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Effect of Climatic Variability on Maize and Soybean Yield under a High Input Farming System in Copperbelt Province, Zambia

Pathias N. Lubinga[1], Lydia M. Chabala[1], Mutisungilire Kachulu[1] & Vernon R. N. Chinene[1]

[1] Department of Soil Science, School of Agricultural Sciences, University of Zambia, Zambia

Correspondence: Pathias N. Lubinga, School of Agricultural Sciences, Department of Soil Science. University of Zambia, P. O. Box 32379, Lusaka, Zambia. Tel: 260-9-7488-9688; 260-9-6521-5964. E-mail: plunbinga@gmail.com

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Abstract

In many developing countries, the effect of climate change on agriculture is evaluated with reference to small scale farmers, mainly under low input systems. As a result, literature on climate variability and its effect on high input farming systems are scanty. We evaluated the impact of climatic variability on maize and soybean yield under a high input management system. The objectives of the study were to: (i) assess rainfall and temperature variability at a high input farm (ii) evaluate the effect of rainfall and temperature on maize and soybean yield under high input management system. (iii) assess the impact of El Niño and La Niña on maize and soybean yield. Data for rainfall and temperature was obtained from the Zambia Meteorological Department which was complimented by records from the weather station located at the study site. Yield data for both maize and soybean was provided by ZAMBEEF farm. The analysis covered 32 years from 1980 to 2012. Time series plot was used to investigate the trend in minimum and maximum temperature and seasonal rainfall. Correlations were done in SPSS to establish the strength and direction of association between climatic variables (temperature and seasonal rainfall) and maize and soybean yield. Multiple Regression in SPSS was then used to analyze variation in maize and soybean yield due to climatic variables. Results revealed that minimum temperature had an increasing linear trend of 0.3°C to 0.5 per decade while maximum temperature showed an increasing linear trend of 0.2°C to 0.3°C per decade. On the other hand, seasonal rainfall was variable over the period studied. The variations in maize and soybean yield explained by seasonal rainfall and temperature was not significant with only 17.2% and 20.1% of the variation explained, respectively. Although there was no significant impact of both El Niño and La Niño on the yields of both crops, regression analysis revealed a negative relationship between El Niño and soybean yield and a positive relationship with maize yield and a positive relationship was showed between La Niña and maize and soybean yields.

Keywords: climatic variability, high input system, soybean, maize, El Niño and La Niña

1. Introduction

1.1 Climate Change Concept

As countries seek to develop reliable sources of food for their citizenry, it is the responsibility of governments to take decisions that ensure reliable and continuous supply of food to increasing populations through timely and proper enlightenment of the farmers on proper adaptation practices in order to lessen the impact of climate change on their outputs (Obasi & Uwanekwu, 2015). Such decisions may involve guidance from research findings to ensure sufficient crop production even under the threat of climate variability. Currently, such interactions between policy making and research are well exemplified in the relationship between climate change and food security. Climate change refers to significant variations in weather conditions that last for an extended period of time, usually a decade or longer, attributed to release of gases such as CO_2, N_2O, CH_4, CFCs and O_3 into the atmosphere (IPCC, 2007). Literature indicates that climate change has been rapid over the past few decades and variability is likely to increase under global warming (Lobell & Gourdji, 2012; Katz & Brown, 1992). According to the 5thAssessment Report of the IPCC (2013) the average annual temperature will rise by more than 2°C in most of Africa by mid of 21st century. The report further states that by the end of the 21st century, with high emission scenarios temperature rise may reach as high as 6°C in some areas while under a low emission scenario, the average temperature rise may be 2°C. Other studies have attributed variability in climate to El Nino and La Nina episodes which occur semi-regularly at intervals of 2-7 years (WHO,2000).

1.2 Agriculture in Zambia

Zambia is endowed with a large land resource base of 42 million hectares out of which only 1.5 million hectares (3%) are under cultivation (ZDA, 2011). Just like in many Sub-Saharan countries, agriculture has the potential to become the main stay of the Zambian economy and therefore represents a huge potential as an alternative to mining. Already agriculture plays a critical role in Zambia's economy, where its contribution to GDP in 2002 was 15.2 % rising to about 20 % in 2009. The agriculture sector is also estimated to contribute about 70% of the national labor force and is a major source of income and livelihood for the majority of the Zambian population (ZDA, 2011)

Notwithstanding this potential, agriculture is prone to the negative impact of climate change and climate variability given that 97% of agricultural land is rain-fed in Sub-Saharan Africa (Rockstrom, 2014). In Zambia, more than 98% of agricultural land is rain-fed (FAO/IFC, 2014). Climate change affects crop yields through its influence on crop production (Acquah & Kyei, 2012). While this is generally agreed by many studies, not much research has been done in Zambia with regard to climate change and its effect on crop yields particularly under high input farm management systems. A few studies which have been undertaken have used low resolution data (Chabala, et al., 2014), leading to generalization of different agro ecological zones, and thereby providing less insights to both policy makers and farmers themselves (Kachulu, 2018). Other than relying on coarse resolution findings to understand the impact of climate change on agriculture, which has usually been the case in the past, this study aimed at using specific regional point data at a high input farm in Zambia. The objectives were to (i) assess rainfall temperature variability 0n high input farm (ii) evaluate the effect of rainfall and temperature on maize and soybean yield under high input management system and (iii) assess the impact of El Niño and La Niña on maize and soybean yield

2. Methodology

2.1 Description of Study Location

The study was conducted at ZAMBEEF farm located in Mpongwe district of the Copperbelt province of Zambia situated on latitude13˚32'0"south and longitude28˚9'0" East, with an elevation of 1,195 meters above sea level. It is in agro-ecological zone three (III) which is characterized by annual rainfall of more than 1,000mm and is mostly dominated by Oxisols (USDA, 2014). Generally, these soils are acidic with pH ranges of 3.8 to 4.4. The soils are strongly weathered with low base saturation. The total area under cultivation at is 9,560 hectares, out of which 2,110 hectares are under irrigation while 7450 hectares are rain fed and the management system at the farm is high input and mechanized.

2.2 Data Sources

The rainfall and temperature data was obtained from the Zambia meteorology Department at Ndola Meteorology Station located in the same agro-ecological zone as the study area. The climatic data was complimented by records available at the farm. Observed yield (1980 to 2013) data for maize and soybean was provided by ZAMBEEF Farm.

2.3 Data Processing and Analysis

Preliminary evaluation of the data was done by calculating average yearly minimum, maximum and mean temperature. Similarly minimum, maximum and the mean seasonal rainfall were calculated. The soybean and maize yields were used as provided. Additional data checks were done to determine the extent of data period which covered both climatic variables and crop yields. Missing data for both climatic variables were omitted from the analysis, thus, 32 years of consistent data for both crop yields and climatic variables was used in the analysis.

2.4 Assessment of Rainfall and Temperature Variability

Trend analysis for both seasonal rainfall and temperature (maximum and minimum) were done in excel and time series plots using a ten year moving average. This was done to explore the variation in the seasonal distribution of both temperature and rainfall over the study period (1980-2012).

2.5 Evaluation of Effects of Rainfall and Temperature Variability on Maize and Soybean Yields

Firstly, the strength and the relationship between climatic variables, maize and soybean was determined using correlations in SPSS. This was explored in a scatter plot and the correlation coefficients were calculated. The first aim was to check whether crop yields correlated with seasonal rainfall and temperature, that is, to determine whether as one variable increases, the other increased or decreased. This test of association was summarized with the ρ value where a significant association means that different values of the independent variables cause different values of the dependent variable. Then multiple regression analysis was done in SPSS to fit models of how much variation in maize and soybean yield was explained by the climatic variables of seasonal rainfall and temperature (maximum and minimum). As a standard, a correlation coefficient of 0.8 was taken to signify strong correlation. The coefficient of multiple determination (R^2) was used to establish the percentage explanation of variation in maize and soybean yield attained by both seasonal rainfall and temperature. This method is desired as it gives the best linear and unprejudiced estimates among other estimators and has been used by many authors to successfully study the effect of climatic variability on crop yield (Chabala, et al., 2014; Adamgbe & Ujoh, 2010)

The general regression equation was:

$$Y=b_0 + b_1X_1 +\dots b_nX_n +\mathcal{E} \quad (1)$$

Where Y is the outcome variable, in this case maize and soybean yield, b_0 is the constant, $b_1 \dots b_n$ are the estimated parameters and X_1, X_n are the explanatory variable (e.g. seasonal rainfall, average yearly minimum and maximum temperature and average yearly maximum temperature) and $\mathcal{E}$ is the error term.

2.6 Assessment of Effect of El Niño and La Niña on Yield of Maize and Soybean

As El Niño and La Niña years were already classified from the data obtained, average yield for each classification was calculated and fit models of how much variation in maize and soybean yield were explained by El Niño and La Niña and R^2 was used to determine the goodness of fit.

3. Results and Discussion

The results showed that the average, maximum and minimum rainfall under the study period were 1073.8mm, 1524.8mm and 596.1mm, respectively (Table 1). The average maximum temperature was 28.4°C with the maximum and minimum being 29.5°C and 26.7°C, respectively. The minimum temperature had an average of 14.2°C, with the maximum of 15.3°C and the minimum of 13.4°C. The average maize output was 7.5 ton/ha with the maximum and minimum output being 9.9ton/*ha* and 4.8ton/ha, respectively and the average output of soybean was 2.5ton/ha with the maximum of 3.9ton/ha and minimum of 0.8ton/ha within the period under study as shown in Table 1. The average yield for both maize and soybean realized at this farm are higher than the Zambia's average yields among smallholder famers. This could be attributed to the high input and management practices. Average yield for smallholder farmers for maize ranges from 1.1ton/ha to 1.5ton/ha, while for Soybean ranges from 0.7ton/ha to 1.0ton/ha (ACF/FSRP, 2010).

Table 1. Summary statistics

Parameters	Mean	Max	Min
Rainfall(mm)	1073.80	1524.80	596.10
Tmax(ºC)	28.40	29.50	26.70
Tmin(°C)	14.20	15.30	13.40
Maize yield(ton/Ha)	7.50	9.90	4.80
Soybean yield(ton/Ha)	2.50	3.90	0.80

Max= maximum, Min= Minimum

3.1 Temperature and Seasonal Rainfall Trend

It was observed that both seasonal maximum and minimum temperatures showed an increasing linear trend as illustrated in Figures 1 and 2, respectively. Maximum temperature presented an increasing linear trend of 0.2°C to 0.3°C per decade while minimum temperature showed an increasing linear trend of 0.3°C to 0.5°C per decade. This means that the area had been experiencing warmer temperature with time. Such temperatures could have negative effects on crop productivity if crops are not well adapted. These results are consistent with the findings of Chabala *et al* (2013) who found an increasing trend in temperature in all selected areas in Zambia (Chabala , et al., 2013). These findings are also consistent with Poudel and Shaw (2016), who reported a similar trend in temperature (Poudel & Shaw, 2016). Seasonal rainfall did not show a definite increasing trend, but rather it showed a variable trend over the period under study as shown in Figure 3. This means that there was no clear indication of increase in seasonal rainfall within the period under study. This variability in rainfall makes it hard for famers to predict the onset and offset of the rainy season which in turn affects their planning for sustainable crop productivity. These results are consistent with Chabala et al (2013), who found a variable trend in rainfall distribution for most areas considered from different parts of the country.

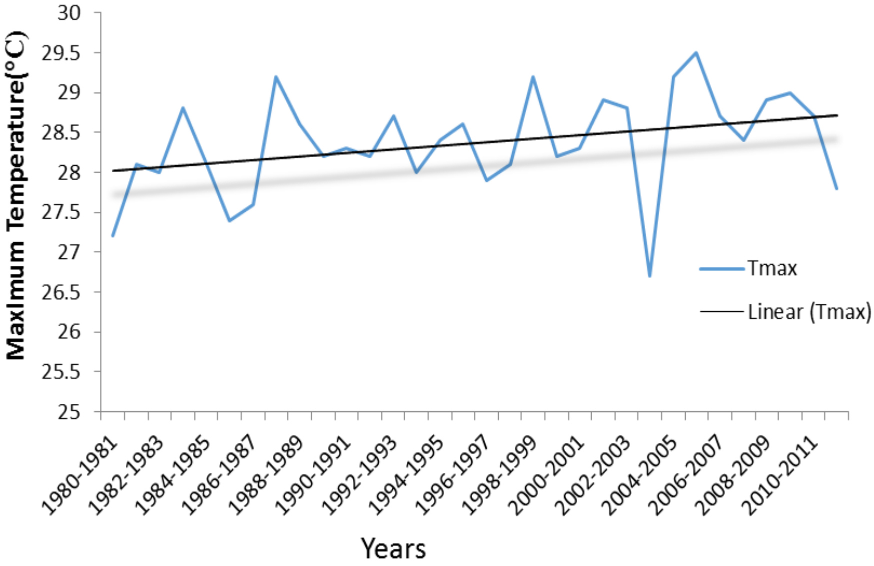

Figure 1. Maximun temperature trend at Mpongwe ZAMBEEF farm 1980-2012

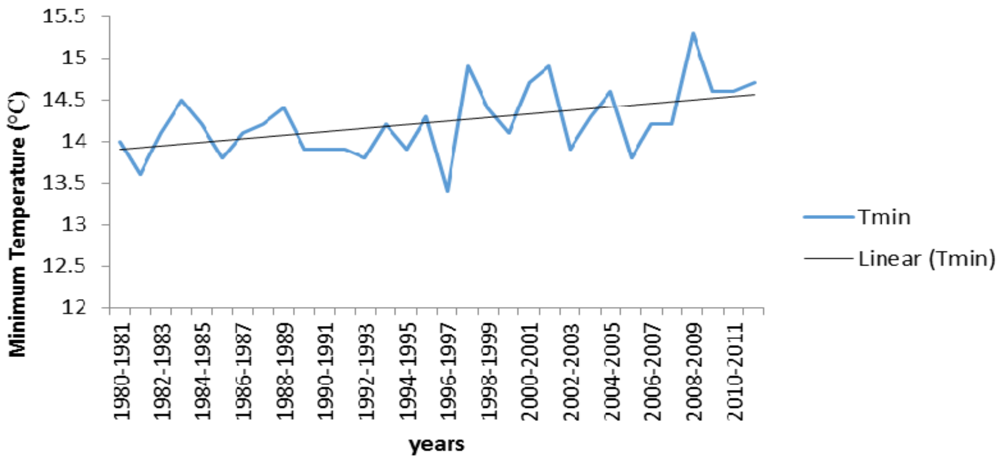

Figure 2. Minimum temperature trend at Mpongwe ZAMBEEF Farn 1980-2012

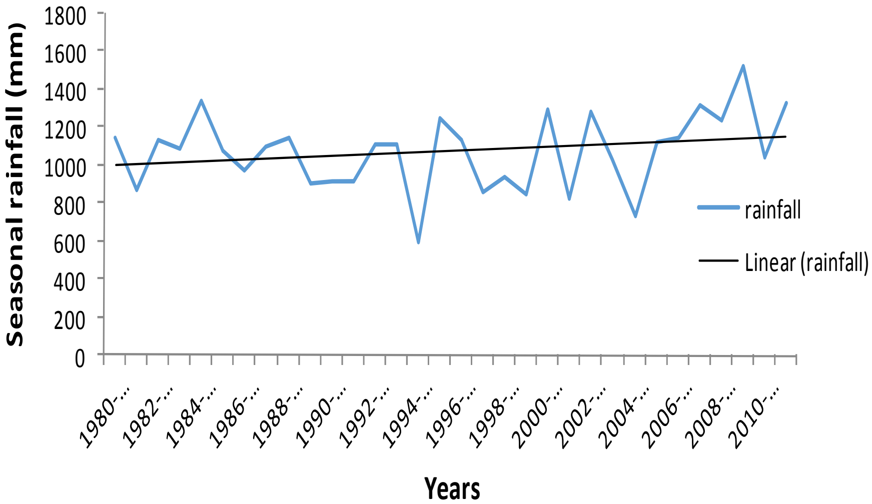

Figure 3. Seasonal rainfall trend at Mpongwe ZAMBEEF Farm from 1980-2012

3.2 Relationship between Maize, Soybean Yield and Selected Climatic Variables

The correlation coefficients of maize yield and climatic variables for Mpongwe ZAMBEEF farm are shown in Table 2. Positive correlation coefficients indicate that as the selected climatic variables increased, maize and soybean yields increased. Generally, a very weak to moderate relationship was observed between maize, and climatic variables. For instance, maximum temperature and seasonal rainfall had positive, non-significant and very weak correlation coefficients of 0.299 and 0.196, respectively. The correlation was significant, moderate and positive between maize yield and minimum temperature at 0.449. The correlation between maximum temperature and rainfall and maize yield was not significant, this means that much of the variation in maize yield could not be attributed to variation in the maximum temperature and seasonal rainfall. This could therefore be attributed to the type of management system being practiced where, in the event that there is insufficient rainfall; mitigation is done by providing moisture to the crop through irrigation. Under subsistence farming where there is no supplementary irrigation the correlation coefficients would have been expected to be much stronger. These results are in line with Schlenker and Roberts, (2009) whose findings showed that where irrigation is practiced, maize is less sensitive to extreme heat (Schlenker & Roberts, 2009). This entails that other than climatic variables, there are several factors that influence maize yield. However, there was a significant relationship between minimum temperature and maize yields. This relationship indicates that the variation in the yields of maize was much influenced by minimum temperature.

The correlation coefficients of soybean yield and the selected climatic variables for Mpongwe ZAMBEEF farm are shown in Table 2. A very weak to moderate relationship was observed between soybean yield and selected climatic variables. For instance, seasonal rainfall and seasonal maximum temperature had a weak, yet non-significant positive correlation of 0.108 and 0.324, respectively. Seasonal minimum temperature had a correlation with soybean yield of 0.484. Positive correlation coefficients indicate that increase in the climatic variables resulted into an increase in soybean yield. Much of the variation in soybean yield could not be linked to variations in both maximum temperature and rainfall due to lack of significance. This is due to improved management practices such as irrigation, high fertilization that buffers against the likely impact of climate change on soybean yield. The results also show that temperature explained more of the variation in crop yields than rainfall. These results agree with those of Lobell, D.B (2013) who found that in scenarios where supplementary irrigation is used in an event of dry spell, temperature explains more of the variation in crop yield (Lobell, 2013)

Table 2. Correlations of maize, soybean and climatic variables

		maize	soybean	rainfall	Tmin	Tmax
maize	Pearson correlation	1	0.69**	**0.19**	**0.45***	**0.29**
	Sig (2-tailed)		0	0.29	0.01	0.10
	N	31	31	31	31	31
Soybean	Pearson correlation	0.696**	1	**0.10**	**0.48****	**0.32**
	Sig (2-tailed)	0		0.55	0.005	0.07
	N	31	32	32	32	32

Note. Tmin= Minimum Temperature; Tmax= Maximum temperature.

3.3 Explanatory Models of Maize and Soybean Yield Variations

Table 3 shows the degree to which seasonal rainfall and temperature explained variations of yield in maize under high input management system. The model showed that variations in maize yield ascribed to maximum and minimum temperature and amount of seasonal rainfall was not significant with only 17% of the variation explained (Table 3). The results also show that an increase in the climatic variables resulted in an increase in maize yield and they also show that minimum temperature had the highest influence on maize followed by maximum temperature and lastly rainfall. These results are in line with the findings of Obasi and Uwanekwa (2015) who found that maize yield increased with an increase in temperature and rainfall (Obasi & Uwanekwu, 2015). These results are also consistent with findings of Chabala et al (2014), who found that much of the variation in maize yield due to climatic variables was not significant for most of the sites considered. This lack of significance means that under a high input management system, maize is less sensitive to climatic variability. However, this trend was not as expected in that under high input system with sufficient fertilizer, crops are likely to be more sensitive to weather changes due to lack of other limiting factors (Schlenker & Lobell, 2010). This could be attributed to the ability of the farm to proactively plan for climate change and as well as incorporation of other agronomic practices that reduce the impact of climate change on crop performance.

Table 3. Model summary for maize yield

Model	R	R Square	Adjusted R Square	Std error of the Estimate
1	0.51[a]	0.25	**0.017**	2.29

3.4 Explanatory Model of Soybean Variations

Similarly, the model was constructed by fitting a regression model of soybean yield with Tmin, Tmax, and seasonal rainfall. The model showed that variations of soybean yield attributed to minimum and maximum temperature and seasonal rainfall was not significant with only 20.1% of the variations explained (Table 4). This lack of significance variation means that soybean is less sensitive to climatic variability under high input management system. The results showed that as the selected climatic variables increased, soybean yield increased. These findings are in line with those of Schlenker and Roberts (2009) who reported that soybean yield increased below a mean annual temperature threshold of 30°C (Schlenker & Roberts, 2009). This trend was as expected since Mpongwe is in Agro-Ecological Zone III with the mean annual temperature of less than 30˚C and besides, it is already a high rainfall zone with seasonal rainfall being more than 1000mm per annum (Wortmann, et al., 1998)

Table 4. Model summary for soybean yield

Model	R	R Square	Adjusted R Square	Std Error of the Estimate
1	.53[a]	0.28	**0.201**	0.64

3.5Explanatory model of the effect of La Niño and El Niña on maize yield:

The analysis indicates that La Niña has a positive non-significant impact on maize yield with only 19% of variations in maize yield explained (Table 5). The results show that during La Nina episodes, maize yield increases. In Zambia, La Niña is associated with rainfall above normal. Therefore, the increase in maize yield could be attributed to management practices such as timely planting and application of fertilizer that ensures that by the time excess rainfall is recorded the crops are already grown. These results bring out a different dimension from what has been revealed by other studies of this kind (Abdolrahimi, 2016). However, these results are consistent with the findings of Lizumi et al (2014), whose results indicated that La Nina is associated with increase in maize yield in West and South part of Africa (Iizumi, et al., 2014) .El Niño showed a positive non-significant impact on maize yield with only 8.6% of the variations in maize yield explained (Table 6). The results indicate that during El Nino episodes, maize yield increases. In Zambia, occurrence of El Nino is associated with rainfall below normal. The expected trend should be a decline in maize yield, but the impact of El Nino on maize yield is mitigated by supplementary irrigation. These results are consistent with the findings of (Iizumi, et al., 2014**)**.Without supplementary irrigation the decrease in yield would have been higher than observed.

Table 5. Model summary of the effect of La Niña on maize yield

Model	R	R Square	Adjusted R square	Std error of the Estimate
1	0.43[a]	0.19	0.057	1.18

Table 6. Model summary of the effect of El Niño on maize yield

Model	R	R Square	Adjusted R square	Std error of the Estimate
1	0.29[a]	0.086	-0.04	1.22

3.6Explanatory model of the effect of La Nino and El Nina on soybean yields:

This study showed the amplitude to which variations in soybean yield was explained by La Nina. The results indicate that La Nina has a positive non-significant influence on maize yield with 14% of the variations explained (Table 7). This means that yield increased during La Nina episodes . Excessive rainfall was probably the reason for the modest increase in yield. However, high moisture can depress yields delaying planting, decreasing plant population, enhancing disease pressure, and causing harvest losses. Hence, the need to intensify disease control measures during such periods. These results are similar to those found by (Iizumi, et al., 2014) . El Niño showed a negative non-significant impact on soybean yield with only 12.2% of the variations explained (Table 8). This indicates that during this episode, yield decreased. This reduction in the average yield could be as a result of dry soils at the time of planting which impedes good germination resulting into low plant population and yield. Nevertheless negative impacts of El Niño are mitigated by irrigation, meaning that without for irrigation, yield reduction would be huge. These results are in line with the findings of Lizumi et al (2014), who showed the negative impact of El Niño on soybean yield (Iizumi, et al., 2014) . Thus, this requires that farmers incorporate other management practices that conserve moisture in soils such as mulching, and as well provision of irrigation schemes to famers in order to abate the negative effects of El Niño.

Table 7. Model summary of the effect of La Niña on soybean yield

Model	R	R Square	Adjusted R square	Std error of the Estimate
1	0.37[a]	0.14	0.17	0.74

Table 8. Model summary of the effect of El Niño on soybean yield

Model	R	R Square	Adjusted R square	Std error of the Estimate
1	0.35[a]	0.12	0.013	0.76

4. Conclusion and Recommendations

This study investigated the variability and impact of climatic variables on maize and soybean yield a under high input management system. It can be concluded that temperature showed an increasing trend while rainfall showed a variable trend for the period under consideration (1980-2012). The effect of El Niño and La Niña on maize yield, though not significant were 8.6% and 19.2%, respectively. For soybean yield, El Niño was associated with decrease in yields accounting for 12% of the variation in soybean yields though not significant. While La Niña episodes were associated with increase in soybean yield accounting for 14% of the yields though not significant. The variation in both maize and soybean yield attributed to climatic variation under high input management system was not significant, meaning that both soybean and maize were less sensitive to climatic variability. Provision of supplementary irrigation abates the impact of climatic variability on crops. Since climatic variables seemed to have influence on maize and soybean yields, inclusion of agronomic practices would go a long way in in achieving sustainable crop productivity. The use of high input system though expensive clearly showed a reduction of the negative impacts of climate change on crop productivity.

It is recommended that further study of this nature be carried out in different districts of different Agro-EcologicalZ to identify the impact of climate variability under high input management system across the country. It is also recommended that a further studies of this nature be carried out in Mpongwe district under a smallholder farming system to assess the impact of climate change on maize and soybean so as to have clear understanding of increase in crop productivity a under high input system in the phase of climatic variation and this type of study be extended to other crops such as wheat and barley, among others

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