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Dear Dr. Ewemoje

ACCEPTANCE OF MANUSCRIPT FOR PUBLICATION

Greetings. Our reviewers have recommended your manuscript (MS 2K10/023) entitled Simulating the impact of climate change on yield .... Co-authored with Ashaolu, P. O. for publication. It will appear in vol. 26(1) 2010 of the journal.

Please remit the sum of paid in bank draft in favour of Journal of Tropical Forest Resources on or before ...—.............. to enable us take further action on the manuscript.

Thank you.

Yours sincerely,

Prof. Labode Popoola
Managing Editor

SIMULATING THE IMPACT OF CLIMATE CHANGE ON YIELD REDUCTION OF VEGETABLE CROP PROPAGATION

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ABSTRACT

Effects of climate change on the yield reduction and prediction of vegetable crop was carried out using CROPWAT 8 with irrigation scheduling conditions; critical depletion at a water application depth of 2mm, definite interval of 3days at a depth of 2mm and no irrigation. The model was run with 9 year weather records for Ibadan, Nigeria spanning 2000 to 2008, the yearly weather records was divided into quarterly records depicting vegetable crop growth period from planting to harvesting. Quarterly growth seasons of January – April (I), April – July (II), July – October (III), October – January (IV) for the vegetable crop with an increase temperature rise of 1°C. Simulation results analyses for 2000 to 2008 under critical depletion reveals that at each 1°C temperature rise from ambient condition to 3°C, yield reduction for season I ranges from 4.3% to 27.1%, 0% - 0.2% for season II, 0% for season III and increasing to 7.1% to 15.9% for season IV. Also, from the prediction analysis (2009 – 2013) obtained from SPSS statistical tool and the method of Least Square Deviation (LSD), for ambient weather condition of the study location there are higher yield reduction from 9% to 11.68% for season I, 0% to 0.77% for season II, 0% to 0.76% for season III, and 12.2% to 12.0% for season IV respectively. Hence, climate change has impacted negatively on higher predicted yield reductions of three out of the four seasons considered from year 2009 to 2013.

Keywords: Vegetable crop, Yield reduction, CROPWAT-8 Model, Yield prediction, Climate change.

INTRODUCTION

Climate variability and environmental sustainability has been a topical issue all over the world including Nigeria. Climate change has been reported to have both positive and negative impacts on agricultural crop production. Over the years, man's activities such as deforestation, bush burning, industrial production has lead to gradual changes in the earth's average temperature, rainfall amount and patterns, rising CO_2 concentrations, increase in pollution levels such as troposphere ozone levels with its associated extreme hydrological events such as drought and flooding, which is generally called climate change (Awotoye and Matthew, 2010).

However, climate change has both positive and negative impact depending on location. Some aspects of Climate change such as longer growing seasons and warmer temperatures in cold temperate regions are associated with benefits (Mimi and Jamous, 2010). For example in Egypt, climate change could decrease national production of many crops (ranging from 11% for rice to 28% for soybeans) by 2050 compared with their production under current climate conditions (Eid et al., 2006). Also, positive impacts include agriculture and the growing seasons in certain areas (e.g. parts of the Ethiopian highlands and parts of southern Africa such as Mozambique), may lengthen under climate change, due to a combination of increased temperature and rainfall changes (Thornton et al., 2006).

Variability in climate has been described as the primary determinant of agricultural productivity influencing the types of vegetation that can grow in a given location. The analysis of climate change/variability impact shows that there is a general reduction of potential crop yields and a decrease in water availability for agriculture and other uses in many parts of the developing world (Tshiala and Olwoch, 2010). Nevertheless, the positive and negative impact of climate change on crop growth and yield can be determined before hand by carrying out sensitivity analysis. Sensitivity analysis can be applied on a wide scale such as risk analysis, policy assessment studies, business and environmental condition. It involves the observed variations of the output of a mathematical model which is apportioned qualitatively or quantitatively, to different sources of variation in the input of a model.

Different simulation model have been developed for use in agriculture, which includes CROPWAT, CERES, CROPGRO and so on; are useful in determining effective means of having high crop yield. Various researchers have used crop models as valuable tools to synthesize the understanding of physiological processes, hypothesizing genetic improvement, evaluate management strategies (Ouda et al., 2010). Crop simulation models can be used for predicting the effects of climatic change and climatic variability on crop growth and yield (Matthews et al., 1997). According to Hoogenboom (2000), the management applications of crop-weather models can be defined as strategic, tactical, and forecasting applications. In strategic applications, the crop models are run prior to planting of a crop to evaluate alternative management strategies. In tactical applications, the crop models are run before planting or during the actual growing season. Forecasting applications can be conducted either prior to planting of a crop or during the growing season.

Biophysical effects, the main driver of agricultural responses to climate change occurs as a result of changing meteorological variables such as rising temperatures, changing precipitation regimes and varying levels of CO_2 (Tshiala and Olwoch, 2010). These biophysical effects over time depend on region and agricultural systems practiced (Adams, 1998). Providing leverage against these effects may require modifying crop growth environment through supplemental irrigation and mulching to reduce or prevent drought stress. For vegetable crops, supplemental or total irrigation are important because many vegetables are shallow rooting and therefore sensitive to water shortage (Tsabedze and Wahome, 2010).

MATERIALS AND METHODS

The experimental field is Ibadan, Nigeria which is located at 7.39^{0}E and 3.90^{0}N. The average elevation of Ibadan above mean sea level is 239 m (Ewemoje and Sangodoyin, 2006). Meteorological data of this study was a daily data for Ibadan, Nigeria for the period 2000 to 2008; with daily values for minimum and maximum air temperature (^{o}C), solar radiation (MJ/m^2/day), evaporation (mm), rainfall (mm), minimum and maximum humidity (%), average wind speed (km/day) and sunshine hours (hour). Weather data were obtained at International Institute of Tropical Agriculture (IITA) Ibadan, meteorological station.

Crop and soil data for this study were standard vegetable crop data already included in the CROPWAT 8 program were used and the crop coefficient (Kc) and crop yield data (Ky) have been updated by FAO. Vegetable crop were planted in the following quarters or periods 1st. January – 5th April, 1st April – 4th July, 1st July – 3rd October, 1st October – 3rd January, respectively. The model simulation soil type data used is medium (loam) soil.

Crop Yield Reduction due to soil moisture stress is expressed as a percentage of the maximum production achievable in the area under optimal conditions and computed with reference to the whole growing season.

Yield reduction is expressed in the CROPWAT model by applying the following equation:

$$(1 - Y_a / Y_{max}) = K_y (1 - ET_{cadj} / ET_c)$$

Where, Y_a = Yield achievable under actual conditions

Y_{max} = Maximum crop yield achievable in case of full satisfaction of crop water needs

K_y = Yield response factor

$ET_{c\ adj}$ = Crop evapotranspiration under non-standard conditions

ET_c = Crop evapotranspiration under standard conditions

Simulations

The daily climatic data was inputted into the Cropwat model. To determine the effect of climate change, maximum and minimum temperatures in the climatic data referred to as the ambient temperature was increased by a 1°C steady rise to 3°C. The yield reduction and crop water requirement from ambient to 3°C increments were then generated for four periods January – April (I), April – July (II), July – October (III) and October – January (IV). Three scheduling criteria used were; no irrigation (rain fed), at definite interval (3 days interval at a depth of 2 mm) and at critical depletion (3 days interval at a depth of 2 mm).

CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of Food Agricultural Organization (FAO). It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rain fed conditions or deficit irrigation (Adriana *et al.*, 1999). CROPWAT for Windows uses the FAO 1992 Penman-Monteith method for calculation reference crop evapotranspiration (Smith, 1992).

RESULTS AND DISCUSSION

The simulation of vegetable crop was done for four growth seasons 1st January – 5th April (I), 1st April – 4th July (II), 1st July – 3rd October (III), 1st October – 3rd January (IV) within the period of 2000 to 2008 inclusive. These growth seasons implied cumulative growth period of

95days. Irrigation scheduling applied includes definite interval with water application depth of 2mm, critical depletion with 2mm water application depth, and no irrigation (rain fed condition). The earlier two irrigation scheduling were irrigated to 70% field capacity.

Effects of climate change on Yield reduction under Critical Depletion

Simulation results analyses for year 2000 to 2008 under critical depletion reveals that at each 1°C temperature rise from ambient condition to 3°C, percentage yield reduction for season I range from 4.3 - 23.4%, 5.4 - 24.8%, 6.3 - 25.7% and 6.8 - 27.1% respectively. While season II ranges from 0 - 0.1% for ambient condition, and 0 - 0.2% for the remaining increase in temperature. Season III had a single yield reduction of 0% while season IV ranges from 7.1 - 14%, 7.9 - 14.4%, 8.2 - 15.4% and 8.7 - 15.9%.

Comparing each seasons for the 9-year period (2000-2008) it shows that for season I there was a gradual percentage yield reduction from 0.5 - 1.4%. Season II had no definite trend for the low yield reduction and similarly Season III had no trend because rainfall is maximum at this period and more water is available for the vegetable crop. Season IV had a gradual percentage reduction in yield from 0.3 - 1.0% which is lower than season I because of late rains and beginning of the dry harmattan season.

Effects of climate change on Yield reduction under Definite Interval

Yield reduction under definite interval reveals that at each 1°C temperature rise from ambient condition to 3°C, percentage yield reduction for season I ranges from 15.6 - 43.8%, 16.9 - 44.9%, 18.3 - 45.9% and 19.7 – 47.0%, while season II ranges from 0 - 0.1%, 0 - 0.2%, 0 -

0.2% and 0 - 0.3%. Season III had a single yield reduction of 0% while season IV ranges from 9.5 - 23.5%, 10.3 - 24.6%, 11 - 25.7% and 11.5 - 26.7%.

Comparing each seasons for the 9-year period (2000-2008) it shows that for season I there was a gradual percentage yield reduction from 1.0 - 1.8% of yield reduction. Season II had no clear-cut trend for the yield reduction because it's the beginning of rainfall in this period therefore crop water requirement for the vegetable crop is met and temperature is reduced. Season III had no trend because rainfall is maximum at this period and more water is available for the vegetable crop thereby negating the effects of climate change as a result of temperature rise and drought. Season IV had a trend of 0.5 - 1.1% yield reduction which is lower than season I because of late rains and beginning of the dry harmattan season. However, these yield reductions are higher under definite interval irrigation schedules compared to that of critical depletion.

Effects of climate change on Yield reduction under No Irrigation

Simulation results analyses obtained from the CROPWAT model for year 2000 to 2008 no irrigation reveals that at each 1°C temperature rise from ambient condition to 3°C, percentage yield reduction for season I ranges from 28.6 - 56.0%, 29.8 - 56.8%, 31.0 - 57.7% and 32.3 - 58.5%. While season II ranges from 0 - 0.8%, 0 - 0.9%, 0 - 1.1% and 0 - 1.2%. Season III had a yield reduction of 0%, 0%, 0 - 0.1% and 0 - 0.1% while season IV ranges from 16.0 - 33.6%, 16.7 - 34.6%, 17.4 - 35.5% and 17.9 - 36.5%.

Comparing each seasons, it was observed for season I there was a gradual percentage yield reduction of 0.8 - 1.3%. Season II had a low gradual percentage reduction of yield from 0 - 0.2% compared to season I. Season III had no specific trend because rainfall is maximum at this period and more water is available for the vegetable crop. Season IV had a gradual reduction in yield from 0.5 - 1.0% which is lower than season I because of late rains and beginning of the dry harmattan season. Worth noting is that season I had the highest percentage yield reduction because of high temperature in this period while season III had the lowest percentage yield reduction.

Statistical analysis on the effect of climate change on yield reduction

From the tables 1 to 4 below, it reveals that at each temperature rise, the mean and standard deviation of the yield reduction increases under the three irrigation schedules used with critical depletion having the least value.

Table 1: Ambient Temperature

Irrigation Schedule	N	Mean	Std deviation	Std error
Critical depletion	36	5.5528	6.33965	1.05661
Definite interval	36	10.9139	12.28086	2.04681
No irrigation	36	16.4694	17.74735	2.95789
Total	108	10.9787	13.62194	1.31077

Table 2: Temperature of 1^{0}C Rise

Irrigation Schedule	N	Mean	Std deviation	Std error
Critical depletion	36	5.9722	6.71347	1.11891
Definite interval	36	11.475	12.79595	2.13266
No irrigation	36	16.975	18.21178	3.0353
Total	108	11.4741	14.04124	1.35112

Table 3: Temperature of 2^0C Rise

Irrigation Schedule	N	Mean	Std deviation	Std error
Critical depletion	36	6.3583	7.07698	1.1795
Definite interval	36	12.0083	13.31183	2.21864
No irrigation	36	17.4722	18.65368	3.10895
Total	108	11.9463	14.45497	1.39093

Table 4: Temperature of 3^0C Rise

Irrigation Schedule	N	Mean	Std deviation	Std error
Critical depletion	36	6.7583	7.47095	1.24516
Definite interval	36	12.5694	13.83478	2.3058
No irrigation	36	17.9917	19.10833	3.18472
Total	108	12.4398	14.88408	1.43222

Prediction of the effect of climate change on yield reduction

A 2009 to 2013 prediction analysis was obtained for the four seasons of vegetable crop under ambient temperature for critical depletion using the t–test. It was observed that for ambient weather condition of the study location there are higher percentage yield reduction from 9-11.68% for season I, 0-0.77% for season II, 0-0.76% for season III, and 12.2-12.0% for season IV respectively. Hence, climate change has impacted negatively on higher predicted percentage yield reductions of three out of the four seasons considered from 2009 to 2013.

Figure 1 shows a linear relationship between the simulated and forecasted yield reduction with a coefficient of determination (R^2) value of 0.998.

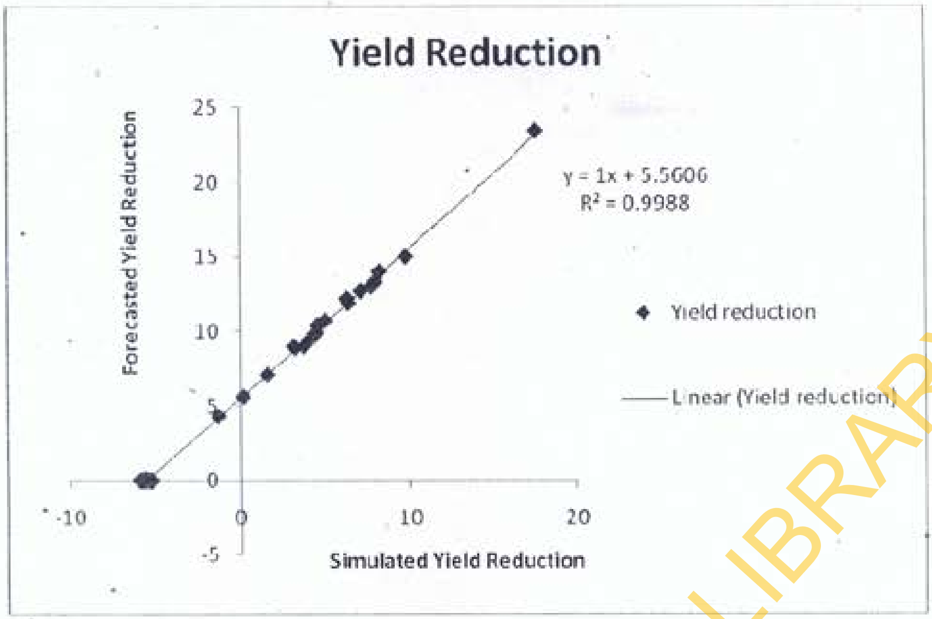

Figure 1: Simulated against Forecasted yield reduction

The results showed that yield reduction was lowest under critical depletion and highest under no irrigation because critical depletion and definite interval had supplemental water to boost its yield while at no irrigation relied mainly on rainfall which is seasonal and erratic. This was also verified using the Least Square Difference (LSD) method, there was no significant difference, at $P < 0.05$, between critical depletion and no irrigation. Significant differences however existed, at $P < 0.05$ between irrigation schedules at definite interval and critical depletion, also between irrigation schedules at definite interval and no irrigation. Irrigation scheduling at critical depletion had a low mean and better significant difference for each temperature rise, therefore the most preferred under uncertainty due to climate variability.

From the prediction analysis, R^2 is close to 1 which shows that the forecasted yield reduction agrees with the simulated yield reduction. Prediction revealed that to attain least yield reduction, planting should be preferably done in the season III (July – October) of the year.

Table 5: Seasonally Estimated Yield Reduction

Year	SEASON I	SEASON II	SEASON III	SEASON IIV
2000	9.807	-5.21	-5.24	7.744
2001	3.723	-5.3	-5.32	7.96
2002	4.039	-5.38	-5.4	4.476
2003	0.155	-5.47	-5.49	1.592
2004	6.371	-5.55	-5.57	7.108
2005	-1.31	-5.63	-5.66	3.224
2006	5.003	-5.62	-5.74	8.24
2007	17.62	-5.8	-5.82	4.556
2008	3.135	-5.89	-5.91	6.272

Table 6: Seasonally Predicted Yield Reduction

Year	SEASON I	SEASON II	SEASON III	SEASON IV
2009	11.3528	0.4412	0.4289	11.7079
2010	11.4368	0.5252	0.5129	11.7919
2011	11.5208	0.6092	0.5969	11.8759
2012	11.6048	0.6932	0.6809	11.9599
2013	11.6888	0.7772	0.7649	12.0439

CONCLUSION

Climate changes have been implied to have significant impacts on the regional vegetable crop production in tropical sub-humid climatic zone. However the extent of these impacts and assessment of its positive effect to negative effect on the environment most especially in the growth of vegetable growth still remain uncertain.

From the simulation results from CROPWAT, there was variation in the upward and downward fluctuations in percentage yield reduction from year 2000 to 2008 which implies that climate change is not constant phenomenon, it is ever changing. Considering the different irrigation schedules of critical depletion, definite interval of irrigation application and no irrigation (i.e. rain fed conditions) over the period 2000 to 2008; CROPWAT model in season I predicted average yield reduction between 0.5% to 1.8% when compared to actual maximum crop yield achievable in case of full satisfaction of crop water needs while taking into consideration the yield response factor for different growth stages of the vegetable crop. Season II and III on the average had negligible yield reduction and this may be attributed to rainy seasons in tropical environment where the experimentation was carried out, hence crop water requirement was fully met without any water deficit stress on planted vegetable crop. Furthermore, average ambient temperature is relatively lower in the rainy season (season II and III) when compared to the dry season (season I and IV) in Ibadan, south west Nigeria. Average predicted yield reduction from CROPWAT model ranged 0.3% to 1.1% in season IV when compared with the actual maximum crop yield achievable.

Therefore, it is inappropriate to ascertain what year or period of time it will be of great negative effect on vegetable crop production, hence adequate measures should be taken to reduce droughts and floods due to climate change on crop production to a reasonable level.

From the statistical analysis, there was a significant difference in the effect of climate change on the percentage yield reduction between irrigation at critical depletion and at definite interval but no significant difference for no irrigation (rain fed condition) for each rise in temperature. Also, irrigation at definite interval has significant difference compared to both irrigation at critical depletion and no irrigation (rain fed condition). The result infers that irrigation at critical depletion is preferred for the production of vegetable crop because low percentage yield reduction achieved.

In the statistical and prediction analysis, season III produced the lowest percentage yield reduction of vegetable production. Therefore, vegetable propagation should be carried out using critical depletion irrigation schedule to obtain high yields for sustainability of vegetable propagation especially in vulnerable seasons I and IV.

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