academicJournals

Vol. 12(26), pp. 2178-2187, 29 June, 2017
DOI: 10.5897/AJAR2017.12421
Article Number: 4D7E0A964989
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Adapting Nyando smallholder farming systems to climate change and variability through modeling

Tobias Okando Recha[1*], Gachene Charles K. K.[1] and Lieven Claessens[2]

[1]Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, P. O. Box 29053, - 00625, Kangemi, Kenya.
[2]Natural Resources (Soil and Water), Resilient Dryland Systems International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Box 39063, 00623 Nairobi, Kenya.

Received 2 May, 2017; Accepted 6 June, 2017

This study was done in Nyando, Kenya to model maize production under different climate scenarios and project the yields up to 2030 and 2050 using Decision Support System for Agrotechnology Transfer (DSSAT) under rain fed conditions. Three maize varieties were used; Katumani Comp B as early maturing variety, Hybrid 511 as a medium maturing variety and Hybrid 614 as a late maturing variety. Global coupled model Hadley Centre Global Environment Model version 2 (HadGEM2-ES) under representative concentration pathways (RCP) 4.5 and 8.5 was used to downscale Nyando's climate data for the years 2030 and 2050. Past climate data for 53 years and current data was obtained from Kisumu Meteorological station while crop growth and farm management data was obtained from 70 farmers in Nyando. Results showed a decrease in yields across the years from 2015, 2030 and 2050 under both RCP 4.5 and 8.5. Average simulated yields for 2015 were 2519 kg ha^{-1} while projected yields under RCP 4.5 were 2212 and 2081 kg ha^{-1} in 2030 and 2050 respectively. Average yield projections under RCP 8.5 were 2184 and 1806 kg ha^{-1} for the years 2030 and 2050 consecutively. The study found out that temperatures will increase and rainfall duration will reduce. In addition, Katumani Comp B maize variety was not very much affected by these changes in temperatures and rainfall compared to H511 and H614.

Key words: Climate change, Decision Support System for Agrotechnology Transfer (DSSAT), global coupled models, maize yield.

INTRODUCTION

Global sectors in agriculture faces a significant need to increase production in order to provide enough food for a population projected to rise to nine billion by mid-21st century while ensuring there's environmental protection and a sustainable functioning ecosystem (Rosenzweig et al., 2012). Households that were engaged in farming in East Africa and other parts of the world faced challenges and changes in the first decade of 21st century in addition to increase in population that resulted into increased food prices, reduced fertility of soil and crop yields, poor

*Corresponding author. E-mail: tobiasrecha@gmail.com. Tel: +254 718 024 480.

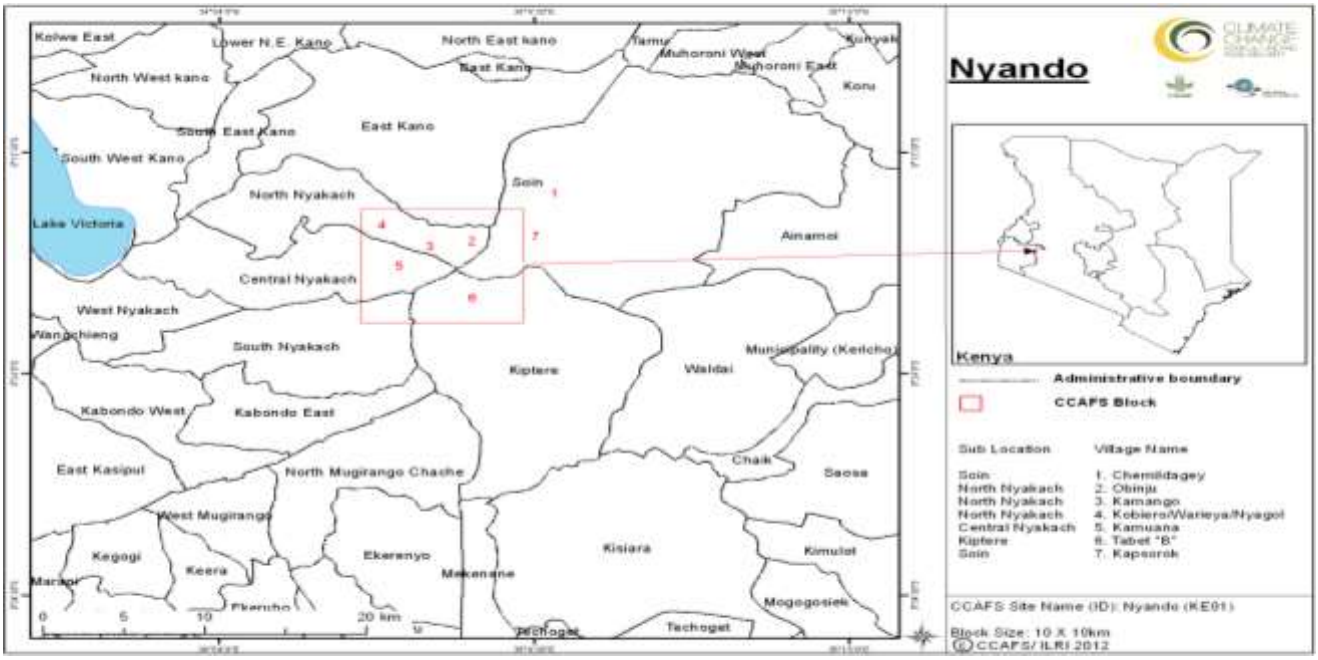

Figure 1. Location of the study area. Source: Climate Change Agriculture and Food Security Site Atlas, Nyando/KatukuOdeyo, Kenya, Sijmons et al. (2013).

access to markets, constrained access to land, and high inflation (Nelson et al., 2010). Despite these challenges, there is an expectation that up to 70% more food will have to be produced by 2050 to feed the growing populations especially in third world countries (Nuerfeldt et al., 2011). Furthermore, Nuerfeldt et al. (2011) explained that climate change will cause rise in temperature and change in precipitation patterns and the resultant weather extremes will negatively reduce global production of food.

Climate change and variability is evident in Nyando Basin in western Kenya. There is an increase in droughts, floods and unpredictable rainfall which affect agriculture and food security (Macoloo et al., 2013). In the villages of Nyando, 81% of the families experiences up to two months of hunger where they do not have enough food for consumption, while 17% of the families experience three to four months of hunger (Kinyangi et al., 2015). The primary source of income and food in Nyando is farming (mixed crop-livestock system), but the farmers have not diversified and show a few agricultural innovations (Macoloo et al., 2013). A household baseline survey carried out in Nyando by Mango et al. (2011) observed that households that had not introduced any new crop were 37%, only one or two new crop varieties had been introduced by 32% and those households that had incorporated three or more new varieties of crops into their farming systems were 32%.

Just like many Kenyan communities, Nyando communities have high preference for maize consumption. The survey report by Mango et al. (2011) showed that the number of households that cited maize as one of their most important crop was 99%, those that cited sorghum were 73% and beans were 35%. Based on this data, it was necessary to carry out a study on maize production in the area which is the most preferred crop amongst farmers and the most likely to be affected by climate change. In this study, model was used because according to Gettinby et al. (2010), modelling has played a very important role in improving efficiency of agricultural production systems in the last 30 years. Therefore using Decision Support System for Agrotechnology Transfer (DSSAT) crop model, maize yields were simulated under the existing climate scenario and the future potential yields of maize were projected up to 2050 under different climate scenarios. The model will help in giving an overview of impacts of climate changes on maize yields to enable coming up with copying and adaptation strategies for Nyando farmers.

MATERIALS AND METHODS

The Lower Nyando block where the study was carried out is located in the lake plain of Lake Victoria in Nyando and Kericho sub-counties (Figure 1). It is within a 10 km by 10 km block known as the Lower Nyando Block (Between 0°13'30''S - 0°24'0''S, 34°54'0''E - 35°4'30''E).

This study used purpose sampling technique in selecting subjects for study according to Marshall (1996). Soil sampling was carried in five farms before sowing. The soil samples were taken by driving soil auger into the soils and samples were taken at different soil depths (0-5, 5-15, 15-20, 20-25 and 25-30) and placed into sampling bags. The samples were air dried, ground and sieved

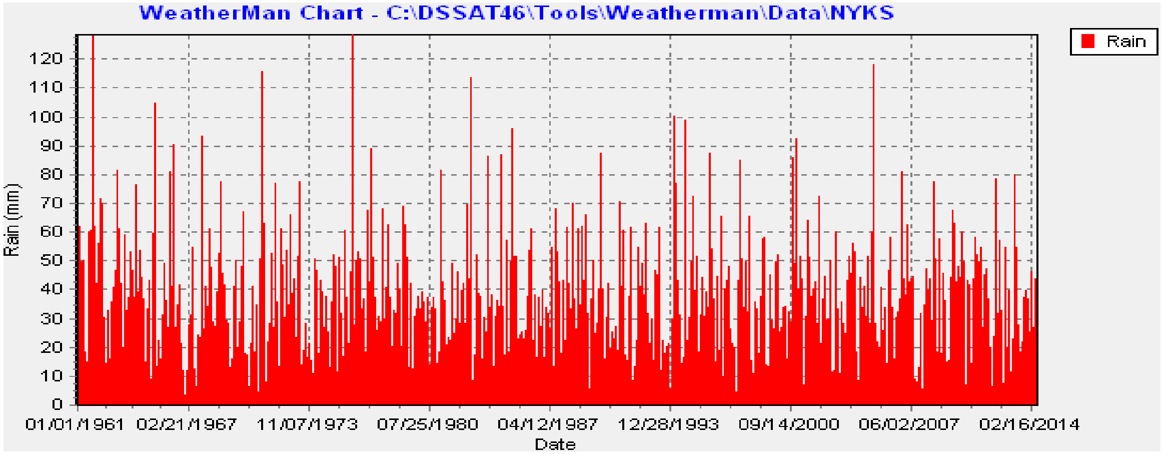

Figure 2. Trends of rainfall in Nyando

through a 2-mm sieve. They were kept in polythene bags for future physical and chemical analysis. The physical soil analysis included particle size distribution and soil bulk density using methods of Okalebo et al. (1993). Volumetric moisture content was also determined. Chemical soil analysis included soil organic carbon determined by Walkley and Black procedure, total N by Kjeldahl method, available P by Olsen method, exchangeable cations and soil pH by methods described in Okalebo et al. (1993). Descriptive data were also used and include: Slope, drainage, runoff and relative humidity. Soil data tool (SBuild) under the tools section in DSSAT v 4.6 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of study site, site coordinates, soil series and classification were among the data entered in this utility. Percent clay, silt and gravel entered in the SBuild utility was used to calculate hydraulic conductivity, saturated upper limit and drained upper limit.

Weather data was obtained from Kisumu meteorological station comprising of rainfall, maximum temperature, minimum temperature and solar radiation. Past climate data was also obtained from Kisumu meteorological station. To assess the impact of climate change under different climate scenarios on maize production; climate data was generated from MarkSim DSSAT weather file generator, a MarkSim web version for IPCC AR5 data in the Coupled Model Intercomparison Project Phase 5 (CMIP5). This data was downscaled using HadGEM2-ES under Representative Concentration Pathways 4.5 and 8.5 for the years 2030 and 2050. Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by international panel on climate change. Under RCP 8.5, there is no future policy change to reduce emissions. This future is characterized by today's CO_2 emission will be three times by 2100, methane emissions will rapidly increase, use of cropland and grassland will increase driven by increase in population, 12 billion world populations by 2100, technological development will be low, increased reliance on fossil fuels, high energy intensity and there is no implementation of climate policies. RCP 4.5 was developed in the United States by the Pacific Northwest National Laboratory. Under this RCP, radiative forcing is stabilized shortly after 2100, consistent with a future with relatively ambitious emissions reductions (Bjones, 2012). This future is characterized by energy intensity that is lower, reforestation programs that are strong, yield increases and dietary changes resulting into decreased use of croplands, climate policies that are stringent, methane emissions that are stable and emissions of CO_2 that increases slightly before decline commences around 2040. The Weatherman utility in DSSAT was used to create the weather file that was used by the CERES-Maize model. Data used to create the weather file include station information: Name of weather station, latitude, longitude and altitude. Daily maximum and minimum temperature, daily solar radiation and daily rainfall for a period of fifty three years (1961-2014) were imported into the DSSAT model. Their units of measurements were converted into those used by the DSSAT. The data was then edited and exported to DSSAT format and was ready for use by the CERES-Maize model. Agronomic data was collected through administration of questionnaires to 70 farmers and measurements. The data collected through questionnaires and measurements include planting dates, spacing, tillage, plant height at physiological maturity (maturity was determined when the silk appeared to be dried and the eye of the grain appeared dark), number of days to 50% silking, number of days to 50% tasseling, plant height at harvest measured from the base of the plant to the flag leaf and yields harvested. This data was fed into XBUILD utility of DSSAT v 4.6.

RESULTS AND DISCUSSION

Rainfall

The annual rainfall in Nyando showed high temporal variability with a coefficient of variation of 25% as shown in Figure 2.

The year 2014 recorded the lowest annual rainfall with a total of 345 mm compared to 2013 and 2012 which recorded 549.3 and 524.4 mm respectively. Generally, since the year 2000, the lowest amount of rainfall received was recorded in 2014; with a range value of 412.3 mm from the maximum amount of 757.3 mm. The destruction of water catchment areas at the upper Nyakach and reduced forest cover were identified as the main causes of reduced amount of rainfall in Nyando.

Temperature

The analysis indicated that the average annual

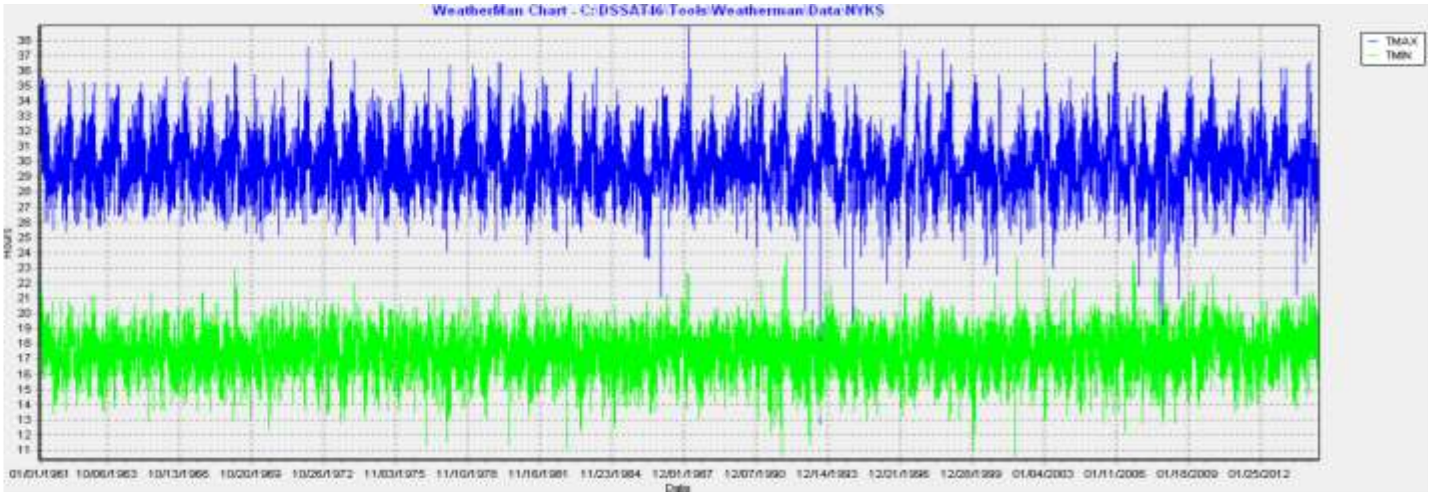

Figure 3. Historical variation in minimum and maximum temperatures in Nyando.

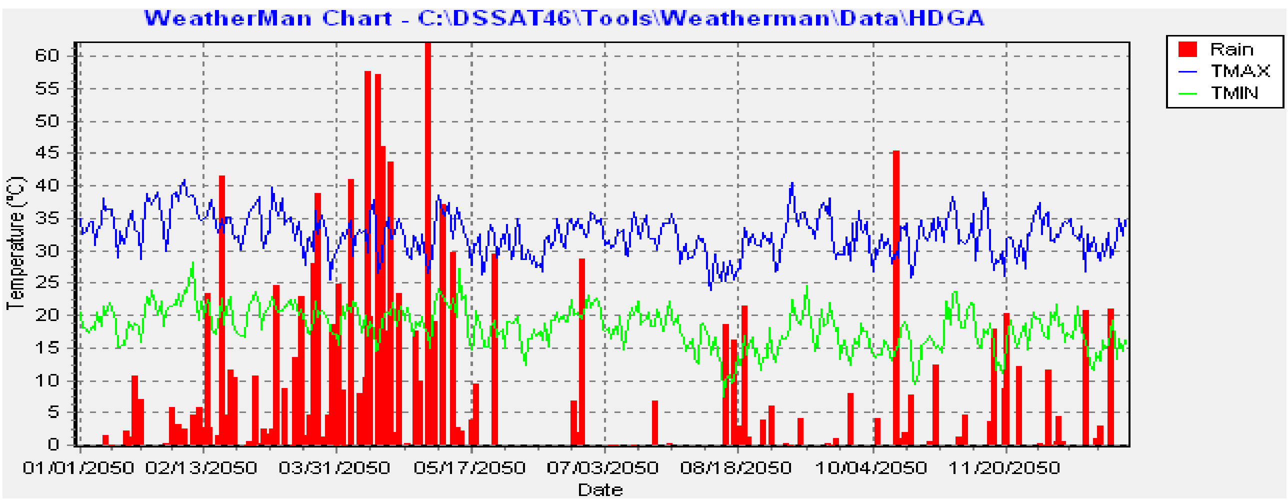

Figure 4. Projected climate in Nyando for 2050.

temperatures were increasing at the rate of 0.011°C every year (Figure 3). Minimum temperatures were getting warmer by 0.005°C every year while the annual increase in maximum temperatures was 0.007°C.

When analyzed for decadal wise increase, the average annual temperature in Nyando during the period 2001-2010 was 0.067°C higher compared to the period 1981 to 1990, an indicator of rise in temperatures therefore change in climate; most farmers' clear vegetation from their land to pave way for cultivation. In addition, the rates of agroforestry and afforestation practices are low in Nyando. This increases the impacts of high temperatures on maize production. This study was carried out in 2015 which had an average of 29.91°C maximum temperature and 18.2°C minimum temperatures.

Projected climatic conditions for the year 2030 and 2050 in Nyando

The model projected maximum temperatures of over 40°C both in 2030 and 2050 as shown in the Figures 4 and 5. The lowest projected minimum temperatures in 2030 are 6 and 8°C for the year 2050.

The increase in projected maximum and minimum temperatures by 2030 and 2050 is due to expected rapid growth in industrialization in Kenya which will result in emission of greenhouse gasses into the atmosphere. In Figures 3 and 4, the long rain periods are also expected to reduce with high concentration of rainfall occurring between March up to mid-May. The shortened rainfall period will be as a result of further encroachment of forest areas and water catchment areas along Lake Victoria

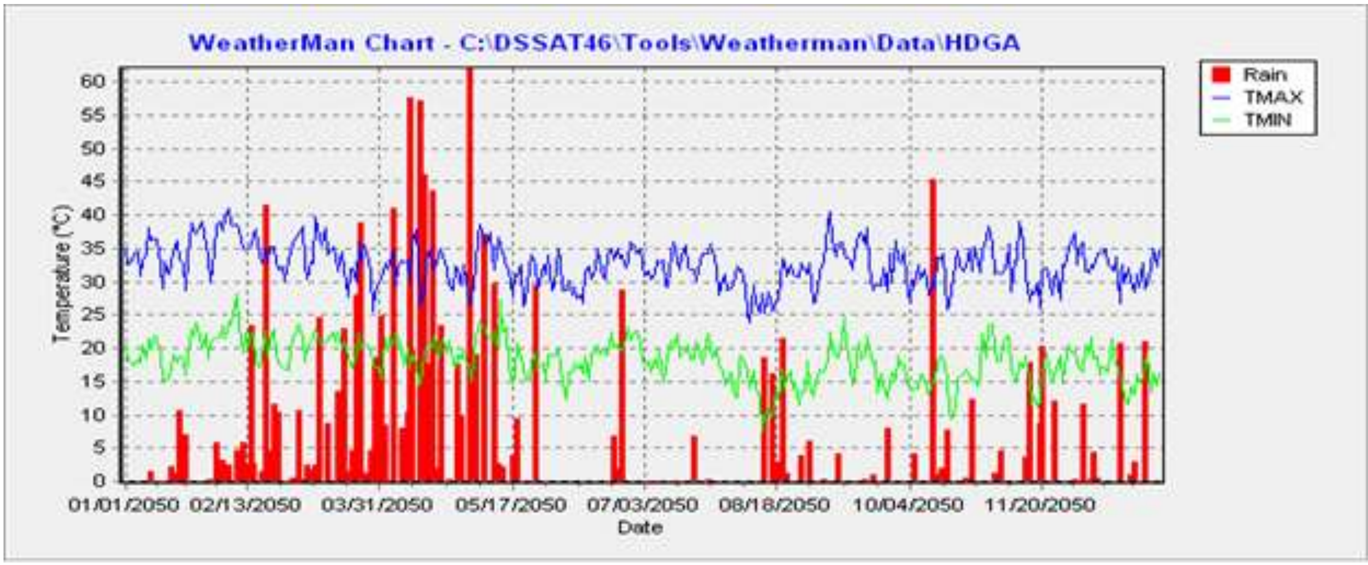

Figure 5. Projected climate in Nyando for 2050

Table 1. Summary of soil parameters.

Soil depth (cm)	Lower limit (cm^3/cm^3)	Upper limit (cm^3/cm^3)	SAT SW (cm^3/cm^3)	EXTR SW (cm^3/cm^3)	INIT SW (cm^3/cm^3)	Root distance (cm^3/cm^3)	BULK density (g/cm^3)	pH	NO_3 (ugN/g)	NH_4 (ugN/g)	ORG C (%)
0 - 5	0.280	0.349	0.530	0.069	0.349	1.00	1.25	6.30	0.00	0.00	1.00
5 - 15	0.282	0.328	0.530	0.046	0.328	0.95	1.33	6.30	0.00	0.00	0.81
15 - 20	0.280	0.311	0.530	0.031	0.311	0.10	1.40	6.30	0.00	0.00	0.62
20 - 25	0.182	0.273	0.338	0.091	0.273	0.64	1.40	6.30	0.00	0.00	0.49
25 - 30	0.174	0.264	0.338	0.090	0.264	0.58	1.40	6.30	0.00	0.00	0.49

SAT SW, Saturated water content; INIT SW, Initial soil water; ORG C, Soil organic carbon.

watershed and clearing of more vegetation in highlands of Upper Nyakach areas.

Soil parameters

The 0 to 5 cm depth which is the main rooting depth for the maize fibrous roots had a bulk density of 1.25 g cm^{-3} and from 15 to 30 had 1.4 g cm^{-3}. The same top layer, 0 to 5 cm deep also had 1.00% organic carbon with saturated water content of 0.53 cm^3/ cm^3 (Table 1).

Crop parameters

Katumani comp B (Table 2) is a fast growing maize variety that takes 60 to 65 days to flowering and maturing within 90 to 120 days. This variety performs well within an altitude range of 500 - 1000 m above sea level and is suitable in marginal areas where there is a rainfall range of 250 to 500 mm.

The harvesting of Katumani maize variety started in late June and ended early July 2015.This maize variety showed no stress in phosphorus which was applied during the planting. However, nitrogen and water stress was observed at 75% silking stage but farmers applied top dressing nitrogen fertilizer to mitigate the impacts of the stress on grain filling. Poor rainfall in the area was the result of water stress. H511 maize variety is commonly grown in coffee growing belts. It takes 4 to 5 months to mature under a favorable rainfall of between 750 and 1000 mm (Table 3).

This variety took 125 days from planting to harvest. It did not show any stress to plant phosphorus apart from water and nitrogen. The water and nitrogen stress occurred at 75% silking stage, 82 days from planting date. Nitrogen stress was because there was no secondary application of nitrogen fertilizer (top dressing). Water stress was basically due to reduced rainfall and no irrigation which would have acted as a secondary source

Table 2. Crop and soil fertility status at main development stages for Katumani Comp B in Nyando.

Date	Crop growth		Biomass	LAI	LEAF	Crop N		Stress				
	Age	Stage	(kg/ha)		NUM	kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
2 APR	19	End Juveni	48	0.10	5.6	2	3.5	0.03	0.00	0.00	0.00	2
7 APR	24	Floral Ini	92	0.20	6.7	3	3.6	0.00	0.00	0.00	0.00	3
24 MAY	71	75% Silkin	2149	0.72	14.3	18	0.8	0.15	0.36	0.00	0.00	4
4 JUN	82	Beg Gr Fil	2221	0.46	14.3	18	0.8	0.69	0.67	0.00	0.00	5
3 JUL	111	End Gr Fil	2675	0.16	14.3	19	0.7	0.60	0.59	0.00	0.00	6
5 JUL	113	Maturity	2675	0.16	14.3	19	0.7	1.00	0.51	0.00	0.00	10
5 JUL	113	Harvest	2675	0.16	14.3	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen, Phos, Phosphorus.

Table 3. Crop and soil fertility status at main development stages for H511in Nyando.

Date	Crop growth		Biomass	LAI	LEAF	Crop N		Stress				
	Age	Stage	(kg/ha)		NUM	kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 APR	24	End Juveni	86	0.19	6.7	3	3.7	0.02	0.00	0.00	0.00	2
12 APR	29	Floral Ini	152	0.31	7.8	5	3.6	0.00	0.00	0.00	0.00	3
4 JUN	82	75% Silkin	2198	0.54	16.6	18	0.8	0.28	0.49	0.00	0.00	4
15 JUN	93	Beg Gr Fil	2437	0.37	16.6	19	0.8	0.15	0.70	0.00	0.00	5
6 JUL	114	End Gr Fil	2583	0.15	16.6	19	0.7	0.91	0.55	0.00	0.00	6
8 JUL	116	Maturity	2583	0.15	16.6	19	0.7	1.00	0.39	0.00	0.00	10
17 JUL	125	Harvest	2583	0.15	16.6	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, leaf number; CROP N, Crop nitrogen, Phos, phosphorus.

of water. This negatively impacted on the grain filling on the cob. Hybrid 614 maize varieties are suitable in medium to high altitudes of 1500 to 2100 m with a rainfall requirement of 800 to 1500 mm (Table 3). The day temperatures should not exceed 28°C and night temperatures can drop as low as 8°C.

In Nyando the harvest for H614 started late August to early September 2015 (Table 4). Crop nitrogen was seen as early as the emergence stages. This implied low use of nitrogen fertilizer by farmers and high rate of volatilization due to high daytime temperatures of 29.91°C (Table 4). Water stress set in at 75% silking stage because at this time in the year (July), rainfall had reduced in Nyando. Therefore, the soil moisture available at the crop root zone was low, and evaporation also was high. This resulted into slowed grain filling on the maize cobs.

Comparison between 2015 observed and simulated yields in Nyando

In the baseline year 2015, Katumani comp B gave the highest observed yields of 2597 kg ha^{-1} as shown in Figure 6, compared to H511 and H614. This variety gave the highest yields because it was able to mature fast and therefore escaped the negative the impacts of low rainfall (KSC, 2010). H514 and H614 observed yields were lower than Katumani comp B because of the climatic challenges. The low rainfalls of 420 mm in 2015 were not sufficient in providing sufficient moisture for these varieties which requires between 750 and 1000 mm for H511 and 800 to 1500 mm for H614. In addition, the high temperatures of 29.91°C in Nyando in 2015 exacerbated the impacts of climate change on available soil moisture necessary for the maize growth. This water stress was

Table 4. Crop and soil fertility status at main development stages for H614.

Date	Crop growth		Biomass (kg/ha)	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage				kg/ha	%	H_2O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 MAY	49	End Juveni	143	0.30	7.8	5	3.7	0.02	0.00	0.00	0.00	2
27 MAY	74	Floral Ini	244	0.47	8.9	9	3.6	0.00	0.00	0.00	0.00	3
28 JUL	135	75% Silkin	2343	0.51	18.8	19	0.8	0.29	0.55	0.00	0.00	4
2 AUG	140	Beg Gr Fil	2276	0.32	18.8	19	0.8	0.86	0.72	0.00	0.00	5
5 SEP	174	End Gr Fil	2299	0.20	18.8	19	0.8	0.98	0.56	0.00	0.00	6
7 SEP	176	Maturity	2299	0.20	18.8	19	0.8	1.00	0.07	0.00	0.00	10
15 SEP	184	Harvest	2299	0.20	18.8	19	0.8	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen, Phos, Phosphorus.

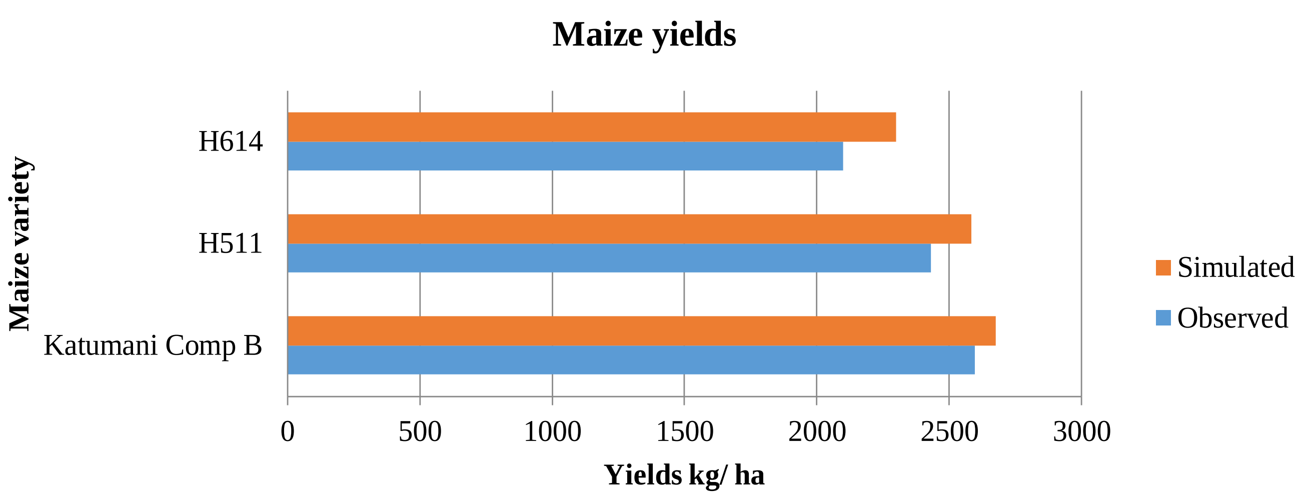

Figure 6. Yield comparison between observed and simulated yields in DSSAT-CERES for the year 2015.

evident especially at 75% silking stage of these maize varieties.

Projected maize yields for the years 2030 and 2050 in Nyando using DSSAT-CERES model

Projected maize yields for the year 2030

The projected yields under both RCP 4.5 and 8.5 in Figures 7 and 8 showed that Katumani Comp B gave the highest yields of 2369 and 2325 kg ha^{-1} respectively compared to H511 and H614.

Katumani composite B did well because it will be able to maximally utilize the projected rainfall which shall take approximately three months only. This maize variety has an advantage of fast growth by flowering within 90 days (KSC, 2010). The difference in the projected yields for the three maize varieties is also associated with the difference in days to completion of the life cycle and the genetic make-up of these maize varieties (Benedicta et al., 2012). Furthermore, Benedicta et al. (2012) explains that this difference in maize yields under the different climate scenarios is attributed to the amount and distribution of rainfall.

Projected maize yields for the year 2050

The 2050 yield projections are lower compared to 2030 for all the three maize varieties. However Katumani comp B still showed higher yields in 2050 compared to H511 and H614 (Figures 9 and 10).

The reduction in yields is associated with climate

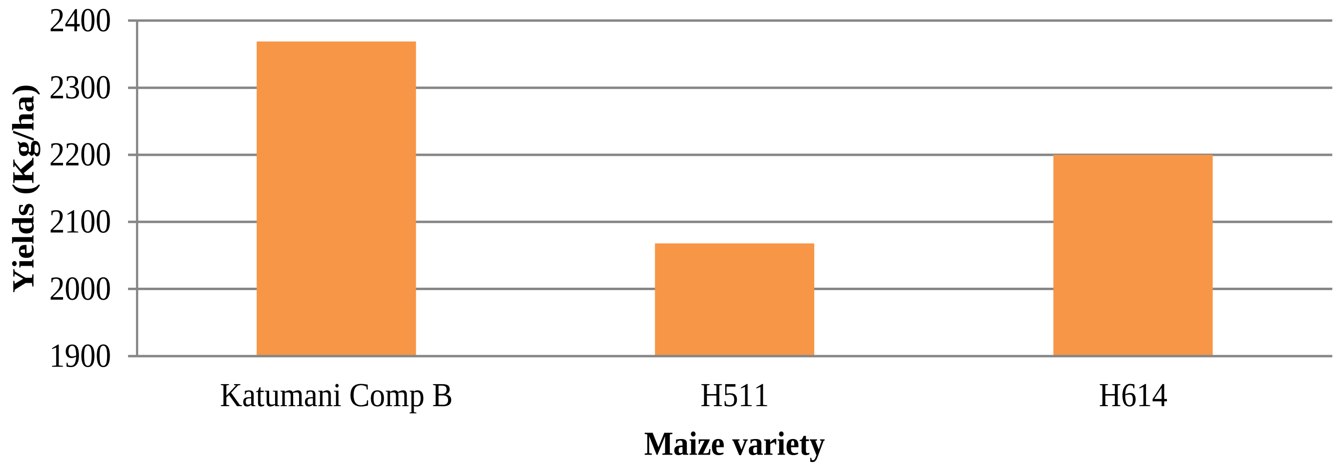

Figure 7. CERES-Maize projected yields for 2030 under representative concentration pathway

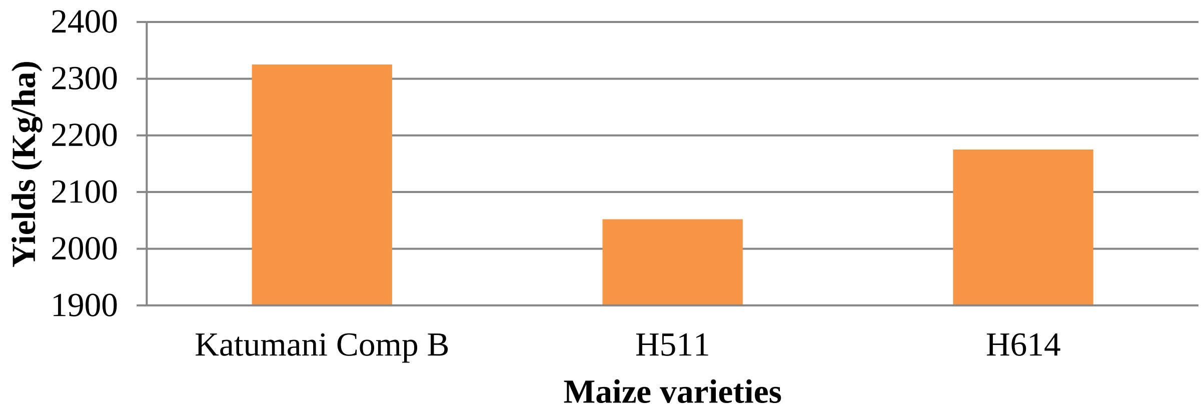

Figure 8. CERES-maize projected yields for 2030 under representative concentration pathway

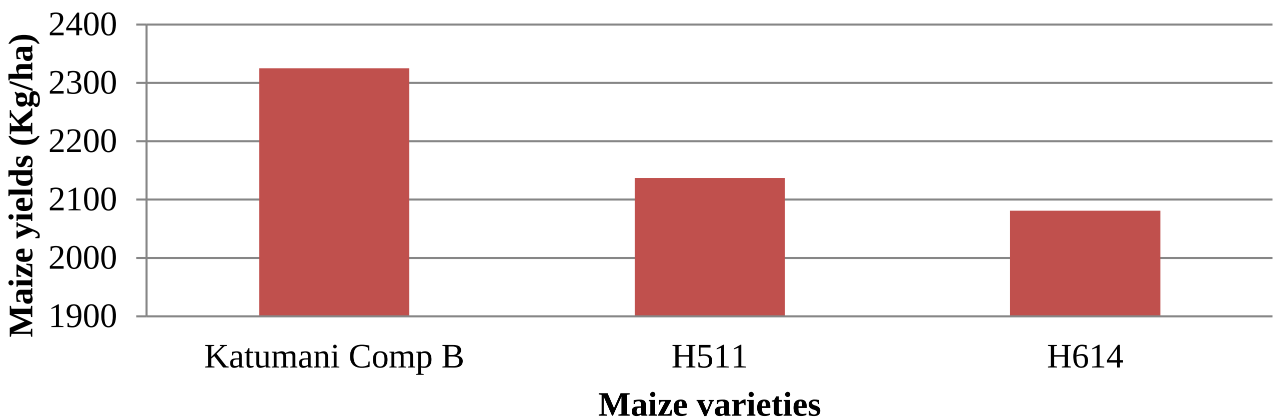

Figure 9. CERES-maize projected yields for 2050 under representative concentration pathway.

changes where maximum day temperatures are expected to rise above 40°C with minimum night temperatures going up to 8°C. The changes in temperatures with reduced rainfall period of only three months negatively impacts H511 and H614 maize varieties which requires up to 125 and 190 days to maturity. This implies that

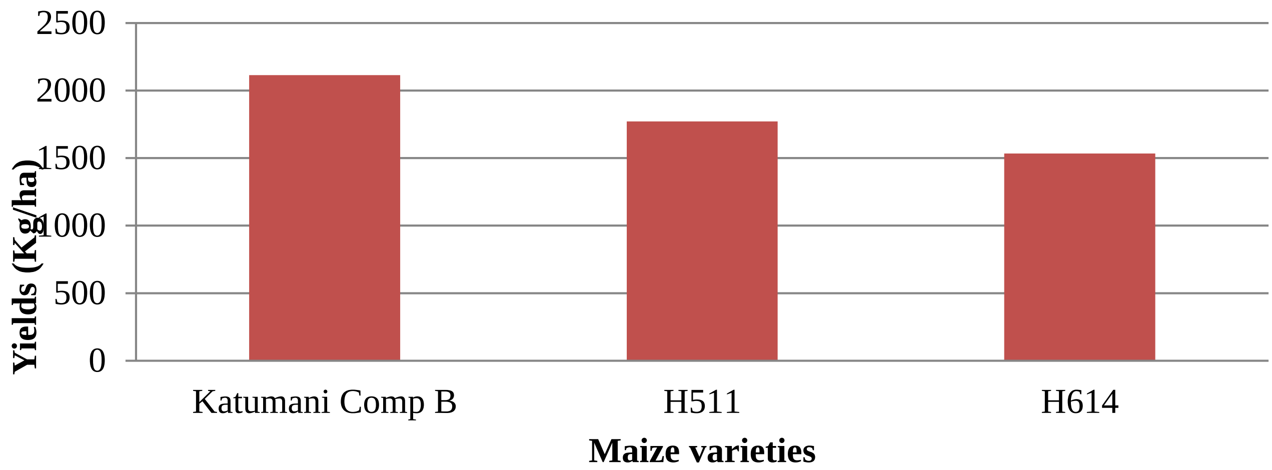

Figure 10. CERES-maize projected yields for 2050 under representative concentration pathway.

H511 and H614 will face a lot of stress during their growth.

Herrero et al. (2010) studied the impacts of climate change on maize crop production in Kenya up to 2050 and found out that the projected impacts of climate change to 2050 results in lower rain fed maize yields for Kenya in 4 out of 6 scenarios. Lobell et al. (2011) associated this reduction in maize yields to increasing maximum (day) temperatures that have a greater negative impact on yields than the minimum (night) temperatures. This increase in day temperatures/ warming exacerbates evaporation and crop water deficits while the rainfall is declining (USAID, 2010 In Bulgaria, Alexandrov and Hoogenboom (2000) investigated the effects of climate change on maize and found out that maize yields could be reduced by between 5 and 10% by 2050. This author deduced that the reason for reduction in yields is due to reduced growing period.

Conclusion

From this study, it is evident that Climate Change in Nyando, Kenya is real and will continue to change in the future. DSSAT-CERES projections for 2030 and 2050 showed that maize yields will reduce by the year 2050 according to the existing climatic projections for this area. On the other hand, Katumani Comp B maize variety will still remain the most suitable to be grown in Nyando up to the year 2050 compared to H511 and H614 under the existing and projected climatic conditions. The projections also indicate that there will be an increase in soil moisture stress due to high evaporation as a result of increase in daytime temperatures. This will require farmers to select more resilient and fast maturing maize varieties like Katumani Comp B. Empowering farmers in the issues of climate change and its effects on the production of maize and other staple crops will also let them understand the interventions that are required to shield themselves against the inevitable impacts of these changes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Alexandrov VA, Hoogenboom G (2000). The impact of climate variability and change on crop yields in Bulgaria. Bulgaria: Agric. For. meteorol. 104(4):315-327.

Benedicta YM, Paul LV, Manfred D, Christopher M, Ahmad M, Janos B (2012). Modelling maize(Zea mays L.) productivity and impact of climate change on yield and nutrient utilization in sub-humid Ghana. Ecol. Dev. Series No. 87.

Bjones C (2012). A guide to Representative Concentration Pathways. CICERO Centre fior. https://www.sei-international.org/mediamanager/documents/A-guide-to-RCPs.pdf Accesed 3rd April 2017

Gettinby G, Revie CW, Forsyth AJ (2010). Modelling: A review of systems and approaches for vector-transmitted and other parasitic diseases in developing countries. University of Strathclyde, Glasgow, United Kingdom: Department of Statistics and Modelling Science and Department of Information Science.

Herrero M, Ringler C, Steeg JV, Thornton P, Zhu T, Bryan E, Notenbaert A (2010). Climate variability and climate change and their impacts on Kenya's agricultural sector. Nairobi, Kenya: Int. Livest. Res. Institute(ILRI),.

Kinyangi J, Recha J, Kimeli P, Atakos V (2015). Climate-smart villages and the hope of food secure households: Preliminary results from climate change adaptation and mitigation initiatives in the Nyando climate-smart villages . ILRI, NAIROBI KENYA: Climate Change, Agric. Food Security, (CCAFS).

KSC (2010). Kenya Seed Company. Maize. Kitale, Kenya. http://www.kenyaseed.com Accessed on 4th May 2015

Lobell DB, Banziger M, Magorokosho C, Viveck B (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Clim. Change 1:42-45.

Macoloo C, Recha J, Radeny M, Kinyangi J (2013). Empowering a local community to address climate risks and food insecurity in Lower Nyando, Kenya. Dublin, Ireland: Hunger. Nutrition. Clim. Justice.

Mango J, Mideva A, Osanya W, Odhiambo A (2011). Summary of

Baseline Household Survey Results: Lower Nyando, Kenya. Nairobi, Kenya.: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
Marshall MN (1996). Sampling for Qualitative Research. London: Oxford University.
Nelson GC, Rosegrant MW, Palazzo A, Gray I, Ingersoll C, Robertson R, You L (2010). Food security, farming, and climate change to 2050: challenges to 2050 and beyond. IFPRI Issue Brief No. 66. Washington DC, USA: International Food Policy Research Institute (IFPRI).
Nuerfeldt H, Kristjanson P, Thorlakson T, Gassner A, Norton-Griffiths M, Place F, Langford K (2011). ICRAF Policy Brief 12: Making climate-smart agriculture work for the poor. Nairobi, Kenya: World Agroforestry Centre(ICRAF).
Okalebo JR, Gathua KW, Woomer PL (1993).Laboratory methods of soil and plant analyis: A working manual. Nairobi, Kenya: Tropical Soil Biology and Fertility Programme
Rosenzweig C, Jones JW, Hartfield JL, Mutter CZ, Adiku SK, Ahmad A, Zubairi L (2012). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Integrated regional assessment projects. In D. Hillel, & C. Rosenzweig (Eds.), In Handbook of Climate Change and Agroecosystems: Global and Regional Aspects and Implications. ICP Series on Climate Change Impacts, Adaptation, and Mitigation 2:263-280. Imperial College Press.
Sijmons K, Kiplimo J, Forch W, Thornton PK, Radeny M, Kinyangi J (2013). CCAFS Site Atlas-Nyando/Katuk Odeyo. CCAFS site atlas series. The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org
USAID (2010). A Climate Trend Analysis of Kenya. Famine Early Warning Systems Network-Informing Climate Change Adaptation Series.