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Predicting the Impacts of Climate Change Scenarios on Maize Yield in The Cattle Corridor of Central Uganda

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Abstract: Anomalies in air temperature and shift in rainfall patterns brought about by climate change are likely to impact agricultural production systems both directly and indirectly. In addition to the direct effect of climate on crop growth and development, weather also affects other processes that may impact on agricultural production systems as a whole. In this study crop-environment resource synthesis (CERES) simulation model was used to examine the relationship between maize yield and changes in weather and climate. Two contrasting maize cultivars i.e., Longe 5 (low yielding) and Longe 9 (high yielding) and other related factors were used to forecast future yield using projected climates. Two future temporal scales i.e., near future (2021-2050) and mid century (2051-2080) and seasons i.e., season one (starting from March) and two (starting from September). The study was conducted in the Central Uganda cattle corridor districts of Nakaseke and Nakasongola. Overall future maize yield is projected to reduce by 5-50% in the near future and by 10-60% in mid century climate period compared to the base climate period of 1980-2010. However, early planting in both seasons potentially can alleviate the yield reductions by about 5%, and should recommend for maize production in the studied area.

Keywords: Crop simulation; crop production; climate change; trend analysis.

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1 Introduction

Climate change and variability are key global challenges that affect agricultural production, food security and livelihoods in Africa (Adenle et al., 2017; Gebreyes et al., 2017; Tumushabe, 2018; Weber et al., 2018). Recent literature has highlighted that global warming is unequivocal, and while some areas are likely to benefit from increasing temperatures, others will suffer significant losses. In the East African region, the current climate variability is mainly manifested as frequent droughts, floods, heat waves, and erratic unreliable rainfall; mainly attributed to the Sea Surface Temperatures (SSTs) especially in the tropical Pacific Ocean and the Indian Ocean (Darand et al., 2017; Endris et al., 2018; Funk et al., 2012; Nicholson et al., 2013; Nicholson, 2015; Ogwang et al., 2016; Ongoma and Chen, 2017; Sonwa et al., 2017). Climate variability is likely to cause increased food insecurity, shifts in the spread of diseases like malaria, crop failure, loss of livestock, increased soil erosion among others (Thornton, et al., 2009). Future projections from Coupled Model Intercomparison Project Phase 5 (CMIP5) indicate that mean near surface temperature in the East African region are likely to increase by 2°C – 3°C by the end of the 21st century compared to the 1981-2010 average (Anyah and Qiu, 2012; Otieno and Anyah, 2013, Ongoma et al.,2018). Similar trends have been reported at national level with Ugandan temperatures projected to be warmer by 1.0 to 3.1°C (2060s) and 1.4 to 4.9°C (2090s) relative to the 1970- 1999 average (Nimusiima et al., 2014). Projections for rainfall show that mean annual precipitation is expected to increase with an ensemble of the models predicting a range of -20 to +46% by the 2090s compared to the 1970-1999 average (Nimusiima et al., 2014). The projected anomalies in future climate are likely to led to lower yields in many crops mainly through reduced growing season length, increased water stress and increased attack of diseases and pests (Adhikari et al., 2015; Amin et al., 2018; Niang et al., 2014; Rehmani et al., 2014).

The expected changes in air temperature and shifting pattern of rainfall brought about by climate change are likely to impact agricultural production system (Niang et al., 2014; Rehmani et al., 2014). In addition to the direct effect of climate on crop growth and development, weather also influences other process that may impact agricultural production system as a whole (Adhikari et al., 2015). For example, farm practices such as land preparation, sowing, fertilizer application, and harvesting are highly weather dependent. Occurrence of crop pest and diseases is also climate driven. Therefore, changes in natural state and patterns of weather will also translate into changes on the above mentioned processes that are involved in agricultural production systems (Niang et al., 2014).

Climate change may be beneficial to the growth of crops. For example, increased atmospheric carbon dioxide concentration may facilitate the photosynthesis process which increases the crop yields (Morison and Lawler, 1999, Kimball et al., 2002). However, increase in the benefits of the photosynthesis process is counteracted by other factors that arise, including increased temperatures leading to increased evaporation and loss of soil moisture, pest and disease outbreaks as well as frequent and intensive extreme weather events which have detrimental effects on crop yields (Morison and Lawler, 1999; Long,et al., 2004).

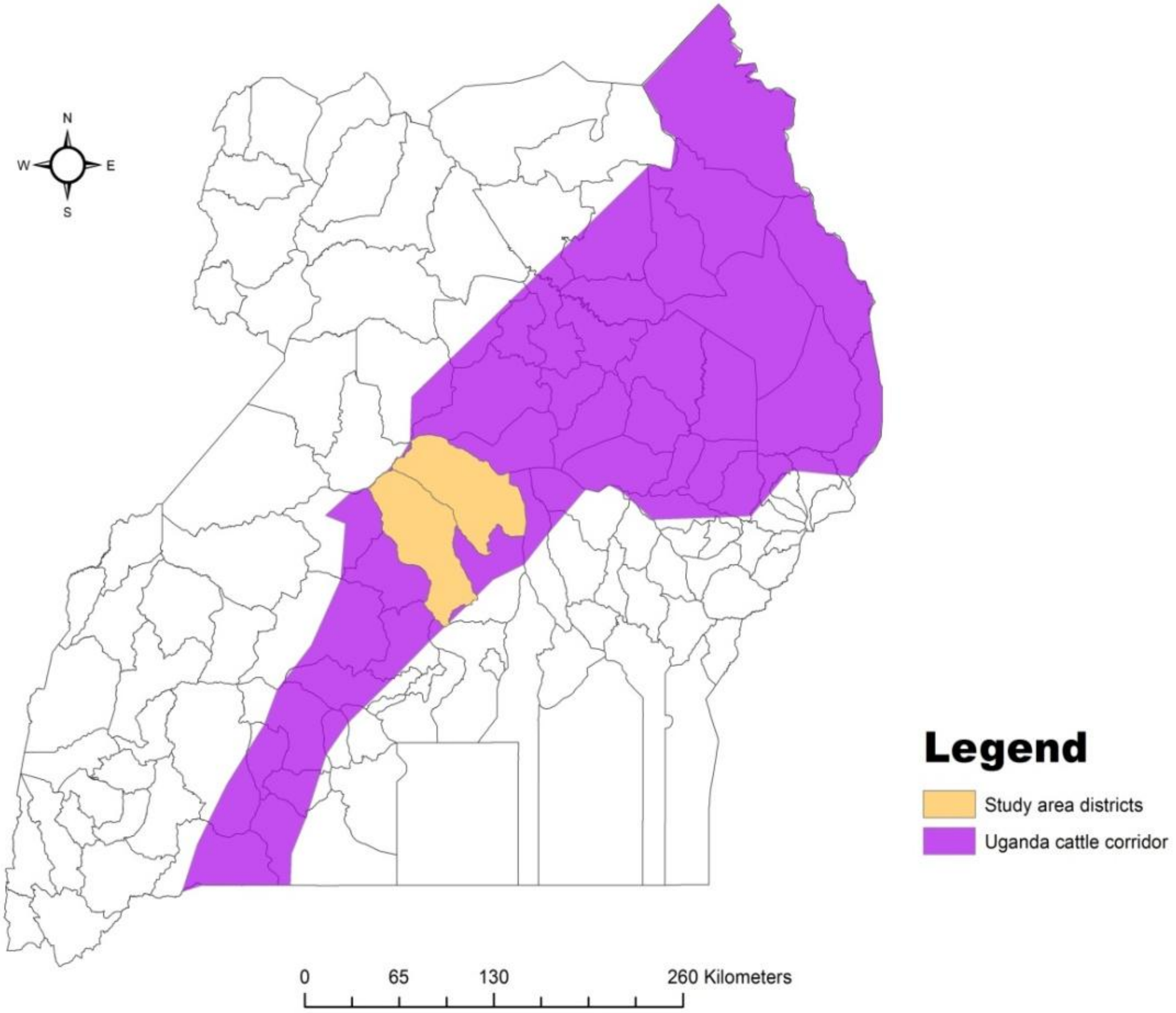

Fig. 1. The Uganda cattle corridor and the study area districts.

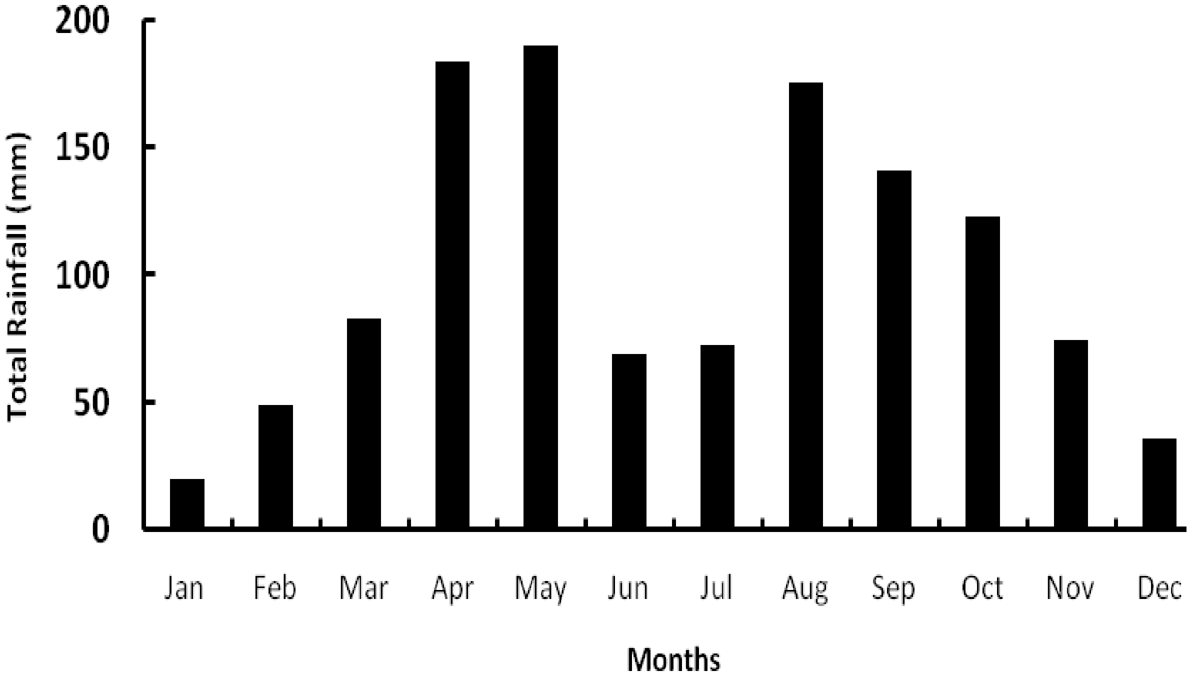

Fig. 2. Long term averages of monthly rainfall distribution over Cattle Corridor of Uganda (1961 to 2010).

Globally, maize is ranked third largest crop grown and is a major food, therefore key to food security in many countries especially in Sub-Sahara Africa (SSA) (Jaleta et al., 2018; Kassie et al., 2014; Shiferaw et al., 2011; Wei et al., 2017). In Sub-Saharan Africa (SSA), it is grown on about 40% of the entire cropland and is a key source of livelihood (Adhikari et al., 2015). In Uganda, maize is one of the most important and highly cultivated crops (UBOS, 2015). Statistics from the 2008-09 Uganda Census of Agriculture (UCA) show that maize was occupied an estimated 1.01 million ha cultivable land and producing 2,743 million tonnes of maize grain (UBOS, 2015). Despite the contributions of agriculture to Gross Domestic Product (GDP) the crop yields in the region are still low as compared to the global average mainly due to anomalous rainfall distribution across the crop seasons (Barron et al., 2013; Adhikari et al., 2015).

Maize is susceptible to anomalies in environment or changing climatic conditions (Ahmad et al., 2015; Shekoofa and Choudhary. 2017; Siebers et al., 2017; Lobell et al., 2011; Zalud et al., 2017). Numerous studies across the globe have investigated potential impact of changing climate on maize growth and yield using various crop simulation models (Basso et al., 2016; Meng et al., 2016;; Peng et al., 2018; Rahimi-Moghaddam et al., 2018; Sheng et al., 2018; Tebaldi and Lobell, 2018; Wang et al., 2018). Thus this study employed a crop simulation model (CERES) to examine the relationship between maize yields and changes in climate and other related factors in order to forecast possible projected future yield.

2. Data and Methodology

2.1 Study Area

The study was conducted in Nakaseke and Nakasongola Districts, located in the central cattle corridor region, stretching from the south west to the north eastern part of Uganda (Fig. 1). The cattle corridor is experiencing contrasting aspects of climate change including prolonged droughts, floods due to shifting rainfall pattern (Nimusiima el al., 2013).

The cattle corridor has traditionally been known for livestock grazing but the land use changes are rapidly changing with more land being opened up for crop farming especially for maize production in the Nakasongola and Nakaseke districts. Bi-modal rainfall distribution prevails in regions with the first rainy season extends from March to June second rainy season extending from late August or early September to November-December (Ogwang et al., 2016) (Fig. 2). Annually daily minimum and maximum temperatures in the region ranged between 18 ^{o}C to 25 ^{o}C and 25 ^{o}C to 35 ^{o}C, respectively.

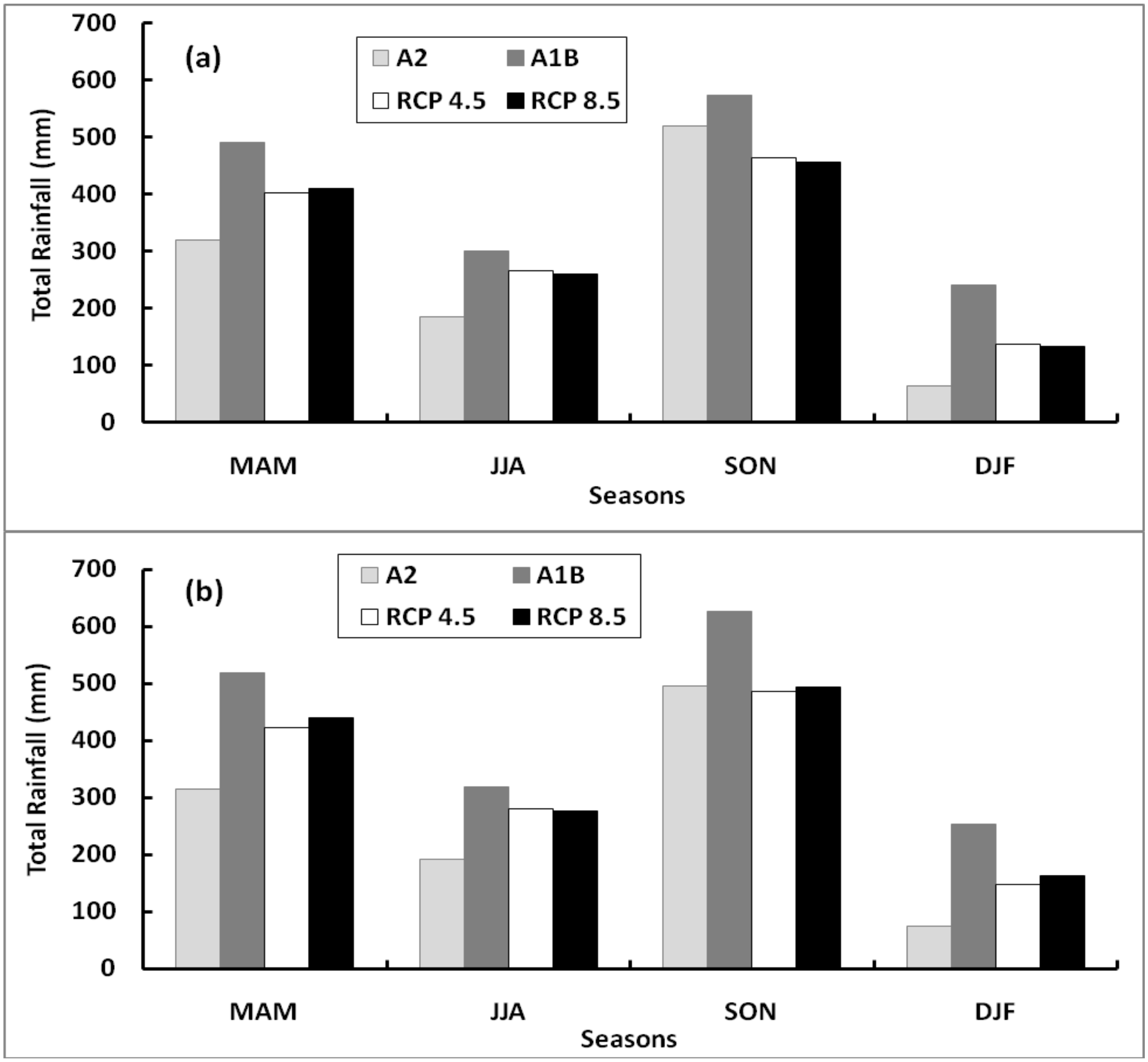

Fig. 3. Seasonal rainfall projections under SRES scenarios and RCPs for the near future (a, 2021-2050) and mid-century (b, 2051-2080). (Adopted from Nimusiima et al., 2014). MAM, March-April-May; JJA, June-July-August; SON, September-October-November; DJF, December-January-February.

2.2. CERES Model

The CERES-Maize (crop-environment resource synthesis) model is part of the Decision Support Systems for Agro-technology Transfer (DSSAT) Version 4.6 models (Hoogenboom et al., 2010) and used to simulate crop growth and yield of maize (Amouzou et al., 2018; de Oliveira et al., 2018; Liu et al., 2011; MacCarthy et al., 2018). DSSAT has a total of 25 model configurations for simulating growth of various crops including cereals and legumes. The CERES-Maize model simulates daily growth and phonological development under varying environmental conditions (soils, weather and management) (Chen et al., 2017; Hammad et al., 2018; Ma et al., 2017; MacCarthy et al., 2017).

The CERES maize model is the most widely used maize model and has been tested in different places across the globe simulating yield within acceptable error limits (Bechir et al., 2000; Asadi and Clemente, 2003; Babel and Turyatunga, 2015). The CERES model was calibrated, validated using experimental data and used to simulate future maize yield for four climate scenarios i.e., A2 and A1B SRES (Special Report on Emission Scenarios) and RCP4.5 and 8.5 (Representative Concentration Pathways) for the near future (2021-2050) and mid-century (2051-2080) climate periods.

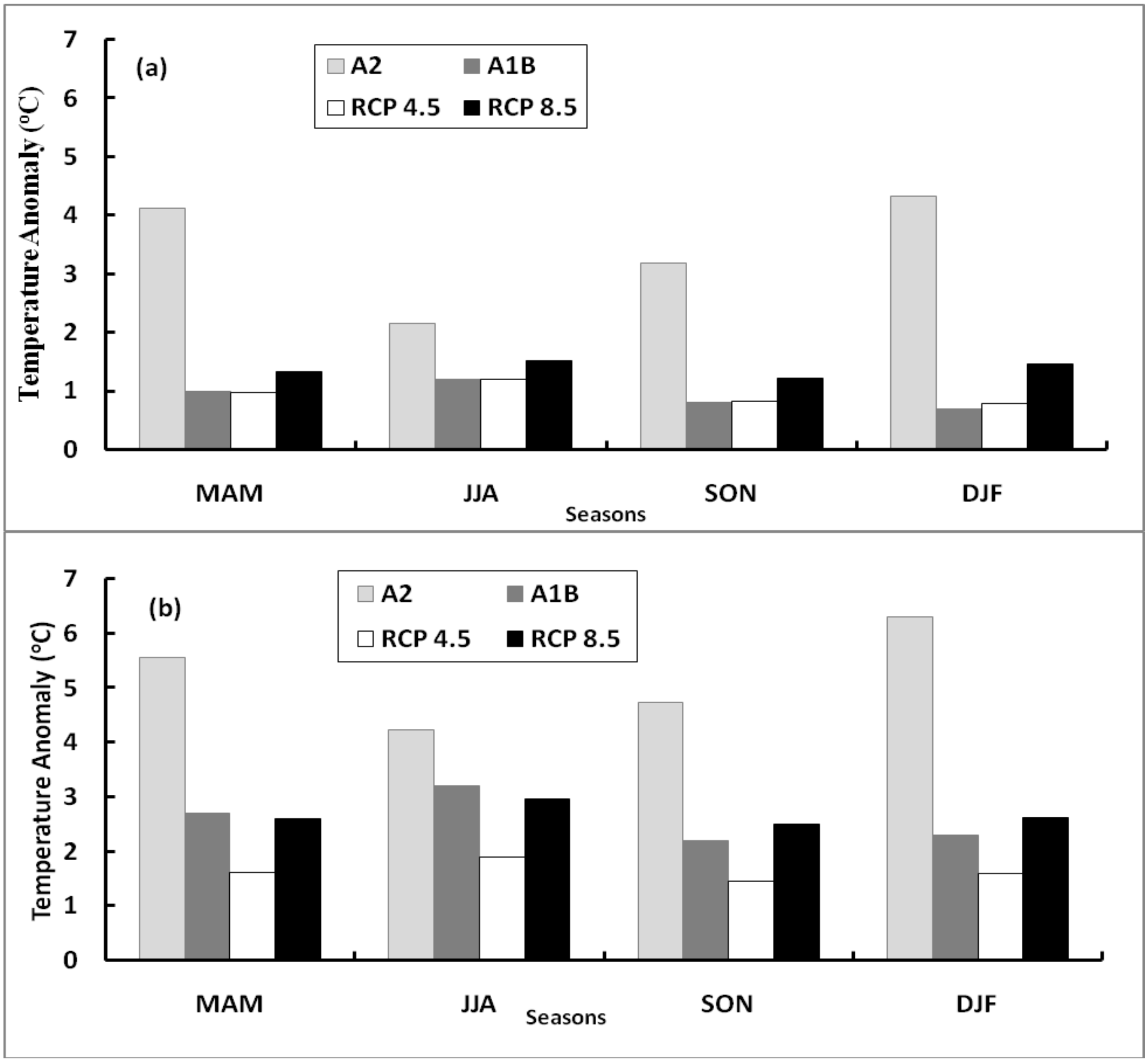

Fig. 4. Seasonal temperature projections under SRES scenarios and RCPs for the near future (a, 2021-2050) and mid-century (b, 2051-2080). (Adopted from Nimusiima et al., 2014). MAM, March-April-May; JJA, June-July-August; SON, September-October-November; DJF, December-January-February.

2.3. Data

2.3.1. Climate Data

This consisted of daily projected values of rainfall, maximum and minimum temperature as well as solar radiation. This data was obtained from Nimusiima et al., (2014). Data consisted of SRES A1B and A2 as well as the recent CMIP5 projections for RCP 4.5 (medium scenario) and RCP 8.5 (high scenario). The seasonal summaries of rainfall and temperature are shown in Fig. 3 and 4 respectively extracted from Nimusiima et al., (2014).

2.3.2 Crop Data

Experimental data used for calibration and validation of the CERES crop model include yield data for contrasting maize cultivars Longe 5 (low yielding) and Longe 9 (high yielding), obtained from experiments conducted at Namulonge by Kaizzi et al., (2012). Validation of model outputs was done using data of the two varieties from National Agricultural Research Laboratories, Kawanda (NARL). The experiments were conducted in the two rainy seasons of 2010. The experimental, design and management practices are briefly described earlier (Kaizzi et al., 2012).

2.3.3 Soil Data

Two experiments sites namely Butalangu (Nakaseke district) and Wabigalo (Nakasongola district) were chosen for the experiment. From these two sites, two points – one from each were randomly selected for sampling. In order to expose the different horizons of the soil profile, soil profile was exposed by digging a 1.5m^2 wide and deep pits. By the help of a tape measure, 5 depths of 0-10cm, 10-20cm, 20-30cm, 33-40cm and 40-50cm were marked. It is from within these depths that the soil samples were taken. To avoid cross contamination during sampling, soil samples were picked in a descending order starting with the deeper layer (40-50cm). Two sets of samples were taken – one using soil cores for the determination of the physical parameters (Soil bulk density, field capacity, wilting point and saturation point) and another set for the chemical properties including (pH, Organic matter, Nitrogen, Phosphorus, Potassium and Calcium). The soil profiles were assumed to remain the same in future projections with only climate varying.

2.4 Data Analysis

The calibrated CERES model was run with climate data obtained from earlier studies of (Nimusiima et al., 2014) for the two contrasting maize cultivars Longe 5 and Longe 9 at two location sites in Nakasongola and Nakaseke districts. Other model inputs like the soil properties and management were obtained from the experimental sites. The planting date of 8th March was adopted for the first season as it was found through model simulations to give maximum maize yield in all the scenarios. For the second season the planting date of 15th August was adapted in the future simulations since it also produced highest maize yield across the scenarios.

Crop model simulations were run for the two future climate periods and for the two maize varieties. Assumptions on soil properties as well as management practices were made where it was assumed that in future the soils would not change much from the current state. The only variable that was changed in the simulations was climate parameters obtained from the climate scenarios.

After running the model simulation results were exported to excel from where further analysis was conducting using R programming to obtain box plots and charts for the various yield components in the study area. The analysis involved comparing simulation yield of the two varieties i.e., Longe 5 (low yielding) and Longe 9 (high yielding) using different climate scenarios for the climatic periods i.e., near future (2021-2050) and mid-century (2051-2080). Further analysis was done on the projected yield in relation to the optimum yield that is expected for each of the varieties across the climate scenarios from which bar graphs were generated.

2.4.1 Soil Data Analysis

The Tables 1 and 2 show the results of the soil analysis from the samples that were collected at the field stations before the beginning of season one in the year 2013.

Table 1. Chemical Properties of the Soil Samples

Lab No	Particulars	pH	Organic Matter	Nitrogen	Available Phosphorus	Calcium	Potassium
			(%)		mg kg^{-1}	C.moles kg^{-1}	
D_1	Nakaseke 0-10cm	7.2	2.75	0.10	49.07	6.18	1.05
D_2	Nakaseke 10-20cm	7.1	1.14	0.08	28.49	4.06	0.73
D_3	Nakaseke 20-30cm	7.0	1.01	0.08	26.81	4.06	0.63
D_4	Nakaseke 30-40cm	6.7	0.87	0.08	13.3	3.42	0.53
D_5	Nakaseke 40-50cm	6.4	0.68	0.05	4.83	2.03	0.34
D_6	Nakasongola 0-10cm	5.2	3.69	0.13	1.05	2.40	0.27
D_7	Nakasongola 10-20cm	5.1	2.61	0.13	0.70	1.75	0.25
D_8	Nakasongola 20-30cm	4.8	2.35	0.13	0.56	1.66	0.25
D_9	Nakasongola 30-40cm	4.8	2.35	0.13	0.56	1.75	0.19
D_{10}	Nakasongola 40-50cm	4.8	1.81	0.13	0.53	1.66	0.17

Table 2. Soil Physical Properties at the Experimental Sites

Sample Details	Field Capacity (%)	Wilting Point (%)	Saturation Point (%)	Bulk Density (g cm^{-3})
Nakasongola 0-10cm	35.4	25.0	57.4	1.14
Nakasongola 10-20cm	37.9	28.1	55.9	1.17
Nakasongola 20-30cm	30.0	15.9	52.3	1.30
Nakasongola 30-40cm	44.5	31.9	57.0	1.16
Nakasongola 40-50cm	40.6	30.4	55.0	1.19
Nakaseke 0-10cm	22.6	10.4	46.9	1.41
Nakaseke 10-20cm	18.0	9.0	41.6	1.41
Nakaseke 20-30cm	17.7	8.9	41.2	1.59
Nakaseke 30-40cm	16.7	7.9	39.7	1.50
Nakaseke 40-50cm	29.9	10.9	47.9	1.58

2.4.2 Calibration

The model parameter coefficients were derived after adjusting existing varieties typical of tropical conditions and also by manipulating various growth parameters until the simulated phonology and yields matched the observed yield. Models were run and relationship between the observed and simulated was demonstrated using observed and simulated days to flowering, days to maturity, stover and grain yield (Kaizzi et al., 2012). Table 3 shows the genetic characteristics after calibration.

P1 = Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 °C) during which the plant is not responsive to changes in photoperiod. P2=Is the extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours. P5= is the Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 °C). G2 = Maximum possible number of kernels per plant. G3 = is the Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day). PHINT is the Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

3. Results

3.1. Projected Yield

This section summarizes the projections results for the two sites (Nakaseke and Nakasongola) as well as the two maize varieties were considered in this simulation (Longe 5 and Longe 9). The soil properties as well as the management practices were assumed to remain the same at the experimental sites in both near and midcentury climate periods in the simulations.

3.1.1 Seasonal projections

Projections for the two seasons have been analyzed in both climate periods of near future and mid century. Presentations are given for each of the sites and for each crop variety with a compulsion across the scenarios in the two climate periods.

3.1.1.1. Nakasongola Site

For the first season in the near future, cultivar Longe 5 yield projections range from the minimum of 2150 kg ha^{-1} (A2 scenario) to 3740 kg ha^{-1} (RCP8.5 scenario) with a mean of 3040kg ha^{-1} for all scenarios (Fig. 5).

Table 3: The CERES Model calibration coefficients

ID	Cultivar	P1	P2	P5	G2	G3	PHINT
IC0005	Longe 5	200.8	0.500	508.5	450.0	10.50	45.60
IC0006	Longe 9	2008.6	0.500	554.0	460.0	10.50	45.00

P1, Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 °C) during which the plant is not responsive to changes in photoperiod. G3 is the Kernel filling rate during the linear grain filling stage. G2 is the Maximum possible number of kernels per plant. P2 is the extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod. P5 is the Thermal time from silking to physiological maturity. PHINT is the Phylochron interval as thermal time (degree days) between successive leaf tip appearances.

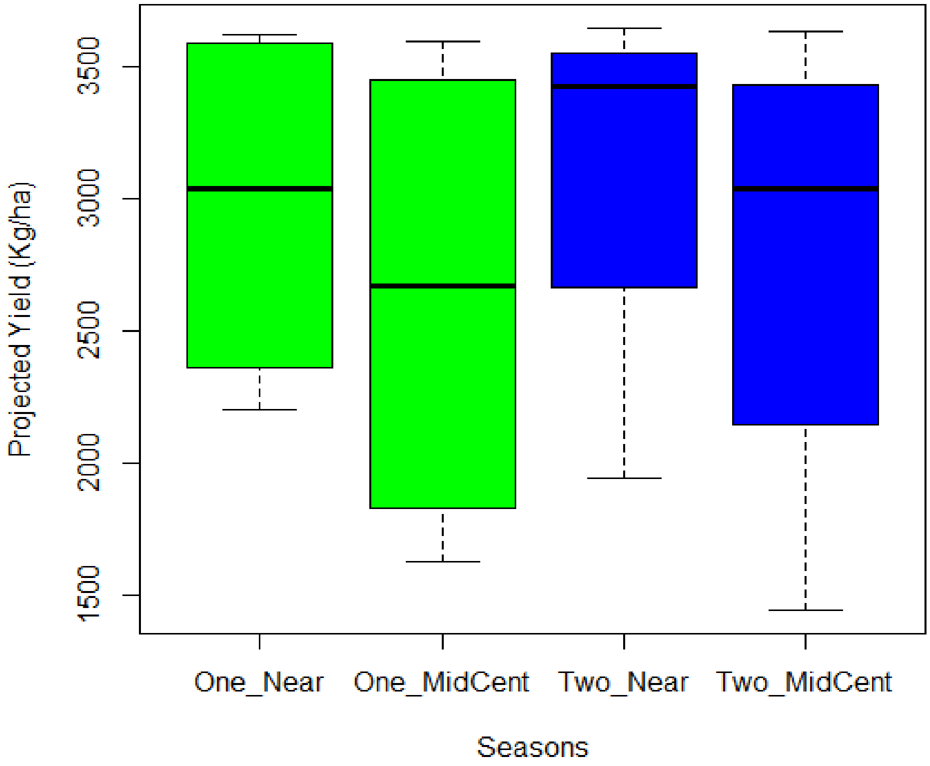

Fig. 5. Projected maize yield for Nakasongola in both seasons for the near future and mid-century climate periods using cultivar Longe 5. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010. Green, Season one (starting from March); Blue, Season two (Starting from September).

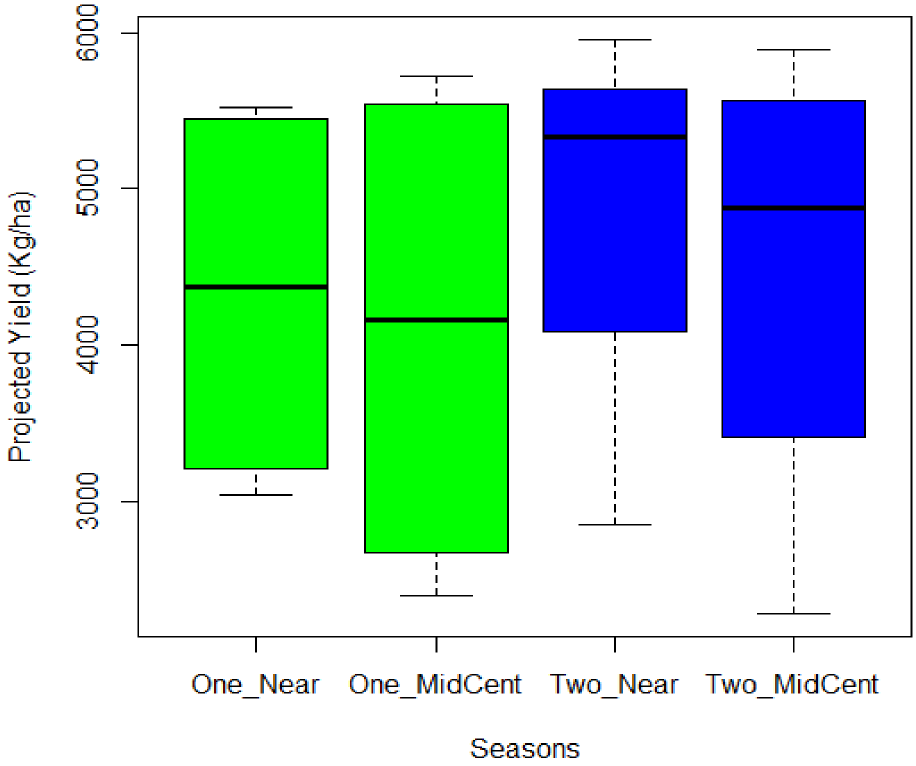

Fig. 6. Projected maize yield for Nakasongola in both seasons for the near future and Mid-century climate periods using cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010. Green, Season one (starting from March); Blue, Season two (Starting from September).

In the mid century however the first season yields are much variable across the scenarios with the minimum for A2 as 1670 kg ha^{-1} and the maximum from RCP 4.5 of 3690 kg ha^{-1} with a mean of 2700 kg ha^{-1} (Fig. 5). For the second season and near future scenario a minimum of 2000 kg ha^{-1} (A2 scenario) and a maximum of 3760 kg ha^{-1} (RCP4.5 scenario) with a mean of 3200 kg ha^{-1} for all scenarios (Fig. 5). The second season of the mid century period is much more variable than the near future with a minimum of 1500 kg ha^{-1} (A2 scenario) and a maximum of 3700 kg ha^{-1} (RCP4.5 scenario) with a mean predicted yield of 2860 kg ha^{-1} for all scenarios. For the first season in the near future, yield prediction for maize cultivar Longe 9 ranged from the minimum of 2990 kg ha^{-1} (A2 scenario) to 5740 kg ha^{-1} (RCP8.5 scenario) with a mean of 4450 kg ha^{-1} for all scenarios (Fig 6). In the mid century however the first season yields are much variable across the scenarios with the minimum yield of 2420 kg ha^{-1} (A2 scenario) and the maximum yield of 5900 kg ha^{-1} (RCP4.5 scenario) with a mean of 4230 kg ha^{-1}. The second season near future a minimum maize yield is predicted to be 2910 kg ha^{-1} (A2 scenario), whereas maximum 6160 kg ha^{-1} yield is predicted (RCP4.5 scenario) with a mean yield prediction of 5090 kg ha^{-1} for all scenarios (Fig 6).

Simulation results predicted more variability for the second season and mid century period as compared to the near future, predicted yield varies from 2400 kg ha^{-1} (A2 scenario) to 6055 kg ha^{-1} (RCP4.5 scenario) with an overall average yield prediction of 4620 kg ha^{-1} for all scenarios. Maize cultivar Longe 9 (high yielding) is projected to produce higher yields consistently in all the scenarios for both seasons and climate periods. From the projections of both crop varieties maize yields are projected to decrease from the near future to the far future in all scenarios for both seasons. The yields for the second season are slightly higher than those for season one in all scenarios for both crop varieties. In both crop varieties and for the mid-century climate period yield predictions are more variable than predictions for the near future yields (Fig. 5 and 6).

3.1.1.2 Nakaseke Site

For the first season in the near future, yield projections for cultivar Longe 5 ranged from the minimum of 2480 kg ha^{-1} (A2 scenario) to 4200 kg ha^{-1} (RCP4.5 scenario) with an overall mean of 3520 kg ha^{-1} for all scenarios (Fig 7). Yield predictions for the mid century and first season are much variable across the scenarios with the minimum yield prediction of 1750 kg ha^{-1} (A2 scenario) and the maximum (RCP 4.5) of 4100 kg ha^{-1}. Overall mean yield prediction for first season of maize remained 3060 kg ha^{-1} for all scenarios for mid century temporal scale (Fig 7). For second maize season and near future temporal scale maize yield predicted ranged from 2420 kg ha^{-1} (A2 scenario) to 4180 kg ha^{-1} (RCP4.5 scenario) with a mean prediction of 3570 kg ha^{-1} for all scenarios (Fig 7). Yield prediction for the second season and mid century period is much more variable than the near future prediction for the same season. Maize yield predicted ranged from 1770 kg ha^{-1} (A2 scenario) to 4030 kg ha^{-1} (RCP4.5 scenario) with a mean predicted yield of 3130 kg ha^{-1}.

For the first season in the near future, yield projections for cultivar Longe 9 ranged from 3760 kg ha^{-1} (A2 scenario) to 6670 kg ha^{-1} (RCP4.5 scenario) with a mean of 5350 kg ha^{-1} for all scenarios (Fig 8). In the mid century period (2051-2080) however the first season yields are much variable across the scenarios with the minimum yield prediction of 2740 kg ha^{-1} (A2 scenario) and the maximum yield prediction of 6560 kg ha^{-1} (RCP 4.5 scenario) with a mean of 4850 kg ha^{-1} (Fig 8). For the second season and near future climate period simulation predicted maize yield from 3600 kg ha^{-1} (A2 scenario) to 6760 kg ha^{-1} (RCP4.5 scenario) with a mean of 3640 kg ha^{-1} for all scenarios (Fig 8). The second season of the mid century period is likely to be more variable than the near future with yield prediction ranging from 2890 kg ha^{-1} (A2 scenario) to 6620 kg ha^{-1} (RCP4.5 scenario) with a mean of 5100 kg ha^{-1} for all scenarios (Fig 7 and Fig 8).

3.2 Projections Relative to the 1981-2010 Average

Simulations were also run using climate baseline data for the period 1981-2010 and were compared with the future projections at each site and for each variety. In general all projections show a decrease in yield with the SRES projecting a much lower yield compared to the RCPs in both climate periods across all the sites and in both varieties. Projections showed a decrease in projected yields in all the scenarios for both climate periods. However the SRES A2 and A1B show much greater decreases in yield of 40-60% in the two climate periods compared the new RCPs of 4.5 and 8.5 which predict decreases of between 10 and 20 % for the same period. Projections for low yielding variety (Longe 5) are slightly lower than those of high yielding cultivar (Longe 9) in both climate periods.

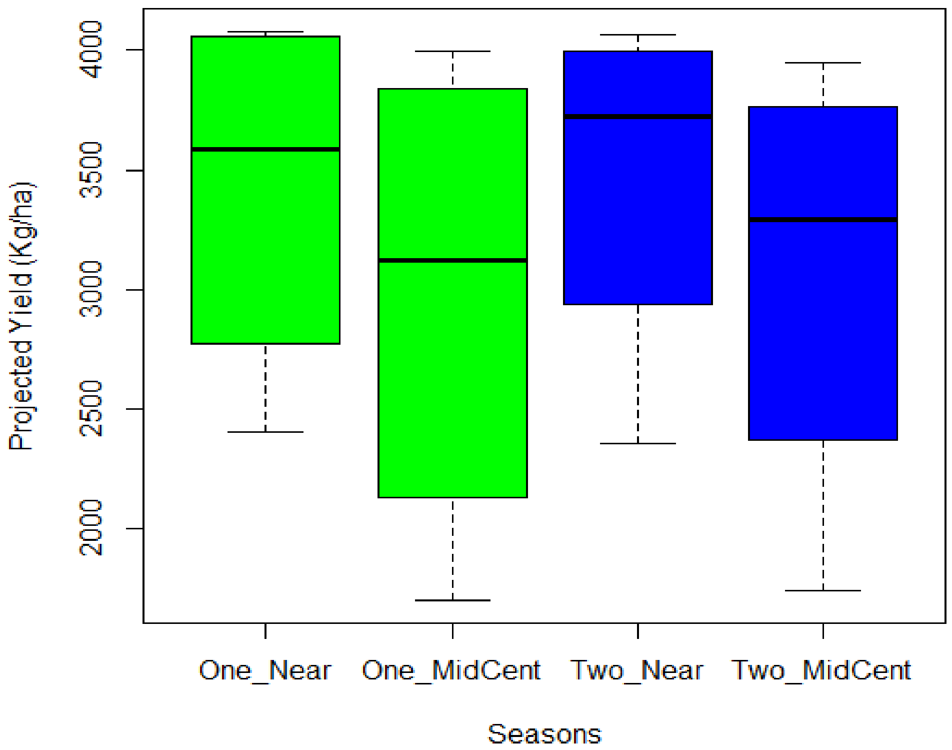

Fig. 7. Projected maize yield for Nakaseke in both seasons for the near future and Mid-century climate periods using cultivar Longe 5. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010. Green, Season one (starting from March); Blue, Season two (Starting from September).

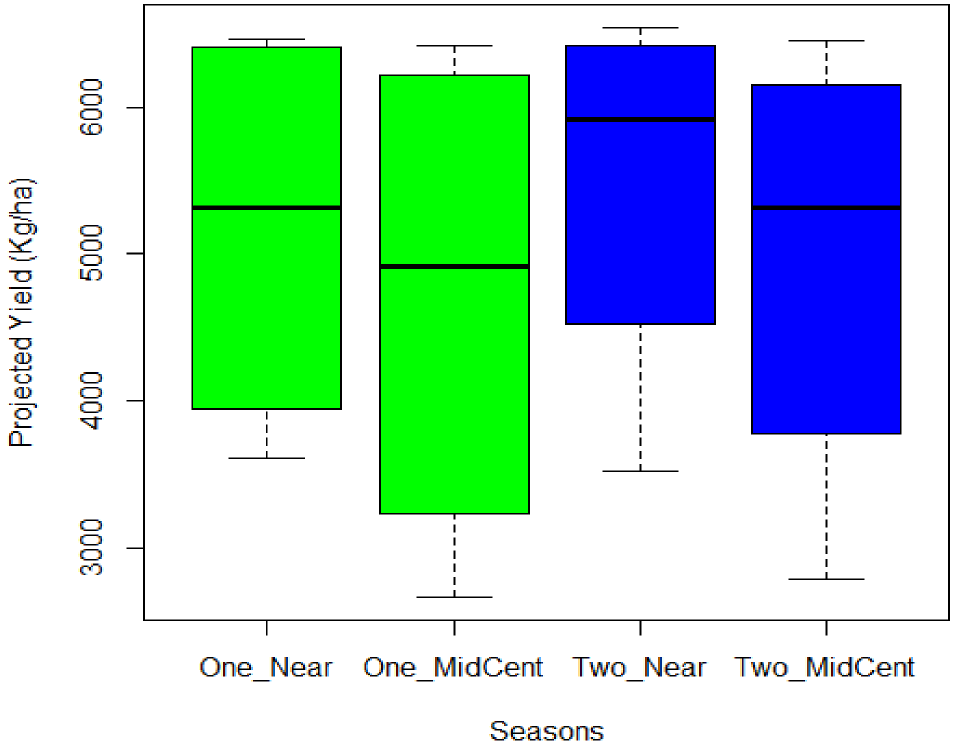

Fig. 8. Projected maize yield for Nakaseke in both seasons for the near future and Mid-century climate periods, using cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010. Green, Season one (starting from March); Blue, Season two (Starting from September).

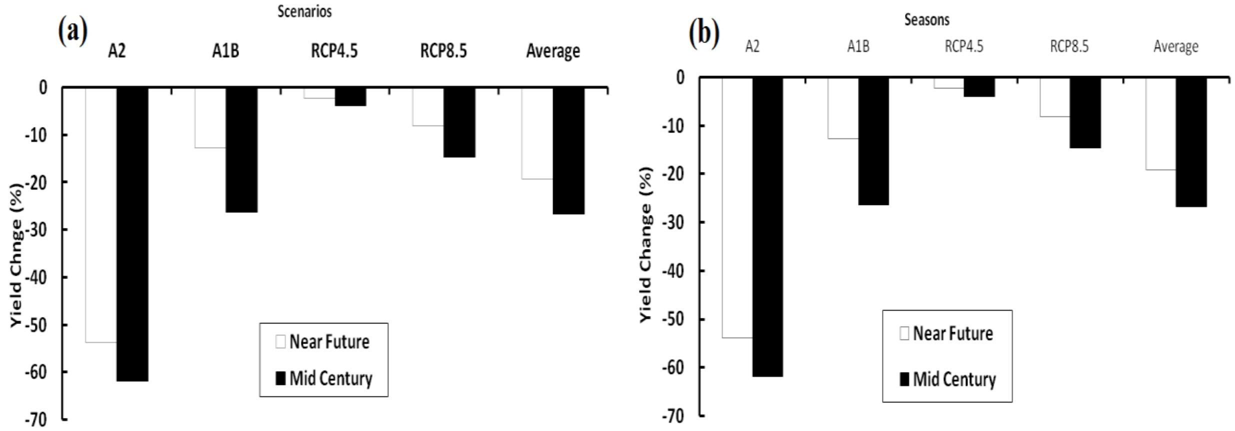

Fig. 9. Changes in maize yield at Nakasongola for different emission scenarios and temporal scales average for season one (Starting from March). (a) cultivar Longe 5 (b) cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010.

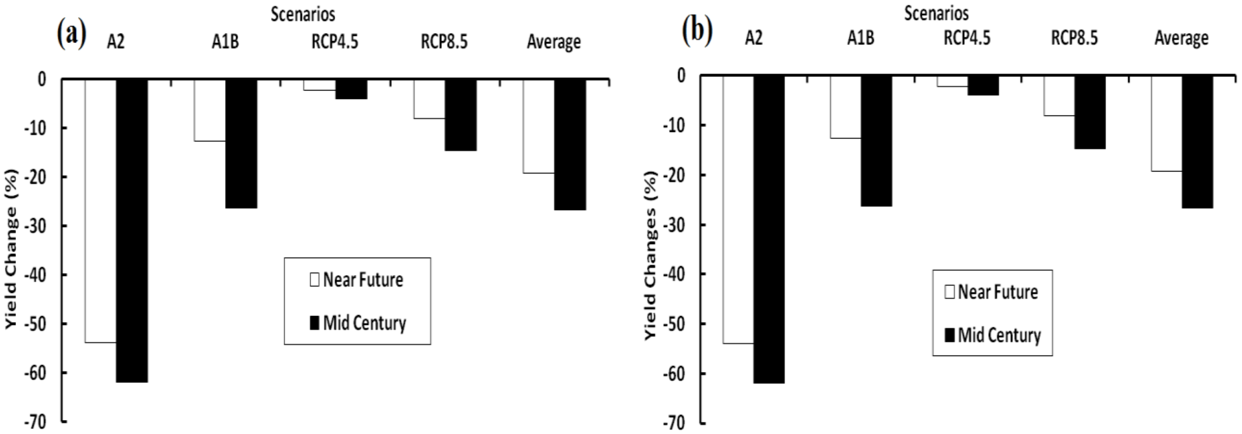

Fig. 10. Changes in maize yield at Nakasongola for different emission scenarios and temporal scales average for season two (Starting from September). (a) cultivar Longe 5 (b) cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010.

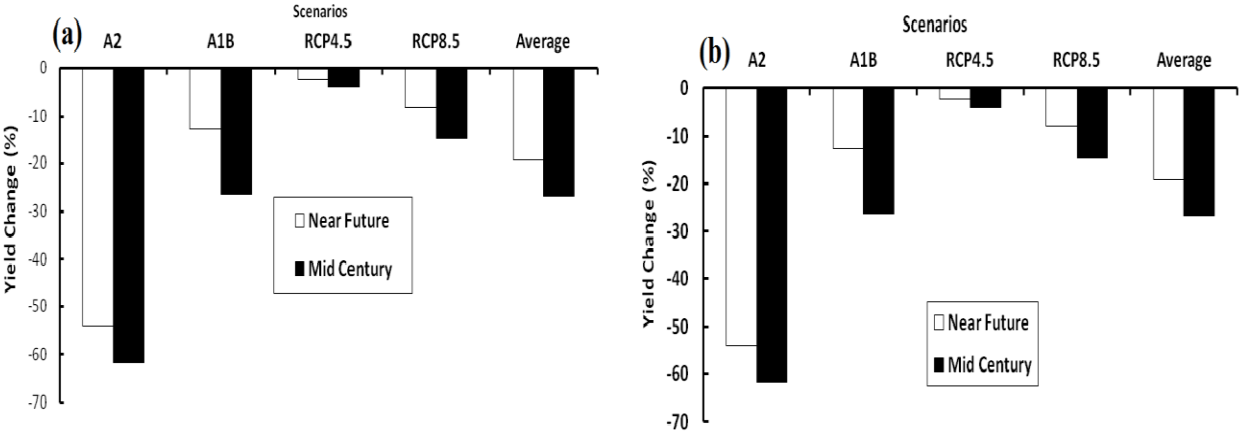

Fig. 11. Changes in maize yield at Nakaseke for different emission scenarios and temporal scales average for season one (Starting from March). (a) cultivar Longe 5 (b) cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010.

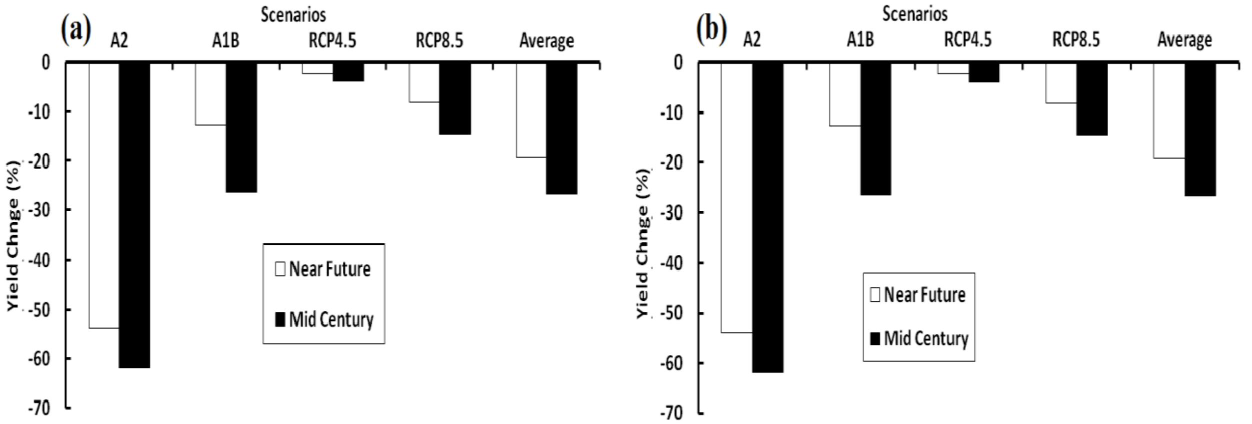

Fig. 12. Changes in maize yield at Nakaseke for different emission scenarios and temporal scales average for season two (Starting from September). (a) cultivar Longe 5 (b) cultivar Longe 9. Near Future (2021-2050) and Mid Century (2051-2080) climate periods relative to 1981-2010.

3.2.1 Nakasongola Site

For season one at Nakasongola site, SRES scenarios predicted yield reductions of between 15-50% in both varieties in the near future climate period and between 25-60% in the mid century climate period (Fig. 9 and 10). On the other hand the RCPs predicted yield reductions of between 2 -10% in the near future climate period for both varieties and yield reductions of between 5-18% in the mid century climate period (Fig. 9 and 10).

For season two of maize, SRES scenarios predicted yield reductions between 12-54% in both varieties in the near future climate period. However, yield reduction ranged between 27-62% forthe mid century climate period. On the other hand the RCPs predicted yield reductions between 1-8% (near future climate period for both varieties) and 4-16% (mid century climate period) (Fig. 9 and 10).

3.2.2. Nakaseke Site

For season one just like Nakasongola site, at Nakaseke site, yield prediction for SRES scenarios showed reductions between 10-55% for both varieties in the near future climate period and between 22-62% in the mid-century climate period (Fig 11 and 12) . On the other hand the RCPs show yield reductions of between 2 -10% in the near future climate period for both varieties and yield reductions of between 5-18% in the mid century climate period (Fig 13 and 14).

4. Discussion

The projected climate of the study area will have a significant impact on the maize yields. In all climate scenarios, maize yields are expected to decrease (up to 50%) compared to the 1981-2010 average for both maize varieties. These results compares well with other studies such as those of Wasige (2009) in Uganda and Thornton et al., (2009) for SSA. Wasige (2009) reported that maize yields in most parts of Uganda were projected to decrease by 2-59% by the year 2100. Thornton et al., (2009) observed that in the most Sub-Saharan African (SSA) countries maize yields were predicted to decrease by 10 to 20% by 2050. Similarly Blanc (2012) in his study about future crop yields in SSA observed that maize yields were expect to decrease between 6 and 19%. Other studies in tropical regions have observed similar declining trends in future maize production for example Tachie et al., (2010) observed a decrease in maize yield of between 5 to 13% in 2046-2065 climate period compared to 1961-2000 baseline period in Ghana. Tachie et al., (2010) also predicted maize yield reductions of between 7 and 57% for the period 2081-2100 compared to 1961-2000 period. Araya et al., (2015) predicted a decrease in future maize yield s in Ethiopia of between 1.3 and 3.5% by 2100 for RCP 4.5 and RCP 8.5 relative to the 1980-2010 climate periods. However this is lower than an average of -20% decreases in maize yield relative to the 1980-2009 average that was reported by Kassie et al., (2015) in central rift valley zone of Ethiopia by the year 2050. Tumbo et al., (2012) also observed a similar trend of declining future maize yield in Tanzania of between 10 and 13% for the period 2046-2065 relative to the baseline period of 1958-2006 especially in the first season of March to May.

The future maize yield reductions are much higher in the SRES ranging from 12 -50% in the near future and 15-60% in the far future compared to the RCPs which predict yield reductions of 1-6% in the near future and 3-11% in the far future. The high loses in the far future may be attributed to the increased temperatures that are expected in the study area which may increase evaporation rates leading to crop stress and hence low yield (USAID, 2013). Cultivar Longe 9 experienced relatively high reduction in maize yield compared to Longe 5 even though its overall yield remained higher than that of Longe 5. This is attributed to the high nutrient input requirement of Longe 9 compared to Longe 5 (Mbuya et al., 2011). The decline in crop yield is due to a number of factors including the inherent soil fertility, management (low fertilizer input, limited applications of soil and water conservation practices) and projected climatic variations. Generally the study areas with haplicacrisols type soils have low to medium fertility (Isabirye, 2004) and therefore a high yield potential from maize production may not be achievable. Soil nutrient will certainly be depleted as cultivation goes on without adequate replenishment.

5. Conclusion

The projections show that maize yields in the study area will decrease in both the near future and far future in all the scenarios. However the reductions in the second growing season of SON are significantly lower than the reductions in the first maize growing season (MAM). The second season therefore is projected to be more productive in terms of maize production than the first season. Therefore temperature and rainfall changes are likely to cause significant change in maize production in the study area. This is likely to lead to reduced yields and therefore increasing food insecurity as well as reduced incomes since maize is one of the major sources of income for the communities. Adaptation to the expected impacts of climate variability and change is therefore essential for future sustainable maize production in the study area.

List of Abbreviations: CERES model, crop-environment resource synthesis model; CMIP5, Coupled Model Inter-comparison Project Phase 5; CV, Coefficient of Variation; DJF, December-January-February; GDP, Gross Domestic Product; JJA, June-July-August; MAM, March-April-May; OND, October-November- December; RCP, Representative Concentration Pathways; SRES, Special Report on Emission Scenarios; SON, September-October-November; SSA, Sub-Saharan Africa; SST, seas surface temperature; UBOS, Uganda Bureau of Statistics; UCA, Uganda Census of Agriculture.

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