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Modelling Nutrient Dynamics and Maize Yields under Different Cropping Systems and Organic Amendments Using APSIM in Central Kenya

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Authors' contributions

This work was carried out in collaboration between both authors. Author OHN designed the study, managed the literature searches, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GRW managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

A simulation study was carried out using APSIM model to assess the maize yield and soil nutrients to changes in temperatures and rainfall in Kabete and Kiserian areas of central Kenya. To obtain data for model calibration and validation, on-station (Kabete) and on-farm experiments (Kiserian) were set out during the short rain season of 2013. The experimental design was a randomized complete block (RCBD) with a split-plot arrangement where the main plots were three cropping systems; monocropping, intercropping and crop rotation and the split plots were farmyard manure (FYM) and Minjingu Rock Phosphate (MRP), and a control. The effect of the changes in rainfall and temperature on maize yields was considered, i.e. current temperature combinations in accordance to the International Panel on Climate Change projections. The model performed better for Kabete (ME=0.6) than Kiserian (ME=0.9). Simulations of crop rotations correlated most (R^2=0.48) with observed results at Kabete and Kiserian. Simulations of the intercrops correlated favourable with coefficient of determination (R^2) values of >0.4 showing a reasonable relationship between observed and simulated values. However, mono-crop simulation varied highly from observed yields (R^2<0.3). The APSIM simulated matched well with the observed data in the trial; root means standard error

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(RMSE) 2.07 for Kabete and 2.49 for Kiserian. Maize-chickpea cropping systems with application of FYM and MRP gave better yields as they resulted in higher predicted yields compared to the monocrop. The impacts of climate change and variability, i.e. reduced rainfall and increased temperatures that led to lower maize yields. These rainfall and temperature regimes call for the development of appropriate adaptation techniques.

Keywords: Organic cropping systems; APSIM; correlation coefficient; CCV.

1. INTRODUCTION

Organic amendments, crop rotations, and intercrops constitute multifunctional management practices that conserve soil organic matter, enhance soil quality, protect soil from erosion, and sequester carbon to help mitigate the effects of climate change [1]. Organic amendments have the ability to sequester carbon and in the long run, reduce its concentration in the environment resulting in lower amounts of greenhouse gases in the atmosphere. According to Palm et al. [2], organic fertilisers play a dominant role in soil fertility management through its short-term effects of nutrient supply and long-term contribution to soil organic matter in different cropping systems. Farmers intercrop and rotate to secure food production by averting risk [3]. The cultivation of chickpea in crop rotation has increased crop productivity and sustainability for the semi-arid regions [4]. A well-planned cropping sequence can reduce insect pest incidences, disease severity, ameliorate soil structure, improve organic matter levels, prevent a proliferation of weeds and consequently increase the yields of crops such as maize [5]. In Kenya, maize is the most dominant cereal crop [6]. The maize growing areas of the country are located in ecological zones that allow maize to grow irrespective of limiting temperature and rainfall environments. The bulk of the small-scale farmers who do not apply fertilisers or manure obtain yields of less than 1.1 tonnes per hectare. To enhance these yields, farmers should be encouraged to adopt organic farming methods. Organic amendments, crop rotations, and intercrops constitute multifunctional management practices that conserve soil organic matter, enhance soil quality, protect soil from erosion, and sequester carbon to help mitigate the effects climate change [1]. Field experiments alone cannot give us the desired results, and hence models come handy as predictive tools of the expected outcomes. Moreover in this era of climate change and/or variability models such APSIM again can yield better results. Adapting APSIM to model development of maize under different cropping systems and organic inputs, future production scenarios will be predicted ensuring food security [7]. The use of Agricultural Production Systems Simulator (APSIM) model, with long runs (>30 years) of daily climatic data provides a quick and less costly opportunity of ‘accelerated learning’ compared with the more traditional multi-seasonal and multi-factorial field trials [8]. The model considers the soil as the central focus and allows for simulations of agricultural scenarios using weather, crop type and management templates. APSIM has shown to be reliable in research carried out on the continent, which includes predicting growth under different climate scenarios [9], simulate intercropping [8], legume crops such as chickpea [10] and cereals such as millet [11], impact of climate change [12] performance of crops under different soil inputs [8] proving its reliability in research. Against this background, a study was carried out to model maize growth and development under different cropping systems and organic inputs to simulate different yield scenarios.

2. MATERIALS AND METHODS

2.1 Model Calibration and Validation

2.1.1 Requirements for APSIM data

2.1.1.1 Crop data

Crop data were collected through direct observation and registration of crop phenological stages and crop management in the trial fields as illustrated in Table 1.

2.1.1.2 Soil data

Measured soil parameters are presented in Tables 2 and 3. The soil profiles did not have significant differences, whereby soil laboratory analyses were conducted at the University of Nairobi.

Table 1. Crop phenological stages and management required for APSIM simulations

Phenological stage/crop management	Observations
Sowing	Seeding
Emergence	Date of 50% emergence
Germination	Date of 50% germination
Flowering	Date of 50% flowering
End_crop	Harvesting
Crop	Type and variety
Planting	Plant spacing (mm)
Organic amendment applied	Date of application, amount and nutrient content

Table 2. Soil profile information of Kabete site

Soil horizon depth	0 - 30 cm	30 - 90 cm	90 - 150 cm
Soil water parameters			
Bulk density (g/cm^3)	0.92	1.03	1.06
Saturated Water content (% vol)	0.68	0.57	0.58
Field Capacity-Drained upper limit (DUL) (% vol)	0.35	0.34	0.36
Permanent wilting point -Lower limit (LL) (% vol)	0.17	0.15	0.19
Particle size			
Sand (%)	5	4	3
Silt (%)	27	30	33
Clay (%)	68	66	64
Texture	Clay	Clay	Clay
Soil fertility parameters			
Soil Organic Matter (%)	2.75	2.43	1.28
Total P (ppm)	10.00	6.20	4.30
Total N (%)	0.32	0.19	0.15
pH H_2O)	5.16	6.10	6.50
CEC (cmol+/kg)	20.00	10.05	9.01
Na (cmol/kg)	0.05	1.88	1.88
K (cmol/kg)	1.05	1.55	1.25
Mg (cmol+/kg)	1.70	1.50	1.20
Ca (cmol+/kg)	8.13	3.24	1.41

Table 3. Soil profile information of Kiserian site

Soil horizon depth	0 - 30 cm	30 - 90 cm	90 - 150 cm
Soil water parameters			
Bulk density (g/cm^3)	0.84	0.94	1.06
Saturated Water content (% vol)	0.61	0.56	0.55
Field capacity-drained upper limit (DUL) (% vol)	0.38	0.39	0.36
Permanent wilting point -Lower limit (LL) (% vol)	0.20	0.21	0.19
Particle size			
Sand (%)	11	10	8
Silt (%)	32	34	36
Clay (%)	57	56	56
Texture	Clay	Clay	Clay
Soil fertility parameters			
Soil organic matter (%)	3.72	2.34	1.28
Total P (ppm)	5.00	4.20	2.40
Total N (%)	0.35	0.31	0.30
pH (H_2O)	5.80	5.50	5.40
CEC (cmol+/kg)	28.20	27.40	26.30
Na (cmol/kg)	0.04	0.07	0.08
K (cmol/kg)	0.80	0.50	0.40
Mg (cmol+/kg)	3.00	2.75	2.13
Ca (cmol+/kg)	19.40	18.20	11.50

2.1.1.3 Meteorological data

The meteorological data for the simulations was used from 1981 – 2013 (32 years). The data in reference was used from October 2012 to October 2013 for the short (October – December) and long (March-May) rainy seasons in the two sites. A complete set of daily data on rainfall, minimum temperature, maximum temperature and incoming solar radiation was gathered for the simulations with the APSIM model used in this study.

2.1.2 Soil, Plant Sampling and Analysis

Initial soil analysis was carried out before planting. Subsequent soil samplings were done at harvesting stage. Soil samples were taken in a systematic random manner at 0-30, 30-90 and 90-150cm depths and composited into one sample to get a single representative sample in each plot for physical and chemical analyses.

Soil Texture*:* Hydrometer method [13]

Bulk Density: Core method [14]

Soil pH*:* a 1: 2.5 ($^{w}/_{v}$) procedure [15 and 16].

Organic Carbon: Walkley-Black method [17].

Total Nitrogen: Kjeldahl method [18]

Extractable phosphorus: Molybdenum Blue method [19 and 20]

Extractable potassium*:* Flame photometer (21 and 22)

2.1.3 APSIM model calibration and validation

On-farm experiments were conducted in Kiserian, Kajiado County and Kabete campus field station, the University of Nairobi during 2012 – 2013. To simulate maize growth in the study area, the required input data for APSIM (version 7.3) was configured accordingly for the following modules: SoilWat (Soil water), SoilN (soil nitrogen), surface (surface organic matter) and Maize (maize crop). The parameters affecting maize yield were obtained based on measured biomass production and grain yield. Cropping systems simulated were sole cropping of maize (with and without organic inputs), intercropping of maize and chickpea (with and without organic inputs) and rotation of maize with chickpea (with and without organic inputs). To reflect the seasonal effect, planting window for the long rains and short rains were between 1st to 30th March and 1st to 30th October of every year respectively. The model was set to sow in any three consecutive days within the sowing window at the rain event of 25 mm.

2.1.4 APSIM model testing and evaluation

Model validation was done using Sensibility test [29] by means of a graphical method providing a quick visual summary of data and of the comparison between model and data (comparison of model predictions with observed data). APSIM was used to simulate maize yields during the 2013 short rain season (September-December) under different cropping systems (maize monocrop, chickpea-maize rotations and maize-chickpea intercrops) and soil organic inputs (farmyard manure, Minjingu rock phosphate and control).

Table 4. Soil parameters for the APSIM simulation and methods used at a representative depth

Soil parameters	Method
Bulk density (g/cm^3)	Oven dried (105deg. C) to constant weight [23]
Saturated water content (cm^3/cm^3)	Initial Drainage Curve (IDC) as described by Klute [24]
Field capacity (cm3/cm3)	Initial Drainage Curve (IDC) as described by Klute [24]
Organic C (g/kg)	Walkley and Black method as described by Nelson and Sommer [25]
Total N (N)	Kjeldahl procedure, as described by Bremner and Mulvaney [26]
Labile P (mg/kg)	Olsen method as described by Olsen and Sommers [27]
pH	1:2.5 soil KCl I1M), by a standardised pH meter
CEC	Walkley and Black method as described by Nelson and Sommer [25]
Ca, Mg, Na and K	Ammonium acetate method
ESP	Calculated
Texture (Particle size; sand, silt and clay	Soil texture classes and size classification; sand (2000-50 µm), silt (50-2 µm), clay (<2 µm), [28 and 13]

Model evaluation was done using the following statistical analysis:

- ✓ Root mean square error
- ✓ Mean error
- ✓ Coefficient of determination

Root mean square error is considered a good measure of model performance [30] as it provides information on overall model performance. Low values are an indication of good model performance.

$$RMSE = \surd[n^{-1}\,\Sigma(p_{1\,-}\;O_i)] \tag{2}$$

Where p_1 and Oi are the simulated and the observed values, respectively and n is the number of observations.

Mean Error (ME) is used to investigate averaged differences between the simulated and observed yields. It is calculated as:

$$ME = n^{-1}\sum_{i=1}^{n}(p_i - o_i)$$

Where n is the number of observations, p_i and o_i are simulated (predicted) and measured (observed) yields respectively. ME is not only used to measure the average magnitude of the errors in the set of simulated maize yields but also to consider their direction.

A coefficient of determination (R^2) is the strength of linear association between x and y representing the proportion of unexplained variation to total variation. It is used to analyse the linear relationship between measured and simulated yields.

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$$

Where SSR is the regression sum of squares, SST is the total sum of squared deviations of the predicted values around their mean, and SSE is the sum of squared differences between the residuals/ errors and their means [31]. For a perfect regression, SSR = SST and SSE = 0, so that $R^2 = 1$.

The calibrated model was then validated using the experimental data during 2012 - 2013. The calibration process aimed at maximising the coefficient of determination (R^2) between observed and simulated parameters. Good model performance was indicated by R^2 values as close to one as possible.

3. RESULTS AND DISCUSSION

3.1 Simulation of Climate Change Scenarios

3.1.1 Climate parameter trends

The rainfall decreased over the years as the temperature, and solar radiation increased over the same period (Fig. 1). Rainfall varies comparatively to the long-term average with some months having more and others less, and thus water stress happened during the maize growing period. According to UNDP [32], air temperature is the most important climatic element for good maize yield during the maturity stage. Climate variability poses a serious threat to food security for millions of communities living in the study areas. Predictions indicate a more severe crop production declines expected to lead to hunger, malnutrition, insecurity and migrations [33].

Understanding the underlying weather conditions behind rainfall trends will help explain their cause and help us to interpret the best climate model data and hence what the future may hold. There have been lower pressure systems, more prevalent high-pressure systems and, since 2000, the rainfall associated with each system has decreased. The changes that have already being experienced in the south-west are projected to continue at the same rate over the next century under increasing levels of atmospheric greenhouse gases [34].

Local factors such as land-use change may also have played a role in the rainfall decline, but this is likely to be secondary compared with the larger scale atmospheric changes [33].

The rainfall drop has led to a stream flow reduction of about 50%, a significant decrease relative to the rainfall decline. This disparity reflects the lack of very wet years and runoff sensitivity to rainfall decreases. The resulting decrease in surface water and groundwater availability has severely reduced regional water resources and is forcing significant enhancement of water supplies. Some ecosystems such as wetlands and woodlands are under severe pressure. Agriculture has also been impacted, as it is dependent on rainfall for crop and pasture establishment. Projections for the future,

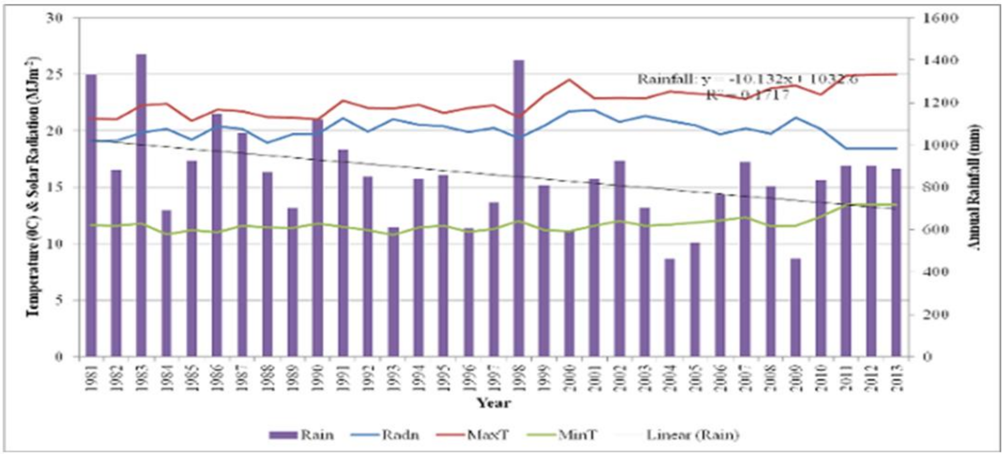

Fig. 1. Climate trend at Kabete

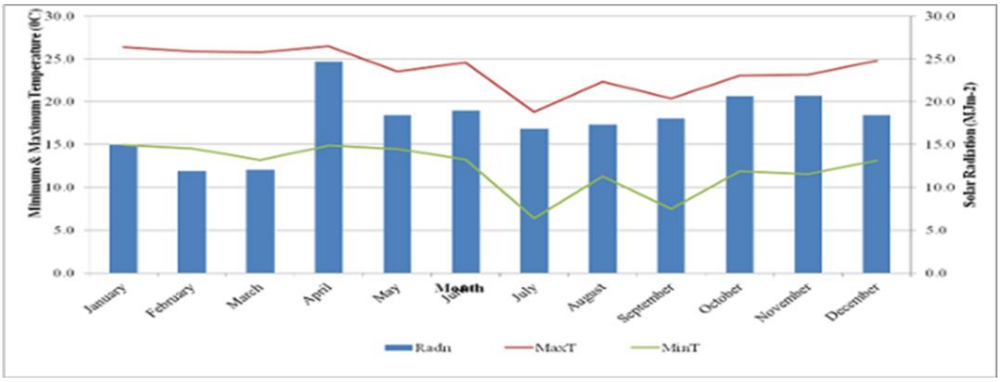

Fig. 2. Monthly incoming solar radiation, minimum and maximum air temperature for years 2012 – 2013 at Kiserian site

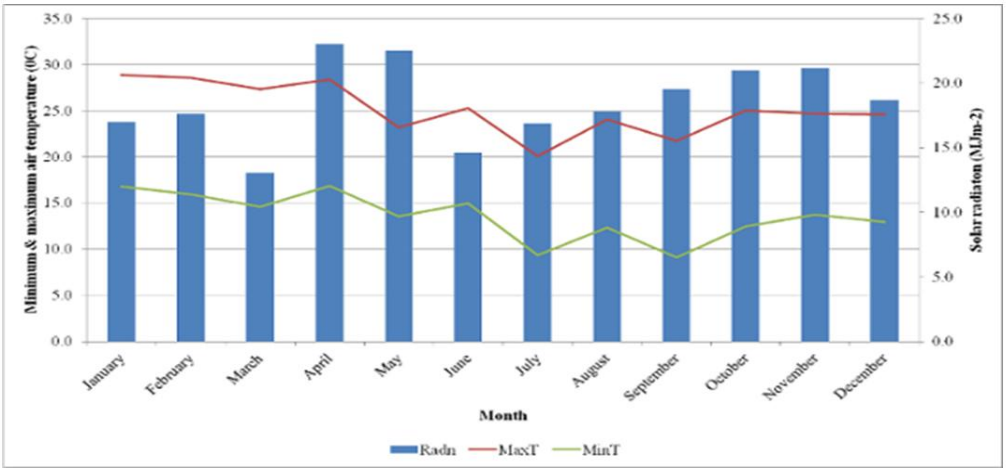

Fig. 3. Monthly incoming solar radiation, minimum and maximum air temperature for years 2012 – 2013 in Kiserian

with increasing greenhouse gas concentrations, suggest that a decline in rainfall may occur [34,35,36]. The observed decline was most likely linked to both enhanced greenhouse gases and natural variability.

Studies indicate that the average global surface temperature has increased by approximately 0.5-1.0°F (0.3-0.6°C) over the last century [34 and 36]. This is the largest increase in surface temperature in the last 1,000 years and scientists are predicting an even greater increase over this century. This warming is largely attributed to the increase of greenhouse gases (primarily carbon dioxide and methane) in the Earth's upper atmosphere caused by human burning of fossil fuels, industrial, farming, and deforestation activities [34 and 35].

Average global temperatures may increase by 1.4-5.8ºC (that's 2.5 - 10.4º F) by the end of the 21st century. Although the numbers sound small, they can trigger significant changes in climate. (The difference between global temperatures during an Ice Age and an ice-free period is only about 5ºC.) Besides resulting in more hot days, many scientists believe an increase in temperatures may lead to changes in precipitation and weather patterns. Warmer ocean water may result in more intense and frequent tropical storms and hurricanes. Sea levels are also expected to increase by 0.09 - 0.88 m. in the next century, mainly from melting glaciers and expanding seawater. Global warming may also affect wildlife and species that cannot survive in warmer environments may become extinct. Finally, human health is also at stake, as global climate change may result in the spreading of certain diseases such as malaria, the flooding of major cities, and a greater risk of heat stroke for individuals, and poor air quality [34 and 36].

Climate change is very likely to have an impact now on our planet and its life, according to the latest instalment of a report published by the Intergovernmental Panel on Climate Change [34 and 35]. And the future problems caused by rising seas, expanding deserts, and more frequent droughts all look set to affect the developing world more than developed countries.

Solar irradiance changes have been measured reliably by satellites for only 30 years. These precise observations show changes of a few tenths of a percent that depend on the level of activity in the 11-year solar cycle [34 and 36]. Changes over longer periods must be inferred from other sources. While a component of recent global climate change may have been caused by the increased solar activity of the last solar cycle, that component was very small compared to the effects of additional greenhouse gases. According to a NASA Goddard Institute for Space Studies (GISS), the solar increases do not have the ability to cause large global temperature increases and thus greenhouse gases are indeed playing the dominant role [34 and 35].

3.2 Model Runs and/or Simulations

3.2.1 Observed and simulated maize yields

APSIM was generally satisfactory in simulation of yields in Kabete and Kiserian. The simulated yields were generally higher than the observed one (Table 5). Yields under control in intercrop were generally lower than in the other treatments. Kabete gave more yields than Kiserian. Crop rotation had higher yields than monocrop and intercrop at both sites.

3.3 Model Validation

The model performance was good for Kabete with a lower ME (0.6) and RMSE (2.07) as compared to Kiserain ME (0.9) and 2.5 RMSE (Table 6). This shows a close relationship/ agreement between simulated and observed yields in Kabete than in Kiserian. Chickpea-maize rotations gave higher R^2 values >0.4 indicating a close agreement between observed and simulated values. Maize-chickpea intercrops gave average R^2 values showing a general agreement between simulated and observed maize yields. The performance for Kabete was poor in monocrop with lower R^2 (0.18) showing that there were major differences between simulated and observed maize yields. This was further confirmed by large differences between observed (3.6 t ha^{-1}) and simulated yields (5.3 t ha^{-1}) for FYM that were significantly ($p<0.05$) different (Table 5). Poor model performance could be attributed to unreliable rainfall experienced in the study area that could have led to poor maize yield production.

The model output was reasonably good for Kiserian maize-chickpea rotation with an R^2 (0.3) and showing a good agreement between simulated and observed yields. Model accuracy was moderate for maize-chickpea intercrops as evidenced by a correlation coefficient R^2 (0.4) indicating a close agreement between observed and simulated values. Maize monocrop yielded low R^2 (0.26) values showing major differences between simulated and observed maize yields (Table 6). At both sites simulated yields were

Table 5. Observed and simulated maize yields (t ha^{-1})

Site	Yield (t/ha)	Cropping system	Control	FYM	MRP
Kabete	Observed	Intercrop	1.2	3.5	2.9
		Monocrop	1.3	3.6	3.0
		Crop rotation	1.6	3.7	3.3
	Simulated	Intercrop	2.2	4.6	3.3
		Monocrop	2.4	5.3	4.3
		Crop rotation	3.1	5.6	4.5
Kiserian	Observed	Intercrop	0.8	3.2	2.5
		Monocrop	0.9	3.3	2.5
		Crop rotation	1.2	3.3	2.9
	Simulated	Intercrop	2.8	4.7	3.8
		Monocrop	2.6	5.6	4.6
		Crop rotation	3.5	5.4	4.7
		Mean	1.97	4.32	3.53
		LSD $_{(p<0.5)}$	0.72	0.49	0.69

generally higher than observed yields (Figs. 4 and 5). This may be a result of crops in the field suffering from environmental stresses such as drought and pest, disease and weed infestations that may lead to reduced yields.

Figs. 6-8 show trends of rainfall, extractable soil water (esw), runoff and drainage at the trial sites during the research period. The trend shows an increase in the rainfall over the seasons and peaking in March-May of each year. Similarly esw, runoff and drainage increased with peaking rainfalls. Rainfall variability which closely correlates with esw, runoff and drainage, comparatively to the long-term average is evident in two years, some months with more and others with less. In all three seasons a tendency to water stress is expected during the maize growing period. Therefore, the impact on maize production depended on the exact amount of stress and the affected growing stage (phenology stage).

Rainfall variability is regarded as the reason for a high risk of crop failure in rain fed agriculture in Kenya [37 and 38]. Other studies realize that water related problems in rain-fed agriculture in water scarcity prone tropics are often related to high intensity and large variability of rainfall, rather than low cumulative volumes of rainfall [39], so that crops suffer from dry spells leading to loss of crops or reduced yield.

However, differences between observed and simulated yields were higher in the crop rotations and intercrops plots than the monocrop ones. This could be attributed to the beneficial effect of biological nitrogen fixation of the incorporated chickpea in both rotations and intercrops.

Table 6. Coefficient of determination (R^2) mean error (ME) and root mean square error (RMSE)

Cropping systems	Kabete	Kiserian
R^2 -Monocrop	0.186	0.264
R^2-Crop rotation	0.479	0.301
R^2-Intercrop	0.428	0.476
ME	0.625	0.947
RMSE	2.078	2.488

Kabete site generally gave higher simulated yields than Kiserian one. This can be attributed to the high soil moisture due to higher rainfall that led to increased water storage (Fig. 6). Similarly, the Kabete site had higher clay content which would have directly reduced soil moisture losses [40].

3.4 Effect of FYM and MRP on Simulated Maize Yields

Simulations of maize growth showed that farm yard manure (FYM) treatments had the highest yields followed by Minjingu rock phosphate and control. Similar results were observed in field experiments and this may be attributed to FYM treatments providing maize plants with the most limiting nutrients (Figs. 9, 10 and 11). Long term simulations showed that FYM treatments would have the highest yields followed by MRP and control at both sites (Fig. 9).

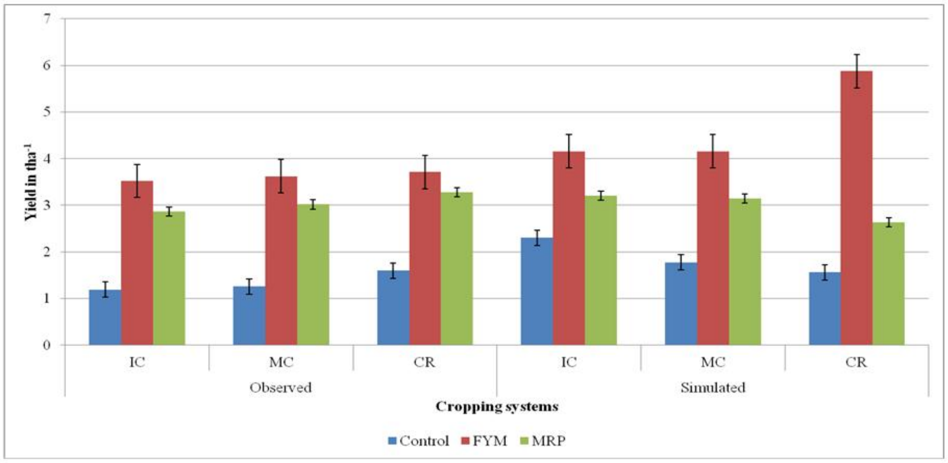

Fig. 4. Effect of inputs on observed and simulated yields in Kabete

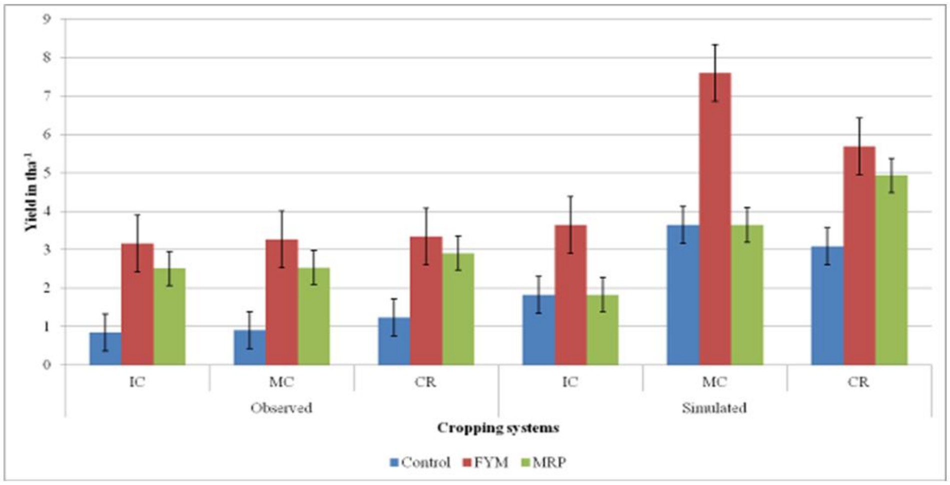

Fig. 5. Effect of inputs on observed and simulated yields in Kiserian

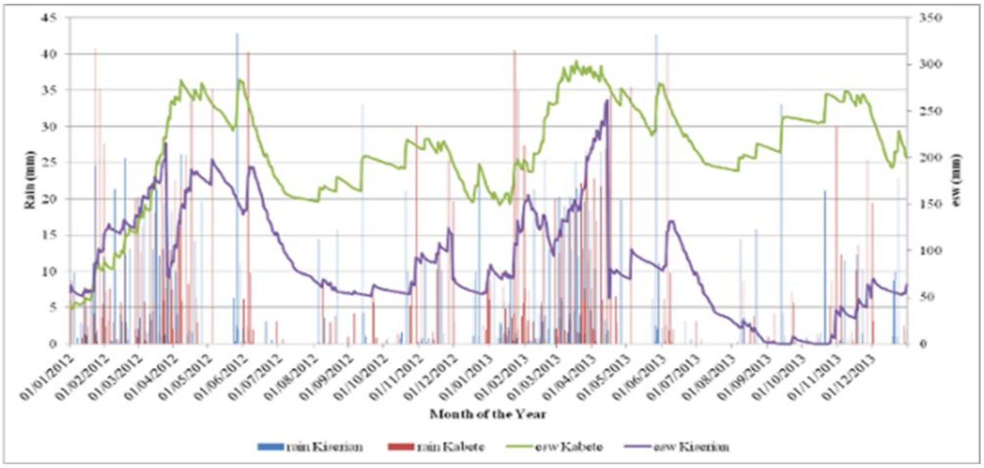

Fig. 6. Water storage in Kiserian and Kabete during trial period

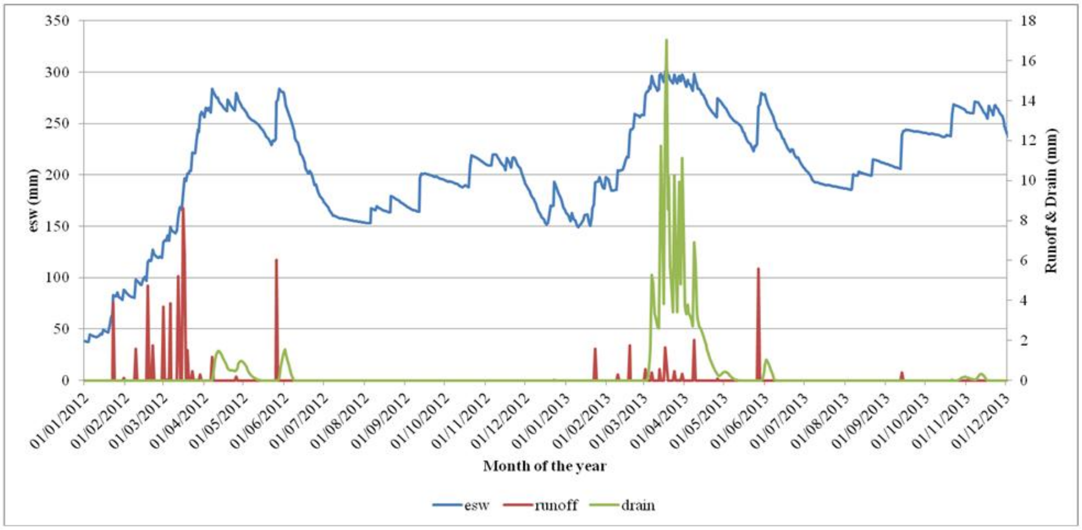

Fig. 7. Runoff, esw and drainage in Kiserian during the trial period

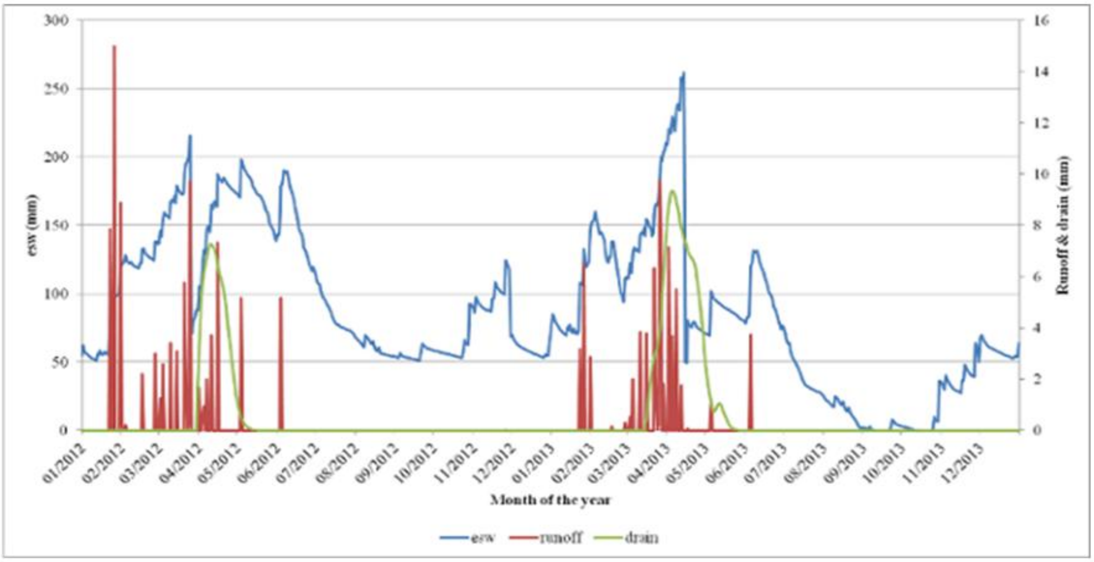

Fig. 8. Runoff, esw and drainage in Kabete during the trial period

Higher maize yields in manure-applied plots could be as a result of nutrient release through decomposition of organic matter as well as improved soil water content through reduced leaching and erosion (Figs. 10 and 11). Manure treatments at both Kabete and Kiserian had the highest soil moisture content followed by MRP and control. This can be explained by manures' ability to hold large amounts of water while reducing erosion and runoff losses [41]. Similar results were found by Micheni et al. [40] through use of APSIM in Machangi Eastern Kenya on the effects of different soil inputs on maize yields. The model was effective in simulation of effects of manure, triple super phosphate (TSP) and control on maize. TSP had the highest yields followed by manure and control attributed to differences in nutrient content of the various inputs [40]. Generally the Kabete site had higher extractable soil moisture than Kiserian one as the former had more clay than the later.

FYM-treated soils had greater simulated maize yields than the MRP treated soils (Figs. 4, 5 and 9). This is because FYM possessed higher organic carbon and nitrogen levels compared to

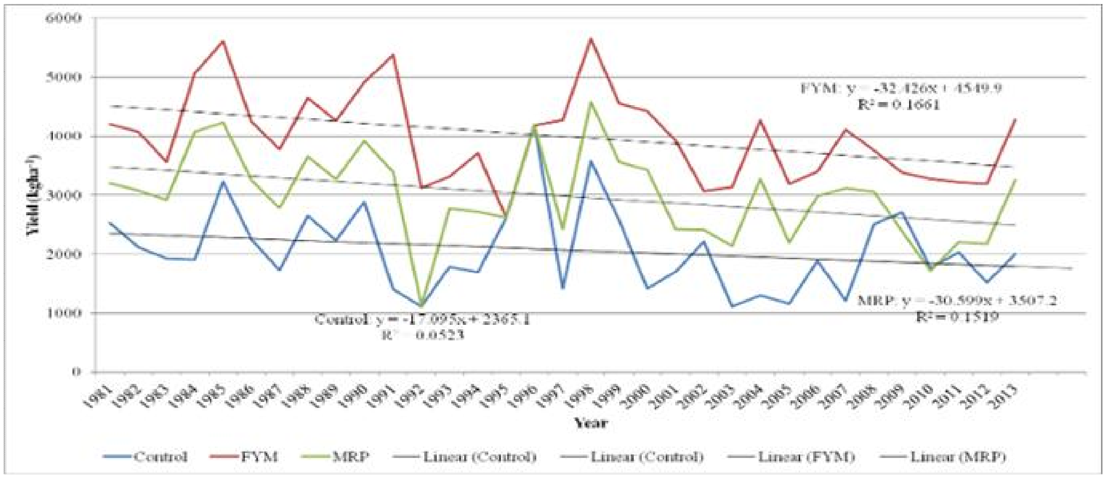

Fig. 9. Average effects of soil organic inputs on long term simulations at Kabete and Kiserian

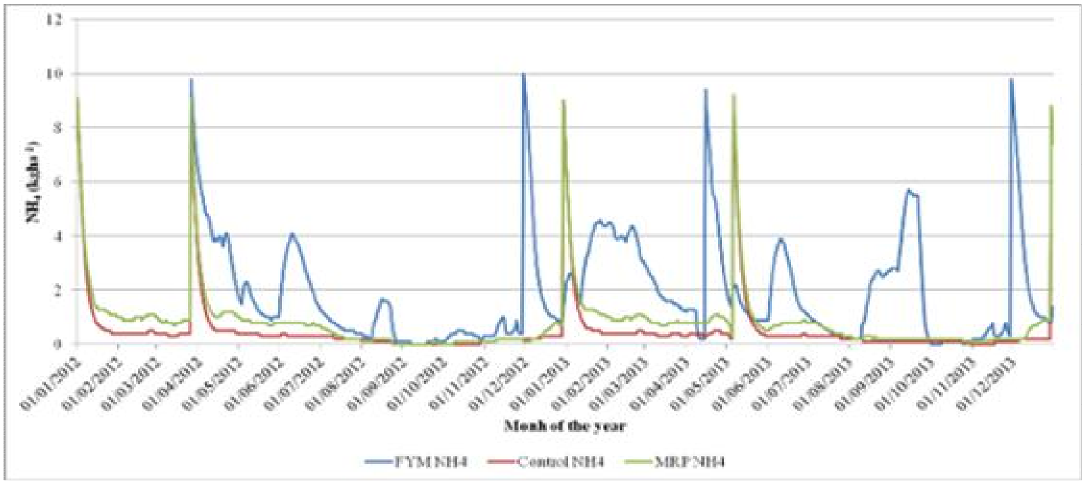

Fig. 10. Average effect of soil inputs on soil ammonia during trial period at Kabete

MRP. It also has the capacity to release NPK slowly over time. This prevents fixation of these nutrients and make them available for a longer time [42] hence greater yield. According to Chiezey and Odunze [43] FYM can increase crop production for five consecutive years. FYM was beneficial to maize by providing plant nutrients and increasing the soil's capacity to hold those nutrients and also by improving soil physical properties such as the water holding capacity and infiltration rates.

3.5 Effect of Cropping Systems on Simulated Maize Yields

Simulated maize and chickpea crop rotations and intercrops had higher yields than the maize monocrop at both sites (Figs. 4 and 5). The higher yields of maize in rotations and intercrops could be attributed to higher biomass added, which in turn could have increased the nutrients content and availability over the monocrop. This could also probably be due to *in situ* incorporation of rotated and integrated crop and its further decomposition in building organic matter content of the soil and uptake of applied nutrients by the succeeding crop leading to higher chickpea yield. This shows the higher residual effect of chickpea. These results were in agreement with the findings of [44].

3.6 Effect of Climate Change and Variability on Maize Yield

APSIM simulations showed that the reduction in rainfall by more than 10% should reduce maize yields by more than 5% (Table 7).

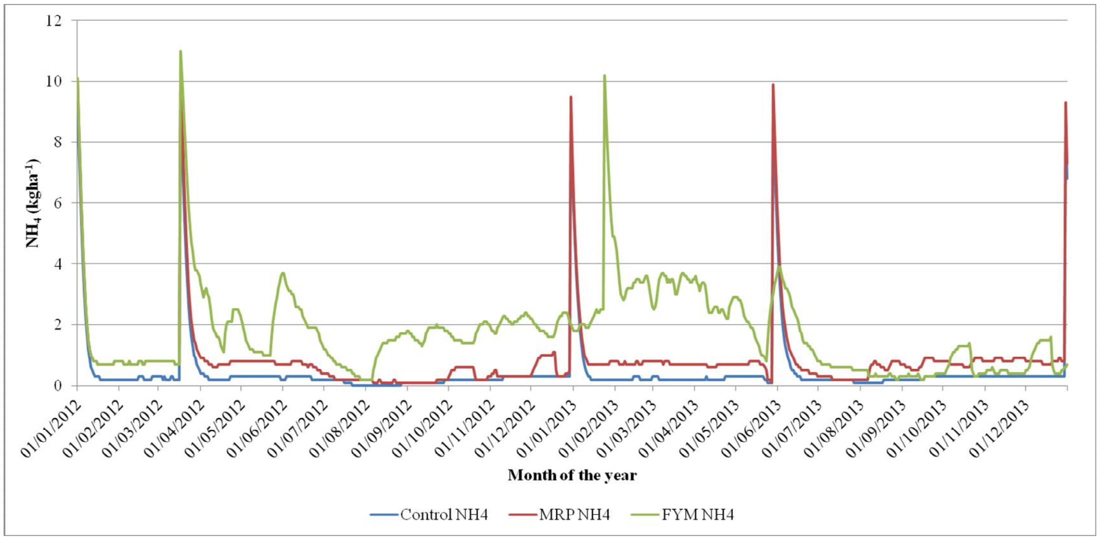

Fig. 11. Average effect of soil inputs on soil ammonia during trial period at Kiserian

Table 7. Effect of climate change on maize yields (t ha^{-1}) in Kabete and Kiserian

	Kabete						
Cropping systems	**Organic inputs**	**Base**	**-10%**	**-10;+2°C**	**-10;+3°C**	**+2°C**	**+3°C**
MC	Control	2.35	2.25	2.17	2.13	2.38	2.35
	FYM	5.24	5.13	4.72	4.90	4.82	4.79
	MRP	4.27	4.17	3.10	3.25	3.46	3.38
IC	Control	2.24	2.11	2.05	2.15	2.17	2.21
	FYM	4.65	4.53	4.46	4.39	4.50	4.39
	MRP	3.28	3.18	3.13	3.15	3.28	3.24
CR	Control	3.15	3.10	3.07	3.09	3.14	3.09
	FYM	5.57	5.45	5.41	5.32	5.42	5.37
	MRP	4.48	4.33	4.31	4.41	4.48	4.40
	Kiserian						
MC	Control	2.62	2.51	2.17	2.12	2.23	2.27
	FYM	5.59	5.41	5.28	5.16	5.70	5.37
	MRP	4.64	4.57	4.48	4.40	4.25	4.20
IC	Control	2.83	2.14	2.69	2.64	2.71	2.66
	FYM	4.68	4.42	4.36	4.43	4.64	4.26
	MRP	3.83	3.64	3.58	3.64	3.71	3.76
CR	Control	3.52	3.32	3.26	3.20	3.32	3.29
	FYM	5.37	5.27	5.18	5.12	5.27	5.15
	MRP	4.72	4.25	4.15	4.29	4.63	4.58
	Means	4.05	3.87	3.77	3.84	3.89	3.84
	LSD	0.57	0.39	0.39	0.71	0.75	0.70

MC: Monocrop, IC: Intercrop, CR: Crop rotation

Various reasons would be responsible for this yield variability and decline ranging from the erratic and poorly distributed seasonal/ annual rainfall that can be attributed to the possible effects of climate change. The observation is in line with views by McCarthy [45] who found that with reduction in rainfall APSIM showed that cereals yields such as maize and millet were bound to decrease. The decrease is caused by water deficit affecting reducing tussling [46], vegetative growth and grain yield production. Water deficit further causes reduced yields due to reduced leaf expansion [45] and reduced leaf appearance [46] consequently lowering photosynthesis. The finding of Dimes [47] was that water deficit reduced grain size by shortening duration of grain filling. Simulations showed that temperature increase caused reduction in yields. Temperature increases of 3^0C had a higher impact on yields than that of 2^0C. It can thus be concluded that an increase in temperature with changing climate is most likely to result in reduced maize productivity. High temperatures lead to low yields due to increased crop physiological maturity that shortens crop development stages [47]. This in turn leads to reduced harvesting index and crop cycle leading to reduced yields. Others reported effects of increased temperatures on crop yields are caused by the reduced rates of photosynthesis, reduced grain filling and early maturity [48].

3.7 Farmers' Perceptions of Climate Change and Variability

In the results of the survey carried in section 4.0, most farmers (80%) attributed reduced crop yields and/or crop failure to impacts of climate change and variability on agricultural productivity. Additionally, about 8% of the interviewed farmers indicated change in planting time and 6% mentioned increased crop pest and disease attack as other impacts of climate change and variability. These impacts lead to a decline in farm production affecting incomes and food security. This exacerbates hunger and poverty, contrary to the aspirations of the Millennium Development Goals (MDGs) of halving extreme hunger and poverty by 2015 [32]. These observations imply that the more dependent a person is on agriculture as a source of income the greater the sensitivity of one to climate related changes. This observation is also in agreement with [49] who noted that the more one is likely to be affected by a given factor, the higher the attention is given to it. The high rating of climate change by farmers who depended on farming solely as their source of income is therefore attributable to the fact that any factor, in this case climate change, that lowers crop production poses a threat to their livelihood and hence considers as a serious risk.

4. CONCLUSION

The survey showed that farmers are aware of climate change and its impacts on their agricultural productivity. With the expected climate change and variability, the simulated results will be significant in ensuring that the farmers can overcome challenges brought about by increasing temperatures and reducing rainfall. This study has also shown that APSIM is capable of simulating the low yield levels and inter-seasonal variability observed in areas of central Kenya. In the simulations, rotation cropping system coupled with the use of farmyard manure realises better yields as well as improves soil nutrients. Increases in rainfall and temperature regimes only were translated into decreased maize yields. The study has also shown that maize yield losses under changing climate elements will be severe in the future. However, use of legume-integrated cropping systems, as well as organic inputs, demonstrated a positive potential in reversing the losses. Considering the effect of climate changes on maize yields as shown in Table 7, it is appropriate to consider management strategies such as cropping systems and use of organic inputs that ensure sustainable agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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