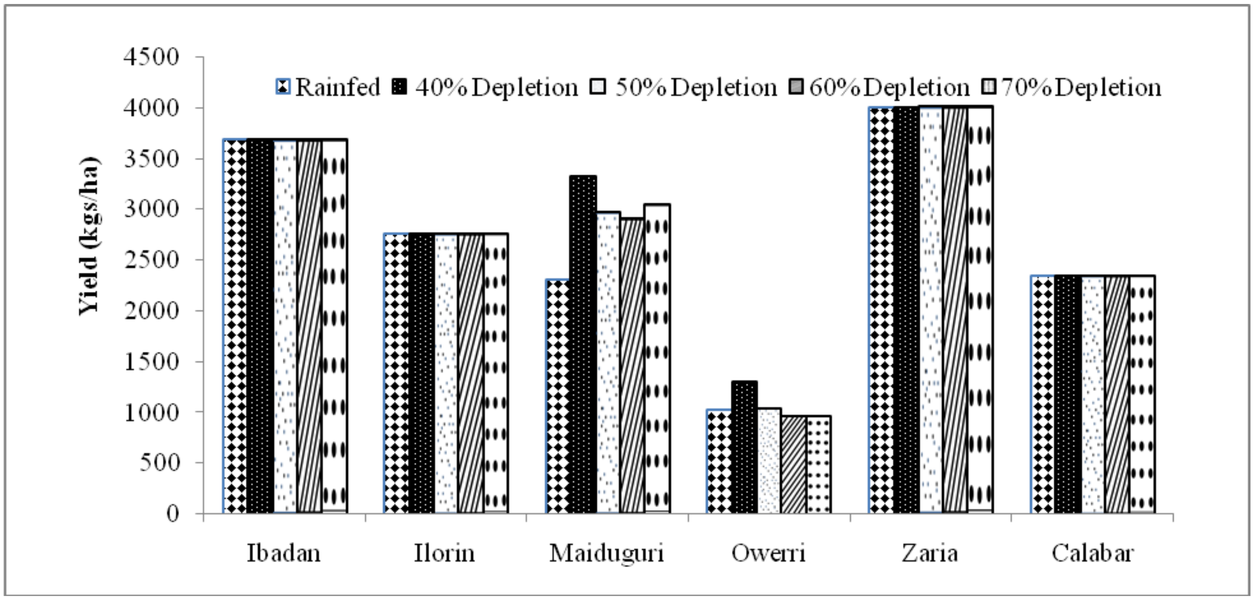

Figure 1: Yield at various irrigation scheduling treatments during the rainy season for the selected studyh sites

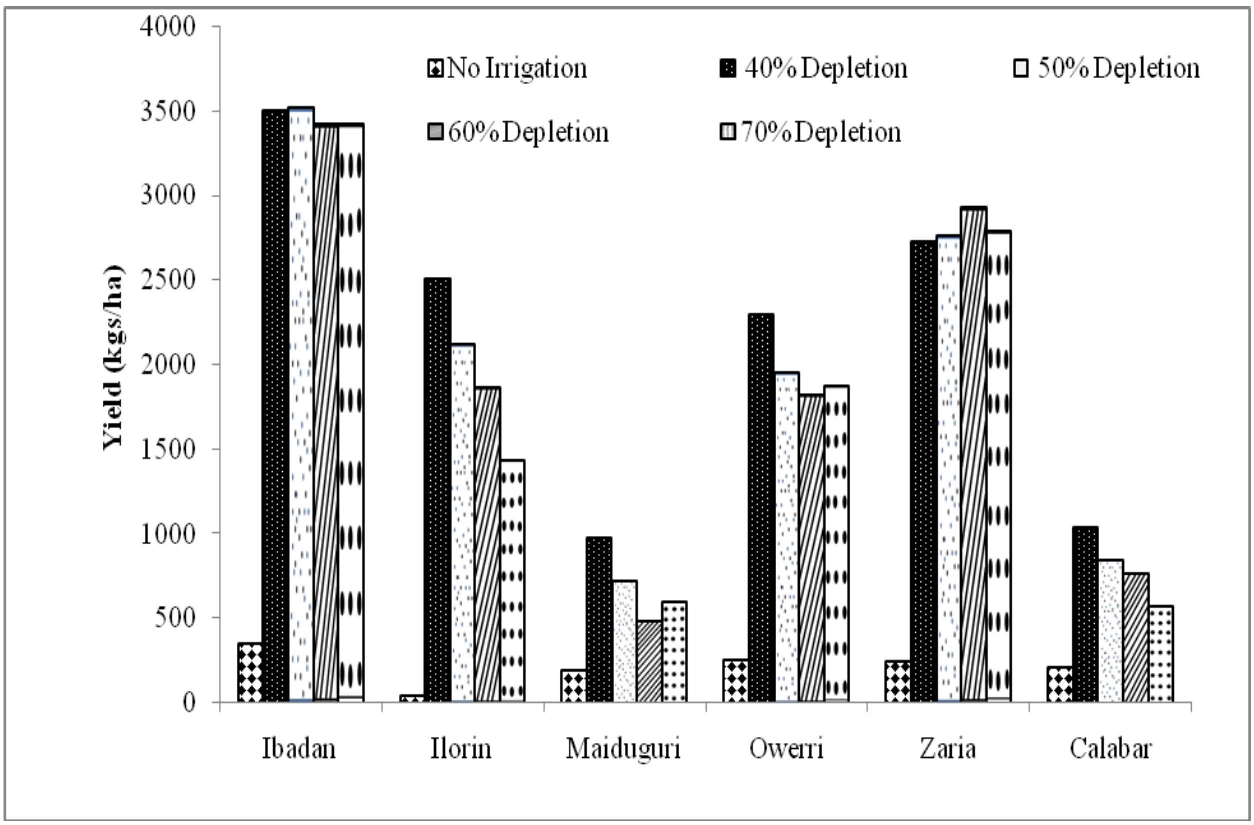

Figure 2: Yield at various irrigation scheduling treatments during the dry season for the selected studt=y sites

with average annual rainfall of 800 –1700mm. The low yield from Owerri site could be attributed to the sandy nature of the soil of the study area. In addition, the results showed that maize crop in Owerri site suffered because of moisture and nitrogen stresses during growth period. This could be related to the low water holding capacity of the soil and leaching of essential nutrient elements which is a common property of sandy soils. The results obtained in

Owerri site are also similar to the finding of Ibeawuchi et al. (2007) and Ihejirika et al., (2007). However, there was no significance ($p>0.05$) effect of irrigation on the maize yield but the soil variable and weather conditions of the sites had significant ($p<0.05$) effects on maize yield. The CROPWAT simulation model scheduled one to three applications of irrigation for the entire growing period of the crop in all study sites except Maiduguri which had more application of irrigation. This further justifies the insignificance of irrigation practices on maize yield during rainy season. Hence, there is no need for irrigation during rainy season in the study sites. Table 1 indicates that maize yields in Zaria and Ibadan sites did not differ significantly but they differed significantly from maize yields obtained from other sites. Maize yield in Ilorin site was not significantly different from the yield obtained from Maiduguri site but they differed significantly from the yields from Owerri and Calabar sites.

Dry season analysis

The maize yields simulated by DSSAT during dry season (Figure 2) under varying irrigation schedules were extremely low (Average of 0.2 t/ha) when grown without irrigation indicating a need for irrigation in maize crop field during dry season. The overall maize yield was highest (2.8 t/ha) in Ibadan site followed by Zaria site (2.3 t/ha) and the lowest yield (0.5 t/ha) was recorded in Maiduguri site. The low maize yield obtained in Maiduguri could be attributed to the extremely dry weather condition in the Sahel Savannah during dry season. However, the results indicated that maize yields in all sites differed significantly ($p<0.05$) because of soil, weather conditions and irrigation scheduling. Furthermore, maize yields differes significantly ($p<0.05$) between maize plants which were grown without irrigation and when grown under irrigation in different sites. However, there was no significant ($p>0.05$) difference between various depletion levels of irrigation. The analysis also showed that maize yield in Ibadan site differed significantly from the yields obtained in other sites. Maize yields obtained from Ilorin and Owerri sites did not differ significantly between sites but they were significantly different from those of Calabar and Maiduguri sites which recorded the lowest yield.

Conclusion

Based on the findings of this study, it can be concluded that Zaria site located in North East and Ibadan located in South West have the highest potential for maize production in Nigeria during rainy and dry seasons. In addition, Owerri site in South East has the lowest potential during rainy season but Maiduguri in North West and Calabar in South South have the lowest potentials during dry season. The study also shows that supplemental irrigation is not required during rainy season in the study sites but it is inevitably pertinent during dry season for optimal maize production. Irrigation scheduling at 70% moisture depletion interval is adequate for maize growth and development during dry season.

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