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IMPACT OF PROJECTED CLIMATE CHANGE ON AGRICULTURAL PRODUCTION IN SEMI-ARID AREAS OF TANZANIA: A CASE OF SAME DISTRICT

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ABSTRACT

Sub-Saharan Africa is one of the most vulnerable regions in the World to climate change because of widespread poverty and limited adaptive capacity. The future climate change is likely to present an additional challenge to the agricultural sector. Therefore, the effects of climate change on the current agronomic management practices were investigated using Same District, Tanzania as a case study area. APSIM software was used to investigate the response of maize (*Zea mays* L.) yield to different agronomic management practices using current and future (2046 - 2065) climate data. The climate change projections data from global climate models were downscaled using self-organising maps technique. Under the conventional practices, results show that during long rainy season (from March to May) there is yield decline of 13% for cultivar *Situka*, no change for cultivar *Kito* and increase of 10% and 15% for cultivars Sc401 and TMV1, respectively. Under the recommended practices, cultivars TMV1 and Sc401 are projected to register a 10% yield increase whereas cultivars *Situka* and *Kito* are projected to register a decrease of 10% and 45%, respectively. Also, under both conventional and recommended management practices, results showed that during short rainy season (from October to December/January) all cultivars are projected to register between 75% and 146% increase in maize yields. This implies that future climate change is going to have positive effects on current management practices during short rainy seasons and it will have negligible impact during long rainy seasons.

Key Words: Adaptive capacity, APSIM, maize, modeling, *Zea mays*

RÉSUMÉ

L'Afrique subsaharienne est une des régions plus vulnérables au changement climatique au monde suite à la pauvreté généralisée et la capacité d'adaptation limitée. Dans l'avenir, le changement climatique présentera probablement des défis additionnels au secteur agricole. Pour ce faire, les effets du changement climatique sur les pratiques courantes de gestion agronomiques étaient étudiés dans le district de Same en Tanzanie. Le logiciel APSIM était utilisé en exploitant les données climatiques actuelles et futures (2046-2065), afin d'évaluer les effets des différentes pratiques agronomiques de gestion sur le rendement du maïs (*Zea mays* L.). La projection des données de changement climatique à partir des modèles climatiques au niveau planétaire a été réduite à l'échelle à l'aide de la technique d'auto-organisation des cartes. Sous les pratiques conventionnelles, les résultats montrent que durant la longue saison de pluie (du Mars au Mai) il ya eu diminution de 13% du rendement du cultivar *Situka*, augmentation 10% et 15% du rendement des cultivars Sc401 et TMV1, respectivement. Le cultivar *Kito* n'a connu aucun changement de rendement. Sous les pratiques recommandées, les projections montrent que les cultivars TMV1 et Sc401 connaitront une augmentation de 10% de rendement pendant que les cultivars *Situka* et *Kito* enregistreront une baisse de rendement de 10% et 45%, respectivement. Aussi, sous les deux pratiques de gestion conventionnelles et recommandées, les résultats de projections montrent que durant la courte saison de pluie (d'Octobre à Décembre/Janvier) tous les cultivars enregistreront une augmentation de rendements d’entre 75% et 146%. Ceci impliquent des effets positifs du future changement climatique sur les pratiques courantes de gestion durant la courte saison de pluie et un effet négligeable pendant la longue saison pluvieuse.

Mots Clés: Capacité d’adaptation, APSIM, Maïs, modélisation, *Zea mays*

INTRODUCTION

Agriculture in sub-Saharan Africa supports between 70 and 80 percent of employment and contributes an average of 30 percent of Gross Domestic Product (GDP) (Commission for Africa, 2005). Rain-fed agriculture dominates agricultural production in the region covering about 97 percent of total cropland, and exposes agricultural production to the risks of high seasonal rainfall variability (Calzadilla *et al*., 2008). Future climate change may present an additional challenge to agricultural production in the region because it is the most vulnerable to climate change due to widespread poverty, which limits its adaptive capacity.

Same district is located in a semi-arid area with bimodal rainfall regime. Rainfall in the area has high variability with annual precipitation averaging 562 mm, with a standard deviation (std) of 193 mm (Enfors and Gordon, 2007). Attempts to promote adoption of drought resistant crops such as sorghum as a food security measure have met resistance in favour of maize (*Zea mays* L.). This is because maize is the favoured staple food crop. However, seasonal soil moisture deficit due to low rainfall and high potential evapotranspiration are the major constraints to maize production. In coping with these challenges, farmers in the area have developed or adopted various types of soil and water conservation technologies. Some of these technologies include use of water storage structures locally known as *ndiva* and canals for irrigation to supplement direct rainfall. They also include *in-situ* rain water harvesting and conservation technologies such as terraces to reduce runoff and increase infiltration of water, and dry planting in order to capture the first rains (Mbilinyi *et al*., 2005).

Downscaled Global Climate Models which are Coupled General Circulation Model (CGCM), Centre National de Recherches Météorologiques (CNRM), Institut Pierre Simon Laplace des Sciences de l’Environnement Global (IPSL), and European Centre for Medium-Range Weather Forecasts (ECMWF) Hamburg (ECHAM) data for Same meteorological station in Western Pare Lowlands have indicated an increase in rainfall and temperature for the period between 2046 - 2065 (Tumbo *et al*., 2010). The seasonal rainfall amounts have been projected to increase by 56 mm (+23%) during March-April-May (MAM), and 42 mm (+26%) during October-November-December (OND) seasons. The atmospheric air temperature is projected to increase by about 2 °C for both seasons (Tumbo *et al*., 2010). Furthermore, it is reported that during MAM, there will be a 2-day decrease in dry spells, and 8 day increase in seasonal length; while for OND, there will be 2-day decrease in dry spells, and 40 day increase in the seasonal length. It is worthwhile to investigate types of impact on agricultural production due to the projected changes, and also identify better agronomic management practices that will take advantage of the opportunities.

The objectives of this study were (i) to predict yield of selected maize cultivars under different agronomic management practices for the 1958-2006 (base) and 2046-2065 (future) periods; and (ii) recommend the most promising agronomic management practices to adapt to climate change.

MATERIALS AND METHODS

Study location. The study was conducted in Same District in the mid and lowlands of the Western Pare Mountains of Tanzania, from March 2005 to June 2009. Figure 1 shows typical seasonal rainfall amounts and events observed between 1958 and 2006. Long rainy season (LRS) starts from March to May and receives about 250 mm of rainfall. Short rainy season (SRS) starts from October to December/January and receives about 200 mm of rainfall.

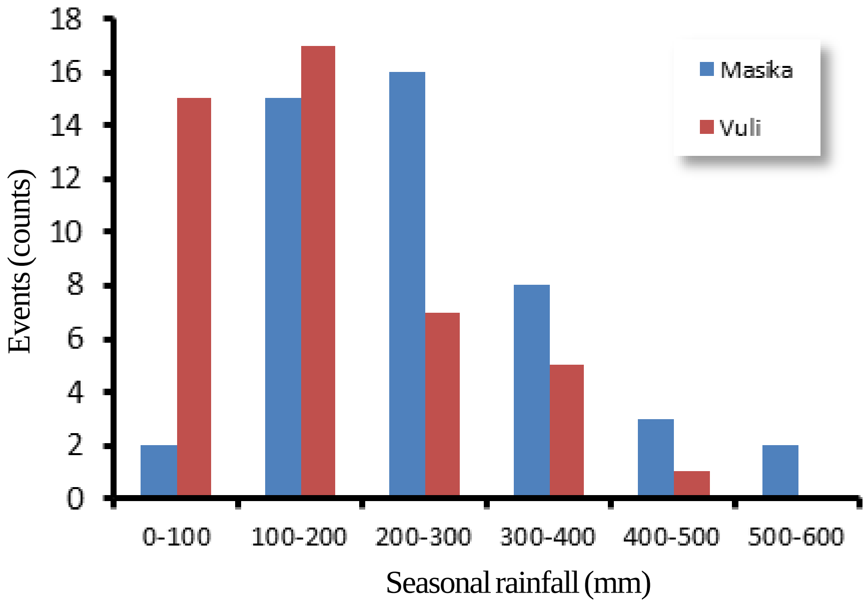


Figure 1. Seasonal rainfall amounts for short rainy season *(Vuli)* and long rainy *season* (*Masika*) between 1958 and 2006 at Same meteorological station.

The APSIM Model. Agricultural Production Systems Simulator (APSIM) is a software tool that enables sub-models to be linked to simulate agricultural systems. The tool has various modules grouped and categorised as Plant, Environment, and Management. Typical parameters are soil characteristics for soil modules, climate measurements for meteorological modules, soil surface characteristics, and surface residue definition. Management is specified using a simple language to define a set of rules, calculations and messages to modules that are used during the simulation. Minimum information required for the meteorological module in the APSIM simulation includes daily rainfall, solar radiation, and maximum and minimum air temperature.

This study used APSIM model because it can handle more modules relevant for simulating current and future climate change in semi-arid areas of Same, Tanzania. The model has been applied in Zimbabwe and Kenya to simulate long-term yields. In Zimbabwe, simulation of 46 years of daily climatic data found that farmers' recommendation of using 17 kg N ha^{-1} on annual basis was more appropriate compared to agricultural extension system recommended rate of 52 kg N ha^{-1}, with exception of very bad years. In Kenya, the study found that climate variability has significant effect on yield especially for rainfall below 200 mm.

Climate data. Historical climatic data (1958-2006) for daily rainfall, and maximum and minimum temperature was obtained from Same meteorological station. Solar radiation data was estimated using Hargreaves-Samani equation (Hargreaves and Samani, 1982).

$$R_s = (KT)(R_a)(TD)^{05} \qquad (1)$$

Where:

TD = maximum daily temperature minus minimum daily temperature (°C);
Ra = extraterrestrial radiation (mm/day); and
KT = empirical coefficient.

The climate data (daily rainfall, and maximum and minimum temperature) representing future scenarios (2046-2065) for Same district were downscaled from four GCMs (CGCM, CNRM, IPSL and ECHAM) using self-organising map (SOM) technique (Tumbo *et al.*, 2010a).

Maize varieties simulation parameters. Maize cultivars used in the simulation were those recommended by the agricultural extension system in the area. The cultivars were *Kito*, *Situka*, TMV1 and Sc403. However, most of the crop simulation models do not include all the crop varieties grown in the sub-Saharan Africa. For example, APSIM model does not contain all four varieties used in the study. Therefore, different techniques and approaches had to be applied to obtain the necessary parameters for simulation purpose. Sc401 was used to represent Sc403 since they have very similar genetic characteristics as they both belong to Seedco 400 series. Simulation parameters for *TMV1* variety were taken from PARCHED-THIRST software, which is an agro-hydrological model for simulating crop yield of mainly maize, sorghum and rice. *Kito* and *Situka* parameters were derived from Tanzania Official Seed Certification Agency (TOSCA) crop variety experimental data and *Katumani* parameters in the APSIM model. *Katumani* is an early maturing maize variety, just like *Situka* and *Kito,* grown in semi-arid areas of Kenya and in some semi-arid areas of Tanzania. Table 1 summarises data from TOSCA crop variety experiments which was used to derive simulation parameters for *Kito* and *Situka*.

Units from TOSCA experimental data, required for calibration purpose, are given in days while those from APSIM are given in thermal time. Thermal time is defined as the time scale in which the development rate of organisms is constant (Campbell and Norman, 1998). Therefore, TOSCA units were converted to thermal time equivalent by directly relating the stage description in days (Table 1) to thermal time equivalent (Table 2) using *Katumani* variety since it is available in both TOSCA database and APSIM model.

Soil and water parameters. Summary of important information on soil and water parameters used for calibration, validation, and long-term simulation are given in Tables 3 and 4. Table 3 shows soil depth, soil texture, organic matter, NH_4-N, and NO_3-N. Table 4 shows soil and water parameters (bulk density, saturation, dry upper limit (DUL), and lower limit at 15bar (LL

TABLE 1. Maize varieties used in the study and their characteristics

Stage description	Maize variety				
	sc403	*TMV1*	*Situka*	*Kito*	Katumani
Days to tasseling	Very early	50 - 65	-	40 - 45	36 - 43
Days to 50% tasseling	Early	55 - 70	45 - 55	45 - 47	40 - 52
Days to Silk emergence	Very early	60 - 75	-	45 - 52	40 - 50
50% silk emergence	-	65 - 80	78	52 - 56	44 - 56
Days to maturity	-	110 - 115	100 -110	90	90
Yield (t ha^{-1})	-	4.0 - 4.5	4.0 - 6.0	2.0 - 3.0	3.0 - 3.5

Source: MAFSC, 2009

TABLE 2. Actual and estimated cultivar thermal times for APSIM simulation software

Stage description	In APSIM 6.1		Estimated		
	Katumani	*Sc401*	*TMV1**	*Kito*	*Situka*
Emergence to end of juvenile	150	230	250	150	160
Flowering to maturity	660	730	700	620	800
Flowering to start of grain	120	170	170	140	170

*Parameters based on PARCHED-THIRST agro-hydrological software

TABLE 3. Soil profile horizon for APSIM model calibration

Horizon	Depth (cm)	Texture	Nutrient (mg kg^{-1})		
			NH_4-N	NO_3-N	OM (%)
1A	0 – 30	Loam	4.31	5.72	1.3
2A	30 – 48	Sandy clay loam	3.15	5.50	0.9
B	48 – 100+	Clay loam	-	-	-

TABLE 4. Soil and water parameters for the APSIM software

Depth (cm)	Bulk density (g cm^{-1})	Saturation (m m^{-1})	DUL (m m^{-1})	LL15 (m m^{-1})	LL-Maize (m m^{-1})
0 – 15	1.38	0.24	0.22	0.11	0.13
15 – 30	1.40	0.24	0.22	0.11	0.13
30 – 60	1.40	0.24	0.22	0.11	0.15
60 – 90	1.41	0.23	0.21	0.12	0.15
90 – 120	1.41	0.23	0.21	0.12	0.17
120 – 150	1.41	0.23	0.21	0.12	0.17

TABLE 5. Observed average yields (kg ha^{-1}) of *Kito* maize cultivar for 2005 to 2006

Statistics	LRS 05	SRS 05	LRS 06	SRS 06
Mean	233	0	2,501	1,764
Standard deviation	247	0	688	842
Maximum	543	0	3,161	2,702
Minimum	0	0	1,392	855

LRS = long rainy season, SRS = short rainy season

15) as obtained from experimental results. Also included is lower limit for maize as given in the APSIM model software. Nutrients from soil analysis such as P, K and Mg were also added in the model.

Calibration of the Model. Kito cultivar was used for calibrating the APSIM model. This variety was planted in five different short and long rainy seasons between 2005 and 2006. The planting and replanting dates for short rainy seasons varied between October 2nd and November 12th whereas for long rainy seasons they varied between February 15th and April 4th. Table 5 presents average yields obtained from the experiment.

For calibration and yield estimation, planting dates for the simulation model were based on planting, germination and replanting dates, observed during field experimentation. The obtained simulated yields based on the three planting dates for each season averaged to get estimated yields.

Model simulation. In order to compare the impact of climate change on maize production, future period in this case 2046-2065 had to be compared with base period, which in this case was 1958-2006. The calibrated model was then used to simulate maize yields of different varieties on three different agronomic management strategies for the periods 1958-2006 (base period) and 2046-

2065 (future period). The three management options were conventional practice, conservation practice, and recommended practice. In conventional practice, no manure or fertiliser was applied. In the conservation practice, the amount of manure applied was 5 t ha^{-1} whereas in the recommended practice, the applied mineral fertiliser was 54 kg ha^{-1} of urea-N at planting and 66 kg ha^{-1} of NH_4NO_3-N as top dressing 35 days after planting.

The planting period in APSIM software were kept flexible between 1st October and 15th November for short rainy season and between 15th February and 25th March for long rainy season. These periods are the normal planting periods for short and long rainy season in Same District. Due to variable and unreliable season starting dates, farmers will normally plant as soon as rains fall within those periods. In case rains start late, farmers apply dry planting. In the APSIM model, planting was done automatically after the model detected that at least 15 mm of rainfall was received and the amount of soil water was 20 mm accumulated within 5 days. However, if within those planting periods conditions were not met, planting was forced at the end of the window.

Soil water was set at 10% of field capacity to ensure that no autocorrelation (dependency between successive terms in the time series) occurred due to carryover of unused soil water. Hence, any remaining autocorrelations achieved are a consequence of the historical climate data.

Yield analysis. Yield frequency plots of each maize cultivar for the base period (1958-2006) and future period (2045-2065) were developed. Also, tabular comparisons of yields between cultivars and between base and future period were made based on conventional and recommended practices. This enabled easy visualisation of trends and effects on climate change scenarios, varietal and resilient attributes of recommended agronomic practices.

RESULTS AND DISCUSSION

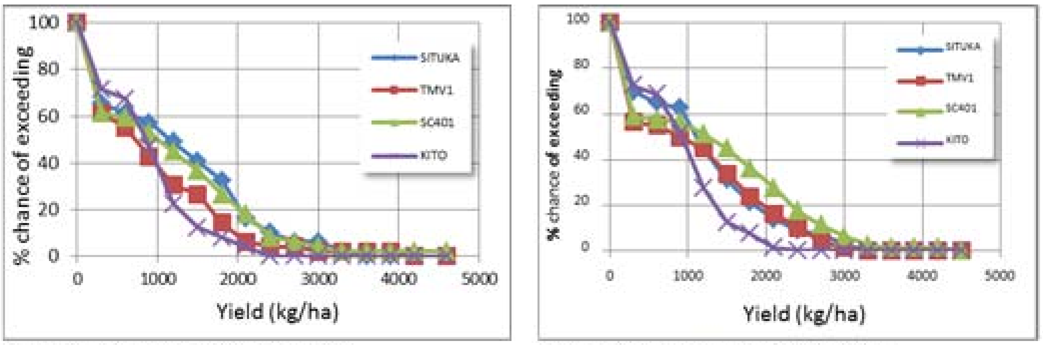
Model calibration. Calibration of APSIM software for yield simulation was challenging because the non-labile organic matter factor, which is one of the system parameters, had significant effect on yield and it had to be adjusted. Values of non-labile organic matter at 0 – 15 cm, 15 – 30 cm, 30 – 60 cm, 60 – 90 cm, 90 – 120 cm, and 120 – 150 cm depth, that provided simulated yields comparable to observed yields, were 0.65, 0.75, 0.90, 0.75, 0.55, and 0.45, respectively. Table 6 shows simulated and observed yields of *kito* maize cultivar. Observed yields have higher standard deviation compared to simulated yields. Also, the simulation under-predicted yields on a good rainfall season and over-predicted on a bad season. Overall, comparison between observed and simulated yields using two-sample t-test for unpaired data showed that the mean values were not statistically different ($P< 0.05$) as indicated in Table 6.

Climate change impact in the long rainy season. Results generally indicate that under conventional practices the change in climate will positively affect Sc401 and TMV1 maize varieties and negatively affect cultivar *Situka*. Figures 2 (a-d) show simulation results of maize varieties based on conventional and recommended practices for

TABLE 6. Observed and simulated yields between 2005 and 2007

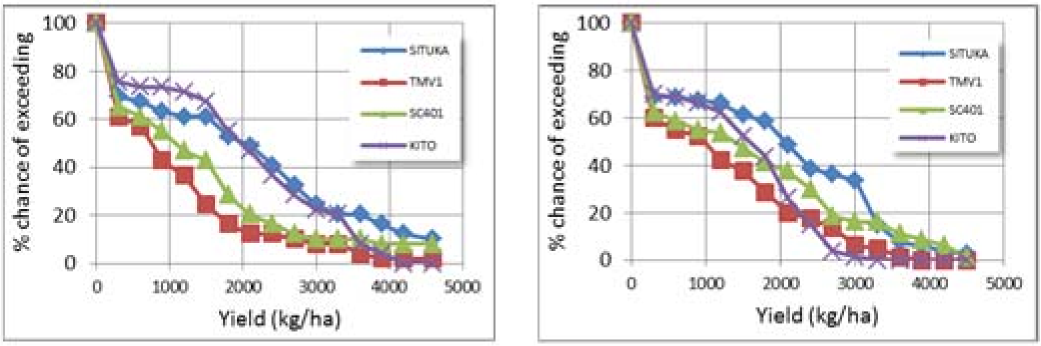
Season	Rainfall (mm)	Observed yields (kg ha^{-1})		Simulated yields (kg ha^{-1})		Two sample t-test for unpaired data**
		Mean	Std	Mean	Std	
LRS 2005	165	233	247	417	723	NS
SRS 2005	95	0	0	96	167	NS
LRS 2006	326	2501	688	2433	130	NS
SRS 2006	549	1764	842	1646	141	NS

LRS – long rainy season, SRS – short rainy season, std - standard deviation, NS - not significant ($P<0.05$)



2(a) conventional practice, 1958-2006

2(b) conventional practice, 2046-2065



2(c) recommended practice, 1958-2006

2(d) recommended practice, 2046-2065

Figure 2. Probability of exceeding a particular maize production threshold for conventional and recommended practices for base period (1958-2006) and future period (2046-2065) during long rainy season (March-May) season.

the 1958-2006 (base period) and 2046-2065 (future period). Figures 2a and 2b show that under conventional practice, the percent chance of exceeding 1 t ha^{-1} is about 50% or higher for all varieties for the period 2046-2065. However, only two varieties (Sc401 and *Situka*) had a chance of exceeding 1 t ha^{-1} in the base period. Given the fact that many farmers in SSA, including Same District, are mostly applying conventional practices, this implies that their current practices are not threatened by the projected change in climate. Essentially, farmers are assured of more options of maize cultivars because their chance of exceeding 1 t ha^{-1} is above 50%.

The probability of exceeding 2 t ha^{-1} for TMV1 increased from 10% in the base period to 20% in the future period (Figs. 2a and 2b). Similarly, maize yields for Sc401 are projected to increase its probability of exceeding 2 t ha^{-1} from 20% for the base period to around 30% for the future period. *Kito* variety seems not to be affected in either way by the climate change since its probability of exceeding 2 t ha^{-1} is almost zero in both periods. *Situka* seems to be negatively affected by the change in climate, especially with respect to the probability of exceeding 2 t ha^{-1} in which the probability decreased from 20% in the base period to slightly below the 20%. This implies that the variety of choice in the future for risk taker type farmers will likely be Sc401 as there is 30% chance of obtaining or exceeding 2 t ha^{-1}. However, for farmers who are risk averse they will likely stick with *Situka* cultivar as it guarantee them with some yields even in a very poor season. The probability of exceeding maize yields beyond 3 t ha^{-1} seems to be similar for the base and future periods, which is about zero.

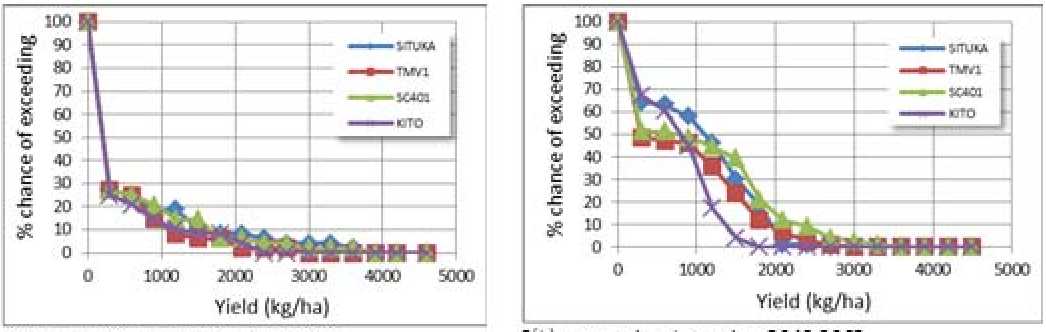
Under recommended practices, the probability of exceeding 1 t ha^{-1} decreases from 70% to slightly below that value for the cultivar *Kito* whereas for cultivars *Situka* and *TMV1* the probability increases from around 60 to 68% and from 40 to 50%, respectively (Figs. 2c and 2d). However, the probability of exceeding the same yield level seems to remain the same for Sc401. Generally, in the base period recommended practice shows higher probability of exceeding a certain yield level compared with conventional practice. However, most farmers go for conventional practice because of risk averse attitude and low capital to invest in agricultural inputs. Also, the difference of chance of yield exceeding a certain threshold between the two practices is less than 10% for *Situka* cultivar (Figs. 2a and 2c). It was noted through interviews with key informants that majority of farmers prefer to plant *Situka* cultivar over other maize varieties. The yield of *Kito* variety is highly affected by climate change as its percentage probabilities of exceeding 2 and 3 t ha^{-1} drops from 50 to 30% and from 20% to almost 0%, respectively. On the contrary, the probabilities of exceeding 2 t ha^{-1} for the two varieties, TMV1 and Sc401, seems to increase, compared to base period, from 10 to 20% for TMV1 and from 20 to 40% for Sc401. Cultivar *Situka,* whose probability of exceeding 2 t ha^{-1} remained the same, its probability of exceeding 3 t ha^{-1} increased from 20% for the base period to slightly above 30% for the future period. Yields beyond 3 t ha^{-1} are negatively affected as the probabilities of exceeding that value seem to decrease or stagnate for the other three cultivars.

In general, TMV1 is projected to slightly gain in yield responding to future climate under both conventional and recommended practices. Sc401 cultivar is projected to fair well under conventional practices but poorly under the recommended practices, which is contrary to *Situka,* which its yield is projected to slightly decrease under conventional practices and increase under recommended practices. Therefore, this analysis has indicated that for the long rainy season farmers may not need to significantly change their maize varieties of choice. *Situka* and Sc401 varieties stand a greater chance to adapt to climate change at least by 2050, where temperature is projected to increase by 2^{o}C and rainfall to increase by 56 mm (Tumbo *et al*., 2010) during the long rainy season. This does not take into account the yield increase that might be brought by carbon fertilisation.

Climate change impact in the short rainy season. Figures 3a-d show the probability of exceeding a particular yield threshold during short rainy season for the base and future periods. Figure 3 (b and d) indicates that for the future period the probability of exceeding a particular threshold is likely to improve with the climate change. For example, under conventional practice, the probability of exceeding 1 t ha^{-1}for all maize varieties is between 10-20%; whereas for the future period this will increase to between 40-60%. Cultivar *Situka* stands to benefit more from climate change compared to other cultivars. However, the benefits of climate change seem to significantly diminish beyond 1 t ha^{-1}. This is indicated by the probability of exceeding 2 t ha^{-1} which has dropped to between 10-15% for TMV1, *Situka,* and Sc401, and zero for *Kito*. Therefore, the yield gain in the future period is only expected just below 2 t ha^{-1} for almost all four maize varieties. Also, the probability of yield gain at 1 t ha^{-1} is quite significant in the short rainy season compared to that expected in the long rainy season under conventional practice. Since the District of Same is in the bimodal rainfall zone, the increased yield probability in the future period implies a reduced risk of failure to farmers.

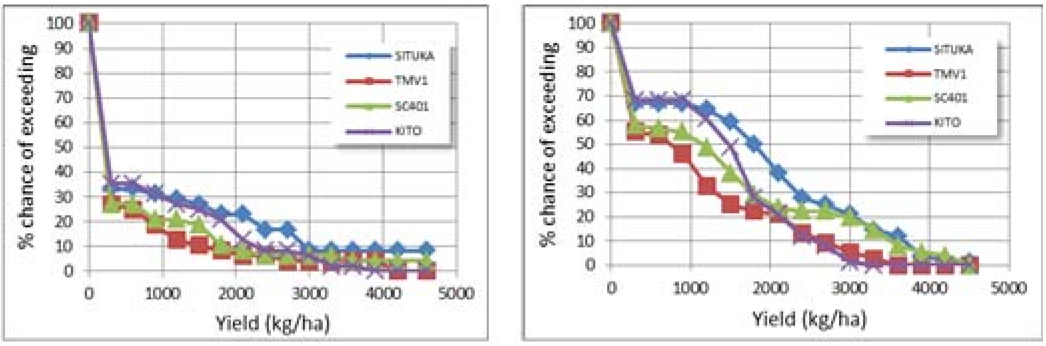
Under recommended practices (Fig. 3c and 3d) there is, again, a projected increase in the probability of exceeding 1 t ha^{-1} from between 20% and 30% under the base period to between 45% and 67% under the future period. Similarly, at 2 t ha^{-1} the probability of exceeding that yield threshold has doubled following an increase from between 10 and 20% to 20 and 40%. Also, there is an increase in the percent chance of exceeding a 3 t ha^{-1} yield threshold from 10% to 20% for *Situka* and Sc401. Similar to results obtained in the long rainy season, the same two varieties *Situka* and Sc401 showed improved performance in the future period based on the projected climate change in the short rainy season.

Mean yield comparison for the long rainy seasons. Under conventional practices and during long rainy season, GCMs predict a 13% decline in future maize yield for cultivar *Situka* (Table 7). Cultivars Sc401 and TMV1 are predicted to register 10 and 15% increase, respectively, in future yield compared to the current values. There will be no change for maize cultivar *Kito*. Under the recommended practices, *Kito* is projected to



3(a) conventional practice, 1958-2006

3(b) conventional practice, 2046-2065



3(c) recommended practice, 1958-2006

3(d) recommended practice, 2046-2065

Figure 3. Probability of exceeding a particular maize production threshold for conventional and recommended practices for base period (1958-2006) and future period (2046 - 2065) during short rainy season (October - December).

TABLE 7. Model predicted average maize variety yields (kg ha^{-1}) for conventional and recommended practices for long rainy season in Tanzania

GCMs & averages	Conventional				Recommended			
	Situka	TMV1	Sc401	*Kito*	*Situka*	TMV1	Sc401	*Kito*
CGCM	768	537	802	526	1299	601	863	929
CRNM	1063	916	1214	670	1960	1039	1436	1397
IPSL	874	997	1183	609	1817	1231	1657	1189
ECHAM	696	694	834	563	1481	775	1119	998
Future average	850	786	1008	592	1639	911	1269	1128
Base average	957	671	913	593	1806	815	1142	1632
% Change	-12.5	+14.7	+9.5	-0.1	-10.2	+10.6	+10.0	-44.7

Situka, TMV1, Sc401 and *Kito* are maize cultivars

register about 45% decline in yield compared to base period (Table 7). A decline in future yield of 10% is projected for cultivar *Situka* during long rainy season. The increase in future grain yield for cultivar TMV1 and SC401 is predicted at about 10% on the current values. All the same, the yield under recommended practices will still be much higher than base or future yield under conventional practices.

Mean yield comparison for the short rainy seasons. Under conventional practices, all

TABLE 8. Model predicted average maize variety yields (kg ha^{-1}) for conventional and recommended practices for short rainy season in Tanzania

GCMs	Conventional				Recommended			
	Situka	TMV1	Sc401	*Kito*	*Situka*	TMV1	Sc401	*Kito*
CGCM	757	622	761	449	1274	715	960	923
CRNM	647	523	678	455	1796	874	1310	1290
IPSL	855	688	921	539	1611	943	1297	1108
ECHAM	784	595	876	522	1192	597	991	930
Future average	761	607	809	491	1468	782	1140	1063
Base average	374	246	342	235	829	365	506	606
% change	+103.2	+146.8	+136.3	+109.0	+77.1	+114.4	+125.3	+75.4

Situka, TMV1, Sc401 and *Kito* are maize cultivars

cultivars are projected to register more than 100% increase in maize yield in the future during short rainy season, except for *situka* and *kito*, which will register about 75% (Table 8). TMV1 and Sc401 are predicted to have increase in yields of 147 and 136%, respectively, compared to base values, thus outperforming *Situka* and *Kito* (Table 8). By using improved practices, all cultivars are predicted to have yield of greater than 75% on the present levels. What is emerging is the fact that future short rainy seasons will be much better than the current situation in relation to maize production.

CONCLUSION AND RECOMMENDATIONS

This study has demonstrated that site-specific studies might provide more insight on the impact of climate change. Using UK89 GCM model Mwandosya *et al*. (1998) showed that under 2xCO_2 (doubling of greenhouse gases) scenario, which is expected to increase temperature to between 2.5°C and 4°C, maize average yield in Tanzania is expected to decrease by 33%. Interpolating results of the same study for Same District, maize yield is projected to decrease by 40%. However, this study has shown that it is only some varieties that are expected to decrease by 2°C rise in temperature and is only during the long rainy season. Therefore, there is a strong need for more site-specific studies that evaluate several crop varieties grown in the area, several downscaled GCM models, the number of seasons, and agronomic management practiced by farmers in that area. Furthermore, majority of crop varieties including indigenous or local varieties in SSA have yet to be modelled and entered into the major crop simulation software such as APSIM and DSSAT. This somehow limits the ability of climate change impact studies. There is a strong need to parameterise these crops and crop varieties for these and other computer models.

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REFERENCES

APSIM. 2008. APSIM 6.1 Documentation. http://www.apsim.info/Wiki/public/Upload/Versions/v61/Documentation_v61/Documentation/index.html. Accessed 20 September, 2010.

Calzadilla, A., Rehdanz, K. and Toll, R. S. J. 2008. Water scarcity and the impact of improved irrigation management: CGE analysis. Research unit Sustainability and Global Change FNU-160. Hamburg, Germany: Hamburg University and Centre for Marine and Atmospheric Science, Germany.

Campbell, G.S. and Norman, J.M. 1998. An introduction to environmental biophysics. 2nd Edition. Springer, NY.

Commission for Africa. 2005. Our common interest: Report of the Commision for Africa. London:Commission for Africa. http://www.commissionforafrica.org/english/report/introduction.html. Accessed: 22nd September, 2010.

Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B. and Twomlow, S. 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment* 126:24-35.

Enfors, E. and Gordon, L. 2007. Analysing resilience in dryland agro-ecosystems. A case study of the Makanya catchment in Tanzania over the past 50 years. *Land Degradation and Development* 18:680-696.

MAFSC. 2009. Tanzania Variety Catalogue. Ministry of Agriculture, Food Security and Cooperatives. http://www.kilimo.go.tz/publications/publications.htm.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M. 1996. APSIM: A novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural Systems* 50:255-271

Mbilinyi, B.P., Tumbo, S.D., Mahoo, H.F., Senkondo, E.M. and Hatibu, N. 2005. Indigenous knowledge as decision support tool in rainwater harvesting. *Physics and Chemistry of the Earth* 30 (11-16):792-798.

Mwandosya, M.J., Nyenzi, B.S. and Luhanga, M.L. 1998. The assessment of vulnerability and adaptation to climate change impacts in Tanzania. The Centre for Energy, Environment, Science and Technology.

Mzirai, O.B., Rwehumbiza, F.B., Tumbo, S.D. and Hatibu, N. 2003. PARCHED THIRST model: Introduction and How to get Started. In: Regional Workshop on System Databases and Simulation Models as Tools for Soil and Water Management in ECA: Towards Increased Research Efficiency and Impact. Hatibu, N. and Rao, K.P.C. (Eds.). SWMnet Discussion Paper No. 2, 54-56. Nairobi, Kenya, 28 - 30 October.

Tumbo, S.D., Mpeta, E., Tadross, M., Kahimba, F.C., Mbilinyi, B.P. and Mahoo, H.F. 2010. Application of self-organizing maps technique in downscaling GCMs climate change projections for Same, Tanzania. *Journal of Physics and Chemistry of the Earth* 35: 608-617.