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Simulating the Sensitivity of Maize Crop Propagation to Seasonal Weather Change

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ABSTRACT

The paper simulates the sensitivity of maize crop yield response to temperature increase with appropriate irrigation scheduling that may obviate the negative impact of temperature increase on crop yield. The model was run with weather records from International Institute of Tropical Agriculture (IITA) Ibadan for the period 2000 to 2008 with the yearly weather records divided into quarterly records depicting maize crop growth seasons from planting to harvesting. Quarterly growth seasons of January – May (I), May – September (II), September – January (III), seasons respectively for maize crop were considered. Simulation results were analyzed using the SPSS statistical tool and the method of Least Square Deviation (LSD). The study revealed that an increase in the average temperature by 1°C, 2°C and 3°C for the growth seasons results in average yield reduction. Average yield reduction ranges were 5.3%-8.7% (season-I), 0% (season-II) and 0.5%-1.7% (season-III) when irrigation was done at interval of 3 days; 6.1%-8.4%(season-I) 0%(season-II) and 1.7%-0.8%(season-III) when irrigating at critical depletion of 2mm water application depth and at rainfed condition; 17%-21%(season-I), 0%(season-II) and 3.6%-7.2%(season-III) respectively. This shows that in season-II, temperature rise has no effect on maize yield due to the availability of rainfall at optimum growth condition. However, temperature negatively impacted on the yield of maize crop in seasons I and III with little or no rainfall. Hence, interval of 3 days and 2mm water application depth is best suitable under the study conditions for the three seasons.

Key-words: Yield reduction, Cropwat-8 model, irrigation Scheduling, Temperature variation and Seasonal change.

1. INTRODUCTION

Climate change and agriculture are interrelated processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements (IPCC, 2007). Due to climate change, western Africa, including Nigeria, could lose more than 30% of its main crop, maize, by 2030 (Naylor, 2008). Weather plays a primary role in productive process of field crops; by and large, it influences crop yield and its quality.

Recent temperature changes have been seemingly noticeable, such that the warming trend in the last 50 years has been 0.13°C per decade; nearly double that of the preceding 100 years. Projections to the end of this century suggest that mean global temperature will increase by 1.8–4.0°C (range 1.1–6.4°C), depending on the greenhouse gas emission scenario, accompanied by changes in rainfall patterns and an increase in climate variability (IPCC, 2007). Such climate changes are expected to have far-reaching impacts on crop yield such as maize worldwide.

The critical weather parameters associated with agricultural production are precipitation, air temperature, and solar radiation. Air temperature is the main weather variable that regulates the rate of vegetative and reproductive development (Hodges, 1991).

Maize or corn (*Zea Mays*) originated in Mexico and from there it became an important major staple food consumed throughout the world (Zhu and Ma, 2011). Maize is one of the most important cereal crops grown in Nigeria. The potential of the crop has not been fully exploited due to very low yields obtained on most farmers' fields. Maize production in Nigeria is characterized by low productivity. The cultivation of maize crop is a critical mainstay of local livelihoods and national Gross Domestic Product (GDP) in many countries of Africa, Nigeria is a good example. The contribution of maize crop to GDP varies across countries but assessments suggest an average contribution of 5% of GDP (Camberlin and Fontaine, 1999). This important staple food is particularly sensitive to climate, including periods of climate variability. In many parts of Africa, farmers also have to contend with other extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. These challenges are usually aggravated by excessive temperature increase (Biggs *et al.*, 2004).

Computer simulation model is an emerging trend in the field of water management and weather variability investigation. Irrigation and water engineers, agronomists and researchers have keen interest in simulation model for the easier solution of problems faced by them (Muhammed, 2009).Computer simulation models of systems soil/plant/weather can help in the understanding of the response of crop yield to climate change. Crop simulation models can also give an idea of how the future yield regime might be. In this regard, CROPWAT is one of the models extensively used in the field of water management throughout the world. It is application software used for irrigation planning and management. It is a practical tool that helps irrigation and water engineers, agrometeorologists, researchers and agronomists to carry out standard calculations for evapotranspiration and crop water use studies, and, more specifically, the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of crop yields under varying weather conditions. It facilitates the estimation of the crop evapotranspiration, irrigation schedule, crop water requirement and yield reduction under varying weather conditions (FAO, 1992).

The objectives of this study are to evaluate the sensitivity of major crop to seasonal weather conditions based on computer simulation and investigation of appropriate irrigation scheduling regime.

2. MATERIALS AND METHODS

2.1 Data collection and management

The study was carried out in Ibadan which lies approximately between latitude7^{0}39'N and longitude3^{0}90'E of Nigeria and altitude 238m above the sea level. The area lies within the Southwest savannah zone of Nigeria. The length of the dry season is about 121-151 days (October to March) during which little or no precipitation occurs. Mean daily air temperatures (minimum and maximum) range between 23.6^{0}C and 33.2^{0}C. The wind speed ranges from 50.3 km/day in December to 735 km/day in April, with a north easterly to south westerly wind direction dominating from November through April. The soil is medium loam, developed on deeply weathered Pre-Cambrian Basement Complex rocks but overlain by aeolian drift of varying thickness (Ewemoje and Sangodoyin, 2008; Sani *et al.*, 2008).

2.1.1 Climate, Crop and Soil Data

Data used were obtained from the International Institute of Tropical Agriculture (IITA) over a period of Nine years (2000-2008) and was inputed into CROPWAT-8 for window. For this study, sets of standard maize crop data that are included in the CROPWAT- 8 model were used. The crop coefficient (Kc) and crop yield data (Ky) are also included in the software by FAO.

In this paper, Maize crop was assumed to be cultivated all year round. Maize growth, from planting to harvesting spans a period of four months (a growth season), i.e. cumulative period of 125 days. Growth seasons were divided into three: January to May – Season I; May to September – Season II and September to January – Season III.

2.1.2 Determination of reference crop evapotranspiration

Reference Evapotranspiration (ETo) represents the potential evaporation of a well-watered grass crop. The water needs of other crops are directly linked to this climatic parameter (Muhammed, 2009). Although several methods exist to determine ETo, the Penman-Monteith Method has been recommended as the appropriate combination method with the climatic data; temperature, humidity, sunshine, wind speed. The FAO Penman-Monteith method used to estimate ETo is expressed as given in equation (1) by Allen et. Al. (1998):

$$ET_O = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T + 273}\mu_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,\mu_2)} \tag{1}$$

where:

ETo = Reference evapotranspiration [mm day^{-1}],
R_n= Net radiation at the crop surface [MJ m^{-2} day^{-1}],
G= Soil heat flux density [MJ m^{-2} day^{-1}],
T= Mean daily air temperature at 2 m height [°C],
μ_2= Wind speed at 2 m height [m s^{-1}],
e_s= Saturation vapour pressure [kPa],
e_a= Actual vapour pressure [kPa],
Δ= Slope vapour pressure curve [kPa °C^{-1}],
γ=Psychrometric constant [kPa °C^{-1}].

2.1.3 Determination of Crop Water Requirements

The amount of water required to compensate evapotranspiration loss from the cropped field is defined as crop water requirement, which is equivalent to crop evapotranspiration (ETc). Crop evapotranspiration was calculated from climatic data by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach with the following expression:

$$ET_C = K_C \times ET_O \tag{2}$$

where:

ETc= Crop Evapotranspiration (Crop water Requirement)
Kc= Crop Coefficient
ETo= Reference Evapotranspiration

2.1.4 Yield reduction Determination

Yield reduction due to soil moisture stress resulting from increase in air temperature, which dries up the available soil water was calculated below from the equation by Allen et. al. (1998):

$$\left(1-\frac{Ya}{Y\max}\right)=Ky\left(1-\frac{ETcadj}{ETc}\right) \quad (3)$$

where:

Ya = Yield achievable under actual conditions
Ymax = Maximum crop yield achievable in case of full satisfaction of crop water needs
Ky = Yield response factor
ETcadj = Crop evapotranspiration under non-standard conditions
ETc = Crop evapotranspiration under standard conditions.

2.2 Irrigation Scheduling

The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigation management conditions. Scheme water supply was calculated according to the cropping pattern provided in the CROPWAT model (Smith, 1992).

The irrigation options adopted for this work were: Irrigation at critical depletion (2mm application depth); Irrigation at definite interval (three days interval and at 2mm application depth) and Rainfed condition (No irrigation)

2.3 Future projection of temperature effect on maize yield

Having provided some background on existing sensitivities of maize yield generated by a range of temperature, the impacts and vulnerabilities that may arise in the future were also examined. For this prediction purpose, ambient temperature and a definite interval (three days) irrigation schedule were considered and the results analysed using t-test in the SPSS statistical tool. The key steps in the simulation process were:

1) CROPWAT-8 model was run for maize crop with the daily climatic data for Ibadan. Simulation was done by increasing the ambient temperature by 1°C, 2°C and 3°C while all other weather parameters remain constant.
2) Maize was simulated under three irrigation timings: irrigation at critical depletion; irrigation at definite interval and rainfed condition.
3) The simulation model results were analyzed using the Statistical Package for Social Science (SPSS) and method of Least Square Deviation (LSD).

3. RESULTS AND DISCUSSION

The simulated maize yield reductions under different degree of temperature for Ibadan as shown in table1. There is marked yield reduction in each of the years (2000 to 2008) with ambient temperature recording the least while the highest yield reduction occurred when ambient temperature was increased by 3°C. For every 1°C rise in temperature from the ambient to 3°C there is noticeable yield reduction depending on the amount of rainfall recorded in each year. Yield reduction recorded the lowest values in the year 2003; this could be as a result of more rainfall recorded in the period. The results show the following percentage yield reduction within 2000 and 2008: at ambient-0-22.3%; 0.1-24% at 1°C; 0.4-25.7% at 2°C and 0.8-27.3% at 3°C temperature rise.

Maize yield was also simulated under varying irrigation schedules: irrigation at critical depletion; irrigation at definite interval and rainfed condition. The result generally showed that there was no yield reduction in growth season II. This is due mainly to the fact that Ibadan receives adequate rainfall between May and September than any other month of the year. It therefore implies that additional water supply is needed to augment the limited rain water available in seasons I and III in order to increase or maintain optimum maize crop yield.). The seasonal yield reduction of maize under different irrigation timing was shown in Table 2. The result reveals that for each 1°C temperature rise from ambient to 3°C, the yield reduction under critical depletion ranges from 3.4%-18.5% for season I, 0% for season II and 0%-2.5% for season III, respectively. These results have shown that temperature has adverse effect on maize yield in season I and III. Under definite interval, the ranges are: 0%-15.3% for season I; 0% for season II and 0%-3% for season III; and under rainfed the results showed 5.3%-38.1% for season I; 0% for season II and for season III, 0.1%-11.7% respectively.

There was significant difference at $P<0.05$ (Table 3) when irrigating at critical depletion and at definite interval when compared with the rain-fed (no irrigation) condition respectively. Furthermore, irrigating at definite interval has the lowest values of mean, standard deviation and standard error in all temperature conditions. This therefore, makes irrigation at definite interval the most preferred irrigation schedule. Statistical analysis of future projection indicates for ambient weather condition, higher yield reductions of maize crop as follows; 9.1% to 12.4% for season I, 0% to 2.1% for season II and 0% to 5.5% for season III (Table 4). This implies that unfavorable weather condition will continue to hinder crop productivity if necessary precautions are not taken.

The correlation of the relationship between the simulated and projected yield reduction was shown in figure 1. Coefficient of determination (R^2) of 0.9675 indicates that forecasted yield reduction agrees with simulated yield reduction obtained with measured weather data of the studied location.

4. CONCLUSION

Simulated maize yield reductions showed the adverse effect of possible continuous rise in temperature in the studied area which is Ibadan. Results showed that yield reduction increases with rise in the temperature. An increase in temperature by 1°C led to a considerable reduction in yield in all the years and within the different seasons. The effect of temperature on maize yield is prominent in seasons I and III while season II is minimally affected due to the associated adequate rainfall in the season. Statistical results indicated that irrigating at definite interval of three days at 2mm application depth will significantly reduce yield loss for maize.

The study of weather variability using the CROPWAT-8 model has highlighted its possible application in the Agricultural sector by carrying out a series of simulations connected to probable future weather conditions and the production response of crops. The simulation of maize yield reduction provides the information necessary for making decisions about various Agricultural activities and allows the assessment of crop productivity under varying weather and irrigation scheduling conditions.

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Table 1: Simulated Maize Crop Yield Reductions under varying degree of temperature

Year	Ambient	Yield Reduction (%)		
		1°C Increase	2°C Increase	3°C Increase
2000	6.1	7.2	9.2	11.1
2001	1.6	2.8	3.2	6.7
2002	3.1	4.1	5.2	6.4
2003	0	0.1	0.4	0.8
2004	2.2	3.7	5.5	7.1
2005	1.7	1.7	4.6	6.3
2006	9.3	10.8	12.3	14
2007	22.3	24	25.7	27.3
2008	5.3	8.5	11.4	14.5

Table 2: Seasonal Yield Reduction of Maize Crop under Different Irrigation schedules

YEAR	CRITICAL DEPLETION			DEFINITE INTERVAL			RAINFED CONDITION		
	I	II	III	I	II	III	I	II	III
2000	7.2	0	0.2	6.1	0	0	20	0	4.6
2001	3.8	0	1.3	1.5	0	0.1	11.7	0	8.7
2002	4.9	0	0	3.1	0	0	15.1	0	0
2003	1.6	0	0	0	0	0	5.3	0	0
2004	3.4	0	1.8	1.2	0	1	7.2	0	9.9
2005	4.6	0	1.2	1.7	0	0	13	0	2.8
2006	7.5	0	0	6.3	0	0	22.9	0	2
2007	18.5	0	0	15.3	0	0	38.1	0	0.1
2008	3.4	0	2.5	2.7	0	3	17.2	0	11.7

Table 3*: Irrigation Scheduling Statistical results

Treatment	Mean	Std deviation	Std error
Critical depletion	11.23	21.326	4.404
Definite interval	8.29	16.193	3.579
No irrigation	28.95	37.964	6.637

*(Level of significance $p < 0.05$)

Table 3b: Estimated Seasonal Maize Yield Reduction (%)

Year	I	II	III
2000	9.1008	-1.8369	-1.6746
2001	1.5877	-2.25	0.6123
2002	3.8746	-2.6631	-2.8008
2003	-2.1385	-3.0762	-3.2139
2004	-0.8516	-3.4893	0.973
2005	1.6353	-3.9024	-3.1401
2006	9.8222	-4.3155	-4.4532
2007	22.7091	-4.7286	-4.8663
2008	2.596	-5.1417	1.6206

Table 4: Predicted Seasonal Maize Yield Reduction (%)

Year	I	II	III
2009	10.7883	2.0652	3.8113
2010	11.2014	2.4783	4.2244
2011	11.6145	2.8914	4.6375
2012	12.0276	3.3045	5.0506
2013	12.4407	3.7176	5.4637

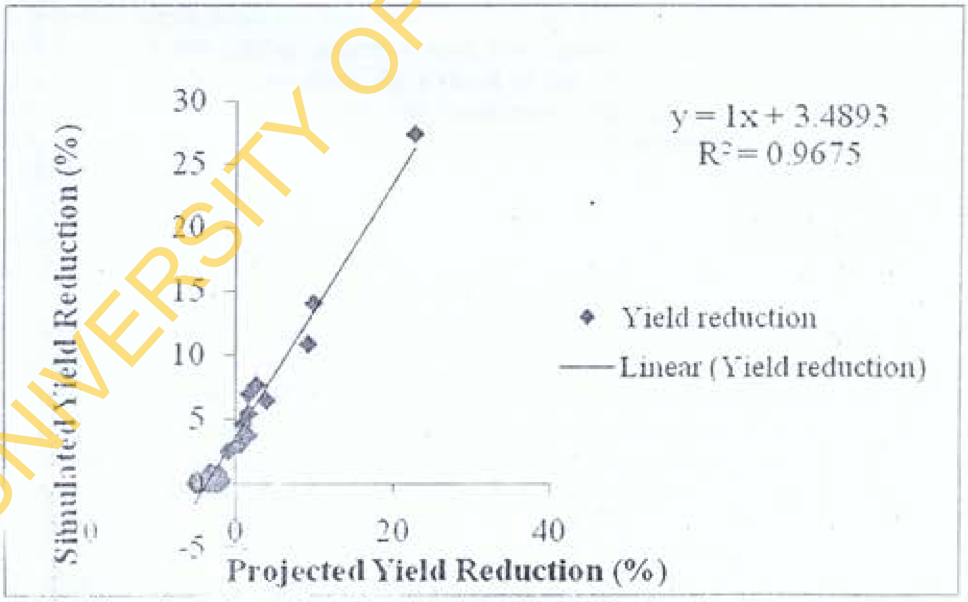

Figure 1: Simulated against Projected Yield Reduction