ISSN 2310-4090

International Journal of Scientific Footprints Open Access

Assessing the Potential of Conservation Agriculture to Off-set the Effects of Climate Change on Crop Productivity using Crop Simulations Model (APSIM)

Fredrick Besa Mwansa[1], Kalaluka Munyinda[2], Alice Mweetwa[2] & Walter Mupangwa[3]

[1]Ministry of Agriculture, Lundazi, Zambia
[2]University of Zambia, School of Agricultural Sciences, Department of Plant Science, Lusaka, Zambia
[2]University of Zambia, School of Agricultural Sciences, Department of Soil Science, Lusaka, Zambia
[3]Maize and Wheat Improvement Centre (CIMMYT), Harare, Zimbabwe

Keywords:
Conservation Agriculture (CA), Conventional Tillage (CT), APSIM, RMSE.

Correspondence:
Fredrick Besa Mwansa. Ministry of Agriculture, Lundazi, Zambia.

Funding Information:
No funding information provided.

Manuscript History:
Received: August 2017
Accepted: September 2017

International Journal of Scientific Footprints 2017; 5(1): 9 - 32

Abstract

Agriculture in sub-Saharan African region has depended mainly on rainfall since 1990s and crop production has faced negative impacts of extreme climate events which are believed to be manifestations of long term climate change. In addition, maize (Zea mays L.) productivity has continued to decline over the past years from 2.5 tons ha-1 in 1964 to 1.5 tons ha-1 in 2013. This is largely due to continuous cultivation, often in mono-cropping with little or no inputs and absence of effective Conservation Agriculture practices. A field experiment for this study was setup on the already established CA long-term trial at Msekera Research Station in Chipata Eastern Province of Zambia. The experimental design used was a split plot with CA and CT treatments as main. During the 2014/15 season CA long-term trials was used with fertilizer application rates of 165 kg ha-1 basal and 200 kg ha-1 top dressing. There was a significant difference of 1802 kg ha-1 on observed grain yield in 2014/15 season compared between Conventional Tillage (CPM2) ridge and furrow and Conservation Agriculture (DS-MC) treatments. CA treatments had maize leaves with greener phenological appearances from 24 to 60 days after planting. Furthermore, APSIM model was used to simulate the long-term effect of climate change on maize productivity for 85 seasons using rainfall increase and decrease of 11.3 percent and temperature rise at +1.0^{o}C, +2.0^{o}C, and +3.0^{o}C as climate change scenarios. Root Mean Square Error was used to assess the performance of the model and the prediction were 22.57 percent for grain yield, 73 percent for biomass yield and 8.6 percent for soil water results for both measured and simulated outputs and that represented fair to excellent performance of the model. The APSIM simulated long term results revealed decrease in annual rainfall by 11.3 percent as climate scenario increased maize grain yield under CA treatments by 4 percent. While increasing temperature by 3.0^{o}C reduced maize grain yield by 31 percent for CT treatments. The model also predicted that 22 growing seasons out of 85 will experience adverse drought that will affect maize grain yield mostly for CT practices.

Introduction

Agriculture in sub-Saharan Africa (SSA) supports between 70 and 80 percent of employment and contributes an average of 30 percent of Gross Domestic Product (GDP) through crop production (Commission for Africa, 2005). Rain-fed agriculture dominates agricultural production in the SSA region covering about 97 percent of total cropland, and exposes agricultural production to the risks of high seasonal rainfall variability (Calzadilla *et al*., 2008). Climate change has significantly affected global agriculture in the 21st century. And according to the Intergovernmental Panel on Climate Change (IPCC,

2007) assessment report that indicates most countries in SSA will experience an increase in average temperature, more frequent heat waves, more stressed water resources, desertification, and periods of heavy precipitation. A similar report (IPCC, 2001) suggested that global surface air temperature may increase by 1.4 ºC to 5.8 ºC at the end of the century. IPCC, (2007) report further revealed that the past three decades have been the warmest in history, with each decade being warmer than the preceding period. Calzadilla *et al*., (2008) added that measureable indicators have proved that the African continent is warmer than it was 100 years ago. In fact, the six warmest years in recent decades in Southern Africa have all occurred since 1980 (Yanda and Mubaya, 2011). Furthermore, future climate change may present an additional challenge to agricultural production in SSA region (Calzadilla *et al*., 2008). Future impacts are projected to worsen as the temperature continues to rise and precipitation becomes more unreliable.

Climate change factors such as increased temperature and erratic rainfall patterns are being addressed through increased employing of technologies such as Conservation Agriculture that increase water infiltration and reduce moisture evaporation from the soil (Marongwe *et al*., 2011). Conservation agriculture (CA) is a crop management system based on three principles; minimum soil movement, soil surface cover with crop residues and/or living plants and crop rotations to avoid pest and diseases (Thierfelder *et al*., 2014). The principles of CA appear to have extremely wide adaptation, and CA systems are currently used by smallholder farmers under a wide range of conditions and with numerous crops (Thierfelder *et al*., 2014). The primary rationale of CA is to protect the natural resources for agriculture thereby sustaining and maintaining agricultural productivity in long run (Marahatta *et al*., 2014). CA generally does not work well without residues, as many benefits come from surface mulch (Thierfelder and Wall, 2014). In CA systems the residues protect the soil surface, water infiltration is increased and water storage improved (Mupangwa *et al*., 2013). Also, under CA systems there are more soil pores because of the increased biological activity with continuous residue cover and because the pores are not continually broken down by tillage (Thierfelder and Wall, 2014). Crop rotation in CA systems is essential as it contributes to reduction in pests and diseases in the cropping system and to control weeds by including smothering crop species or green manure cover crops (Thierfelder *et al*., 2014). Further, crop rotation in CA systems may also give benefits in terms of improved soil quality, better distribution of nutrients in the soil profile and to increased biological activity (Mupangwa *et al*., 2012).

The other primary aim of CA is to reduce soil movement and soil disturbances and ensures that soil moisture is conserved and more water becomes available for crop growth (Thierfelder and Wall, 2010a). Overall, CA systems have a higher adaptability, minimized runoff and soil erosion as well as greater soil moisture-holding capacity. According to report by Hobbs P.R. *et al*., (2007) revealed that benefits of CA are a suggested improvement on conventional tillage, where no-tillage, mulch and rotations significantly improve soil properties and other biotic factors. Mupangwa *et al*., (2012) reported that the long-term benefits of CA includes; increased soil organic matter (SOM) resulting in better soil structure, higher cation exchange capacity and nutrient availability, and greater water-holding capacity. Others are increased and more stable crop yields, reduced production costs, and increased biological activity in both the soil and the aerial environment leading to improved biological soil fertility and pest control. Therefore, all these CA benefits culminate into improved crop yield, soil health, and soil water storage increased soil biological activities. The soil moisture conditions in rooting zones through growing seasons under CA are better than under conventional tillage (Kassam *et al*., 2009).

Increasing concerns about the future of agriculture in SSA in light of accelerating soil degradation (Oldeman *et al*., 1990; Kumwenda *et al*,. 1997; Sanginga and Woomer, 2009) and potential threats of climate change (Lobell *et al*., 2008), have increased the need for new and more adapted cropping systems that increase production, whilst conserving the natural resource base (Wall, 2007; Kassam *et al*., 2009; Thierfelder and Wall, 2009). CA is one of the 'greener' solutions currently being discussed (Gilbert, 2012) as a potential cropping system that can mitigate the negative effects of declining soil fertility and climate change, under a range of farming systems (Hobbs, 2007; Kassam *et al*., 2009). In coping with these challenges, farmers in the eastern region of Zambia have developed or adopted various types of soil and water conservation technologies through the intervention of government change agents and other collaborating partners such as the CG Centers and FAO. Some of these technologies include the use of water harvesting planting basins locally known as Gampani which harvest water in the cropping field.

In order to understand the future effects of the aforementioned climate variability and provide solution, Agricultural Production Simulation Model (APSIM) was used in the study. Agricultural systems models worldwide are increasingly being used to explore options and solutions for food security, climate change adaptation and mitigation and carbon trading problem domains (Keating *et al*., 2003). And according to (McCown *et al*., 1996), APSIM simulates the dynamics of crop growth, soil water, and nitrogen and soil carbon in a farming system. APSIM is one such model that continues to be applied and adapted to this challenging research agenda (Shamudzarira and Robertson, 2002). It operates on daily time steps and when driven by long-term or current daily weather data, can be used to predict the impact of seasonally variable rainfall, both amounts and distribution, on the climate-induced risk associated with a range of crop, water and soil management strategies (McCown *et al*., 1996). And according to Keating *et al*., (2003), who reported that from its inception twenty years ago, APSIM has evolved into a framework containing many of the key models required to explore changes in agricultural landscapes with capability ranging from simulation of gene expression through to multi-field farms and beyond. Furthermore, agricultural simulation models have an important role in informing farmer practice (Hochman *et al*., 2009b), breeding strategies (Cooper *et al*., 2009) and government policy (Bezlepkina *et al*., 2010) that aim at addressing challenges such as food security and climate mitigation and adaptation. The demand for tools that can assist in the analysis of complex problems are more pronounced than ever. For this study APSIM was preferred as a result of its ability to provide accurate simulation of actual crop yields across a range of soil types and seasons when properly calibrated.

Therefore, this study was conducted to assess the potential of CA to off-set the effects of increased temperature and reduced rainfall on crop productivity using long term on-station trial at Msekera Research Station using the APSIM crop simulation model.

MATERIAL AND METHODS

Site Description

This study was conducted at Msekera Research Station which is located about 12 km due West of Chipata town in the Eastern Province. Msekera Research station lies between the Great East Road and Msoro Road. The co-ordinates are Latitude 13^{o} 38.74' S and Longitude 32^{o} 33.51'E and covers an area of about 406 ha at an altitude of 1016 m. Msekera is drained by a stream perennial which has an earth dam. Msekera Research Station is located in the Agro-ecological Region II A and receives annual rainfall of about 1092 mm. The rainy season extends from November to April, while the dry cool season extends from May to August. A hot spell with low humidity and high sunshine hours characterizes September and October. The average minimum temperature is 9.5 ^{o} C in the month of June and average maximum temperature is 35.1 ^{o} C in the month of October. The weather shows two distinct periods, the rainy season from November to April, dry season and the coldest from May to September. Temperature and rainfall distribution show that the wet season is cool and the dry season is relatively hot in this Agro-ecological Region II A. The predominant soil types at Msekera Research Station are Ferralsols (haplics and rhodics), Haplic Lixisols and Haplic Acrisols (Shitumbanuma, 2008). In the experimental plots, the soil types are Haplic Lixisols, according to FAO soil classification system, with a sandy loam surface soil texture, the slope is generally 1-2percent (Wijnhoud, 1997). The soils on the experimental site present good physical characteristics; low fertility especially for Nitrogen and they are moderately acidity with a range between 4.5 to 5.5 pH. Therefore, a good crop yield under rain fed agriculture can be granted with liming and fertilizer application, especially nitrogen and phosphorus (Wijnhoud, 1997).

Experimental Design

The experimental design used was a split plot with CA and CT treatments as main plot factor. The main plot consisted of CT method that had two treatments namely; moldboard ploughing on flat (T1) and ridge and furrow (T2) both with sole maize and no crop residue retention. And CA methods that comprised both manual (Basins-T3 and Dibble stick-T4 both with sole maize) and animal traction (Direct seeder with sole maize-T5, Direct seeder maize/cowpea intercrop-T6, Direct seeder maize cowpea rotation-T7, Direct seeder cowpea maize rotation-T8, Direct seeder maize soybeans rotation-T9 and Direct seeder soybeans maize rotation-T10) seeding technologies. The study used two cropping systems under CA namely; rotation and intercrop with residue retention as mulch in both systems. Therefore, the trial comprised of ten treatments per replication and four replications with each plot measured 10 m x 20 m.

Experimental Treatments

The treatments for the long term trial at Msekera Research station were:-

T1: (CPM 1) Traditional farmers practice using the mouldboard plough on flat, maize as a sole crop, no residue retention, stubble incorporated into the row for the following season

T2: (CPM2) Ridge and furrow system dug by hand, maize as a sole crop, no residue retention, stubble incorporated into the row for the following season

T3: Basin (BA-M), residue retention on the surface, maize as a sole crop

T4: Dibble stick (DIS-M), residue retention on the surface, maize as a sole crop

T5: Direct seeder (DS-M), residue retention on the surface, maize as a sole crop

T6: Direct seeding maize/cowpea intercropping (DS-M/C), residue retention on the surface

T7: Direct seeding maize-cowpea rotation (DS-MC), residue retention on the surface

T8: Direct seeding cowpea-maize rotation (DS-CM), residue retention on the surface

T9: Direct seeding maize-soybean rotation (DS-MS, residue retention on the surface

T10: Direct seeding soybeans-maize rotation (DS-SM), residue retention on surface

Data Collection from the Field Experiment

The study adopted the already established CA long-term trial layout to conduct this study at Msekera Research Station. The same experimental design was used by the study during the 2014/15 season. Crop data was collected through direct observation and registration of crop phenology stages and crop management. Crop yield (grain and above ground biomass) was measured from the field experiment.

Soil Moisture

Access tubes already installed on the CA long-term trial at Msekera Research Station were used to measure moisture from CPM 1&2, BAM, DISM, DSM, DS-M/C and DS-MC treatments. The study measured up to 60 cm depth with capacitance probes (PR-2 probes, Delta-T Device Ltd, UK) twice per week during the cropping season. Data collected from the 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-60 cm depth was further analyzed in this study. Mean soil moisture in mm for each depth layer was determined for the cropping seasons during 2014/2015 season.

Normalized Differences Vegetation Index (NDVI)

To collect greenness of the crops, the Green Seeker Handheld equipment was used. The study obtained data first at 24 days after planting (DAP). Thereafter, the NDVI readings were collected on weekly interval. NDVI measurements were taken from the central rows of a growing crop in all the treatments and replications used in this study during the 2014/2015 season. NDVI readings were collected by simply pressing the Green Seeker Handheld equipment at least 30 cm above the leaves of maize, cowpea and soybeans whilst moving along the central row of each treatment and getting instant digital readings. Theoretically, NDVI is calculated from the reflectance measurements in the red and near infrared (NIR) portion of the spectrum. NDVI provides an estimate of vegetation health and a means of monitoring changes in vegetation over time. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4nm to 0.7nm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7nm to 1.1nm). The more leaves a plant has, the more these wavelengths of light are affected, respectively (Holme *et al.,* 1987). The typical range of NDVI is between -0.1 (NIR less than VIS for not very green area) to 0.6 (for a very green area). In a nutshell, NDVI is a measure of near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The result of this formula is called the Normalized Difference Vegetation Index (NDVI).

Crop Yield

Maize: Five sub plots of (5 meters x 2 rows) were measured out of each plot. Growth and yield parameters were then obtained for each of these sub-plots. And these were; plant count, plant height, ear height, number of cobs, the distance between four rows over the sub-plot, fresh weight of cobs, and the fresh weight of biomass. Then a sub-sample of 10 cobs that is 2 cobs from each sub-plot was collected and the fresh weight obtained. A maize stalk sample (biomass) was also obtained from the plot ranging between 500 g to 1000 g. Finally the dry weight was obtained in order to extrapolate the fresh weights obtained at harvest.

Cowpea: Five sub-plots of (5 m x 4 rows) were measured out of each plot containing Cowpeas. Growth and yield parameters were then obtained for each sub-plot. The parameters measured were plant count, fresh weight of biomass and the fresh weights of all fertile pods. Also a sub sample of the pods was then obtained and weighed immediately and later used to determine the fresh and dry weights. A stalk sample was also obtained and weighed immediately as well as after drying. Distance between six rows was also obtained to determine the actual area harvested. Finally the dry weights were obtained in order to extrapolate the fresh weights obtained at harvest.

Soybeans: Five sub plots of (5 m x 4 rows) were measured out of each plot containing Soybeans. Growth and yield parameters were then obtained for each sub-plot. The parameters measured were plant count, pods per plant, plant height, pod clearance, fresh weight of biomass including all fertile pods. Also a sub-sample of the pods was then obtained and weighed immediately and later to determine the fresh and dry weights. A stalk sample was also obtained and weighed immediately as well as after drying. Distance between six rows was also obtained. Finally the dry weights were obtained in order to extrapolate the fresh weights obtained at harvest.

Biomass Yield

The harvest area was identified and before each plant was harvested, the plant height was measured. The plant was cut off at as close to ground level as possible, any brace roots removed, and the plant cut into segments and placed in a bag. All dead leaves still attached to the plant were placed in the bag as well. The plant material were placed in a control temperature ovens in the laboratory to quickly as possible facilitate the gradual drying. Once all samples were taken, they were moved to an air conditioned laboratory for dissection and measurement.

Agricultural Production Simulation Model (APSIM) Model Calibration

Model calibration and validation against an independent data set was an essential step in model setup. APSIM model was parameterized and evaluated for maize grain and biomass yield and soil water under rainfall and temperature climate change scenarios. The inputs used for the evaluation of model simulation included; days after sowing, crop phenology, soil N, weather, and crop management information as these were the major constituent of optimal crop productivity. Others were the soil chemical and physical properties input data used for calibration that was sourced from *(Mwaanga Unpublished)* who conducted a similar study on the same CA long term trial the previous year. Genotypic coefficients were incorporated into maize in file of model until observed and simulated results were close to each other.

Table 1: Soil Chemical and Physical Properties Input Data Used For Calibration of the APSIM Model at Msekera Research Station Experimental Site

Soil depth (cm)	pH ($CaCl_2$)	SOC (percent)	BD (g/cm^3)	Total N (percent)	P (mg/kg)
0-10	4.35	1.191	1.56	0.08	11.0
10-20	4.47	0.978	1.6	0.09	11.0
20-30	4.53	0.652	1.63	0.11	11.6
30-40	4.53	0.614	1.69	0.12	7.4
40-60	4.8	0.59	1.70	0.12	6.9
60-80	4.8	0.46	1.73	0.l2	5.2

During the long term crop simulation calibration SC 501 cultivar for maize was used representing medium to late maturity similar to MRI 624 used at Msekera Research Station experimental site. On the other hand, Banjo cultivar was used for cowpea with similar characteristics to Bubebe seed. Also Magoye cultivar was used for soybeans with similar characteristics to Lukanga seed.

Table 2: The APSIM Data Inputs Used For the Calibration of the Model with Curve Numbers 70 for CA and 85 for Conventional Practice at Msekera Research Station Experimental Site

Depth (cm)	Lower Limit (percent)	DUL (percent)	SAT (percent)
0-10	5	15	27
10-20	7.9	16	31
20-30	8.6	19	33
30-40	13	23	33
40-60	17.7	24	34
60-100	18	24	36

** Since APSIM model maintained a daily balance of both crop and residue cover for both CA and CT systems. **Curve number (CN)** was a dynamic parameter that changed on a daily basis during the simulation*.

The other parameters used in this calibrating were SAT (Saturated soil water content), DUL (Drained upper limit of soil water content) and LL15 (Lower limit of soil water content) as shown in Table 2. LL15 is the Bar lower limit of soil water content (Jones and Kiniry, 1986). It was approximately the driest water content achievable by plant extraction. This defined the "bottom of the bucket". DUL is the drained upper limit of soil water content. It was the content of water retained after gravitational flow (Jones and Kiniry, 1986). DUL is sometimes referred to as "Field Capacity". SAT is the saturated water content. This defines the "top of the bucket" or volumetric soil water.

Model Evaluation

The model was validated using the data collected by the study from the CA long-term field experiment during 2014/2015 season. The main focus was to simulate maize grain and biomass yield and soil water content using rainfall and temperature climate change scenarios. To compare simulated with observed data under 2014/15 season the linear regression (R^2) was used in this study. Furthermore, the performance of the APSIM model was assessed through a validation skill scores using Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE) and Modeling Efficiency (ME).

Simulation of Long Term Effects of CA Practices on Grain Yield and Soil Water Dynamics

The calibrated APSIM model was used to simulate the CA long term climate change scenarios based on four treatments tested in the field experiment. The treatments used for crop simulation were Conventional Tillage (CT) also referred to as Farmer Check, Basins, Dibble Stick and Direct Seeder. During calibration crop residues were not retained on the farmer check treatment. However, 37.5 percent crop residues were retained on the soil surface in the model for the rest of the CA treatments during calibration. Msekera Research Station currently does not have digitalized soil and weather data. Therefore, the study suggested using simulation data calibration input for soil and weather from Chitedze Research Station in Malawi. Chitedze Research Station was preferred as a result of its proximity to the experimental site and similarities in soil and weather conditions. Simulation outputs for maize grain yields and soil moisture content were plotted for the four treatments to give a trend on crop productivity and soil water for the period of 85 years (2015-2099).

Statistical Analysis

Analysis of variance (ANOVA) is a statistical method in which the variation in a set of observations is divided into distinct components. Comparison of treatments effects for observed data on NDVI, maize grain, biomass yields and soil water were analyzed using ANOVA. Also mean separation was determined by standard error of difference method using GenStat version 17. Furthermore, linear regression (R^2) was used to compare results between the observed and simulated for biomass and grain yield and soil water.

Results

Effect Of Conventional and CA Practices on Normalized Difference Vegetation Index (NDVI)

The NDVI results showed variations between the CT and CA treatments and days after planting (DAP). CT treatments had lower ($P<0.001$) NDVI values in the initial growth period compared to CA treatments with residue retention on the surface and with rotation treatment (Table 3). There were significant differences in treatment, Days after Planting (DAP) and interaction on NDVI, biomass and grain yield. Sole maize planted on CT plots had poor influence on crop development with early lower NDVI values compared to CA practices (Figure 7). CA treatment with Direct seeder maize-cowpea (DS-MC) rotation at maize phase treatment had higher ($P<0.001$) NDVI on average at initial crop development as generated by the ANOVA (Table 3). There was significant difference ($P<0.001$) between CT and CA treatments later in the season. CT treatment with mouldboard plough (CPM 1) had lower ($P<0.001$) NDVI values compared to all other treatments (Table 3). However, zero NDVI values meant that the crop was either at seeding or harvest stage during the time of obtaining the readings.

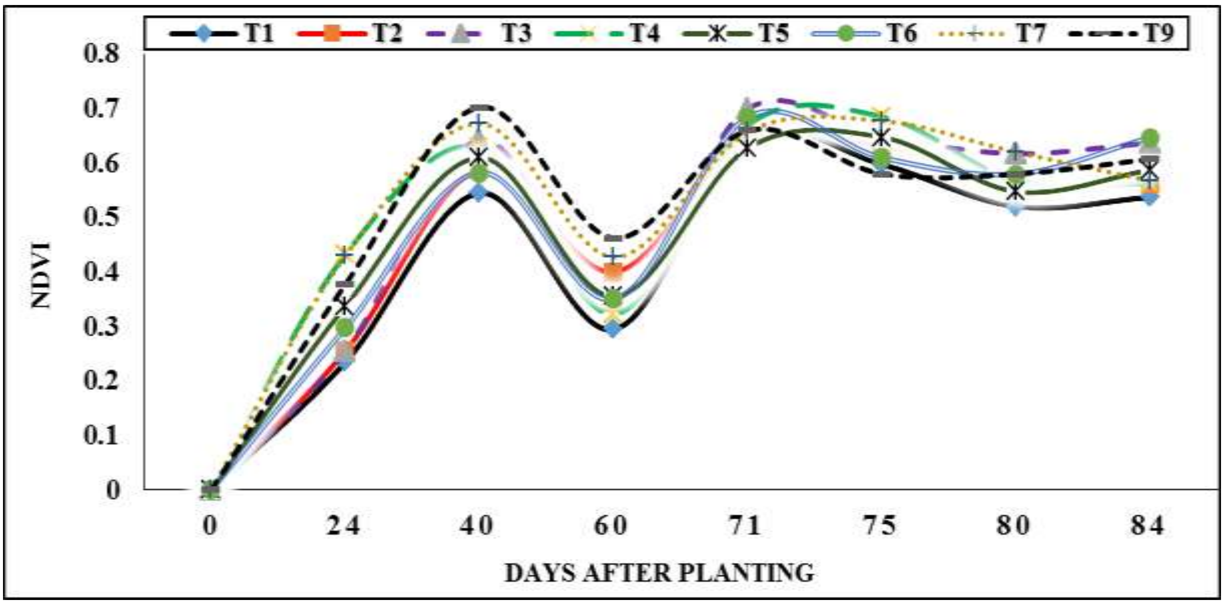
Table 1: Summary of Analysis Of Variance (ANOVA) Means of Squares for Measured NDVI, Biomass and Maize Grain Yields

Sources of Variance	Degree of freedom	NDVI	Biomass yield	Maize grain yield
Replication	3	0.004040^{NS}	4479758***	3202689***
Treatment	7	0.274388***	1142382**	1836726***
Days after Planting	6	0.548922***		
Treatment x DAP	56	0.074513***		

^{Ns} *Not significant, ***Significant at 1percent probability level, **Significant at 5percent probability level*

NDVI line graph results for ten treatments both for CT and CA treatments were represented in Figure 1. Results revealed that CT treatment (T1) had the lowest NDVI value initially compared to CA practice (T4) that had the highest value (Figure 1). There was a significant difference observed at every interval of NDVI readings between CT and CA treatments. Statistically, this was supported in Table 3 were there was significant difference between NDVI and treatment at 1percent probability level. The NDVI values for all the treatments dropped at 60 DAP as this was attributed to the prolonged dry spell experienced at Msekera Research Station. The results revealed that T7 treatments had higher NDVI values at 80 DAP and later started declining (Figure 7).

Figure 1: Observed Normalized Difference Vegetation Index (NDVI) Based on Crop Growth Development between Conventional and CA Practices at Msekera Research Station



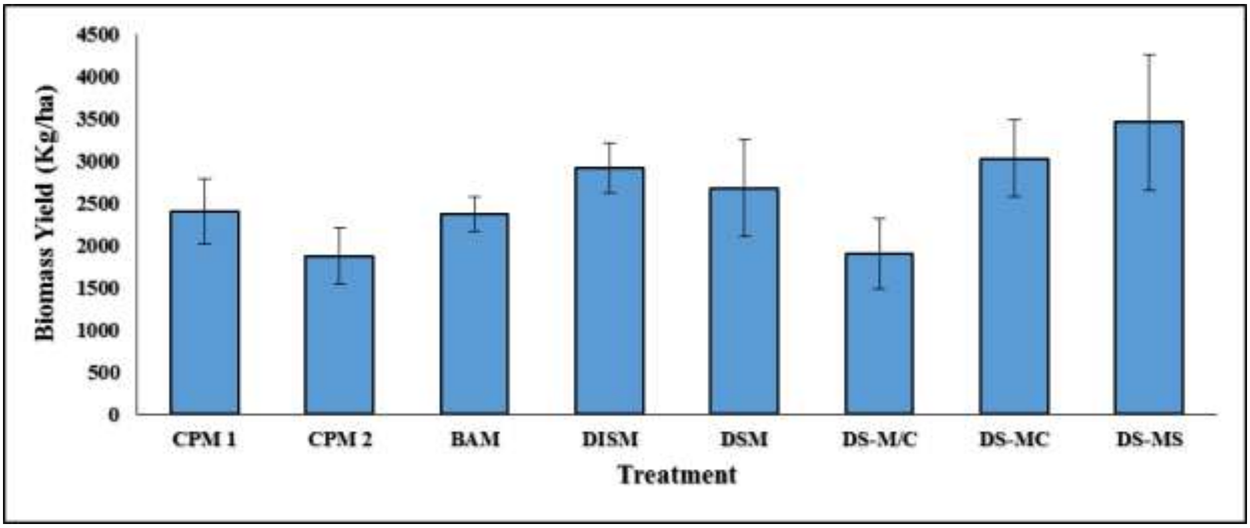
Furthermore, the study revealed that NDVI results had highly significant difference among the eight treatments at every time interval of data collection (Figure 1). Also the generated ANOVA (Table 3) for

NDVI revealed highly significant difference (P<0.001) among the seven intervals of DAP.

Effect of Conventional and CA Practices on Maize Grain and Biomass Yield

CT treatments were compared with CA treatments in terms of biomass yield that was tested at 95percent confidence level with 24.05percent coefficient of variation, 620.8 Standard Error and with P<0.025 across treatments as generated by the ANOVA (Table 3) for biomass yield. There were variations observed in terms of biomass yield among treatments. Ridge and furrow treatment (CPM2) had lower (P<0.025) biomass yield compared with Direct Seeder with maize-soybean rotation at maize phase (DS-MS) that had the highest biomass yield (Figure 2). In addition, there were highly significant difference in biomass yield between CT treatment (CMP2) and CA treatment (DS-MS) as shown in Figure 2. Furthermore, there was no significant difference between the two CT treatments (CMP1 and CMP2). However, there was significant difference among the six CA practiced treatments with more prominence between DS-M/C and DS-MS respectively.

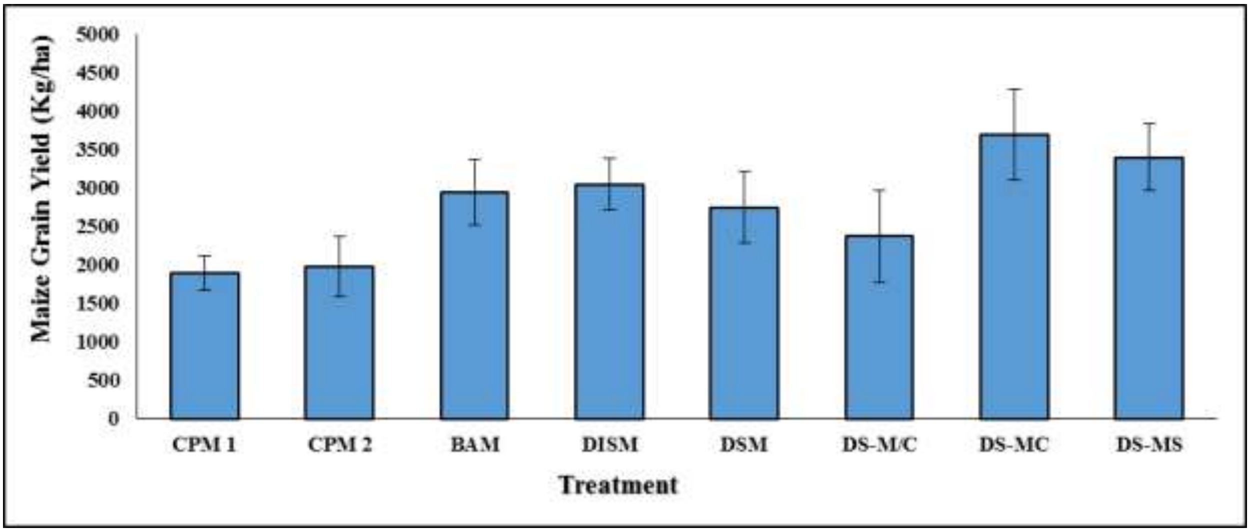
Figure 2: Biomass Yield Measured From the Long Term CA Trials at Msekera Research Station during 2014/15 Season



Similarly, the same statistical analysis was used to compare maize grain yield tested at 95percent confidence level with 23percent coefficient of variation and 632.8 Standard Error. There was significant difference (P< 0.003) within treatments for measured maize grain yield as generated by the ANOVA (Table 3). CT treatment (CPM 1) had the lowest maize grain yield as compared CA treatment (DS-MC) that had the highest maize grain yield (Figure 3). There was a significant difference of 1,802 Kg ha^{-1} on observed maize grain yield compared between CT treatment (CPM1) and CA treatment (DS-MC) treatments. Furthermore, maize grain yield also generated highly significant difference (P<0.003) among treatments (Table 3). This statistical analysis from the ANOVA table also confirmed this variation and is graphically shown in Figure 3. In addition, there was highly significant difference (P<0.003) between CT treatment

(CPM1) and CA treatments (DS-MC) were the later had higher maize grain yield (Figure 3). Also results revealed significant difference (P<0.003) among the CA treatment with DS-MC having a higher maize yield than DS-M/C (Figure 9).

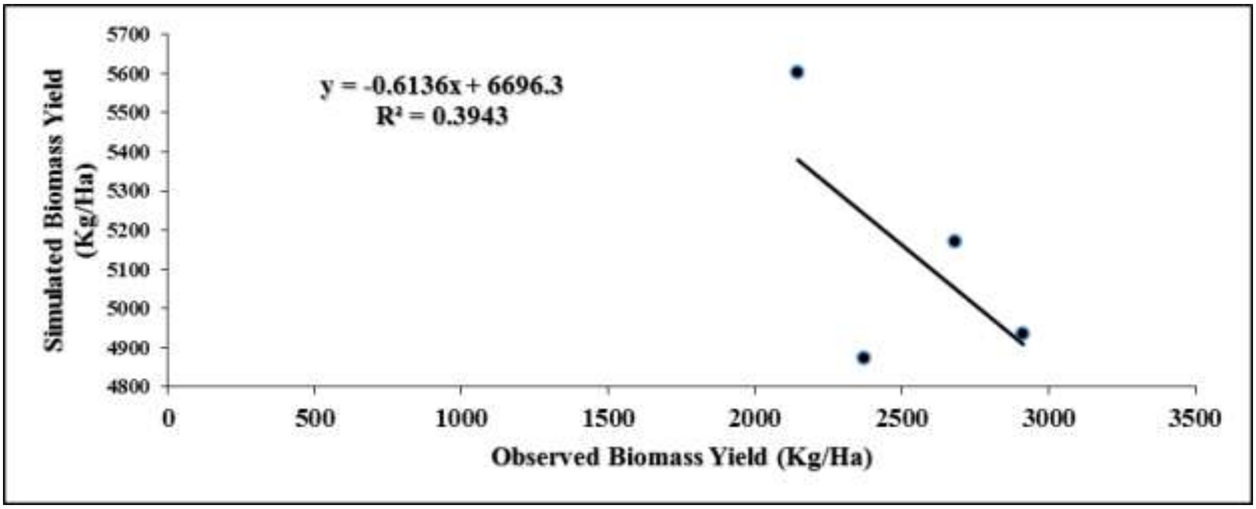
Figure 3: Maize Grain Yield Measured From the Long Term Trial at Msekera Research Station during 2014/15 Season



Evaluation of the Long-Term Effects of Rainfall and Temperature Changes on Crop Yields under CA Predicted Using APSIM

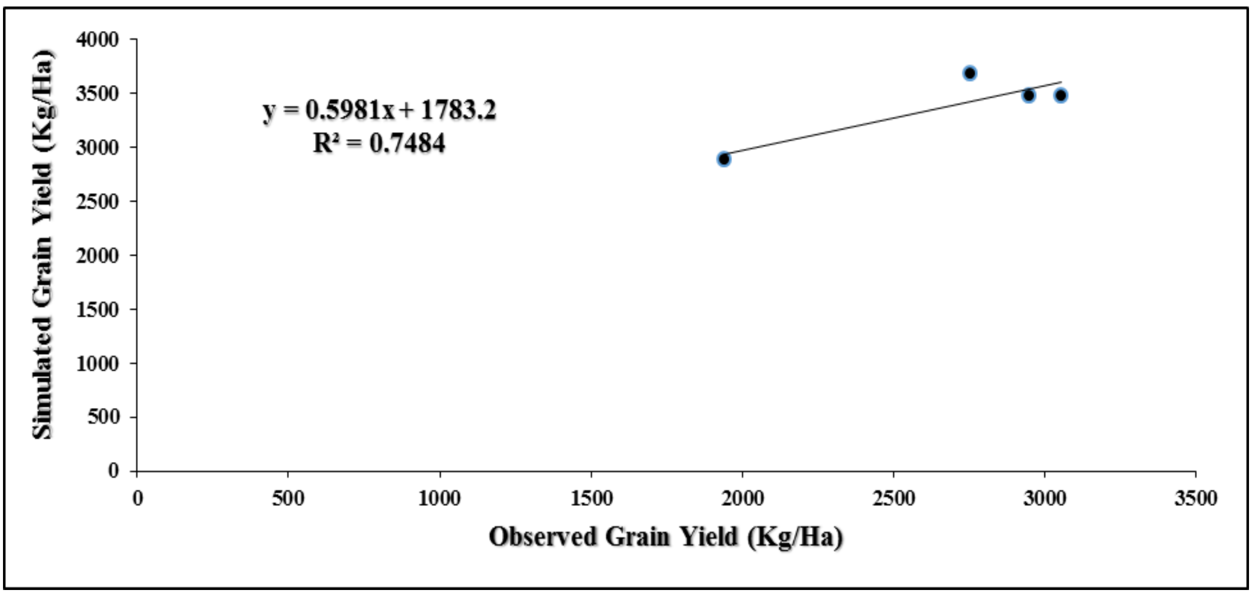
APSIM long term simulated and observed outputs for maize biomass yield for CT treatments was compared with CA treatments using linear regression R-squared (Figure 4). R-squared provided an estimate of the strength of the relationship between the observed and simulated values of the model. R-squared is a statistical measure of how close the data are to the fitted regression line. The R-squared obtained accounted for 39.4percent that was low. This meant that there was less variance that was accounted for by the regression model and the far apart the data points fall to the fitted regression line (Figure 4). Furthermore, the magnitude of the differences (p<0.001) between observed and simulated results is generated in the ANOVA table (Appendix 7). The simulated resulted had higher average biomass yields compared with the observed results that had lower results. However, there was no significant difference (p<0.076) within treatments on biomass yield for the observed results as generated by ANOVA table (Appendix 7). Nevertheless, the model over-predicted the observed biomass yield for the four treatments compared to the measured results as confirmed by low R-squared value (Figure 4).

Figure 4: Comparison Between the Observed and Simulated Biomass Yield From Both Conventional Tillage and CA Practices for 2014/15 Growing Season at Msekera Research Statio



The comparison between observed and simulated results on maize grain yield showed a positive correlation (Figure 5). The regression model below (Figure 5) accounts for 74.8percent of the variance. There was more variance that was accounted for by the regression model and the closer the data points felled to the fitted regression line. The generated ANOVA on maize grain yield (Appendix 8) confirmed this variation. There was significant differences ($p<0.001$) between average observed and simulated measurements (Appendix 8). There was significant differences ($p<0.031$) among the observed results for maize grain yield as generated by the ANOVA table (Appendix 8).

Figure 5: Comparison between Observed and Simulated Maize Grain Yield from both Conventional Tillage and CA Practices for 2014/15 Growing Season at Msekera Research Station



The baseline weather data used for the long-term simulation comprised of the following climate change scenarios namely; Baseline-Default no climate change (Figure 6), 11.3percent increase in rainfall (Figure 7), 11.3percent decrease in rainfall (Figure 8), 1^{o}C increase in temperature (Figure 9), 2^{o}C increase in temperature (Figure 10) and 3^{o}C increase in temperature (Figure 11) respectively

Figure 6: Predicted Maize Grain Yield from Conventional Tillage and CA Practices Using APSIM Simulation for 85 Growing Seasons Long-Term Trial with Baseline No Climate Change Scenarios Application at Msekera Research Station

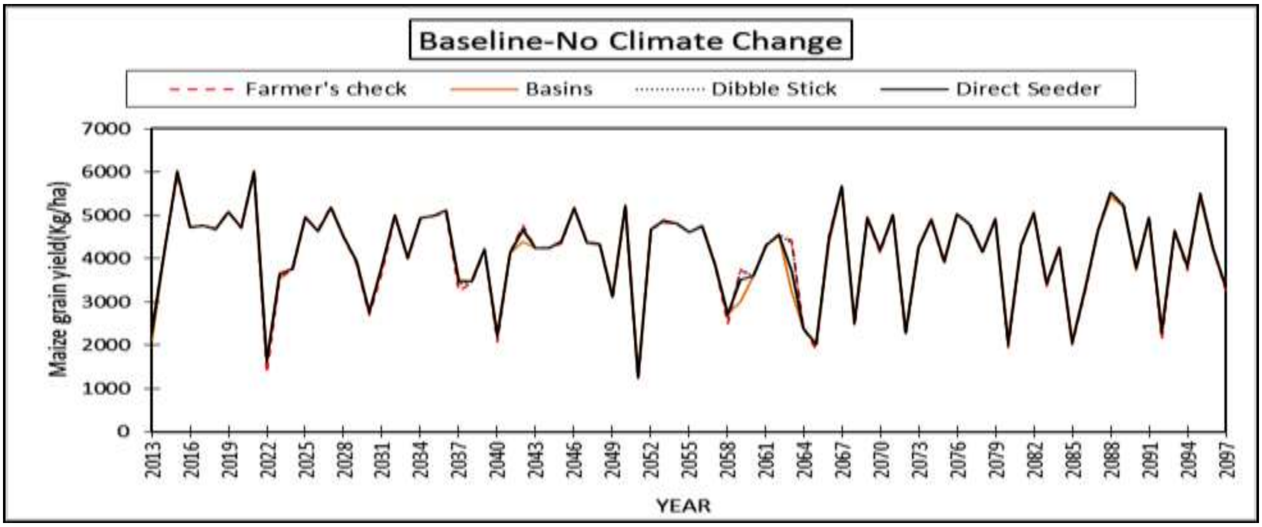
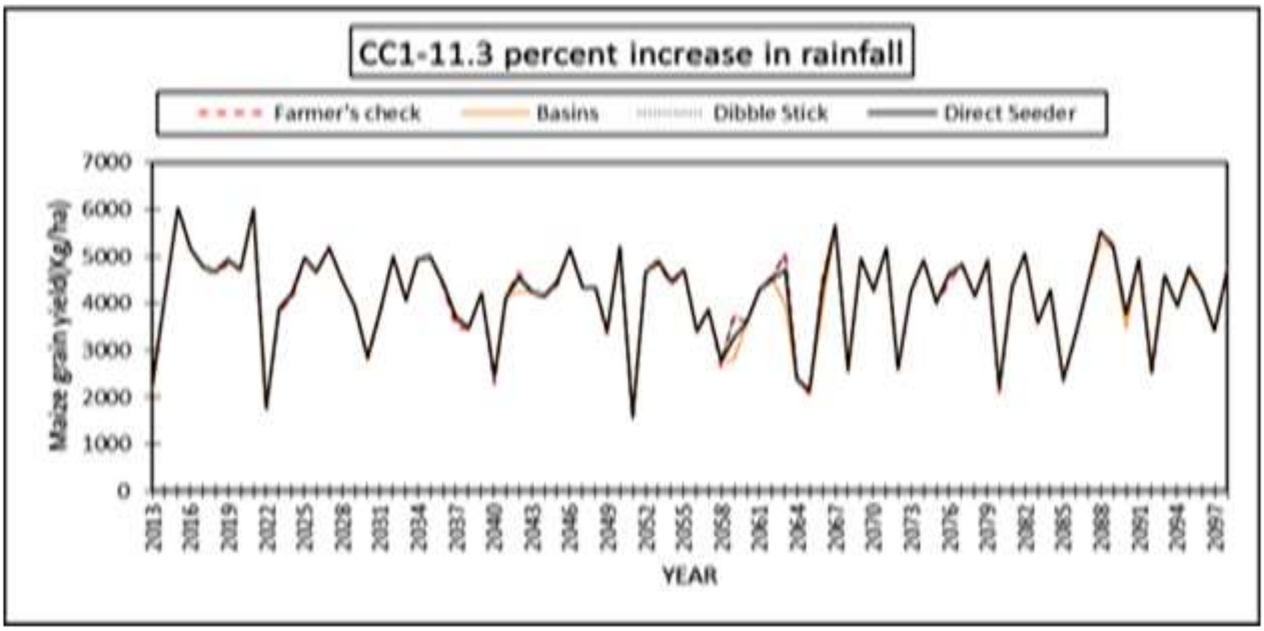


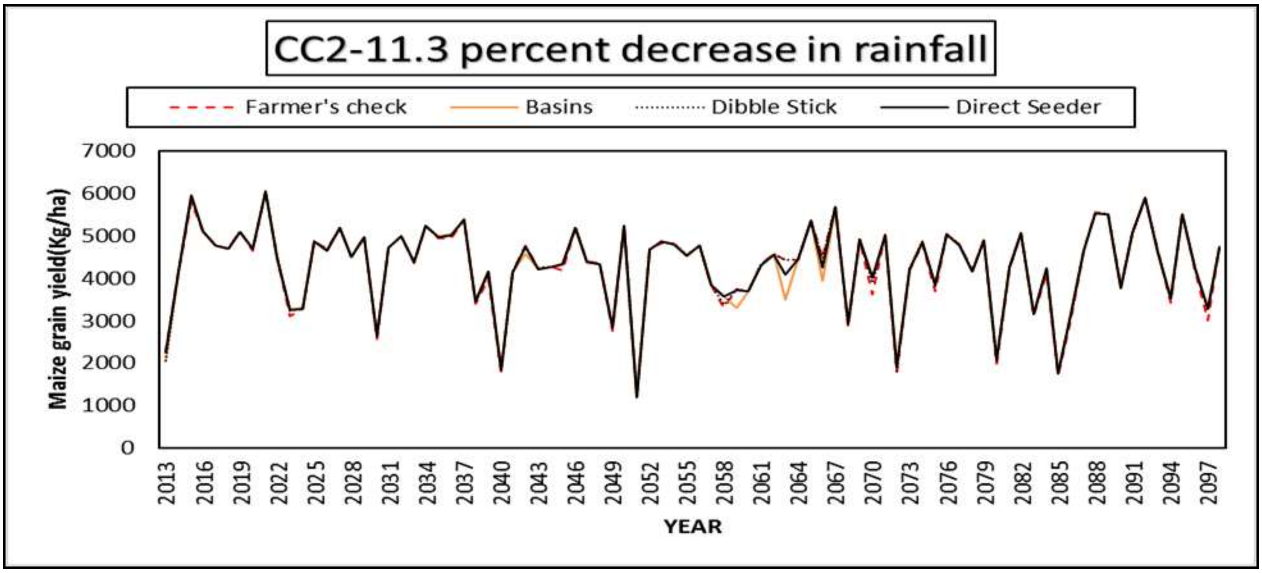
Figure 7 shows the graphical APSIM simulated output results for maize grain yield for 85 seasons. Increase in rainfall by 11.3percent per annum applied to the APSIM model CA long term simulation increased maize yield for CA treatments by 0.4percent compared with the baseline no climate change scenario

Figure 7: Predicted Maize Grain Yield From Conventional Tillage And CA Practices Using APSIM Simulation For 85 Growing Seasons Long-Term Trial With 11.3 percent Rainfall Increment As Climate Change Scenario At Msekera Research Station



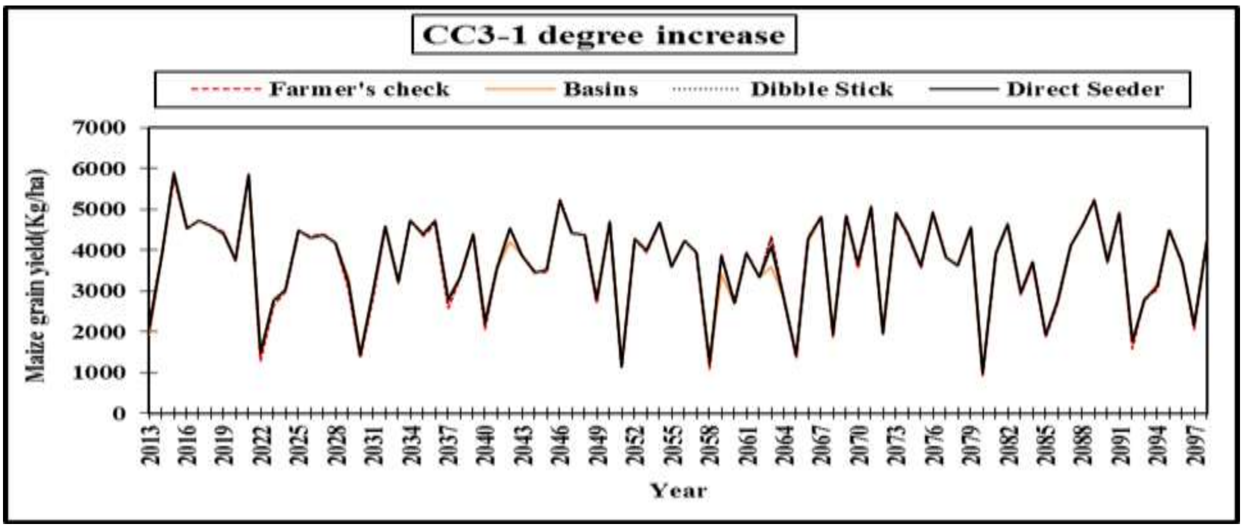
When rainfall was reduced by 11.3percent per annum (CC2-11.3percent rainfall decrease) there was an increase in simulated average maize grain yield for CA treatments (Figure 8). Therefore, simulated average maize grain yield for CA treatments increased by 4percent compared with baseline-no climate change scenario. Moreover, maize grain yield outputs for CA treatments varied among different seasons used in the APSIM model simulation for 85 seasons

Figure 8: Predicted Maize Grain Yield from Conventional Tillage and CA Practices Using APSIM Simulation For 85 Growing Seasons Long-Term Trial With 11.3 percent Rainfall Decrease As Climate Change Scenario at Msekera Research Station



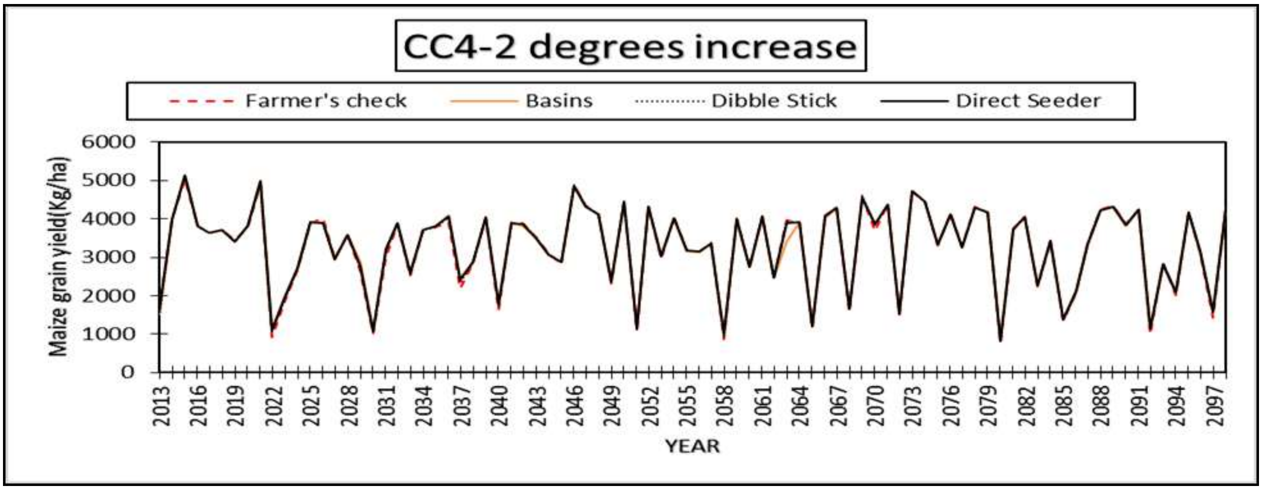
The simulated results revealed that temperature variability had a negative effect on maize grain yield for CT treatment. When temperature increase of 1°C was applied to the crop simulation model as a climate change scenario, the average maize grain yield decreased for CT treatment (Figure 9). Simulated average maize grain yield for CT treatment decreased by 11percent (454 Kg ha-1) compared with the baseline-no climate change scenario application to the model (Figure 9). Furthermore, the increase in temperature resulted into 22 seasons experiencing adverse drought out of the total 85 seasons simulated by the APSIM model

Figure 9: Predicted Maize Grain Yield from Conventional Tillage and CA Practices Using APSIM Simulation for 85 Growing Seasons Long-Term Trial with 1°C Temperature Increment as Climate Change Scenario at Msekera ResearchStation



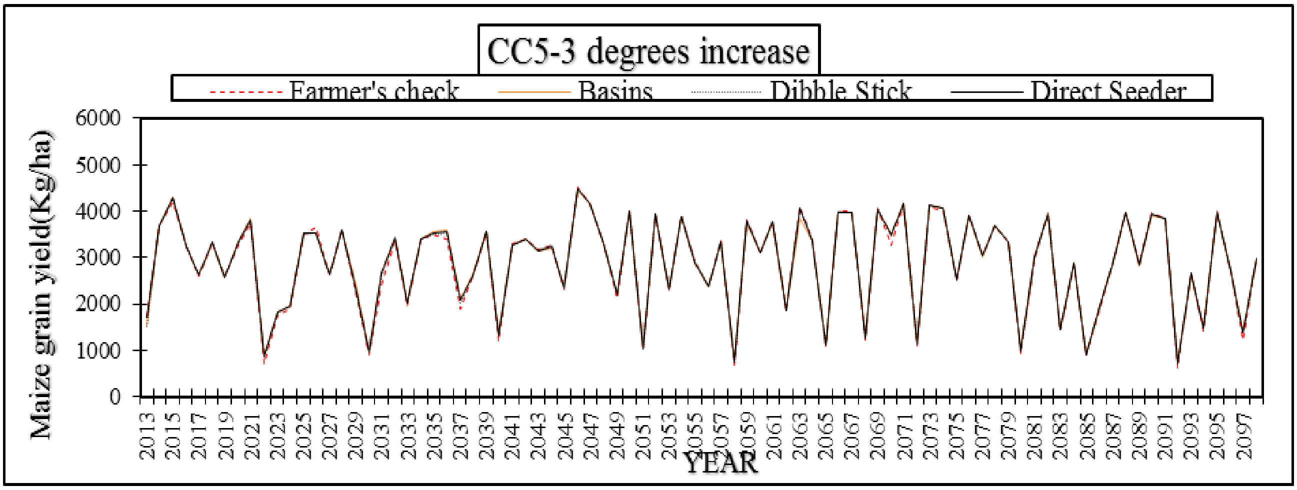
Similarly, when temperature was increased by 2°C as climate change scenario (CC4-2 degree increase) the simulated average grain yield for CT treatment continued to decrease (Figure 10). The simulated output results showed a negative effect of temperature rise on maize grain yield for CT treatment. There was a 21 percent (868 Kg ha-1) reduction in maize grain yield compared with the baseline-no climate change simulation (Figure 10)

Figure 10: Predicted Maize Grain Yield from Conventional Tillage and CA Practices Using APSIM Simulation for 85 Growing Seasons Long-Term Trial with 2°C Temperature Increment as Climate Change Scenario at Msekera Research Station



When temperature of 3°C increase was applied as climate change scenario (CC5-3 degree increase) to the crop simulation model, a further negative effect on maize grain yield for CT treatment happened as shown in Figure 11. As a result of temperature rise by 3°C, the APSIM model predicted an average maize grain yield reduction of 31 percent (1278 Kg ha-1) for CT treatments compared with the baseline-no climate change scenario output results. In addition, application of (CC5-3 degree increase) as climate change scenario in this crop simulation model further revealed that apart from the maize grain yield reduction for CT treatment, 28 seasons will experience adverse drought that will complement reduction in yields (Figure 11)

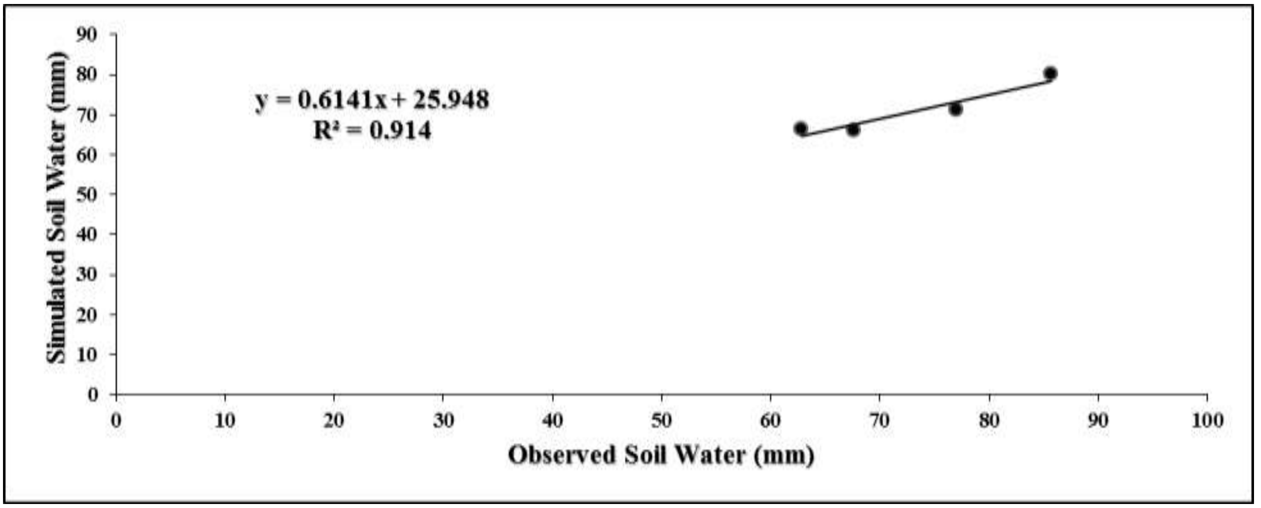
Figure 11: Predicted Maize Grain Yield from Conventional Tillage and CA Practices Using APSIM Simulation for 85 Growing Seasons Long-Term Trial with 3°C Temperature Increment as Climate Change Scenario at Msekera Research Station



Evaluation of the long-term effects of rainfall and temperature changes on soil water under CA predicted using APSIM

The comparison between the observed and simulated data using a linear regression (R2) on soil water is shown in Figure 12. The regression model accounts for 91.40percent of the variance, which was a high value. The graphical linear regression analysis revealed that the more variance that was accounted for by the regression model the closer the data points fall to the fitted regression line. Theoretically, if a model could explain 100percent of the variance, the fitted values would always equal the observed values and, therefore, all the data points would fall on the fitted regression line. The R-squared value in this case was higher and closer to 100percent, and this explained that the model was perfectly calibrated (Figure 12). The average values for accumulated soil water from the different soil layers were 73.29mm for observed and 70.95mm for the simulated results respectively. Whilst, the average RMSE was 5.57 and NRMSE was 8.6percent confirming that the model perfectly predicted the long term effects of rainfall and temperature changes on soil water accumulation for the four treatments.

Figure 12: Comparison between Observed and Simulated Soil Water from both Conventional Tillage and CA Practices for 2014/15 Growing Season at Msekera Research Station



Discussions

Effect of Conventional and CA Practices on Normalized Difference Vegetation Index (NDVI)

The application of NDVI that combined the readings at different wavelengths provided a more precise determination of the plant nutritional status for maize crop. NDVI showed nitrogen content in the leaves through chlorophyll at various phenological stages in this case of maize crop that was grown under different treatments at Msekera Research Station. In this study, results revealed CA treatments had higher NDVI values at the initial stage of growth compared with CT treatments. This was attributed to the availability of soil N the maize crop was getting under CA practice through N mineralization process in addition to the applied inorganic N. It was further clear that the two CT treatments had lower initial NDVI readings as compared to the CA treatments. This was attributed to the absence of additional soil N from residue retention apart from the synthetic N uptake by the maize crop. It is important to note that nitrogen is primarily introduced to the soil either through synthetic fertilizer,

or the breaking down of crop residue and soil organic matter. Previous work has shown that NDVI values were most closely correlated with the nitrogen content of the leaves (Raun *et al*. 2001). Therefore, it was observed that the absence of crop residue in the CT treatments contributed to unavailability of soil N from the breakdown of crop residue.

Generally, CA treatments had higher NDVI values that translated into maize leaves with greener phenological appearances at the initial 24 days after planting (DAP). The same greenness of the leaves prevailed in the CA treatments up to 60 DAP despite the experienced prolonged dry spell at Msekera Research Station. The greenness of leaves for maize crop was attributed to availability of N from both SOM and inorganic supplemented fertilizer in the CA treatments. And also the residue on the soil surface increased water infiltration and storage that was cardinal requirement for plant growth. After 60 days of planting, the supply of N to the leaf of maize crop was reduced and concentrated on grain filling of the cobs. At that time of maize crop grain filling, the chlorophyll content in the leaves started to decrease due to translocation of assimilates from leaf to grain that led to the conversion of the lower color of leaves to yellow most predominately in the CT treatments. From the phenological observation, the greenness of the leaves changed to pale green colour and the lower leaves eventually started yellowing. At that stage of plant growth, the NDVI values started going down for all the treatments more especially the CT treatments.

NDVI values were able to show the maize crop growth at several stages, it was also observed that under CT treatments the nitrogen supply to the plant was not adequate. This was because ploughing and hoe ridging under CT treatments disturbed soil layers and thereby destroying the structure of soil. When the soil structure was destroyed, water infiltration and soil organic matter was also reduced. Also absence of organic matter under CT treatments rendered soil less capable of retaining sufficient nutrients and water in the soil. The opposite was observed in the CA treatments were the presence of SOM lasted longer in the soil as humus. And according to Thierfelder and Wall (2014) plant nutrients associated with humus are more available than inorganic forms of the same nutrients. This confirmed the higher NDVI values and the greener maize leaves obtained from the CA treatments as compared with the CT treatments.

Effect of Conventional and CA Practices on Maize Yield

There was a highly significant difference between the biomass yield from CT and CA treatments (Figure 2). Direct seeder maize-soybeans (CA) treatment had higher biomass compared with conventional practice ridge and furrow (CT) treatment that had lower biomass yield. This was attributed to the presence of crop residue on the surface of the soil for CA treatment during the growth. Crop residue retained on the surface of the soil improved the soil structure and nutrient availability through decomposition. This was beneficial to the growth of maize crop under CA treatment that culminated into higher biomass yield. Phenological assessments of germination on CA treatments showed an earlier and more even germination compared to CT treatments, and that contributed to the biomass yield advantages. In addition, crop residues were retained in CA treatments, whereas they were removed from CT treatments in line with the current farmer practices in Zambia. The field observation further revealed that CA treatments generally worked well with residues retention, as many benefits were derived from surface mulch.

However, the drawback from the on-farm fields for most smallholder farmers is that they manage mixed crop-livestock systems and depend on the residues for fodder during the dry season. And according to similar findings by Thierfelder *et al.,* (2014), who observed that residues retained on the surface of the soil increased infiltration, more of the rainfall went into the soil and less was lost by evaporation. So there was enough water in the soil for plant growth. Some water may have been lost to the crop by drainage, but in most cases especially during the prolonged dry spell periods experienced during the study, there was sufficient water available for plant growth. Thierfelder *et al.,* (2014), further confirmed that crop residues protect against soil erosion because more water goes into the soil, less water runs off the land. Therefore, the study suggested that residues retained on the soil surface slowed the flow of runoff water across the land. The combination of these two factors leads to large reductions in water erosion. Mupangwa *et al*., (2012), further reported that residues also protected the soil from the wind, and as the soil was not loosened by tillage in CA systems, there was markedly less wind erosion. The field observations further revealed that crop residues increased biological activity. The other observation was that residues provided a constant food source for soil fauna and flora, and a habitat for many organisms. Therefore, it was obvious that the populations of soil organisms increased under CA. Most of these soil organisms were beneficial to plant growth as they assisted to produce soil pores or attacked crop pests found in the CA treatments. Contrary to the CT treatments that had no crop residue retention, the plots were under clean tilled agriculture only the crop was present and there was no food source except the crop itself for soil organisms and there was no habitat for predatory insects.

There was variability that existed on maize grain yield among treatments with highly significant difference between observed DS-MC and CPM1 treatments under CA and CT systems respectively (Figure 3). DS-MC treatment had higher measured maize grain compared with CPM1 treatment that had lower grain yield. The significant difference observed between the two treatments was attributed to the role CA played as its rotation effects could not be separated from the effect of tillage. This clearly explained why observed yields from the CA treatments with rotation were higher on the CA long-term trial at Msekera Research Station during the 2014/15 season. The combination of a leguminous rotational crop (cowpea) with maize added more nitrogen to the cropping systems, reduced pests and diseases such as Striga (*Striga asiatica L.*), a parasitic maize weed that is common in Zambia, and improved soil structure. According to Thierfelder *et al*., (2014), who reported that under CA, rotations will often be better than a monoculture even if legumes are not included in rotation? He further suggested that, the best economic returns from rotations can be obtained if legumes are included because of the nitrogen they add to the system. Meanwhile, the study revealed that rotations alone were not sufficient to maintain high crop productivity, but extracted nutrients had to be replaced by synthetic fertilizers. The two legume crops (cowpea and soybean) were rotated with the cereal (maize) in this study from the recommended growth strategy of nutrient accumulation versus nutrient depleting crops. Furthermore, the combination took into account the importance of rotating different species, and especially species that have different pests and disease prevalence.

Generally, the maize yields from various CA treatments performed better than yields of farmers in Chipata district with observed 439 Kg ha $^{-1}$ average increase. However, in Zambia maize productivity is still low and the average yield is 1,700 Kg ha $^{-1}$ (CSO report, 2013).Therefore, the measured field results confirmed that CA rotational treatment with cereals and legumes outperformed the other CA treatments at both on-station and on-farm CA long term trials. Mupangwa *et al*., (2012) also confirmed that results from Kayowozi on-farm experimental site in Chipata district showed that maize yields in a Direct seeded CA treatment, using cowpea seeded with a dibble stick in full rotation, increased by up to 78percent after four cropping seasons in comparison to a conventional control using a ridge and furrow system. As for CA treatment with maize intercropped with cowpea in order to benefit from both crops, the effectiveness of this strategy in controlling pests and diseases was uncertain. The treatment showed very strong competition between the cereal (maize) and the intercropped legume (cowpea). As a result, maize yields in DS-M/C were the lowest among the observed CA treatments during the 2013/14 season (Figure 3). This was attributed to the fact that crops grown as intercrops should be of different growth habits, canopy structure and rooting architecture. Under this treatment relay-intercropping was used to grow two crops (maize-cowpea) simultaneously during part of the life cycle of each. The second crop (cowpea) was planted after ten days of planting the first crop (maize) but of course before reaching reproductive stage. Furthermore, spatial arrangement of cereal and legume crops in intercropping system was used with an arrangement of component crops in an alternating row manner with one row of cereal followed by a row of legume. The study observed that the 10 days phase seeding of cereal (maize) and legume (cowpea) crops in the intercrop treatment was too short and resulted in high competition between the two crops. This subsequently contributed to the low yields for biomass and grain obtained from CA intercropped treatments as compared to the others under the same cropping system. However, a high cereal and legume yield when compatible crop species are intercropped improves soil fertility when grain legumes or leguminous green manure cover crops are intercropped with cereals. And according to (Shitumbanuma *et al*., 2014), intercropping helps to break the cycles of diseases, weeds and pests. Therefore there was need to increase the period between seeding of cereals and that of the legumes in this intercropping system in order to avoid intercrop competition for light and nutrients. But according to Wall, (2009), when compatible crops are selected, no negative effects on crop growth and yield are experienced on different dates that are relay planting. The cereal is often seeded first and the legume can be seeded up to eight or more weeks after seeding the cereal depending on the species and purpose of the legume selected (Wall *et al*., 2014).

Evaluation of the Long-Term Effects of Rainfall and Temperature Changes on Crop Yields under CA Predicted Using APSIM

Model Calibration and Simulation of Long Term CA Effects under Climate Change

The model predicted that there will be approximately 0.4percent increase in maize grain yield on average for CA treatments when 11.3percent increase in rainfall climate change scenario was applied to the model. Mkonga *et al*., (2013) also confirmed that the increase in yield on CA treatments does not necessarily depend on the increase in rainfall. In addition, the model predicted an average increase in maize crop yield for CA treatments of 4percent (171 Kg ha^{-1}) with the application of 11.3percent decrease in rainfall as climate change scenario. The model prediction on the decrease in cumulative rainfall or drought consistently confirms the potential of CA to off-set the future effects of climate change on crop productivity. And according to the finding of Dimes *et al*., (2010) that revealed that APSIM output showed that increasing CO_2 concentrations increased maize crop yields in the order of 6–8percent. The simulated results revealed that reduction in annual rainfall had a positive impact on maize grain yield. However, Dimes *et al*., (2010) concluded that it is increasing of temperature and not reducing rainfall that has the most dramatic impact on crop grain yields with simulated results showing a reduction of 16percent for the two cereals (maize and wheat), 31percent for groundnut, but only 3percent for pigeon pea respectively. On temperature, the model predicted an 11percent (454 Kg ha-1) decrease in average maize grain yield for CT treatment when 1 ^{o}C increase climate change scenario was applied to the crop simulation model. The results further revealed that there was significant decrease in average maize grain yield for CT treatments as compared to the CA treatments when temperature was raised as climate change scenario. The study suggests that in future smallholder farmers who will want to continue practicing CT should not adopt longer duration cultivar rather than shorter duration germplasm. The shorter duration germplasm will seem to be more appropriate response in dealing with the effects of climate change. Another preliminary indicator is that opportunities for increased cropping intensity and accelerated use of legumes in the farming system could emerge under climate change. Furthermore, the APSIM model predicted a of 21percent (868 Kg ha^{-1}) decrease in average maize grain yield when 2 ^{o}C increase in temperature was applied as climate change scenario. The simulated results further revealed a 31percent (1,278Kg ha^{-1}) when 3 ^{o}C increase in temperature was applied as climate change scenario respectively. In support of the model's prediction, Tumbo *et al*., (2010) observed that maize grain yield in the future seasons are only expected just below 2 t ha^{-1} for CT practice as a result of climate variability. He further reported that, probability of maize grain yield gain of 2 t ha^{-1} is quite significant in the long period of CA practice adoption in future amidst climate change.

According to IPCC, (2001) report that suggested that global surface air temperature may increase by 1.4 ºC to 5.8 ºC at the end of the century. Tumbo *et al*., (2010), confirmed that CA practices stand a greater chance to adapt to climate change at least by 2050, where temperature is projected to increase by 2 ºC and rainfall to increase by 56 mm during the long rainy season. Therefore, this temperature rise prediction will greatly contribute to decrease in crop yield mostly for major crops like maize that is a staple food for most Southern African countries. Suffice to mention that despite the decrease in maize grain yield in response to temperature rise, CA will continue to perform better than the CT practices as shown in the results of this study. And according to Watson *et al*., (2000) who reported that for temperature increase to above 3 °C, yield losses are expected to occur everywhere and be particularly severe in tropical regions. He further reported that in parts of Africa, Asia, and Central America yields of wheat and maize could decline by around 20 to 40 percent as temperature rises by 3 °C to 4 °C, even assuming farm-level adjustments to higher average temperatures. The decrease in cumulative rainfall has no significant impact on grain yield and productivity as it led to an increase in maize crop yield especially as predicted by the model for 85 cropping seasons under the three CA treatments. By adopting CA practices in a long run, higher maize yields are predicted compared to the CT practices, averaging 24-30percent estimated increases in the long run. Therefore, the findings of the study emphasizes on the need to continue practicing CA in seasons to come so as to expect much better crop yields than the current situation in relation to maize production. However, the largest scope for dealing with reduced crop yields and food insecurity under future climate change is to raise the productivity of smallholder rain fed cropping systems in Zambia.

Evaluation of the Long-Term Effects of Rainfall and Temperature Changes on Soil Water under CA Predicted Using APSIM

The APSIM model simulated that rainfall had a positive effect on the soil water accumulation mostly for CA treatments. Increase in annual rainfall had an advantage on CA treatments as the soil water accumulation was equally increased and coupled with the presence of crop residue on the soil surface improved soil water storage. Reducing the annual rainfall in the crop simulation model by 11.3 percent as climate change scenario showed no significant effect on soil water accumulation in the CA treatments. Furthermore, when temperature was raised from 1 to 3 ^{o}C, there was no significant decrease in soil water accumulation in the CA treatments. However, the CT treatment had significant effects of raised temperature as compared to CA treatments.

During the drying out phases after the cropping season, APSIM model simulated that direct seeder maize-cowpea rotation (DS-MC) treatment maintained more soil moisture than the other CA and CT treatments as a result of available crop residue cover on the soil surface that was able to maintain good and conducive temperature. The basins with maize (BAM) treatment under CA system maintained the lowest moisture content at drying out period among the three CA treatments. This was contrary to the principles of CA in most cases. There was a positive correlation on the simulated APSIM outputs between the maize grain yield and soil water in this experiment as was analyzed using the linear regression. However, on average, the first two layers at 10-20 cm and 20–30 cm were particularly interesting in this comparison, with a greater distinction between treatments. When all four layers were combined into one soil moisture profile of 0–40 cm, it was observed that the three CA treatments had more moisture (in mm) than the conventional control plot.

The presence of soil moisture in the CA treatments confirmed that this technology has higher potential to mitigate the effect on climate change on crop production and water harvesting. The APSIM model also revealed that soil moisture retention in CA treatments was not affected by drought but slightly as a result of increase in temperature. And according to the study by Chen *et al*., (2013) who reported that APSIM model showed promise in simulating soil water balance, crop growth and grain yield measured in the field experiments for different cropping systems and CA technologies in the Loess Plateau of Gansu in China. In addition, Connolly *et al*., (2002) also reported that APSIM model generally simulated infiltration, runoff, soil water and water balance, and yield as accurately and reliably as other soil crop models. He was able to demonstrate that the model is suitable for evaluating effects of infiltration and soil water relations on crop growth. However, the long term simulation on the effect of rainfall and temperature on soil water revealed that out of 85 years simulation 22 seasons will experience adverse drought and that will consequently result in yield reduction most especially for the CT practices.

Conclusion

Conservation Agriculture aims at increasing crop productivity and production mostly among smallholder farmers in Sub-Saharan Africa. The anticipated long-term CA intervention will increase adoption of resilient farming systems leading to improved food supply, reduce hunger, counter rising food prices, and improve responses to food emergency crisis by extending the area of land under CA practices. The canopy analysis on the effect of treatment on maize yield through a NDVI revealed that CA treatments had greener vegetation compared to CT treatments. CA treatments had higher positive NDVI values an indication of healthier maize with more chlorophyll for plant growth. NDVI analysis positively correlated to maize grain and biomass yields for observed treatments. In addition, NDVI analysis proved to be a very helpful tool in estimating photosynthesizing ability of plants, primary production, and maize yield. Furthermore, the performance of the APSIM model on crop simulations was perfect on the effect of rainfall and temperature changes on both crop yields and soil water dynamics under CA practices. Even though the APSIM model over-predicted maize biomass yield as a result of failure to recognized some variability that existed in the environment during the 2014/15 season at Msekera Research Station. The variability includes the severe moisture deficit that characterized the season most especially during the prolonged dry spells. The crop simulation model was performed for 85 seasons and the simulation model outcome considered five rainfall and temperature related climate change scenarios. The reduction on the amount of rainfall under simulation had a positive effect on crop production has it raised maize grain yield by 4percent on average for CA treatments. Nevertheless, the research revealed that increase in temperature had a negative effect on maize crop yield for CT treatment. Increase in temperature to 3 ^{o}C resulted in average maize crop yield decrease of up to 31 percent compared with the baseline no climate change. Moreover, under the same climate change scenarios, the ASPIM model similarly simulated high soil moisture under CA treatments compared with CT treatment. The long term simulation on the effect of rainfall and temperature on soil water also revealed that out of the 85 years predictions, 22 seasons will experience adverse drought and that will consequently result in yield reduction especially for the CT practices. Nevertheless, the long-term future climate change simulations revealed that CA was less vulnerable to climate variability expressed by higher yields in drier seasons compared to CT practices. Similarly, cumulative probability distribution indicated that CT was more of a risky system compared with CA systems. Therefore, the study has proved that adoption of CA systems in Eastern Province of Zambia will prepare smallholder farmers for the anticipated future threats of climate variability and changes in agriculture sector. While application of full principles of CA system indicated benefits in terms of less vulnerability to lower grain yields in dry seasons like the current one that had more than 21 days prolonged dry spell.

References

[1] Antonopoulos, V.Z. (1997). Simulation of soil moisture dynamics in irrigated cotton in semi-arid climates. Agricultural Water Management 34, 233-246.

[2] Bezlepkina, I.V., Adenaeur, M., Kuiper, M.H., Jansen, S.J.C., Knapen, M.J.R., Kanellopoulos, A., Brouwer, F.M., Wien, J.J.F., Ittersum, M.K.V., 2010. Using the SEAMLESS Integrated Framework for Ex-ante Assessment of Trade Policies, Wageningen Academic Publishers, and Wageningen, Netherlands.

[3] Calzadilla A., Rehdanz K., Betts R., Falloon P., Wiltshire A, and Richard S.J. 2008. Climate change impacts on global agriculture. Kiel Institute for the World Economy 24100 Kiel, Germany.

[4] Chen, C., Baethgen, W.E., Robertson A., 2013. Contributions of individual variation in temperature, solar radiation and precipitation to crop yield in the North China Plain, 1961-2003 Clim. Change, 116 (3–4) (2013), pp. 767–788.

[5] Commission for Africa. 2005. Our common interest: Report of the Commission for Africa. London: Commission for Africa. http:// www.commissionforafrica.org/english/report/ introduction.html. Accessed: 20th October, 2015.

[6] Connolly, R.D., Bell, M., Huth, N., Freebairn, D.M., Thomas, G., 2002. Simulating infiltration and the water balance in cropping systems with APSIM-SWIM. Aust. J. Soil Res., 40 (2) (2002), pp. 221–242.

[7] Cooper, M. van Eeuwijk, F.A., Hammer, G.I., Podlich, D.W., Messina, C., 2009. Modeling QTL for complex traits: detection and context for plant breeding. Curr. Opin, Plant Biol. 12(2), 231-240.

[8] Dalgliesh, N.P. and Foale, M.A. (1998) Soil matters-Monitoring soil water and nutrients in dryland farming systems. CSIRO/Agricultural Production Systems Research Unit. Technical Manual-ISBN 0 643 06375 7.

[9] Dimes J.P., Cooperb P., and Rao K.P.C. 2010. Climate change impact on crop productivity in the semi-arid tropics of Zimbabwe in the 21st century, ICRISAT – Bulawayo, Zimbabwe.

[10] Gardner, E.A. 1988. Soil Water. In Understanding soils and soils data, 153-186. I.F. Fergus ed., Brisbane, Queensland: Australian Society of Soil Science Inc.

[11] Hobbs, P.R. 2007. Conservation agriculture. What it is and why it is important for sustainable food production. Paper presented at the International Workshop on Increased Wheat Yield Potential, CIMMYT, Obregon, Mexico. Journal on Agricultural Science 145 (02), 127-137.

[12] Hochman, Z., van Rees, H., Carberry, P.S., Hunt, J.R., McCown, R.L, Gartman, A., Holzworth, D., van Rees, S., Dalgliesh, N.P., Long, W., Peake, A.S., Poulton, P.L., McClelland, T., 2009b. Re-inventing model-based decision support with Australian dryland farmers. 4. Yield Prophet Helps monitor and manage crops in a variable climate. Crop Past. Sci 60 (11), 1057-1070.

[13] IPCC 2001. Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

[14] IPCC 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge University Press.

[15] Jones, C.A., and J.R. Kiniry. 1986. CERES-Maize: A simulation model of maize growth and development. Texas A&M University Press, College Station, Texas.

[16] Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J., Serraj R. 2012. Conservation agriculture in the dry Mediterranean climate Field Crops Research, 132 (2012), pp. 7–17.

[17] Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009.The spread of conservation agriculture: justification, sustainability and uptake. Int.J.Agr.Sustain.7, 292–320.

[18] Keating B.A.; Carberry P.S.; Hammer G.L.; Probert M.E.; Robertson M.J.; Holzworth D.; Huth N.I.; Hargreaves J.N.G.; Meinke H.; Hochman Z.; McLean G.; Verburg K.; Snow V.; Dimes J.P.; Silburn M.; Wang E.; Brown S.; Bristow K.L.; Asseng S.; Chapman S.; McCown R.L.; Freebairn D.M.; Smith C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. Source: European Journal of Agronomy, Volume 18: (3) 267-288

[19] Kumwenda, J.D.T., Waddington, S.R., Snapp, S.S., Jones, R.B., Blackie, M.J., 1997.Soil fertility management in the smallholder maize-based cropping systems of Africa. In: The Emerging Maize Revolution in Africa: The Role of Technology, Institution and Policy, Michigan State University, USA.

[20] Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, and R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science 319, 607-610).

[21] Mahdian, M. H. and Gallichand, J. 1995. Validation of the SUBSTOR model for simulating soil water content. Transactions of the American Society of Agricultural Engineering 38: 513-520.

[22] Marahatta, S., Sah, S.K., MacDonald, A., Timilnisa, J., Devkota, P.K., 2014. Influence of conservation agriculture practices on physical and chemical properties of soil. Department of Agronomy, Institute of Agriculture and Animal Science, Tribhuvan University (TU), Nepal.

[23] Marongwe L. S., Kwazira K., Jenrich M., Thierfelder C., Kassam A., and Friedrich T. 2011. An African success; the case of conservation agriculture in Zimbabwe. International Journal of Agricultural Sustainability 9(1) Earthscan.

[24] McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., Freebairn, D.M., 1996. APSIM: a novel software system for model development, model testing, and

simulation in agricultural systems research. Agric. Syst. 50, 255-/271.

[25] Mkonga, Z.J., Tumbo, S. D., Kihupi, N., and Semoka, J. 2013. Extrapolating effects of conservation tillage on dry spell mitigation, yield and productivity of water using simulation modeling. Sokoine University of Agriculture Department of Agricultural Engineering and Land Planning, Morogoro, Tanzania.

[26] Mupangwa W., Dimes J., Walker. S., and Twomlow S. 2011. Measuring and simulating maize (Zea mays L.) yield responses to reduced tillage and mulching under semi-arid conditions. CRISAT, Matopos Research Station, Bulawayo, Zimbabwe.

[27] Mupangwa, W., Twomlow, S. and Walker, S. 2012. Reduced tillage, mulching and rotational effects on maize (Zea mays L.), cowpea (Vigna unguiculata (Walp) L.) and sorghum (Sorghum bicolor L. (Moench)) yields under semi-arid conditions. Field Crops Research 132, 139–148.

[28] Raun W.R., Solie J.B., Johnson G.V., Stone M.L., Lukina E.V., Thomason W.E., Schepers J.S. 2001: In-season prediction of potential grain yield in winter wheat using canopy reflectance. Agronomy Journal, 93: 131–138.

[29] Shitumbanuma V., Simfukwe P., Kalala D., Kaninga B., Gondwe P., Nambala M., Kabwe S., Siulemba G., Kapulu N., Lungu O. and Mutegi J. 2014. Integrated Soil Fertility Management in Zambia. The Zambia Soil Health Consortium. Zambia**.**

[30] Thierfelder C. and Wall P.C. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105, 217-227.

[31] Thierfelder C. and Wall P.C. 2010. Rotations in conservation agriculture systems of Zambia: Effects on soil quality and water relations. Experimental Agriculture 46, 309-325.

[32] Thierfelder C. and Wall P.C. 2010a. Investigating Conservation Agriculture (CA) Systems in Zambia and Zimbabwe to Mitigate Future Effects of Climate Change, Journal of Crop Improvement, 24:2, and 113-121).

[33] Thierfelder C., and Wall P.C. 2014. Bulletin SIMLEZA-AR; Conservation Agriculture in Zambia, Less Labor and Higher Yields, CGIAR Research Program MAIZE, USAID funded, CIMMYT Zimbabwe.

[34] Thierfelder C., Mupangwa W. and Wall P.C. 2014. Bulletin SIMLEZA-AR; Conservation Agriculture in Zambia, Less Labor and Higher Yields, CGIAR Research Program MAIZE, USAID funded, CIMMYT Zimbabwe.

[35] Tumbo, S.D., Mpeta, E., Tadross, M., Kahimba, F.C., Mbilinyi, B.P. and Mahoo, H.F. 2010. Application of self-organizing maps technique in downscaling GCMs climate change projections for Same, Tanzania. Journal of Physics and Chemistry of the Earth 35: 608617.

[36] Wall, P.C. 2009. Strategies to Overcome the Competition for Crop Residues in Southern Africa: Some Light at the End of the Tunnel. In: Innovations for Improving Efficiency, Equity and Environment. 4th World Congress on Conservation Agriculture. Lead Papers. New Dehli, pp. 65–70.

[37] Wall, P.C., 2007. Tailoring conservation agriculture to the needs of small farmers in developing countries: an analysis of issues. Journal of Crop Improvement 19, 137–155.

[38] Yanda P. Z. and Mubaya C.P. 2011. Managing a Changing Climate in Africa. Local Level Vulnerabilities and Adaptation Experiences. Dar-ES-salaam, Mkuki na Nyota.