Agronomic Management Strategies for Adaptation to the Current Climate Variability: The Case of North-Eastern Tanzania

Siza D. Tumbo[a], Filbert B. Rwehumbiza[b], Frederick C. Kahimba[a]*, Elin Enfors[c], Henry F. Mahoo[a], Boniface P. Mbilinyi[a], Zacharia Mkoga[d], and Ayubu Churi[a]

[a]Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture, P. O. Box 3003 Morogoro, Tanzania
[b]Department of Soil Science, Sokoine University of Agriculture, P. O. Box 3000 Morogoro, Tanzania
[c]Department of Systems Ecology, Stockholm University, Sweden
[d]Uyole Agricultural Research Institute, Uyole, Mbeya, Tanzania
*Email: kahimbafcs@yahoo.com

Abstract

Rainfed agriculture in semi-arid areas of sub-Saharan Africa faces a great challenge due to increasingly high variability and unreliability of rainfall. Two of the effective adaptive responses to reduce the vulnerability to the changing climate are through use of soil and water conservation technologies and employment of improved agronomic practices. A study was conducted to quantify the risk and profitability of agronomic management strategies for maize using long-term climatic data and a crop simulation model. APSIM model was used to perform long-term simulations of different management strategies. Simulated maize grain yield for different cultivars and sets of management strategies were evaluated to establish the associated risks and benefits. Results indicate that planting *Situka* or SC401 during *Masika* season instead of *Kito* or other cultivars, gives a yield of more than 1 ton/ha under conventional methods. Maize yield increases to 2t/ha or even higher with the use of fertilizers and recommended management practices. The cost benefit analysis indicated that income greater than USD 700 per ha could be obtained when recommended practices are applied, with *Situka* and SC401 as the maize varieties planted. Based on the results of the study, it is recommended that farmers should employ improved agronomic management practices only when the seasonal forecast indicates above normal rainfall. The early availability of seasonal rainfall forecast is thus vital. Alternatively, farmers are much safer if they continue to employ their conventional approaches of farming because these have lower risks.

Keywords: APSIM, agronomic management strategies, climate change, rainfall variability

1 Introduction

One of the main challenges that confront farmers in semi-arid areas of sub-Saharan Africa include managing unreliable, highly variable, and insufficient rainfall for their crop and livestock production (BHATT *et al.* 2006; COOPER *et al.* 2008; DOWDING *et al.* 1997). The western lowlands and midlands of the *Pare* Mountains in North-Eastern Tanzania are among areas having semi-arid climatic conditions that are characterized by frequent drought events (SWMRG, 2001; TUMBO *et al.* 2009). Attempts to promote adoption of drought resistant crops such as sorghum as food security measure have been met with resistance in favor of maize. However, seasonal soil-water deficit is a major constraint to maize production due to low rainfall and high potential evapotranspiration. In coping with these challenges, farmers in these areas have developed or adopted various types of soil and water conservation technologies and management strategies. Some of these technologies include use of water storage structures, locally known as *ndiva*, and diversion of canals to supplement direct rainfall, terraces to reduce runoff and increase infiltration of water, and dry planting in order to capture the first rains (MBILINYI *et al.* 2005). Nevertheless, not all farmers have access to these technologies, and for those with access they hardly get the adequate amounts to meet the seasonal crop water requirements. For example, considering farmers living in the uplands and midlands, only 48% of them have terraces in the highlands and 19% in the midlands (BHATT *et al.* 2006). In addition, only 25% and 22% of the farmers have access to water from *Ndivas* in the uplands and midlands, respectively. In the midlands and lowlands only 40% and 20% of the farmers have access to diversion canals, respectively. On the other hand, the use of improved seeds and chemical as well as organic fertilizer, as recommended by agricultural extension system, has also faced resistance. COOPER *et al.* (2008) noted that farmers in sub-Saharan Africa may not use improved inputs because they often over-estimate the frequency of negative impacts of climate variability and under-estimate the positive opportunities. In most cases they usually fail to exploit the positive opportunities of average and better than average seasons. COOPER *et al.* (2008) also noted that rainfall variability, both within and between seasons, affects investment decisions of farmers and other stakeholders. Since the outcomes and returns seem to be so uncertain, most farmers are reluctant to invest.

In a recent study in *Same* District, ENFORS *et al.* (2010) found that there was a clear breakpoint between good and poor yields at around 300 mm seasonal rainfall. With 326 mm, maize yield of about 2 t/ha was obtained without any treatment, while with 244 mm, only 0.5 t/ha was obtained with conventional tillage or ripping without manure or water harvesting. In general, a combination of ripping, application of 5 t/ha of manure, and 100 mm of runoff water improved the yield of *Kito* maize variety from 1 to 2 t/ha with only 300 mm of rainfall (ENFORS & GORDON 2007; ENFORS *et al.* 2010). Similarly, COPPER *et al.* (2008) found that in *Machakos*, a semi-arid area in Kenya, there is a general trend of increasing maize yields as seasonal rainfall totals increase from 100 to 500 mm; but there are also considerable yield variations, particularly in drier seasons with below 200 mm rainfall. The analysis combined field experiments and simulations of 80 years of climatic data. This means that in order to guide farmers and other stakeholders, long term analysis of crop performance that evaluates current agronomic management options is necessary.

Crop simulation models, such as APSIM, DSSAT, PARCHED-THIRST, VEMAP and others (e.g. MAVROMATIS 2001; KOO *et al.* 2007; APSIM 2008; WU *et al.* 2009) are capable of performing long-term simulations of different management strategies in a short period and at very low costs. PROBERT *et al.* (1998) states that “models are the means of extrapolation of knowledge, derived from experimentation, to other situations – other seasons, other soils, and different management practices such as crop sequences, tillage, and residue management”. In this study APSIM model was used because it can handle more modules relevant for simulating long-term yields in semi-arid areas. As reported by COOPER *et al.* (2008), APSIM model has been used to perform long-term yield simulations in Zimbabwe and Kenya. In Zimbabwe, simulation of 46 years of daily climatic data found that farmers’ recommendation of using 17 kg N/ha on annual basis was more appropriate than the recommended rate by agricultural extension system of 52 kg N/ha, with exception of very bad years.

The main objective of this study was to quantify risk and profitability of agronomic management strategies for maize using long-term climatic data and crop simulation models and recommend the most promising strategies to adapt to the current climatic change and variability for the western lowlands and midlands of *Pare* Mountains. Specific objectives of the study were to: (i) simulate yield of different maize varieties based on different sets of agronomic management strategies; (ii) evaluate the risks and benefits of sets of simulated yields and their respective management strategies; and (iii) recommend the most promising strategies based on the current climate variability.

2 Materials and methods

2.1 Study location

The study was carried out in *Same* District, *Kilimanjaro* Region, in the western lowlands and midlands of the *Pare* Mountains, northern Tanzania (Fig. 1(a)). Field data used for calibration of APSIM simulation model was obtained from field experiments conducted between 2005 and 2007 in *Mwembe* ward (Fig. 1(b)), in two villages of *Bangalala* and *Mwembe*. Since climatic information for the area was only from March 2004 to December 2007, climate data from the weather station in *Same* town in *Same* ward located adjacent to *Mwembe* ward (Fig. 1(b)) was used. The rainfall distribution in the study area is bimodal, with two (short and long) rainy seasons. The short rainy season, locally known as *Vuli* starts from October to December (OND) and the long rainy season locally called *Masika* starts from March to May (MAM).

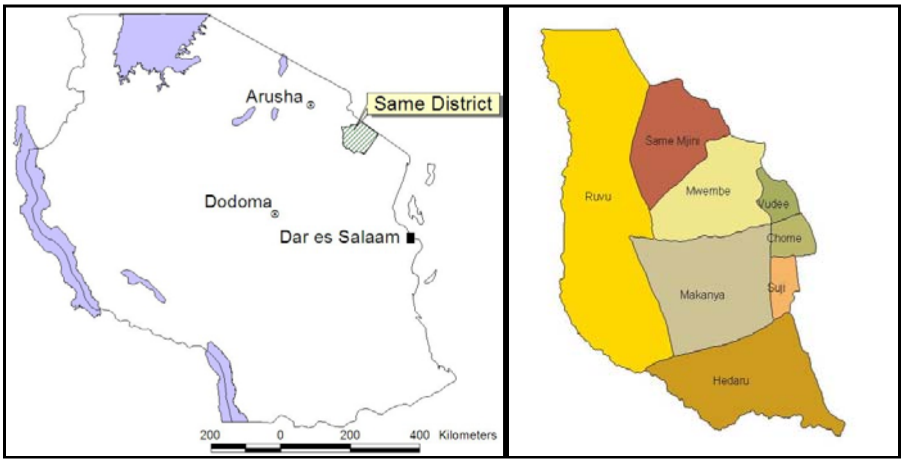


Figure 1: Map of Tanzania showing (a) *Same* District and (b) wards including *Same* and *Mwembe*

Fig. 2 (a) shows comparison of weather data (April 2004 to December 2006) for Bangalala in *Mwembe* ward and *Same* station. From Fig. 2 (a) it is clear that in the year 2005, the amount of rainfall in the two areas was very similar. For year 2006, *Same* received more rains than Bangalala but it was contrary in *Vuli*. The average rainfall from April 2004 to December 2006 (abbreviated as Bangalala-avg and *Same*-avg) shows that the difference is not significant (α= 0.05). Since *Same* station has climatic data from 1958 to 2006 and the weather in the two areas is very similar, its data was used for long-term simulation.

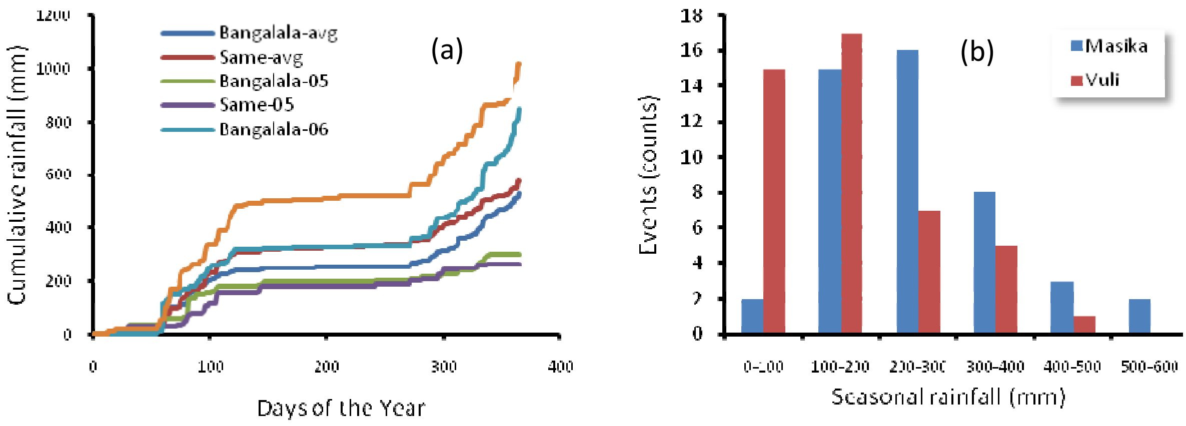


Figure 2: (a) Cumulative rainfall in 2005 and 2006 for Bangalala and *Same* stations, (b) seasonal rainfall events and amounts for *Vuli* and *Masika* between 1958 and 2003 at *Same* station

Fig. 2(b) shows typical seasonal rainfall amounts and events observed between 1958 and 2006. *Masika* is seen to receive more events of rainfall greater than 200 mm whereas *Vuli* receives more events less than 200 mm.

2.2 Data and simulation settings

The APSIM model was calibrated and validated using experiments conducted between 2005 and 2007 in *Bangalala* and *Mwembe* wards. In the experiments, information on climatic data (daily rainfall, maximum and minimum temperature), soil, water, and yield was monitored, collected, and analysed. Climatic data from *Same* weather station was used for long-term simulations. The subsequent subsections describe the details on the collected information.

2.2.1 Climate data

The minimum information required for APSIM simulation includes daily rainfall, maximum and minimum temperature and solar radiation. A weather station that monitored the first three variables was installed in the study area around the experimental plots. However, radiation data was estimated using Hargreaves-Samani equation (HARGREAVES AND SAMANI 1982).

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

where TD = maximum daily temperature minus minimum daily temperature (^{0}C) for weekly or monthly periods; Ra = extraterrestrial radiation (mm/day); and KT = empirical coefficient.

2.2.2 Parameters for maize varieties

The maize variety that was grown in the experimental plots was *Kito,* which is one of the composite cultivars of maize. Other varieties grown in the area include *Situka*, *TMV1,* SC403, which are also composite cultivars of maize, and local varieties (MOSHI 1998). APSIM model contains parameters for *TMV1* and SC401 varieties. However, it does not contain parameters for SC403 and *Situka* varieties. Since characteristics for SC401 and SC403 varieties are similar (MOSHI 1998; MAFSC 2009), *SC401* was used in the APSIM simulation and parameters for *Kito* and *Situka* varieties had to be estimated by using *Katumani* parameters.

Important parameters for simulation that are required by the APSIM software were collected. The most important parameters are (a) grain growth rate (mg/grain/day), (b) thermal time from emergence to end of juvenile, (c) thermal time from end of juvenile to floral initiation, (d) thermal time from flowering to maturity, and (e) thermal time from flowering to start of grain filling (APSIM 2008). The Tanzania Official Seed Certification Agency (TOSCA) certifies all varieties by performing field experimentation and collects a set of basic information to validate information on the variety before its release. Part of the information that is collected and which is relevant for estimating parameters required by APSIM simulation software include (a) tassel emergence, (b) days to 50% tasseling, (c) silk emergence, (d) days to 50% silking, (e) days to maturity, and (f) yield data.

Table 1: Maize varieties characteristics

Item	Stage description	*Katumani*	*TMV1*	sc403	*Kito*	*Situka*

no						
1	Days to tasseling	36 - 43	50 – 65	Very early	40 – 45	-
2	Days to 50% tasseling	40 – 52	55 – 70	Early	45 – 47	45 – 55
3	Days to Silk emergence	40 – 50	60 – 75	Very early	45 – 52	-
4	50% silk emergence	44 – 56	65 – 80	-	52 – 56	78
5	Days to maturity	90	110 – 115	-	90	100 – 110
6	Yield (t/ha)	3.0 – 3.5	4.0 – 4.5	-	2.0 – 3.0	4.0 – 6.0

Source: *(MAFSI, 2009)*

The parameters of *Katumani* and *SC401* maize varieties are already provided in the APSIM software. 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 (MZIRAI *et al.* 2003). Parameters of *Katumani* were used to estimate APSIM parameters for *Kito* and *Situka* varieties (Table 2) by modifying data provided by the Tanzania Seed Certification Agency (TOSCA). *Katumani* variety was developed in *Machakos* in Kenya, an area having climatic condition very similar to the midlands and lowlands of *Same* District. Since the TOSCA crop stage data are given in days while the APSIM parameters are given in thermal time, the thermal time were related directly to days with an assumption that the longer the period of a particular stage in days the longer is the thermal time.

Table 2: APSIM parameters for *Katumani* and SC401 maize varieties and estimated *Kito* and *Situka* parameters for APSIM software

		In APSIM 6.1			Estimated	
Item no	Stage description	*Katumani*	*TMV1**	*SC401*	*Kito*	*Situka*
1	emergence to end of juvenile	150	250	230	150	160
2	flowering to maturity	660	700	730	620	800
3	flowering to start of grain	120	170	170	140	170

*Parameters taken from PARCHED-THIRST agro-hydrological software.

2.2.3 Planting and yield information

Table 3 shows planting, germination and replanting dates for *Kito* maize variety in the experimental plots. The planting and replanting dates for *Vuli* ranged between October 2nd and November 12th whereas for *Masika* it ranged between February 15th and April 4th. For calibration and validation purposes, the three different dates (planting, germination and replanting) were used to simulate yields because it could not be known when replanting was done, how much plants could not germinate and the model does not simulate germination.

Table 3: Initial planting, germination and replanting dates for Kito maize variety

Season	Planting	Germination	Replanting	Seasonal rains (mm)
Masika 2005	1st March	28th March	4th April	165
Vuli 2005	5th October	1st November	12th November	99
Masika 2006	15th February	2nd March	5th March	326
Vuli 2006	2nd October	15th October	22nd October	549
Masika 2007	15th February	10th March	20th March	163

Source: Enfors et al. 2010.

The experiments conducted in *Mwembe* ward were located in various experimental plots with different soil and other biophysical parameters. The outcome of the yields on individual plots is shown in Table 4 with *Vuli* season showing total crop failure in all the plots. One yield in Table 4 (*Vuli* 2006) for the first replication shows a very high yield compared to the rest of the yields. It is considered in this case as an outlier because even the TOSCA variety catalogue shows that *Kito* yields range between 2.0 and 3.0 t/ha. Also, the soil profile for W replication is used for calibration and simulation because its yield results are close to the average yields of the plots.

Table 4: Observed yields for *Kito* maize variety

Replication	*Masika* 05	*Vuli* 05	*Masika* 06	*Vuli* 06	*Masika* 07
I1	223	0	3161	4294*	475
I2	528	0	3142	2702	907
E1	19	0	1392	899	0
E2	543	0	2808	2302	108
E3	0	0	2065	855	0
W	84	0	2441	2064	206
Mean	232.8	0.0	2501.5	1764.5	282.7
Standard deviation	247.2	0.0	687.6	841.8	352.9
Maximum	543	0	3161	2702	907
Minimum	0	0	1392	855	0

*value considered outlier because yield range for *Kito* variety range between 2 – 3 t/ha and therefore was not considered in statistical computation; (Source: Enfors (2010) field experimental results).

2.2.4 Soil and water parameters

Summary of important information on soil and water used for calibration, validation and long-term simulation are given in Tables 5 and 6. Table 5 shows soil depth, soil texture, organic matter, and NH_4-N and NO_3-N. Table 6 shows bulk density, saturation, dry upper limit and lower limit at 15bar as obtained from experimental results. Also, it includes lower limit for maize as given in the APSIM model software. Additional nutrients from soil analysis such as P, K, and Mg were also added in the model.

Table 5: Horizon for plot W used in the APSIM software

Horizon	Depth (cm)	Texture	Nutrient (mg/kg)		OM (%)
			NH_4-N	NO_3-N	
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	-	-	-

Source: refer Irene data

Table 6: Soil and water parameters used in APSIM software

Depth (cm)	Bulk density (g/cc)	Saturation (m/m)	DUL* (m/m)	LL15** (m/m)	LL-Maize*** (m/m)
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

*DUL = dry upper limits;
**LL15 = lower limit at 15kPa;
***LL = lower limit for maize

2.2.5 Calibration, validation and simulation

Three different simulations were performed. The first simulation was performed to calibrate and validate the APSIM model based on experimental yield results of *Kito* maize variety. The second simulation involved long-term simulation from 1958 to 2006 for *Kito* maize variety. The third simulation involved long-term simulation using other maize varieties.

In the first stage, the model was set to simulate yields of conventional practice based on different planting, germination and replanting dates as shown in Table 3. The main challenge was to calibrate the model to provide similar yields as obtained in the experimental results especially setting values for component known as "*finert*", which represent part of the non-labile soil organic matter pool (non-susceptible to decomposition). The second simulation was done to simulate long-term yields of *Kito* using *Same* weather data from 1958 to 2006. The simulation was done using three management options with flexible planting dates but with the *Same* plant conditions. The three management options were conventional; ripping and application of manure; and application of chemical fertilizers. In conventional tillage, no manure or fertilizer was applied. For the ripping and application of manure option the amount of manure applied was 5 t/ha. For the chemical fertilizer option the amount applied was 54 kg/ha of Urea-N at planting and 66 kg/ha of NH_4NO_3-N as top dressing 35 days after planting (DAP).

In the third simulation, additional maize varieties (*Situka*, TMV1 and SC401) (which are the recommended varieties by extension agents and also most used in the area) were simulated. The planting windows for the second and third simulation were kept to be flexible between October 1st and November 15th for *Vuli* season, and February 15th and March 25th for *Masika* season. Planting condition was set such that planting was to be performed when 15 mm of rainfall is received and amount of soil water accumulated within 5 days is 20 mm. However, if within that window conditions are not met, planting was done without considering the conditions.

2.3 Long term yield simulations

The APSIM model was used to study scenarios of the effects of current climate variability (1958 – 2006). The APSIM crop model requires thirty years of continuous daily time series of at least temperature (maximum and minimum) and rainfall.

To quantify the impact of climate variability on maize production at *Same*, variable planting windows of maize were simulated between October 1st and November 15th for *Vuli* and between February 15th and March 25th for *Masika* seasons. Planting condition was set such that planting was to be done when 15 mm of rainfall is received and amount of soil water is 20 mm accumulated within 5 days. However, if within that window conditions are not met, planting was still done.

A soil profile with physical and chemical parameters used in calibration as shown in Tables 5 and 6 was used in the simulations. Soil water was set to 10% of field capacity (FC) at each harvest to ensure that no autocorrelation (dependency between successive terms in the time series) occurred due to carryover of unused soil moisture. Hence, any remaining autocorrelations are a consequence of the historical climate data. The long term simulations were done using conventional and conservation tillage management options as explained in section 2.2.5. Four maize varieties, namely; *Situka, TMV1, SC401, and Kito* were used in the simulations to assess the effect of climate variability on yield of common maize cultivars in *Same* district.

The frequency of plots with yields exceeding 2 t/ha for each maize cultivar for the current (1958 – 2006) climate scenarios were developed. Also tabular comparisons of yields between cultivars were made based on conventional and recommended practices. This enabled easy visualization of trends and effects on the current climate variability scenarios, and varietal and resilient attributes of recommended agronomic practices.

2.4 Social and economic analysis

Standard cost-benefit analysis was performed to evaluate the benefits of different agronomic management options. The analysis was done to replicate the farming reality as much as possible. For example, most farmers in conventional practice use local varieties, which are healthy seeds selected from their farms during harvesting. Since the productivity of the local varieties is not well known, all the composite cultivated varieties were used to provide productivity options that constitute the variability of the local varieties. Also, other costs beyond planting were only considered if at least some yield was obtained assuming that farmers will only apply top dressing fertilizer and pesticides if crops will be established. Costs of inputs were obtained by interviewing key informants (Table 7).

Table 7: Costs for various field operations and inputs

No.	Activity	Unity Quantity	Unity Price (USD)	Total Cost (USD)	Sub-total (USD)
Land preparation	Ox ploughing	1	53.57*	53.57	
Planting	Maize seeds (Kg)	20	2.50**	50.00	
	DAP fertilizer (Bags)	2	71.43	142.86	
	Labor (mandays/ha)	1	8.93	8.93	255.36
Pesticides	Dursban in Litres	2	7.86	15.71	
	Spraying labour	2	1.79	3.57	
Top dressing	Urea (Bags)	2	25.00	50.00	
	Labour (mandays/ha)	2	1.79	3.57	115.71
Weeding	Weeding by hand hoe	1	42.86	42.86	
Harvesting***	Harvesting by hand	1	0.36	0.36	
	Threshing and bagging	1	0.36	0.36	
	Transportation (bags)1	1	0.14	0.14	0.86

Benefits	Price (kg)	1	0.21	0.21

*Slashing only (*kitang'ang'a*) = 8.93 USD/ha; **Local variety estimated at 0.21 USD/kg;

****Cost per 100 kg of maize harvested (1 bag)**

3 Results and discussion

3.1 Calibration and validation

Calibration of the APSIM software for yield simulation was challenging because even with proper input of soil water parameters, variety parameters, and weather data, still the obtained yield predictions were not similar to the observed ones. The main parameter that was noted to affect yield was non-labile organic matter factor at different soil depths as shown in Table 8. As it can be seen, finert values between 0.01 and 0.50 resulted into similar yields. At 0.75, the yield for *Vuli* 2006 dropped significantly while in other seasons the yields were not affected. At 0.90 and 0.99 yields dropped significantly.

Table 8: Non-labile organic matter factors and yield effect

	Finert values and yield (kg/ha)				
Season	0.01	0.50	0.75	0.90	0.99
Masika 2005	1243	1241	1274	112	0
Vuli 2005	0	0	0	0	0
Masika 2006	2561	2520	2464	976	0
Vuli 2006	3009	2958	1212	391	0
Masika 2007	1250	1254	1203	337	0

Further calibration of non-labile organic matter indicated that parameters that provided reasonable yields highly comparable to observed yields were 0.65, 0.75, 0.90, 0.75, 0.55 and 0.45 for 0 – 15 cm, 15 – 30 cm, 30 – 60 cm, 60 – 90 cm, 90 – 120 cm, and 120 – 150 cm, respectively. Simulated yields based on initial planting, germination and replanting together with average simulated yields are provided in Tables 9 and 10. As it can be seen in Table 9, the yields for *Vuli* 2005, *Masika* 2006, *Vuli* 2006 and *Masika* 2007 are very similar for all the three planting dates. For *Masika* 2005, maize planted March 1st gave higher yields than observed (1252 kg/ha vs. 232 kg/ha), however, maize planted on germination date and replanting date both ended with zero yields.

Table 9: Simulated maize yields for different planting dates

Season	Initial Planting		Germination		Re-planting		Average	
	Date	Yield (kg/ha)	Date	Yield (kg/ha)	Date	Yield (kg/ha)	Yield (kg/ha)	std
Masika 2005	01-Mar	1252	28-Mar	0	04-Apr	0	417.3	722.8
Vuli 2005	05-Oct	0	01-Nov	289	12-Nov	0	96.3	166.9
Masika 2006	15-Feb	2313	02-Mar	2415	05-Mar	2571	2433.0	129.9
Vuli 2006	02-Oct	1484	15-Oct	1735	22-Oct	1720	1646.3	140.8
Masika 2007	15-Feb	888	10-Mar	917	20-Mar	1057	954.0	90.4

Table 10 shows observed and simulated yield for plot W1 and initial planting dates and also average observed and simulated yields. The yields based on simulated and observed values were not significantly different ($\alpha = 0.05$). It is only that observed yields have significant variation by looking at the standard deviation while simulated yields tend to under-predict yields on a good rain season and over-predict yield on a bad rain season.

Table 10: Observed and simulated maize yields between 2005 and 2007

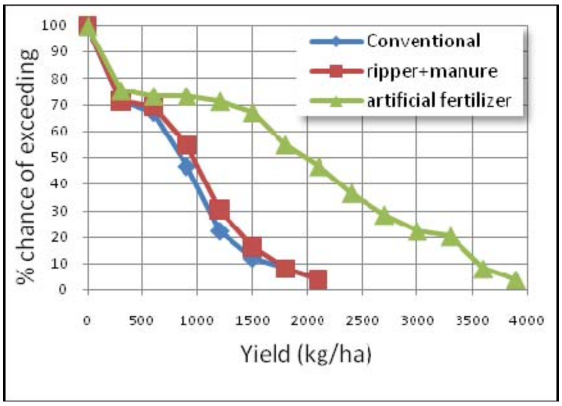
Season	Observed yields			Simulated yields		
	W1 plot (kg/ha)	Average (kg/ha)*	Standard deviation	Initial planting (kg/ha)	Average (kg/ha)**	Standard deviation
Masika 2005	84	233	247	1252	417.3	722.8
Vuli 2005	0	0	0	0	96.3	166.9
Masika 2006	2441	2501	688	2313	2433.0	129.9
Vuli 2006	2064	1764	842	1484	1646.3	140.8
Masika 2007	206	283	353	888	954.0	90.4

*Average yield for all the experimental plots.

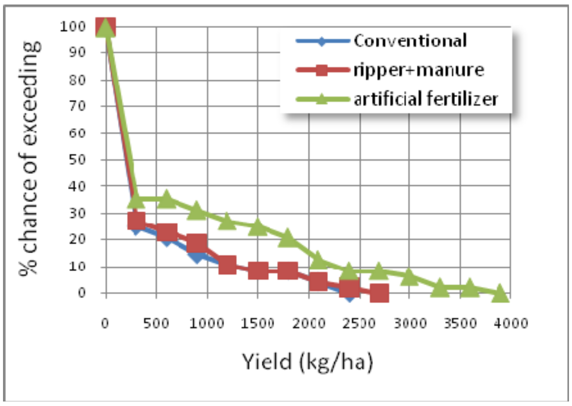
** Average simulated yield of initial planting, germination and re-planting.

3.2 Long term yield simulation of Kito maize variety

Fig. 3 (a and b) shows long term yield simulation (1958 – 2006) using *Kito* maize variety. The option of using ripper and manure application, and that of not using, had the *Same* outcome in *Vuli but not in Masika season*. In *Masika*, the probability of exceeding 1.5 t/ha stands at 70% if chemical fertilizer is used whereas the *Same* yield is obtained with a probability of about 10% and 15% for conventional and using ripper and manure. Fig. 3(a) also shows that there is 50% chance of obtaining yields beyond 2 t/ha with the use of chemical fertilizers. In contrast, there is no real advantage of adopting either of the management strategies in *Vuli* because the outcomes are very similar. In this case, techniques that use minimum inputs, i.e., conventional agriculture, should be given a higher priority



3(a) Probability of exceeding a certain maize yield under conventional tillage, ripper-manure, and artificial fertilizer in *Masika* season

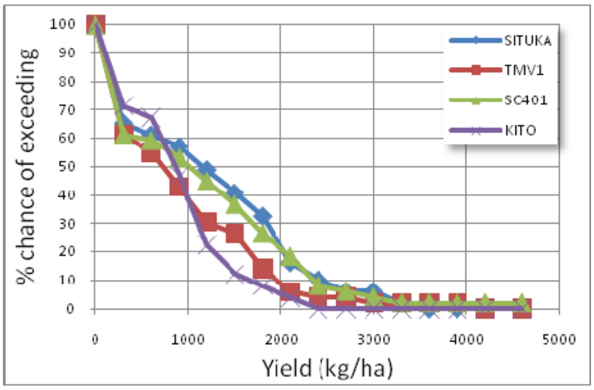


3(b) Probability of exceeding a certain maize yield under conventional tillage, ripper-manure, and artificial fertilizer in *Vuli* season

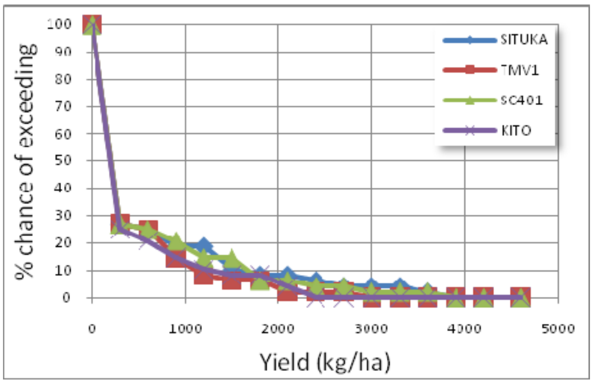
Figure 3: Long-term simulation of maize yields for *Kito* variety under conventional tillage, ripper + manure and artificial fertilizer

3.3 Simulation of other common maize varieties in the area

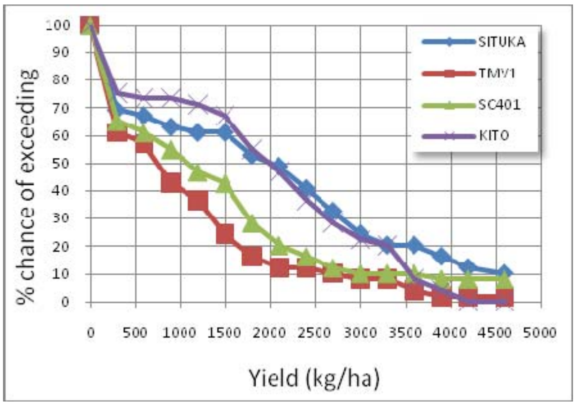
Fig. 4 (a-d) shows simulation results of common maize varieties that are grown in the area. This time, simulation is limited to conventional agriculture and use of chemical fertilizer. *Situka* and SC401 variety performed better in *Masika* with yields of between 1 and 2 t/ha under conventional practices. For *Vuli* (Fig. 4(b) no variety seemed to have a significant advantage over the other.



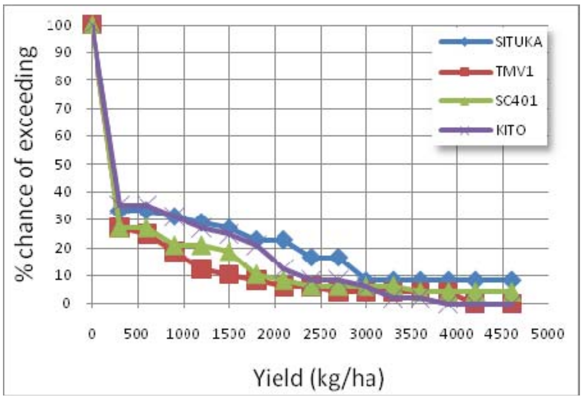
4(a) Probability of exceeding a certain maize yield using *SITUKA*, TMV1, SC401 and *KITO* maize varieties without fertilizer application in *Masika* season



4(b) Probability of exceeding a certain maize yield using *SITUKA*, TMV1, SC401 and *KITO* maize varieties without fertilizer application in *Vuli* season



4(c) Probability of exceeding a certain maize yield using *SITUKA*, TMV1, SC401 and *KITO* maize varieties with fertilizer application in *Masika* season



4(d) Probability of exceeding a certain maize yield using *SITUKA*, TMV1, SC401 and *KITO* maize varieties with fertilizer application in *Vuli* season

Figure 4: Comparison of probability of exceeding a certain maize yield by growing different varieties with and without fertilizer application in both *Vuli* and *Masika* seasons

On the use of artificial fertilizers and other inputs, *Kito* had an upper hand at lower yields (less than 1.5 t/ha) and comparable to *Situka* at yields greater than 1.5 t/ha. At yields greater than 3.5 t/ha, *Situka* was most superior followed by SC401. At low yields, probabilities of exceeding those yields (e.g. 1.5 t/ha) under the use of chemical fertilizer in *Masika* season is very high (at around 70% for *Situka* variety). However, when the cost of chemical fertilizer and other inputs are considered, this advantage may likely not be seen.

3.4 Cost benefit analysis

Table 11 shows benefits of three management practices using four different maize varieties. Maximum benefits (income greater than USD 700 per ha) are obtained when recommended practices are applied, and *Situka* and SC401 are planted. However, the most profitable varieties and strategies are the most risky because the loss can be as high as USD 350 per ha. The most conservative approach is the conventional method, which can yield more benefits compared to conservational tillage and suffer minimum loss in case of a bad season.

Table 11: Income (in USD) from different management practices

Practice	Income	*Situka*	*TMV1*	*SC401*	*Kito*
Conservation tillage + improved seeds	average	-217.14	-208.44	-88.72	-86.66
	maximum	202.00	334.73	568.35	107.84
	minimum	-425.74	-355.57	-249.85	-260.71
recommended practice	average	35.85	-158.52	-96.07	-6.93
	maximum	836.72	493.90	782.35	396.90
	minimum	-348.15	-344.93	-366.67	-340.46
Conventional + local seeds*	average	-2.85	-47.72	18.42	-33.09
	maximum	416.29	495.45	675.50	161.41
	minimum	-211.45	-194.86	-142.71	-207.14

*the seeds used are local seeds, which as an assumption might resemble any of the improved seeds.

Table 12 shows the yield difference between the conventional and recommended practices for normal, below normal, and above normal seasonal rainfalls. If rainfall is above normal it is more appropriate for farmers to plant *Situka* or *Kito* and apply chemical fertilizer and recommended inputs to maximize yields because it will pay. The average income for *Situka* is estimated at greater than USD 350 per ha. However, in a poor (below normal rainfall) or normal season it is better for farmers to employ their conventional practices because that way they suffer minimum loss for a poor season or get some profit if the season is normal by growing SC401, *Kito*, or *Situka*.

Table 12: Income differences between conventional and recommended practices for the normal, below normal, and above normal seasonal rainfalls

Practice	Seasonal rainfall	Income differences for each maize variety			
		Situka	*TMV1*	*SC401*	*Kito*
Conventional practice	Below normal	-66.02	-72.12	-34.18	-27.79
	Normal	85.79	-3.20	89.61	-7.94
	Above normal	-16.82	-44.83	31.06	-71.34
Recommended practice	Below normal	-196.47	-252.49	-238.84	-172.48
	Normal	90.72	-157.38	-84.19	37.79
	Above normal	403.35	21.28	167.49	240.50

Masika rainfall: above normal = 345 mm, below normal = 206 mm, mean = 276mm; analysis based on data between 1960 and 2004.

4 Conclusions and recommendations

4.1 Conclusions

A study was performed to quantify risk and profitability of agronomic management strategies for maize using long-term climatic data and crop simulation models. The yields of different maize varieties based on different sets of agronomic management strategies were simulated and the risks and benefits of sets of simulated yields and their respective management strategies were evaluated. In view of the analysis of the options of conventional and recommended management practices, it is apparent that farming under rainfed conditions is a risky business. Results show that the use of conventional management practices does not result into good yields in almost all cultivars of maize. However, it may prove to be useful during poor seasons.

Farmers are advised to use recommended management practices if a seasonal forecast is above normal. In this way, a farmer is guaranteed of a return to investments and profit, otherwise the conventional methods may be used when a normal and below normal forecasts are given. This goes hand in hand with the improvements of the forecasts.

4.2 Recommendations

Under rainfed system, it is apparent that farmers in *Same* District may be better off if they plant *Situka* or SC401 in *Masika* season than *Kito* or other cultivars. This will guarantee a yield of more than 1 ton/ha with conventional methods, but, in good season, the yields increase to more than 2t/ha with the use of chemical fertilizers and even better if recommended management practices are employed. During *Vuli* season it is recommended that less risky methods (conventional methods) be used because results show high chances of crop failures during the *Vuli* season in all the maize cultivars. However, if the forecast is above normal, farmers are advised to use recommended practices, apply chemical fertilizer, and plant

Situka and SC401 because they will get a guaranteed profit. In most cases, however, *Situka* variety is recommended by extensionists regardless of the forecast.

Although it has been shown that farmers will get a guaranteed profit if they use improved agronomic management practices in above normal rainfall, the accurate forecast of the seasonal variation is crucial. Otherwise, farmers are much safer if they continue to use their conventional approaches of farming because the techniques have fewer risks.

Acknowledgements

The authors would like to thank the Tanzania Meteorological Agency for providing long-term climatic data for *Same* district. This project is supported by the Climate Change Adaptation in Africa (CCAA) program, a joint initiative of Canada's International Development Research Centre (IDRC) and the United Kingdom's Department for International Development (DFID). The views expressed are those of the authors and do not necessarily represent those of DFID or IDRC.

References

APSIM. (2008) APSIM 6.1 Documentation. http://www.apsim.info/Wiki/public/Upload/Versions/v61/Documentation_v61/Documentation/index.html [Accessed 20 Sept, 2009].

Bhatt, Y., Bossio, D., Gordon, L., Kongo, V., Kosgei, J. R., Makurira, H., Masuki, K., Mul, M. & Tumbo, S. D. (2006) Smallholder system innovations in integrated watershed management (SSI): Strategies of water for food and environmental security in drought-prone tropical and subtropical agro-ecosystems. Colombo, Sri Lanka: International Water Management Institute. 59p. IWMI Working Paper 109.

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferano, B. & Twomlow, S. (2008) Copping better with current climate variability in the rainfed farming systems of sub-saharan Africa: an essential first step in adapting to future climate change? Agriculture Agro Ecosystems and Environment J. 126(1-2), 24–35.

Downing, T. E., Ringius, L., Hulme, M. & Waughray, D. (1997) Adapting to climate change in Africa. Mitigation and Adaptation Strategies for Global Change 2(1), 19-44.

Enfors, E. & 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.

Enfors, E., Barron, J., Makurira, H., Rockstrom, J. & Tumbo, S. (2010) Yield and soil system changes from conservation tillage in dryland farming: A case study from North Eastern Tanzania. Agricultural Water Management (In Press, doi:10.1016/j.agwat.2010.02.013).

Hargreaves, G. H. & Samani, Z. A. (1982) Estimating potential evapotranspiration. J. Irrig. and Drain Engr. 108(IR3), 223-230.

Koo, J., Bostick, W. M., Jones, J. W., Gijsman, A. J. & Naab, J. B. (2007) Estimating soil carbon in agricultural systems using ensemble kalman filter and DSSAT-CENTURY. Transactions of the ASABE. 50(5), 1851-1865.

MAFSC. (2009) Tanzania Variety Catalogue. Ministry of Agriculture, Food Security and Cooperatives, The United Republic of Tanzania.

Mavromatis, T. K., Boote, J., Jones, J. W., Irmak, A., Shinde, D. & Hoogenboom, G. (2001) Developing genetic coefficients for crop simulation models with data from crop performance trials. Crop Sci. 41, 40-51.

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

Moshi, A. J. (1998) Adoption of maize production technologies in central Tanzania. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and the Southern Africa Centre for Cooperation in Agricultural Research (SACCAR).

Mzirai, O. B., Rwehumbiza, F. B., Tumbo, S. D. & 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. (ed. by N. Hatibu & K. P. C. Rao) SWMnet Discussion Paper No. 2, 54-56. Nairobi, Kenya, 28 – 30 October.

Probert, M. E., Dimes, J. P., Keating, B. A., Dalal, R. C. & Strong, W. M. (1998) APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. Agricultural Systems. 56, 1-28.

Tumbo, S. D, Mpeta, E., Mbilinyi, B. P., Kahimba, F. C., Mahoo, H. F. & Tadross, M. (2009) Comparison of GCM Downscaled Climate Change Projections Generated Using Self-Organizing-Maps Technique: The Case of *Same*, Tanzania. In: Proc. 10th WaterNet/WARFSA/GWP-SA Symposium. Entebbe, Uganda: 28 - 30 October.

Wu, W, Chen, J., Liu, H., Garcia, A. G. & Hoogenboom, G. (2009) Parameterizing soil and weather inputs for crop simulation models using the VEMAP database. Agriculture, Ecosystems and Environment. Doi: 10.1016/j.agee.2009.08.016.