Predicted changes in suitability and agro climatic factors due to climate change for yam production in Nigeria

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Abstract

Monthly data outputs on rainfall and temperature from 18 SRES models for emission scenario obtained from CIAT and *w*hite yam production extracted from FAO's Ecocrop were utilized to predict changes in suitability and effect of agro climatic change on yam production in Nigeria. The average outputs for all 18 models were used for calculating area changes to compare the 1951-2000 period with the predicted 2040-2069. The prediction showed that there will be increase of 10% by 2050 on the areas with "Excellent" suitability for growing white yam as a result of predicted increases in rainfall amounts in the north as well as rising temperatures in mid altitude and highland areas of Nigeria. For the areas classified as "Very Suitable", "Suitable" and "Marginal" there were only slightly reductions in areas with 3, 1 and 8% respectively as compared to the climate averages of 1951 to 2000. The "Very Marginal" showed the highest area increase (175%) as it went from 37,000 km^2 to over 65,000 km^2 for the 2050 period when compared to current long term averages. The predicted average annual temperature changes showed that all states are going to face increased temperatures. The predicted increases in temperature in the northern parts of the country were higher than coastal areas with a standard deviations between 0.01 and 0.11 C. In order to properly relate impact of changing climate on productivity and yield and the economic and food security implications time series of production and yield data and the respective climate data would be needed to derive linear or other relations.

Key words: Yams, *Dioscorea rotundata* agro climatic change

Introduction

Yam, genus Dioscorea, family Dioscoreaceae, are economically an important multi-species crop for sustainable food production in tropical and subtropical regions (Ayensu and Coursey 1972). Yam serve as a valuable source of food across Africa, Asia, South America, the Caribbean and the Pacific 1976)

Out of about 600 species known, six are grown in Nigeria: (D. rotundata (white Guinea yam), D. alata (water yam), D. cayenensis (yellow yam), D. dumetorum, (trifoliate yam), D. bulbifera (aerial yam), and D. esculenta (Chinese yam). However, the most important food species are D. rotundata, indigenous to West Africa, and D. alata introduced from Asia to Africa during the sixteenth century. The variety most cultivated and consumed is D. rotundata and it also has the highest market value owing to the superior suitability of its tubers for preferred food uses in West Africa.

Yam constitute an important source of food and income and play a major role in socio-cultural life for a wide range of smallholder households. Nigeria is the world's largest producer with an estimated 35 million tonnes in 2008 grown on 3.1 million ha (FAO, 2011).

Yam play an important role as a food and cash crop for millions of consumers and hundreds of thousands of small-scale producers in Nigeria and some other West African countries. It is estimated to provide 60 million people with an average of 200 cal/day from Côte d'Ivoire to Cameroon (Nweke et al., 1991) so it is an important food security crop. It is also clearly a major source of revenue for many people, including a good proportion of women as producers, processors and traders. Production is carried out in three major ecological zones in Nigeria: the northern section of the rainforest, the southern Guinea or derived savanna, and the southern portion of the northern Guinea savanna. Originally, yam was a rainforest crop grown throughout the West African forest zone. In Nigeria, these yam ecological zones extend from 5°N latitude up to 9°N latitude. These areas predominantly have a monomodal rainfall distribution with two marked seasons; the rainy season (April to September) and the dry season (October to March). Production has been shifting northwards from the humid forest zone, (4°N latitude) to the subhumid Guinea savanna ecological zones, between 8 to 10°N latitude (Manyong et al. 1996).

Yam are essentially a tropical crop, and require good fertile soil, adequate and well distributed rainfall, and considerable labour input for agronomic operations such as land preparation, planting, staking, weeding, and training the vines.

Being a crop of the more humid and subhumid areas yam has higher dependency on the amount of rainfall and is more vulnerable to drought compared with crops such as cassava. Climatic factors (soil moisture, temperature, light, and photoperiod) affect the growth and performance of yam.

Yam require rainfall for at least 5 of their 8 months of growth in the field. The distribution of rainfall is more important than the volume. Yam grow better in areas that have 1,000-1,500 mm of rain well distributed over a period of 6 to 7 months in the cropping season (Onwueme, 1975). Yam require water throughout the active growth period for vine and leaf development, tuber initiation and bulking; the most critical stages are at tuber initiation and bulking. Moisture stress affects yam more when intercropped. Moisture stress has also been reported to delay tuber initiation in water yam (Onwueme 1975).

Africa is predicted to be the continent most vulnerable to the negative effects of climate change. At the same time it has the lowest adaptive capacity worldwide because of developmental challenges (Magrath, 2006, Stern, 2006, Boko et al., 2007, Collier et al., 2008, Eriksen et al., 2008). Higher temperatures and changes in rainfall patterns and intensity are expected to have impacts on crop production through higher pest and disease pressure, drought as well as floods, and increased water erosion (Rosenzweig et al., 2001, Fields, 2005, FAO, 2005, Orindi and Murray, 2005, Simms et al. 2005, Nyong and Niang-Diop, 2006, Easterling et al. 2007, Boko et al. 2007, Lobell et al. 2008, Battisti and Naylor, 2009, Burke et al., 2009, Gregory et al., 2009, Mertz et al., 2009; Smith et al., 2009, Thornton et al. 2009). Temperature increases due to climate variability that are already being monitored are expected to have serious impacts on crop yields as they are an important factor for production variations (Lobell and Burke, 2008, Battisti and Naylor, 2009). Many areas in Africa are predicted to receive less rain but others such as parts of East Africa could receive more, which is expected to fall at higher intensities (Boko et al., 2007). Some studies also predict decreasing rainfall for East Africa (Funk et al., 2008) Climate change is expected to have serious negative impacts on food security for large populations in Africa through reduced yields and also on the economy of many States that are largely dependent on agriculture (Warren et al, 2006. FAO, 2007; Lobell et al., 2008; Brown and Funk, 2008). Owing to the high dependency of African cropping systems on rainfall and the low capacity for adaptation, the impact of increased climate stresses is expected to be higher than on other continents (Challinor et al., 2007, Funk et al., 2008). Jones and Thornton (2003) predicted yield losses of 10-20% in many areas of Africa by 2050 as a result of increasing temperatures and declining rainfall.

Materials and Methods

The climate data used were obtained from CIAT and are described in Ramirez and Jarvis (2008). The data represent an estimated average of the time span yet to come. Monthly data outputs on rainfall and temperature from 18 SRES models for the emission scenario A2 were utilized. Emission scenarios each represent a possible future with differences in social, political, environmental and technological developments in global societies. The A2 scenario is commonly referred to as “business as usual” with no reduction in carbon emissions and is considered to be a medium-high scenario. It is defined by high global population estimates, no efforts to reduce global warming, high energy use, and a more regional approach to solving social and environmental issues (Nakicenvoic et al., 2000) Models used were: BCCR-BCM 2.0, CCCMA-CGM2, CCCMA-CGCM3.1 T47, CCCMA-CGCM3.1 T63, CNRM-CM3, IAP-FGOALS-1.0G, GISS-AOM, GFDL-CM2.1, GFDL-CM2.0, CSIRO-MK3.0, IPSL-CM4, MIROC 3.2-HIRES, MIROC 3.2-MEDRES, MIUB-ECHO-G, MPI-ECHAM5, MIUB-ECHO-G, MPI-ECHAM5, MRI-CGCM2.3.2A.,NCAR-PCM1,UKMO-HADCM3. The data was downscaled to 2.5 min (ca 5 km) resolution using an empirical statistical approach. For this, linear or other relationships are established between historical observed climate data at local scales such as meteorological station measurements and climate model outputs. ArcGIS software (Ormsby et al., 2009) was used to calculate averages and standard deviations of model outputs for all 18 models. Thresholds of climatic parameters for the suitability calculations for *D. rotundata* Poir., commonly known as white yam, were extracted from FAO's Ecocrop database (FAO, 2011) that is included in the DIVA Gis (Hijmans et al. 2005) software utilized. Ecocrop uses monthly rainfall and temperature values to calculate the suitability of a given location for the crops in the Ecocrop data base. The outputs for all 18 models were averaged and the average used for area change calculations comparing the period 1951-2000 with the predictions for 2040-2069. The environmental parameters utilized in DIVA GIS for *D. rotundata* Poir. were used as shown in Table 1.

Changes in rainfall amount were mapped comparing the worldclim 1.4 dataset (Hijmans et al, 2005b) for average annual rainfall covering the period 1951-2000 to the datasets provided by Ramirez and Jarvis (2008) as mentioned above. Both were available at a resolution of 2.5 minutes.

Results

Changes in suitability. The suitability changes as calculated with DIVA-GIS showed that the areas with "Excellent" suitability for growing white yam are predicted to increase by 10% for the 2050 period (see Table 2). This change brought about by predicted increases in rainfall amounts in the North as well as rising temperatures in the mid-altitude and highland areas in the East. Areas classified as "Very Suitable", "Suitable" and "Marginal" changed only slightly with 3, 1 and 8% reductions compared with the climate averages from 1951 to 2000. The "Very Marginal" category showed the highest area increase as it went up by 175% from 37,000 km^2 to over 65,000 km^2 for the 2050 period compared with current long-term averages. This additional area gain came mainly from the previously "Unsuitable" areas because of the increases in rainfall in the northern parts of the country. By 2050 the "Unsuitable" areas are predicted to be reduced by 72%. Standard deviations of the rainfall means of the 18 models calculated were up to 37% for some areas.

Predicted temperature and rainfall changes. Analyzing the predicted annual temperature changes averaged from the outputs of the 18 GCMs to State areas in Nigeria showed that all States are going to face increased temperatures (see Table 3). The range of average increased temperatures for States varied between 2.0 and 2.9°C, the lowest being Bayelsa and Rivers and the highest being Borno, Jigawa, Kano, Katsina and Yobe. Generally predicted increases in the northern parts of the country were higher than in the coastal areas. Standard deviations between the 18 models averaged for the predicted temperatures varied between 0.01 and 0.11°C.

Average annual rainfall amounts for most States increased slightly when predicted future rainfall amounts as an average of 18 GCM models for 2040-2069 were compared with the average historic rainfall from 1951 to 2000 (see Table 4). The range of differences expressed in mm was from +90 to 2mm. Standard deviations calculated for the States, however, were high in comparison and indicated considerable variation among some of the model outputs.

Figure 2 shows the predicted rainfall changes for the 18 models utilized for the whole country compared with the current long-term average (1951-2000) shown in Figure 1. Most areas of the country (see Fig 3.) except the coastal areas of the south west including the Niger Delta would experience slight increases, between 1 and 10%, according to the predictions of the 18 models.

Table 1. Ecocrop parameters used for the suitability calculations with Diva

Parameter	Definition	Values
Gmin	Minimum length of growing season (days)	180
Gmax	Maximum length (days)	300
KTMP	Absolute temperature that will kill the plant (°C)	9
TMIN	Minimum average temperature at which the plant will grow (°C)	15
TOPMN	Minimum average temperature at which the plant will grow optimally (°C)	25
TOPMX	Maximum average temperature at which the plant will grow optimally (°C)	35
TMAX	Maximum average temperature at which the plant will cease to grow (°C)	38
Rmin	Minimum rainfall (mm) during the growing season	800
Ropmin	Optimal minimum rainfall (mm) during the growing season	1,000
Ropmax	Optimal maximum rainfall (mm) during the growing season	1,500
Rmax	Maximum rainfall (mm) during the growing season	3,000

Table 2.) Predicted suitability area changes for white yam in Nigeria.

Class	Current (km^2)	2050 (km^2)	% change
Unsuitable	226,768	162,160	72
Very Marginal	37,477	65,527	175
Marginal	48,830	45,024	92
Suitable	66,596	65,912	99
Very Suitable	90,690	87,804	97
Excellent	452,637	496,571	110

The south western coastal areas would experience a slight decrease of up to -2% but when the generally high annual precipitation in the area is considered this can be of minor importance. A relatively small area in the north east (mainly Kebbi State) would experience increases between 20 and 30% according top the predictions. Standard deviations for this spot, however, are also high with values between 100 and 200 mm. The area of highest differences between the outputs of the 18 models expressed through the standard deviations was in the south west bordering Benin Republic mainly in Oyo State but also the

Table 3.) Predicted temperature changes in Nigeria averaged for Federal states

State	Average Temperature 1951-2000 18 models (°C)	Average temperature 2040-2069 18 models (°C)	Average temperature SDEV 18 models (°C)	Average temperature Difference 18 models (°C)
Abia	26.4	28.5	0.03	2.1
Abuja FCT	26.6	29.1	0.02	2.5
Adamawa	26.2	28.8	0.07	2.6
Akwa Ibom	26.6	28.6	0.02	2.1
Anambra	27.0	29.2	0.02	2.2
Bauchi	25.7	28.4	0.11	2.7
Bayelsa	26.7	28.7	0.02	2.0
Benue	26.8	29.2	0.04	2.4
Borno	26.3	29.0	0.09	2.8
Cross River	26.5	28.7	0.05	2.2
Delta	26.7	28.7	0.03	2.1
Ebonyi	27.4	29.7	0.02	2.2
Edo	26.2	28.4	0.03	2.2
Ekiti	25.0	27.3	0.02	2.3
Enugu	26.3	28.6	0.02	2.2
Gombe	25.7	28.4	0.05	2.7
Imo	26.4	28.5	0.02	2.1
Jigawa	26.8	29.7	0.07	2.8
Kaduna	25.1	27.7	0.10	2.6
Kano	25.9	28.7	0.08	2.8
Katsina	25.9	28.6	0.10	2.8
Kebbi	27.8	30.4	0.11	2.7
Kogi	26.3	28.6	0.03	2.3
Kwara	26.7	29.1	0.05	2.4
Lagos	27.2	29.3	0.01	2.1
Lake Chad*	27.2	30.1	0.02	2.9
Nasarawa	27.0	29.4	0.04	2.5
Niger	27.1	29.6	0.08	2.5
Ogun	27.1	29.3	0.04	2.2
Ondo	26.1	28.3	0.03	2.2
Osun	26.1	28.4	0.03	2.3
Oyo	26.4	28.7	0.04	2.3
Plateau	25.6	28.1	0.04	2.6
Rivers	26.6	28.6	0.02	2.0
Sokoto	28.2	30.9	0.06	2.7
Taraba	26.1	28.6	0.07	2.5
Yobe	26.1	28.9	0.06	2.8
Zamfara	26.6	29.3	0.08	2.7

* Lake Chad refers to Eastern Borno State

Table 4.) Predicted rainfall changes in Nigeria averaged for federal states

State	Average annual Rainfall 1951-2000 18 model, a2a (mm)	Average annual rainfall 2040-2069 18 models, a2a (mm)	SDEV 18 models a2a (mm)	Diff. in (mm)	Diff in (%)
Abia	2,204	2,205	63	1	0.0
Abuja FCT	1,297	1,378	106	81	6.2
Adamawa	1,039	1,091	78	52	5.0
Akwa Ibom	2,722	2,720	70	-2	-0.1
Anambra	1,808	1,827	64	19	1.1
Bauchi	924	980	68	56	6.1
Bayelsa	3,163	3,166	89	2	0.1
Benue	1,477	1,528	81	52	3.5
Borno	608	650	61	42	6.9
Cross River	2,281	2,287	68	6	0.3
Delta	2,492	2,495	74	3	0.1
Ebonyi	1,892	1,911	66	18	1.0
Edo	1,751	1,778	81	26	1.5
Ekiti	1,314	1,369	136	55	4.2
Enugu	1,686	1,712	71	26	1.5
Gombe	882	928	72	45	5.1
Imo	2,172	2,176	63	4	0.2
Jigawa	619	656	49	37	6.0
Kaduna	1,252	1,324	93	73	5.8
Kano	825	869	61	44	5.3
Katsina	755	803	64	48	6.4
Kebbi	873	958	100	85	9.7
Kogi	1,271	1,327	99	57	4.5
Kwara	1,169	1,259	139	90	7.7
Lagos	1,636	1,658	123	22	1.3
Lake Chad	324	367	56	43	13.3
Nasarawa	1,338	1,406	93	67	5.0
Niger	1,156	1,224	102	67	5.8
Ogun	1,372	1,420	172	49	3.6
Ondo	1,640	1,673	109	32	2.0
Osun	1,340	1,402	175	62	4.6
Oyo	1,181	1,269	209	88	7.5
Plateau	1,184	1,244	82	60	5.1
Rivers	2,798	2,800	77	2	0.1
Sokoto	622	678	70	56	9.0
Taraba	1,286	1,335	65	49	3.8
Yobe	534	562	51	27	5.1
Zamfara	861	915	77	54	6.3

* Lake Chad refers to Eastern Borno State

neighbouring areas. Here the standard deviation values reached up to 250 mm. For most parts of the country, the standard deviations were between 50 and 100 mm, while the most homogenous area comparing all 18 models was in the north east stretching from Jigawa through Jobe and Borno States.

Discussion

According to the model outputs, utilized suitable areas for White Yam production would slightly increase in Nigeria when changes in average monthly rainfall and temperatures are considered. Suitabilities for white yam would increase in most areas which would indicate that the growing conditions for the crop would get slightly better and from the average rainfall patterns, no negative impact could be expected.

In the mid-altitude areas of Nigeria, conditions for white yam production would improve due to higher temperatures together with stable or slightly increasing rainfall amounts. In the lower areas these increasing temperatures, however, would increase physiological stress on the plants.

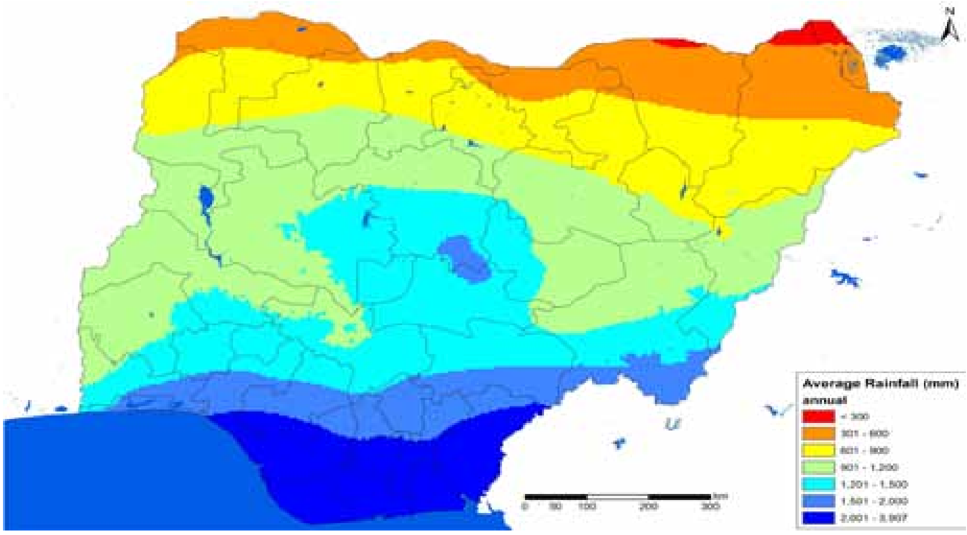

Figure 1. Average annual rainfall (1951-2000)

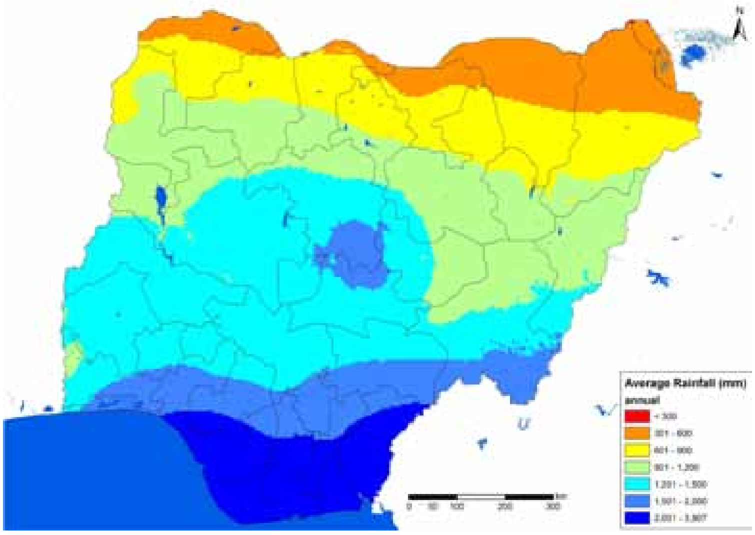

Figure 2. Predicted average annual rainfall (2040-2069) (average of 18 GCM models, a2a scenario)

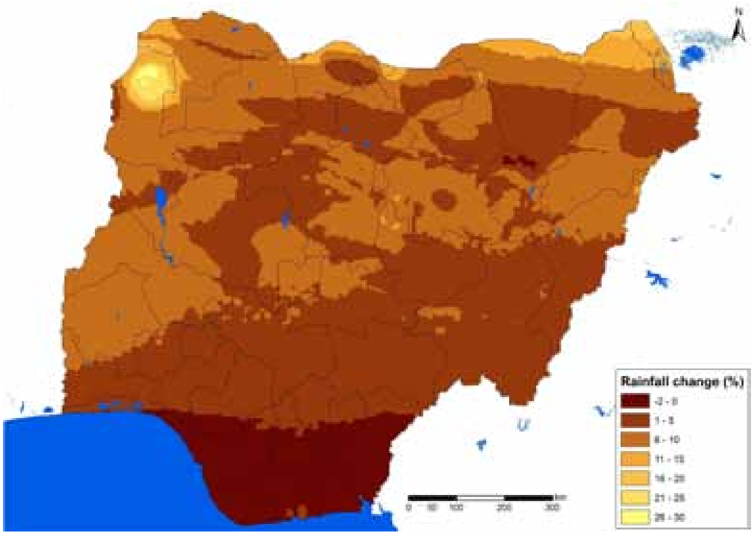

Figure 3. Annual average rainfall change in % period 1951-2000 in comparison with 2040-2069 (average of 18 GCM models, a2a scenario)

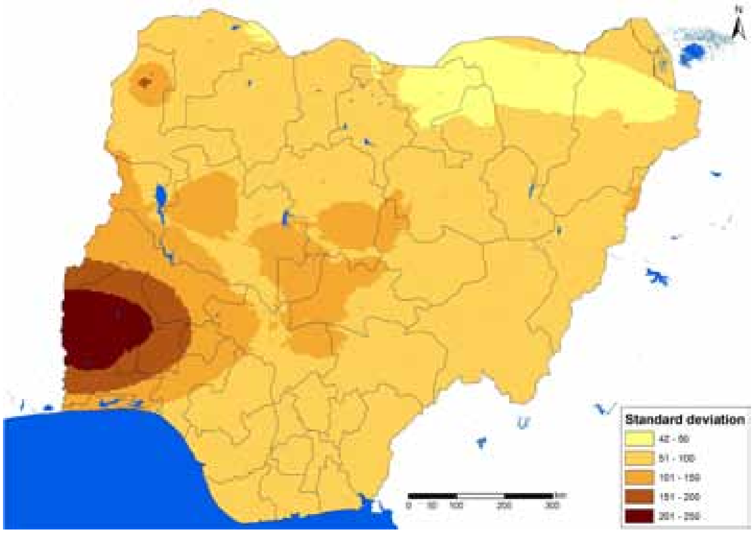

Figure 4. Standard deviations of predicted average annual rainfall (2040-2069) (average of 18 GCM models, a2a scenario)

Additionally the increased concentrations of CO_2 in the atmosphere are expected to have positive effects on crop yields, especially if rainfall is not reduced and temperatures do not rise considerably. In areas of high or mid-latitude, positive effects of rising CO_2 levels are expected to increase yields. (Parry et al., 2004; Parry et al., 2005)

Global climate model outputs vary quite considerably and there are no probabilities attached to any of the models' outputs. The models are validated by using them to predict climate for the past century and if the model outputs describe past climate satisfactorily it is assumed that they would also describe future climate. One way to address these issues is to use a number of models and average them as has been done in this work. In this way, more extreme outputs of drier and wetter models are balanced while standard deviations allow conclusions about how much the model outputs agree.

The model outputs cover only long-term average values and can give no indications about rainfall and temperatures in individual years. According to Boko et al. (2007) it is expected that variability of climate would increase as well as the intensity of precipitation and that growing periods would be reduced.

Conclusions

In order to properly relate impact of changing climate on productivity and yield and the economic and food security implications, a time series of production and yield data and the respective climate data would be needed to derive linear or other relations. For this, ideally on-station yield trials for a number of consecutive years are needed together with meteorological data and the application of identical production parameters. For yam where yield is related to kind and size of planting material utilized, however, this may not fully represent. Alternatively reliable sub-national, e.g., district or LGA level production data for a number of years could be used and related to measured rainfall data for these locations. This would represent an average of production conditions in the field as used by farmers but figures obtained would have to be very reliable. Outputs of crop models could also be utilized if deemed reliable enough to represent reality.

Alternatively crop models could be used in combination with downscaled outputs of CGMs, recent research has utilized EPIC to work on yam (Srivasta, 2010). Further work to integrate yam in common crop modelling packages like DSSAT would be needed.

To get a more complete picture of the uncertainties of climate change predictions, more SRES scenarios outputs should be utilized. It is hoped that a reliable regional climate change model for Africa will be available in the near future as current models work on global scales due to the low density of reliable meteorological stations.

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