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An Econometric Analysis of the Effects of Climate Change on Arable Crop Production in Botswana from 1980-2008

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Abstract
Climate variability and change have been implicated to have had significant impacts on global and regional food production particularly the common stable food crops performance. However, the extent and nature of these impacts still remain are uncertain. In this study, records of crop production (maize and sorghum), climatic variables and non-climatic variables were used to carry out a comprehensive study of the effects of climate change on arable farming in Botswana. It estimates the effect of random year-to-year variation in weather on agricultural output using a 28-years district-level panel data. Crops differed markedly in their responses to the climate variables. Maize production performed badly compared to sorghum which proved to be drought resistant and performed very well under the climate environment of Botswana. The results further showed that the inclusion of area planted is very important in this analysis. When considering area planted as an exogenous explanatory variable, we found a monotonic positive relationship between the production of maize and sorghum with area planted, indicating that economies of scale are dominant throughout the plot size distribution. In general, the analysis indicated that increasing temperature and decreasing rainfalls are both damaging to Botswana's agriculture. These results suggest that climate change is likely to impose significant costs on the Botswana economy unless farmers can quickly recognize and adapt to increasing temperatures. Such rapid adaptation may be less plausible in a developing country, where access to information and capital is limited. Even though the analysis did not incorporate the carbon fertilization effect or the role of technology and change in prices for the future, significant information for policy making can be extracted. By filling these gaps, more information for decision making can be generated.
Keywords: climate change, Botswana, arable farming, panel data

1.0 INTRODUCTION

Global climate change is a situation caused by destruction of natural environment through multitudes of interventions, injecting into the atmosphere trace gases like greenhouse gases or ozone-depleting chemicals which would have severe negative effects on the environment (IPCC, 2007). In this study, climate change is defined as a statistically significant variation in the mean state of the climate or its variability, persisting for an extended period (typically decades or longer) (IPCC, 2007). Climate change, as defined above, may be caused by natural internal processes and by persistent anthropogenic changes in the composition of the atmosphere or land use. Climate change is likely to have different effects on different sectors in the economy. However, climate change is seen as a cross-cutting theme which does not only affect agriculture and forestry but also affects construction, fisheries, tourism, energy and health.

In Botswana an incident of high rainfall occurred twice since 1980, thus in early 2000 and recently in early 2017, record rainfall caused serious flooding. These floods were destructive in nature, causing physical damage ranging from collapse of bridges, buildings and roads to other properties. Human and animal fatalities were common due to drowning (CSO, 2017). In this study, the objective is to focus on the effects of climate change on arable farming in Botswana. Botswana has a dual agricultural system: traditional and commercial and the study focuses on both arable farming where the rural poor depend on them for survival and reduce poverty in the rural villages by providing food and raw materials. Climate change has negative effects on crop production and these impacts can be seen in terms of effects on crop growth, and other inhabitants. Higher temperatures cause heat stress in plants. Temperature changes causes alteration in relative humidity, vapor pressure and evaporation from the land and water bodies. All these climatic variables will affect crop growth durations and crop water requirements which will negatively affect the ability of the crops to yield. According to the Ministry of Environment (MOE) (2010), temperatures throughout Botswana vary with average daily maximum temperature in summer of about 32 degrees Celsius in January while the extreme temperature can reach about 42 degrees Celsius. The average daily minimum temperature is about 18 degrees Celsius in January while the extreme can fall to about 7 degrees Celsius (MOE, 2010). Botswana's climate permits the cultivation of different varieties of cereal crops in a pattern that emerged in earlier centuries in response to local conditions (CSO, 2015). The staple cereal crops in Botswana are maize and sorghum (BIDPA, 2010). Their output depends mainly on the amount of rainfall and temperatures.

In order to ensure food security in Botswana, information on the extent to which climate change contribute to the decline in agricultural production may assist in the formulation of management strategies for a sustainable and improved crop production. Therefore, integration of climate change responses into national development planning is critical. Sustainable development measures and climate change responses, including mitigation and adaptation, can reinforce each other. Furthermore, the study examines the effects of climate change on arable farming in Botswana, with the view to determining the response of different cereal crops to observed varying climatic conditions. This will contribute in shedding light on which cereal crop is suitable for Botswana's climatic conditions to enable policy makers to make the right policies to mitigate the problems associated with climate change in Botswana.

2.0 LITERATURE REVIEW

CLIMATE AND AGRICULTURE IN BOTSWANA

Agriculture used to be the mainstay of Botswana's economy. About 40% of Botswana's gross domestic product used to originate from agriculture, with close to 80% of the labour force employed in this sector (CSO, 2006). Most importantly, this sector used to be responsible for providing food security to both the rural and urban populations from domestic production. However, this has changed and may not be true in the future because of changing climate conditions. The trends of the contribution of agriculture to total GDP of the country clearly explain the relationship between the performance of agriculture, climate and the total economy. The impact of the agricultural sector on the economy in terms of contribution to the Gross Domestic Product (GDP) is quite small when compared to the other sectors like mining, manufacturing, trade and tourism. According to the GOB (2010) the sector's contribution has been declining from 42.7% since independence in 1966 to 5.6% in 1985/86 twenty years later. Furthermore, current statistics show that the GDP contribution of the sector nearly more than 40 years after independence has dropped to 2.1 % GOB (2010).

Climate, vegetation and land use potential have been used to assess land suitability for different uses. The major elements of climate that affect crop growth are the intensity and duration of rainfall, the relationship between annual rainfall and potential evapo-transpiration and the year-to-year variation in rainfall. Annual rainfall brought by winds from the Indian Ocean, averages 460 mm, including a range from 640 mm in the extreme north-east to less than 130 mm in the extreme south-west. The rains are almost entirely limited to summer downpours between December and April, which also mark the season for plowing and planting. Hence, due to low, unreliable and unevenly distributed rainfall in Botswana, surface water is scarce and most rivers are ephemeral. In addition, due to the scarcity of surface water, groundwater abstraction constitutes over half of the country's annual consumption (CSO, 2005). Hence, for most rain-fed crops, the growing season is the rainy season. Moreover, much of the country's socioeconomic life is dominated by the onset and cessation of the rainy season, and the amount of rain it brings. The annual climate ranges from months of dry temperate weather during winter to days or weeks of sub-tropical humidity interspersed with drier hot weather during summer. In summer (which lasts from October to March) temperatures rise to above 34 degree Celsius in the extreme north and south-west. In winter (which lasts from April to September), there is frequent frost at night and temperatures may fall below 2 degree Celsius during the day, but skies are usually cloudless and sunny. Summer is heralded by a windy season, carrying dust from the Kalahari, from about late August to early October (McLeod et al, 1989). Furthermore, most soils in Botswana are relatively poor and traditionally, the distinction is made between the sand veld in western and northern Botswana and the hard veld in eastern Botswana. Sand veld soils are generally deep, course sandy with little structure and very low water and nutrient holding capacity. The hard veld has some more fertile soils consisting mainly of sandy loams and loamy sands. The agricultural sector has been characterized by low productivity levels which result in low returns to capital investment and labour (Seleka, 1999). Therefore the level of labour productivity in arable crop farming may be attributed to unreliable rainfall, high temperatures and persistent occurrence of drought in Botswana.

Climate change will compound existing poverty. Climate change is therefore a serious threat to agriculture and poverty eradication. The potential impacts of climate change on human health would increase vulnerability and reduce opportunities by prying with education and the ability to work. This will negatively affect labour productivity of the workers in the agricultural sector to produce more food as agriculture sector needs healthy workers to be productive. According to IPCC (2007), it is likely that climate change will have both direct and indirect adverse effects on human health. A direct effect is an increase in temperature-related illnesses and deaths. Prolonged intense heat waves coupled with humidity may increase mortality and morbidity rates, particularly among the urban poor and the elderly. Another direct effect will be increased death and injury from extreme weather events such as flooding and storms – over 96 percent of disaster-related deaths in recent years have taken place in developing countries. Climate change induces droughts, flooding and other extreme weather events, degrades and reduces potable water supplies and increases water-associated diseases such as cholera and diarrhea, particularly in areas with inadequate sanitary infrastructures. Inadequate access to safe drinking water and sanitation, combined with poor hygiene practices, are major causes of ill health and life-threatening disease in developing countries (IPCC, 2007). Furthermore, flooding causes soil erosions which destroy good soil characteristics such as soil structures and compositions and also lead to loss of soil nutrients which are required for crop production.

However, the available climate change projections and the impact studies conducted suggest that Botswana is highly vulnerable to climate change, with a particularly strong negative influence on water resources and crop production. The variable nature of the country's rainfall frequency and magnitude make Botswana particularly vulnerable. A variety of climate simulation models predicted that temperatures in Botswana will on average rise by 1-3$^o{}_C$ by the year 2050 (Maddison, 2006). Drought is a recurring feature of Botswana's climate, and desertification is a national concern (Kgathi et al, 2007).Women's responsibilities and vulnerabilities are often amplified by environmental and climate change. Climate change therefore magnifies existing inequalities, reinforcing the disparity between women and men in their vulnerability to and capability to cope with climate change (Kgathi et al, 2007).

Botswana is vulnerable to climatic shocks and stresses due to low adaptive capacity and high economic dependence on climate sensitive sectors. The low adaptive capacity, especially in Botswana, is associated with low levels of human, financial, physical and natural capital, as well as weak institutional and organizational capacity (Leary et al., 2008) .This raises doubt on the ability of Botswana to deal with the impacts of future climate change. According to Bates et al, (2008) semi-arid southern African countries including Botswana will have increased intensity of droughts, low precipitation and general scarcities in fresh water by the 2050s. Due to low ability and capacity to adapt to these climatic conditions rural households and communities are highly vulnerable (Bates et al, 2008). The climate change mitigation and adaptation strategies adopted by Botswana are: priorities related to water resources which are inter-basin water transfers, water purchase from neighbouring countries, internal recycling of water, and water conservation. Other Adaptation includes; encouragement of traditional coping mechanisms such as shifting to other agricultural activities during poor yield years, early drought warning systems, and minimum tillage farming methods for conservation of soil, water, and carbon (Chipanshi et al, 2003).

3.0 RESEARCH METHODOLOGY

This paper employed a panel data methodology to show the effects of climate change on arable farming in Botswana, with particular emphasis on examining the relationship between climate change and crop production from 1980 to date. The study relied only on secondary data that have been collected from documented literature. The variables crop production and area planted data was sourced from the Central Statistics Office, Ministry of Agriculture provided the data for drought periods, Department of Water Utilities (hydrological) provided the data for runoff flow, and Ministry of Environment and wildlife (Department of Metrologies) provided the data for rainfall, temperatures and sunshine. In the study, the researchers have estimated the proposed model using panel data. Prior to estimation, the panel data set was tested to ensure that it was stationary because a regression based on non-stationary data set yields spurious relationships, which dampen the validity of the statistical tests. The Fisher test of unit root was used. The test suggests the order of integration of each variable and tests for the presence of unit root. In addition, a cointegration analysis was conducted to analyze if there was a group of variables that drift together. Hence, Pedroni test for residual cointegration was also employed to investigate the long run relationship between the dependent variable (crop yield) and the independent variables (Pedroni, 1999). If there is no cointegration then a Vector Autoregressive Model (VAR) in levels was employed to estimate the model and if there was cointegration then VAR-Vector Error Correction Model (VECM) was employed to tie the short run behavior of the dependent variable to its long run value. In this study before estimation, VAR appropriateness was checked so that we do not end up with spurious VAR. Hence, VAR diagnostic statistics were conducted.

4.0 DATA FINDINGS

4.1 ANALYSIS OF THE VAR MODEL RESULTS FOR THE MAIZE YIELD

Dependent variable: Maize production

	Area maize	Evap-maize	Drought	Rainfall	Runoff	Constant
Coefficients	0.0608	-46.7150	-19.5058	51.0172	-7.48E-0.5	-8653.327
Standard errors	0.0242	19.2814	10.900	12.8015	8.3E-05	3887.18
t-statistics	2.5174	-2.4428	-1.7889	3.9852	-0.8999	-2.2261
R-squared: 0.710677 Adjusted R-squared: 0.694756 sum sq.residuals: 2.24E+08 S.E equation: 1705.970 F-statistic: 8.9431 Log likelihood: -740.6551 Akaike AIC: 17.8013 Schwarz SIC: 17.9387						

INTERPRETATION OF RESULTS OF THE VAR FOR MAIZE YIELD

From table 4.1 above, the results of the VAR indicates that the variables used in the model explain 71.06 percent of the variations in the dependent variable (Maize production). The implication is that the remaining 28.94 percent of changes in Maize production is not explained by the variables employed in explaining the effects of climate change on arable farming in Botswana from 1980 to date. It means that there are other variables not captured by the model whose absence is captured by the error term. The values of the Adjusted R-squared show that overall the data is relatively a good fit for the model. Furthermore, by observing the F-statistic we can reject the null hypothesis of an insignificant relationship between Maize production and the explanatory variables. This decision is informed by the F-statistic of 8.94 which is significant at 10 percent level of significance. The results indicates that out of five variables used in the model to consider the effects of climate change on arable farming in Botswana, only four proved to be significant. These are the area-maize; evap-maize, rainfall and the dummy variable (drought) are all significant at 10% level of significance. Critical value is obtained by the following degree of freedom (n-k,a), where n is the sample size, k is the number of variables included in the model including the intercept. We have (30-6, 0.1) = 1.318 as the critical level. However the runoff water variable is insignificant in explaining its impact on the Maize production.

In addition, area-maize, evap-maize, drought and rainfall have the expected signs. The area planted for maize was included in the model because Maize production depends on the amount of area utilized for production. Average production is in tons per hectare and represents the amount of cereal grain that is extracted from 1 hectare of combine harvested area. Therefore, the variable is observed to have the correct sign and also statistically significant. A one unit increase in the level of area planted for maize causes Maize production to increase by 0.0608 per metric ton as shown by the coefficient. Therefore, size of the area planted for maize plays a significant role in increasing Maize production in Botswana. These results are similar to the one that Ashraf (1988), from Pakistan found out, hence according to Ashraf (1988), “grain yield of maize correlate positively with area planted”. Since almost all the arable land is not under cultivation in Botswana (CSO, 2008) future increase in maize production will heavily depend on yield improvement and expansion in area under production. Therefore, the increase in Maize production will lead to reduction in poverty and also become a source of employment for the poor-rural people.

Water use efficiency increases with higher quantities of rainfall (irrigation) provided that soil aeration is not impeded and potential evapo-transpiration is not exceeded. It is concluded that a ‘wet’ irrigation regime, permitting the crop to transpire at a rate approaching the climatically induced potential and simultaneously preventing the occurrence of moisture deficits, can help to realize the full productivity of the crop (Hille and Guron, 1973). From the above table 4.1 the variable evap-maize which is the amount of water loss from maize and soil has the expected sign and it’s significant. This means that evapo-transpiration is also the main factor that explains the spatial variation of maize yield in Botswana. The evapo-transpiration in maize is negatively related to Maize production. An increase in the evapo-transpiration in maize will lead to decreases of about 47 units in the maize production per metric ton. Therefore, crop water evapo-transpiration refers to water used by a crop for growth, tissue building, cooling purposes as well as soil evaporation (Broner and Law, 1991). Hence, crop water use is influenced by prevailing weather conditions, available water in the soil, crop species and growth stages. Water deficits, and the resulting stress on the plant, have an effect on crop evapo-transpiration and crop production. When the full crop water requirements are not met, water deficit in the plant will develop to a point where crop growth and production are adversely affected. Therefore, increases in the evapo-transpiration adversely lead to reduction in the maize yields. A study by Zhang (2011), entitled impacts of climate change on People’s Republic of China’s grain output supports this study because they also found that as temperatures increases that negatively impacts the grain output in China.

Water availability is the most critical factor for sustaining crop productivity in rain-fed arable agriculture. Rainfall variability from season to season greatly affects soil water availability to crops, and thus poses crop production risks. Ideally, crop cultivations should be situated in areas with high rainfall with low variability. However, subsistence farming can be found in a wide range of environmental conditions from very suitable to marginal lands. From table 4.1 above rainfall variable is significant at 10 percent level of significance. Furthermore, the results have an expected sign which is positive. Therefore, there is a positive relationship between rainfall amount and maize production. A unit increase in the rainfall amount will lead to 51.02 increases in the Maize production per metric ton. A study similar to this one by Ouedraogo et al (2006), from Burkina Faso, also showed the same results and concluded that rainfall or precipitation affects the crop production positively up to a certain level, above which it causes damage to the crops. Another study in Kenya by Mariara, (2006), found out that both fall and summer precipitation are, however, positively correlated with net crop revenue and exhibit a hill-shaped relationship with it. The results further showed that climate exhibits a non-linear relationship with net revenue, which is consistent with the available literature. Therefore, the results of Botswana are robust; hence this climate variable (rainfall) plays a significant role in the production of maize in Botswana which heavily depends on rain-fed arable farming.

Drought is a potential major constraint to maize production in all areas where it is grown. It affects plant growth and considerably reduces yields of most agricultural crops. Depending on the time of drought occurrence, duration and intensity, agricultural crops suffer yield reductions of various magnitudes. Drought occurs in various forms – as soil, air and physiological drought, although these forms are mutually associated and interdependent.

Agricultural crops are most seriously damaged by soil drought which occurs as a result of insufficient amounts and unfavourable distribution of rainfall relative to plant water requirements. From this study, drought is treated as a dummy variable in which years of persistent drought is 1 and zero otherwise. A dummy variable is used to capture the effect that climate variables had on maize production. The sign is negative and statistically significant. From the table 4.1 above, it shows that during the period without drought which is the intercept dummy, Maize production decreased by 8653.33 per metric ton. Furthermore, years with drought which is the slope dummy (-8653.33+ -19.506)) = -8672.836, shows that maize yield decreased by 8672.84 per metric ton hence, drought impacts maize production negatively.

4.2 ANALYSIS OF THE VEC MODEL RESULTS FOR THE SORGHUM YIELD

Dependent variable: sorghum production

	D(area sorghum)	D(Evap-sorghum)	Drought	D(Rainfall)	D(Runoff)	Constant(c)
Coefficients	0.0265	-41.0617	-492.7600	29.2459	-0.000173	-1373.086
Standard errors	0.0139	24.4158	290.605	11.2015	0.00025	22.878
t-statistics	1.896	-1.6817	-1.6992	2.6108	-0.70713	-6.2145
R-squared:0.7894 Adjusted R-squared: 0.7460 sum sq.residuals: 1.43E+08 S.E equation: 1570.953 F-statistic: 66.6138 Log likelihood: -575.1089 Akaike AIC: 16.6699 Schwarz SIC: 16.9898						

INTERPRETATION OF THE VEC MODEL FOR SORGHUM YIELD

The results of the VAR-VEC From table 4.2 above, indicates that the variables used in the model explain 78.9 percent of the variations in the dependent variable (sorghum production). The implication is that the remaining 21.1 percent of changes in sorghum production is not explained by the variables employed in explaining the effects of climate change on arable farming in Botswana from 1980 to date. It means that there are other variables not captured by the model whose absence is captured by the error term. The value of the Adjusted R-squared show that overall the data is relatively a good fit for the model. In addition, using the F-statistic we can reject the null hypothesis of an insignificant relationship between sorghum production and the explanatory variables. This decision is informed by the F-statistic of 66.61 which is significant at 10 percent level. The results indicates that out of five variables used in the model to consider the effects of climate change on arable farming in Botswana, only four proved to be significant. These are the area-sorghum; evap-sorghum, rainfall and the dummy variable (drought) are all significant at 10% level of significance. Critical value was obtained by the following degree of freedom (n-k,a), where n is the sample size, k is the number of variables included in the model including the intercept. We have (30-6, 0.1) = 1.318 as the critical level. However the runoff flow variable is insignificant in explaining the impact on sorghum production model.

Declining area planted to sorghum is a factor resulting in decreasing production. As more area is devoted to maize providing farmers with higher returns, area planted for sorghum in Botswana (CSO, 2008) has declined over time. Sorghum is typically grown in regions that experience frequent droughts because the crop is more tolerant than maize to hot and dry conditions. From table 4.2 above, the sign of area-sorghum is as expected. It is positively related to sorghum production. A unit increase in area planted for sorghum will lead to 0.0264 increases in sorghum production per metric ton. Therefore, area planted for sorghum plays a vital role in sorghum production in Botswana. In a study in Mexico by Liu and Malaga (2010), they found out that area planted for sorghum was important in sorghum production, the large the area planted the more sorghum production is expected.

The most obvious effect of high temperature is the subsequent overall reduction in plant size. Evapo-transpiration, it is directly associated with leaf water potential and available soil nutrients (Berry and Downton, 1982). Plants growing in environments of high irradiance are more prone to photo-inhibition; a sustained decrease in the efficiency of photosynthetic energy conversion, and more so when high irradiance occurs with high temperature and drought (Farar, 1987). High temperatures influence photosynthetic function of plants by affecting the rate of chemical reactions and structural organization. From the above table 4.2, the evapo-transpiration for sorghum has the expected sign which shows a negative relationship between sorghum production and evapo-transpiration. Therefore, a unit increase in Evapo-transpiration in sorghum will lead to 41.0617 decreases in sorghum production per metric ton. A study by Mutava, 2006: in South Africa also found that similar direction in sorghum yield and increased temperatures. Sorghum the effects go in different direction, with higher temperatures reducing yields but also reducing variability. Therefore, high temperatures have a significant impact in reducing sorghum production in Botswana.

The climatic conditions of the agricultural parts of Botswana are characterized by non-uniform rainfall both among years and within a single year, especially during the vegetation season. The non-uniform rainfall typically causes a discrepancy between water supply and plant requirements. The more the rainfall the expectation is the increase in sorghum yields and also increases variability. From table 4.2 the sign of rainfall variable is as expected, which is positive. A unit increase in the amount of rainfall will lead to 29.24 increases in the sorghum production per metric ton; hence precipitation also increases the variability of sorghum yields, which is not surprising given the tolerance of sorghum to dry conditions. In a study by Mutava, 2006, also found a positive relationship between sorghum production and the amount of rainfall in South Africa.

Drought is one of the major environmental factors limiting sorghum production in the semi-arid regions in Africa including Botswana. Although drought has several definitions, it involves a condition where there is a deficiency of precipitation (rainfall) over an extended period of time resulting in a water shortage for some activity, group, or environmental sector (Mutava, 2006). In its definition and evaluation, it should be considered relative to some long-term average condition of balance between precipitation and evapo-transpiration. Drought is also related to the timing and the effectiveness of precipitation. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it. At the plant level, drought stresses will result in reduction in growth and affect photosynthesis by reducing leaf area, enhancing stomatal closure, decreasing water status in the leaf tissues, and reducing the rate of carbon dioxide (CO_2) assimilation. In sorghum production, stages that are susceptible to drought stress will include vegetative growth, biomass accumulation and panicle emergence at pre-flowering as well as seed set and seed numbers at flowering. From this study, drought is treated as a dummy variable in which years of persistent drought is 1 and zero otherwise. A dummy variable is used to capture the effect that climate variables had on sorghum production. The sign is negative and statistically significant. From table 4.2 above, it shows that during the period without drought which is the intercept dummy, sorghum production decreased by 1373.086 per metric ton while, during the years with drought which is the slope dummy (-1373.086+ -492.76)) = -1865.846, this shows that sorghum production decreased by 1865.846 per metric ton. Therefore, drought has a significant impact on sorghum production in Botswana. In a similar study by Mutava: 2006, they also found out that drought plays a significant role in reducing sorghum production in South Africa.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The panel data properties were observed and we reported the results of the Vector Autoregressive Model (VAR) in levels. Evident from the empirical analysis, is the significance of area planted, evapotranspiration, rainfall and drought (A dummy variable used to capture the effect that climate variables had on maize and sorghum production). All these variables had the expected impact on maize and sorghum production in Botswana. However, the runoff water variable had the desired impact, though it was insignificant. Moreover, the results of the study showed that climate change affects crop production. The impact of temperature on both crop production captured under evapo-transpiration showed that if the temperature increases by 1°C, the maize production falls by 46.7 metric ton per hectare while for sorghum the production falls by 41.06 metric ton per hectare. On the other hand, if the rainfall increases by 1 mm, both crop productions will increase by 51.02 metric ton and 29.25 metric ton respectively. The analysis of the climate change showed that decreasing rainfall with rising temperatures will cause more damage to arable farming in Botswana. In addition, climate change in Botswana has substantially varying impacts on different grain crops. All in all arable farming is especially vulnerable and forms the primary impact channel, with climate variability reducing agriculture's annual GDP growth rate. This will greatly reduce Botswana's chances of achieving the national development goal of strengthening agricultural and rural income growth. Indeed, we found that the negative effect of climate variability is especially severe for maize, the country's main food staple crop, and that it therefore greatly threatens basic food security in both rural and urban areas while sorghum grains have proved to be drought resistant because it requires less water and performs better in high temperatures.

5.2 POLICY RECOMMENDATIONS

The results of the study confirm the importance of climate change on arable farming and the need to take steps to reinforce existing adaptation options and develop new ones. The major actions to be undertaken are (i) promoting ways of adapting to climate change, (ii) developing new ways of adapting, and (iii) creating a unit for research into climate and development. Furthermore, these results imply that adaptation to climate change in Botswana is important if arable farmers are to counter the expected impacts of long-term climate change. The government should therefore play a more critical role in encouraging adaptations. Monitoring of climate change and disseminating information to farmers would be a critical intervention, while knowledge on adaptation measures could encourage both short- and long-term adaptations to climate change. To gather such knowledge requires a multidisciplinary approach involving soil scientists, hydrologists, climate experts and agronomists. Using this knowledge, farmers should be sensitized, through extension networks, to the implications of climate change, including the vulnerability of crop production and the necessity for adaptation strategies. In addition, the government and private sectors must reinforce the link between research and development for a better transfer of adaptation measures to farmers. This study constitutes a first step in assessing the impact of climate changes in the country. It will serve as reference for other research on impacts of climate change in Botswana. Therefore, Botswana should concentrate on planting sorghum as it has proved to be drought resistant and does well in the climate of Botswana.

6.0 IMPLICATIONS OF THE STUDY

The major problem was that of the lack of data for soil samples, economic data for prices of maize and sorghum per their districts and fertilizer data used for each district. The future studies need to be focused on specific crop responses and adaptations, particularly the vegetables and citrus fruits which also have long-term implications for food security in the country. This study did not take into account the impact of climate change on livestock production, yet most farmers in Botswana combine livestock and crop production for both subsistence and commercial purposes. Our results show that most of Botswana is expected to be much more adversely affected by global warming. However, these areas are best suited for livestock production by both small scale producers (pastoralists) and large scale ones (ranchers). Analysis of the impact of climate change on livestock production would give a better picture of the impact in Botswana. There is also a need for studies to model the impact of climate change with and without the impact of adaptations that farmers make to counter the impact of climate change.

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