WPS4291

Policy Research Working Paper 4291

An Empirical Economic Assessment of Impacts of Climate Change on Agriculture in Zambia

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Development Research Group
Sustainable Rural and Urban Development Team
July 2007

Abstract

This report assesses the economic impacts of climate change on agriculture in Zambia, using the Ricardian method.

A multiple linear regression model with net revenue per hectare as response variable has been fitted with climate, hydrological, soil, and socioeconomic variables as explanatory variables. There is one main cropping season in Zambia, lasting from November to April. Crop production in this period depends solely on rains. Considering crop progression in three stages—germination, growing, and maturing, which require different amounts of water and temperature—the climate variables included in the model are long-term averages of the temperature and wetness index for the periods November to December, January to February, and March to April. Assuming a nonlinear relationship of farm revenue with the climate variables, quadratic terms for climate variables were also included in the model.

The results indicate that most socioeconomic variables are not significant, whereas some climate variables and the corresponding quadratic variables are significant in the model. Further findings are that an increase in the November-December mean temperature and a decrease in the January-February mean rainfall have negative impacts on net farm revenue, whereas an increase in the January-February mean temperature and mean annual runoff has a positive impact.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the group to mainstream climate change research. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Pauline Kokila, room MC3-446, telephone 202-473-3716, fax 202-522-1151, email address pkokila@worldbank.org. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at sjain@natsci.unza.zm. July 2007. (31 pages)

AN EMPIRICAL ECONOMIC ASSESSMENT OF IMPACTS OF CLIMATE CHANGE ON AGRICULTURE IN ZAMBIA[1]

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[1] An earlier version of this Working Paper was published as CEEPA Discussion Paper number 27.

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This paper was funded by the GEF and the World Bank. It is part of a larger study on the effect of climate change on agriculture in Africa, managed by the World Bank and coordinated by the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

SUMMARY

Agriculture is a major economic sector for many African nations, contributing about 30% to Africa's GDP. About 70% of the population of the continent depend on this sector for their livelihood. Most agricultural production on the continent is rain dependent.

The increasing concentration of greenhouse gases in the earth's atmosphere is changing the global and regional climate. The global mean temperature has increased by over 0.5°C since the 19th century. It has been noted that the mean temperature is rising more rapidly at the regional scale for Africa. Rainfall in Africa is also varying from year to year, in volume and seasonal distribution, and showing erratic patterns. Droughts have become more frequent in the last 30 years. Such climatic changes have enormous consequences for the food security of the continent. Lack of capital and technology make it hard for poor countries in Africa to adapt.

This report is part of a three year Global Environment Facility (GEF) and World Bank funded project *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa* undertaken in eleven African countries. It assesses the economic impacts of climate change on agriculture in Zambia, based on the Ricardian method which measures the effect of climate on the value of agricultural land. For a country like Zambia with abundant free farming land for subsistence farming, it is difficult to attach a value to land. The Ricardian method has therefore been modified here to replace land value with net farm revenue.

A multiple linear regression model with net farm revenue as response variable has been fitted with climate, hydrological, soil and socio-economic variables as explanatory variables. There is one main cropping season in Zambia, lasting from November to April. Crop production in this period depends solely on rains. Considering crop progression in three stages – germination, growing and maturing, which require different amounts of water and temperature – the climate variables included in the model are long-term averages of the temperature and wetness index for the periods November to December, January to February, and March to April, representing crop progression in the three stages. Assuming a non-linear relationship of farm revenue with the climate variables, quadratic terms for climate variables were also included in the model.

The results indicate that most socioeconomic variables are not significant, whereas some climate variables and the corresponding quadratic variables are significant in the model. Further findings are that an increase in the November–December mean temperature and a decrease in the January–February mean rainfall have negative impacts on net farm revenue, whereas an increase in the January–February mean temperature and mean annual runoff has a positive impact.

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1. Introduction

Agriculture is becoming an increasingly important sector in the Zambian economy since the mineral sector, which was the backbone of the economy from post-independence times (1964) till the late 1980s, has declined. The agriculture sector generates about 18% to 20% of the country's GDP and provides a livelihood for more than 60% of the population. It employs about two-thirds of the labor force.

In 1991 there was a major shift in the country's agricultural policy with the liberalization of the marketing of agricultural inputs and produce. This new policy has resulted in low agricultural productivity as subsistence farmers, who make up about 75% of the entire farming community in Zambia, find difficulty in procuring farm necessities such as seeds and fertilizer in terms of accessibility and funds. Their difficulties are further compounded by the erratic seasonal rainfall patterns which have been experienced by the country in the last 20 years. Almost all subsistence farming in Zambia relies on rainfall.

Over the last two decades, the frequency of extreme climate events such as high surface temperatures, floods and droughts has increased over the entire globe. Although such extreme events are attributed to climate variability, they also signal that the earth is going through long-term climate changes in mean temperature and rainfall norms. Zambia has experienced an increase in drought frequency and intensity in the last 20 years. The droughts of $1991/92$, $1994/95$ and $1997/98$ worsened the quality of life for vulnerable groups such as subsistence farmers (Muchinda, 2001).

This study has attempted to assess the economic impacts of long-term climate change such as the increase in mean surface temperature and the decrease in mean seasonal rainfall and mean annual runoff on farming activities in Zambia, in order to provide information for appropriate adaptation policies at national level so as to minimize the adverse impacts of climate change on agriculture.

2. Overview of Zambia

2.1 Physical attributes

Zambia covers a land area of 752,615km^2 and lies between 22° to 34° east of Greenwich and 8° to 18° south of the equator. The country consists mostly of plateau with an elevation between 950 meters to 1,500 meters above sea level. The country has a sub-tropical climate and vegetation. There are three distinct seasons: a warm wet season stretching from November through April during which 95% of the annual precipitation falls, a cool dry winter season from May to July with the mean temperature varying between 15°C and 27°C, and a hot dry season prevailing from August to October with an average maximum temperature of 27°C to 32°C. The annual rainfall varies from over 1200mm in the north to about 700mm in the central part of the country and less than 700mm in the south.

Zambia is divided into three agro-ecological zones with rainfall as the dominant distinguishing climatic factor (Figure 1).

Zone I lies in the western and southern part of the country and accounts for about 15% of the land area. It receives less than 800mm of rain annually. It used to be considered the bread basket of the nation but for the last 20 years it has been experiencing low, unpredictable and poorly distributed rainfall. The observed meteorological data suggests that it is currently the driest zone, very prone to drought and has limited potential for crop production.

Zone II covers the central part of the country, extending from the east through to the west. It is the most populous zone with over 4 million inhabitants and has the highest agricultural potential. The soils here are relatively fertile. It receives about 800–1000mm of rainfall annually, which is evenly distributed throughout the crop growing season.

Zone III spans the northern part of the country and has a population of over 3.5 million. It receives over 1000mm of rainfall annually. The high rainfall in this region has resulted in the soils becoming leached. It is suitable for late maturing varieties of crop. About 65% of the region in this zone has yet to be exploited (Figure 2).

2.2 Administrative attributes

Zambia is divided into nine provinces which are further divided into 72 districts. About 60% of the population is concentrated in four provinces: Southern, Central, Lusaka and the Copperbelt along the railway line.

2.3 Agricultural attributes

Zambia has an estimated nine million hectares of land (12% of its total land area) suitable for cultivation and 16 million hectares suitable for rangeland grazing. There are approximately one million farmers, who can be grouped into three main categories: small-scale farmers (having five hectares or fewer of farming land), emerging farmers (having a farmland area of between five and 20 hectares) and large-scale commercial farmers (having more than 20 hectares of farmland). However, there are very few with farms comprising more than 60 hectares. The large-scale commercial farmers are located near major urban centers, whereas the majority of small-scale farmers are rural. About 95% of the rural households are occupied with crop production. Small- and medium-scale agriculture is dominated by the production of crops for two main reasons: for subsistence and as a source of income from marketed produce (CSO 1992, 2002a,b; MoA 2000).

The major crops grown are maize, sorghum, millet, rice (paddy), wheat, cassava, ground nuts, sunflower, cotton, soya beans, mixed beans and tobacco. Most of these are summer crops which almost entirely depend on rains. Wheat is a winter crop and is grown by large-scale farmers using irrigation (MoA, 2000). Figure 3 indicates the area planted for the various crops in 2001/02 (CSO 2002a,b).

3. Climate analysis

3.1 Temperature

It has been scientifically established that anthropogenic emissions of greenhouse gases and other atmospheric pollutants are changing global and regional climates. Global surface temperature has increased by over 0.5°C in the past 100 years. A similar rate of warming of about 0.05°C per decade in southern Africa has been observed during the present century (Hulme 1996). The six warmest years in this century in southern Africa have all occurred since 1980.

The observed temperature from 32 meteorological stations in Zambia was analyzed to detect trends in temperature change over last 30 years. The mean temperatures computed for the agro-ecological zones for three time periods, November–December, January–February and March–April, indicate that the summer temperature in Zambia is increasing at the rate of about 0.6°C per decade, which is ten times higher than the global or Southern African rate of increase of temperature (Figures 4 to12). The rate of increase is highest in November–December as compared to other periods across all agro-ecological zones (Hulme 1996).

3.2 Rainfall

The rainfall in the southern African region has been decreasing in the last 25 years (Hulme 1996). The annual rainfall anomalies from the 1970–2000 annual averages were computed using observed data from all 32 meteorological stations in Zambia for the agro-ecological zones. For each agro-ecological zone, data was pooled from meteorological stations within the zone. These annual rainfall anomalies, plotted in Figures 13 to 15, indicate that of the 14 years from 1990/1991 to 2003/2004, at least ten years in each agro-ecological zone had below normal rainfall. We further note that the variability in annual totals across the three agro-ecological zones has not been uniform. The southern zone (Zone I) has experienced more severe dry seasons than the central zone (Zone II) in the last 20 years.

4. Climate and crop production in Zambia

There is strong scientific evidence that human activities are causing an increase in the concentration of greenhouse gases (GHG) in the atmosphere and that the increasing concentration of GHG is causing long-term changes in mean earth temperature and rainfall normals. This is what we call climate change (Mendelsohn et al. 1994).

Climate change is believed to have more severe effects on tropical than on temperate countries. It may lead to a rise in temperature, an increase in the frequency and intensity of droughts and floods, long-term water shortages, poor soils, desertification, disease outbreak, and so on. It is believed to have serious economic consequences for developing countries, many of which are located in the tropics and rely heavily on rainfed agriculture (Mendelsohn et al. 1994; Kurukulasuriya & Rosenthal 2003).

Agriculture in Zambia depends on rainfall to a very large extent. Since the 1990s, crop production in the country has faced negative impacts of extreme climate events which are believed to be manifestations of long-term climate change. Zambia has experienced some of its worst droughts and floods in the last two decades. Significant rainfall deficits at critical stages of crop growth have frequently led to a serious shortfall in crop production. Maize is a staple grain in Zambian meals. The yield during the severe drought of 1991/92 was less than half that of 1990/91. Notable shortfalls in maize yield were also recorded in the seasons 1972/73, 1979/80, 1981/82, 1983/84, 1986/87, 1993/94 and 1994/95, most of which were characterized as seasons with below normal rainfall by the Zambian meteorological department. Drought has been the biggest shock to food security in the country during the last two decades (MoA 2000; Muchinda 2001). The impact of extreme climate events has been felt in substantial loss of livestock and fertile soil. Low productivity in the agricultural sector has contributed to a low GDP. In short, changes in the supply of rainfall, whether in the total volume or in its distribution within a season, have enormous consequences for agriculture in Zambia.

Maize production has been quite variable, as can be seen in Figure 16. In some years the yield has been only 40% of the long-term average. Major factors contributing to this low yield have been the long dry spells within a season and the shorter rainfall seasons which have been experienced by the country in the past 20 years.

Crop production data obtained from the Central Statistical Office (CSO) indicates that the major crop of the Southern, Central and Eastern Provinces is maize which occupies more than 70% of the total area cultivated in these provinces. In the Northern Province, only about 18% of the total cultivated area is planted with maize. Table 1 shows the percentage of the area planted with various crops in the Southern, Central, Eastern and Northern Provinces.

As may be noted from Figures 17 and 18, the maize yield in the Southern, Central and Eastern Provinces shows a high positive correlation with the total seasonal rainfall. Figure 19 shows that the maize yield in the Northern Province does not indicate a correlation with the total seasonal rainfall. The reason is evident from Table 1, which shows that maize is the main crop in the Southern, Central and Eastern Provinces, whereas little maize is grown in the Northern Province.

Sorghum is a crop widely grown throughout the country, though the number of households engaged in its production is relatively small as compared to the number engaged in growing maize. It is promoted especially in drought prone areas as it is a drought tolerant crop. Sorghum production is being promoted so as to improve food security in areas where short rain periods are frequent.

In conclusion, climate change is a phenomenon which represents a risk to sustainable agricultural practices and has significant consequences for food security and the country's GDP. Its probable effects can, however, be estimated and guarded against.

5. Research methodology: The Ricardian approach

The Ricardian approach is a cross-sectional analysis of farm value across different climate zones. It measures the effect of climate on farm value. It assumes that farm value has a quadratic relationship with climate variables such as temperature and precipitation (Mendelsohn et al. 1994; Dinar et al. 1998). It aims to provide insights into sustainable agricultural practices that are compatible with the constraints of the present climate. It places emphasis on meeting the long-term needs of small-, medium- and large-scale farmers to minimize the negative impacts of climate change on agriculture (Munalula et al. 1999).

One major drawback of the Ricardian approach is that it takes into account only current farming practices. Hence it does not capture future changes in agriculture as a result of changes in farm technology or carbon dioxide fertilization.

Zambia has abundant land available free of cost for subsistence farming. Therefore land value does not appear an appropriate response variable in the Ricardian multiple linear regression econometric model. In this analysis net farm revenue per hectare (NR_h) has been used as response variable to assess farm performance as a function of climate, soil, hydrological and socio-economic variables.

The net farm revenue has been approximated from the following equation:

$$NR_h = \frac{\left[\sum_{i=1}^{n} P_i C_i - \left(\sum_{j=1}^{m} Y_j X_{ij}\right)\right]}{A_h}$$

where

NR_h = Net farm revenue per hectare for household h

P_i = Unit price of crop i

C_i = Quantity produced of crop i

X_{ij} = Quantity of input j purchased for producing crop i

Y_j = Unit price of input j

A_h = Total area planted by household h

The explanatory variables are classified into the following categories: climate, soils, hydrological indicators, socio-economic factors and planting and harvesting months.

6. Data sources

6.1 Household data

A field survey by means of a questionnaire was carried out with the assistance of trained supervisors and enumerators from the CSO of Zambia on a total of 1015 households. The survey included small-, medium- and large-scale households from 30 districts out of the total of 72 districts in Zambia.

The sample frame for survey was designed on stratified multistage cluster sampling technique which had four stages of selection.

Stage 1: Selection of number of districts from each agro-ecological zone

Zambia is classified into three agro-ecological zones on the basis of total annual rainfall and soil types. These three zones are widely diverse in area, soil type, population density, number of districts and agricultural practices, so to have a representative sample it was considered inappropriate to select the same number of districts from each zone. The probability proportions of districts (PPi) included in the sample from each of the three zones was therefore estimated as follows:

$$PP_i = \frac{p_i}{\sum p_i}$$

$$D_i = PP_i * N$$

Where

p_i	=	total number of districts in the ith zone
N	=	total number of districts included in the sample.
D_i	=	number of districts included in the sample from the ith zone

Stage 2: Selection of districts from each agro-ecological zone

Systematic sampling was used for selecting districts from zones. The method employed was as follows:

Districts in Zone i	Number of households	Cumulative households
X_1	n_1	n_1
X_2	n_2	$n_1 + n_2$
.	.	.
.	.	.
.	.	.
X_N	n_N	$n_1 + n_2 + \ldots. + n_N$

Define sampling interval $= \dfrac{(n_1 + n_2 + ... + n_N)}{D_i}$ and denote it by K.

Choose a random number j between 1 and K, then select districts having cumulative households j, j + K, j + 2K, …., j + (D_i –1) K.

Stage 3: Selection of three SEAs from each sampled district

Each district in Zambia has been divided into Standard Enumeration Areas (SEA) as an Agricultural Census exercise by the Central Statistics Office of Zambia who carry out crop forecasting and post-harvesting surveys every year (CSO 1992, 2002a,b). The number of SEAs in each district is different. The selection of three SEAs from each district included in the sample was also done by systematic sampling. The sampling interval was calculated as:

$$\text{Sampling interval} = \frac{\text{Total households in Districts i}}{3}$$

Stage 4: Selection of ten households from each sampled SEA

Finally, after selecting 30 districts, three SEAs from each district, to select ten households from each SEA, serial numbers were assigned to households in each SEA and the sampling interval was calculated by:

$$\frac{\text{Last serial number in SEA i}}{10}$$

Systematic sampling was applied to select farm households from each sampled district. In total a sample of 900 small- and medium-scale farm households were selected. Of the approximately 3000 commercial farms in the country, 15 from each of the nine provinces were also included in the survey.

6.2 Climate data

Satellite temperature and soil wetness data was obtained from the US Department of Defense. This data is derived from a set of polar orbiting satellites that are equipped with sensors to detect microwaves through clouds. The satellites make daily overpasses between 6 am and 6pm. The monthly averages for the period 1988–2004 for temperature and wetness indices were used in the analyses (Basist et al. 2001).

6.3 Soil and hydrological data

Soil data was obtained from the Food and Agriculture Organization (FAO) database (FAO 2003). From various soil types classified by the FAO world map, the soil types which were found in Zambia in more than 30% of the sample units were included in the study. The runoff data was obtained from the University of Colorado (IWMI & University of Colorado 2003).

7. Model formulation

7.1 Response variable

The response variable is the net farm revenue per hectare (nr1_3), which is computed as the total revenue from the farm produce minus the cost of seeds and fertilizer. The summary statistics of the net revenue in US$ computed from the household survey are shown in Table 2.

7.2 Explanatory variables

Climate variables

The major cropping season in Zambia runs from November through April. Agriculture in this season depends on the rains to a very large extent. There is a minor cropping season from June through September. The main crop of the minor season is wheat, which is grown only by commercial farmers using irrigation. This minor season is not included in the analysis.

A plant has three growth stages: germination (initial period), growth (middle period) and maturing (ripening period). To correspond to these stages, the long-term (1988–2004) mean climate variables (temperature measured in degrees Celsius and wetness index measured on a scale of 0 to 10) were generated for three time composites: composite 1 (November + December), composite 2 (January + February) and composite 3 (March + April). Assuming a quadratic relationship of climate variables with the net farm revenue, the square terms of the temperature and wetness index for each of the composites were added to the model. The summary statistics of the climate variables are shown in Table 3.

Soil variables

Soil types from the FAO classification which appear in at least 30% of the sampled units are included in the model. Tables 4 to 6 show the existence of the selected soil types in Zambia. The values of the soil variable are the proportions of plot area covered by a particular soil type.

Hydrological variables

Runoff is defined as excess precipitation which is not absorbed by soils. It runs on the soil surface and eventually joins a stream. Runoff takes away soil nutrients. Excessive runoff may have a negative impact on farm yield. Table 7 shows summary statistics of the sample mean runoff (in cm). Assuming a hill-shaped relationship of net farm revenue with mean annual runoff, a quadratic term of mean annual runoff has been added to the model.

Socio-economic variables

Table 8 summarizes the values in kilometers of variables distance to market from where inputs were purchased (distpmktkm) and output sold (distsmktkm).

Table 9 shows a summary of two variables: access to public extension services (extc) and access to credit (inc1), each of which has two response values: 1 representing household responding positive to receiving public extension services or having access to different types of credit and 2 if the response is negative to either of these variables.

Variables landhhcd1, landhhfd1 and landhhmd1 represent number of days spent by household children, females and males in land preparation for planting. The summary statistics from the sample are shown in Table 10.

Other socio-economic explanatory variables included in the model are shown in Table 11.

Variables representing planting and harvesting months

Dummy variables representing the planting and harvesting months were included in the model. These variables are shown in Table 12.

8. Results and discussion

The highlighted values in Table 13 show the significant regressors at the 5% level of significance. We note that the net farm revenue (nr1_3) has a quadratic relationship with the climate variables tcom1, tcom2 and wcom2 and hydrological variable mean runoff (roff_mean). Net revenue (nr1_3) has a U-shaped relationship with November–December temperature (tcom1), whereas the relationship of net revenue (nr1_3) with the other two climate variables: January–February temperature (tcom2) and January–February wetness (wcom2) and the mean runoff variable (roff_mean) is hill-shaped. The other significant variables are soil types chromic luvisosls (perclcMFU) and lithosols (percilqHS), farm type (farmtype) and the June harvest period (harvjune).

Analyzing the U-shaped relationship of net revenue (nr1_3) with the November–December temperature (tcom1), we note that net revenue decreases through values greater than the sample mean value 21.72°C for tcom1 and keeps decreasing up to 23.48°C (turning point) when net revenue is at its minimum. Marginal net revenue per hectare for an increase of 1°C in the mean temperature of November and December is US$322.628, indicating that if the temperature rises at the beginning of the cropping season, when plants are germinating, this may have a negative effect on the crop.

Analyzing the hill-shaped relationship of net revenue with the average temperature of January and February (tcom2), we note that net revenue increases as tcom2 increases through values greater than the sample mean 19.7°C and attains the maximum value at a temperature of 20.7°C. The marginal net revenue per hectare for an increase of 1°C in the mean temperature of January and February is US$315.70, indicating that if the temperature rises during the growing stage of the plant, this may have a positive effect on the crop. Usually temperatures are lower in January–February (tcom2) than in November–December (tcom1). It implies that in the mean range of 10–20°C a 1^{o}C increase in the mean temperature in January–February (tcom2) may have a positive effect on crop growth.

We note from Table 13 that the quadratic term of the mean wetness index for the period January and February (wcom2sq) is significant. Precipitation is represented by a wetness index which indicates the extent of moisture in the land surface area. The total range of the wetness index is from 0 to 10. The wetness index for sampled households ranges from 0.5 to 5.5. Therefore an index of one represents about 20% precipitation for Zambia.

The marginal net revenue per hectare for a unit increase in the mean wetness index (20% precipitation) for January and February is US$334.67. Since the negative coefficient of the square term confirms the hill-shaped relationship of the net farm revenue with variable January–February wetness (wcom2), we can deduce that a decrease of about 20% in the precipitation for this period can reduce the net revenue by about US$334.67.

The annual mean runoff (roff_mean) and its squared term (roff_mean2) are both significant. The negative coefficient of roff_mean2 indicates a hill-shaped relationship of net revenue per hectare with the mean runoff variable (roff_mean). The sample mean of the mean runoff is 30.03cm, which lies on the left part of the hill-shaped curve of net revenue, indicating that the net revenue will increase per cm increase in mean runoff until the optimum level (the turning point) which happens at 32.5cm. The marginal revenue for a 1cm increase in runoff from the long-term annual average is US$3.39.

Table 14 shows the change in net revenue per hectare corresponding to a unit increase (1°C) in mean temperature in November–December and January–February. It also indicates the changes in net revenue per hectare corresponding to a 20% reduction in the mean precipitation in January–February (wcom2) and a 1 cm increase in annual mean runoff respectively.

We further calculate the marginal net revenue per hectare for the above climate scenarios as a percentage of the observed mean net revenue per hectare. Table 15 summarizes the percentage values. Losses of more than 100% of the mean net revenue are attributed to the fact that in the event of crop failure or low harvest due to unfavorable climate conditions the farmer's total loss will be the sum of the costs of the farm inputs (seeds and fertilizer) and the proportion of the gross revenue that he has lost, which he would have gained in a normal year.

9. Conclusion and recommendations

This study has attempted to estimate the economic impact of climate change on rain dependent agriculture in Zambia by regressing the net farm revenue on the climate, soil, hydrological and socio-economic variables. The results indicate that an increase in mean temperature in November and December and a reduction in mean precipitation in January and February have negative impacts on net farm revenue, whereas an increase in mean temperature in January and February and an increase in mean annual runoff have positive impacts on net farm revenue.

Hence we find that agricultural production in Zambia is subject to the uncertainties of extreme climate events, which are indicative of an increasing mean temperature and reduction in total seasonal rain on a long-term time scale.

Assuming that the climate induced impact on farm produce will be slow, the national government and all other stakeholders should respond to climate change by formulating and implementing adaptive measures to minimize the negative effects of climate on agriculture which may pose a serious threat to food security.

Zambia, being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), has an obligation to reduce greenhouse gas emissions to mitigate climate change. However, in addition to implementing mitigation strategies there is an urgent need to make appropriate adjustments in farming systems to adapt to climate change which is occurring gradually but may have irreversible impacts. Some recommended adaptations are listed below.

Farm level adaptations

- Development of new varieties of crops which mature faster and are heat resistant.
- Diversification from traditional crops to other types of crops which can withstand drought and higher temperatures, such as millet and sorghum.
- Rotation of land use between crop and livestock to replenish soil nutrients.

- A shift to more productive new lands, for example moving farming from the Southern to the Central Province.

National level adaptations

- Provision of a rural credit facility to enable subsistence farmers to buy new varieties of seeds and fertilizer.
- Dissemination of information to farmers on various adaptation options through extension services.
- Removal of subsidies on crops which do not perform well in a changing climate.
- Formulation of appropriate policies for marketing agricultural input and output products which are advantageous to subsistence farmers in particular, as this group makes up almost 80% of the entire farming community in the country and is most vulnerable to the negative impacts of climate.
- Investment in research on agricultural issues such as climate resistant crop varieties, water harvesting, irrigation schemes, water rights, etc.
- Investment in technological innovations, seed banks, etc.
- A feasibility study to migrate farmers from agro-ecological Zone I to Zone II which has more potential for agriculture.
- Provision of opportunities for alternative employment in non-farming activities to enable rural farmers make a livelihood.
- Allocation of adequate funding to the National Meteorological Department to procure measuring equipment and build capacity in climate data collection, storage, analysis and forecasting.
- Dissemination of climate forecasts in everyday language, not in scientific terms.
- Formulation of policies to encourage the NGOs, private sector and civil societies to complement the government's efforts to implement adaptation policies.

This study did not focus on the impacts of climate change on individual crops. Further research that investigates how the different crops respond to climate change is needed.

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Table 1: Provincial crop area (%) planted in 2002/03

Crop	% crop area in Southern Province	% crop area in Central and Eastern Provinces	% crop area in Northern Province
Maize	83.9	72.4	18.3
Sorghum	3.6	1.7	1.1
Millet	1.8	1.3	12.6
Paddy rice		0.1	2.1
Groundnuts	5.7	16.0	3.5
Soya beans		0.3	0.01
Sunflower	0.4	0.1	0.006
Mixed beans	1.7	1.5	9.9
Cassava	0.9	3.9	40.8
Sweet potatoes	1.9	2.4	1.5

Table 2: Net farm revenue per hectare in US$

Variable	Observations	Mean	Std dev	Min	Max
nr1_3	955	132.77	212.2	-340.55	3572.26

Table 3: Summary statistics of climate variables

Variable	Obser-vations	Mean	Std dev	Min	Max
Mean temperature (November-December) (tcom1)	1008	21.71873	1.678403	19.09018	24.31125
Mean temperature (January-February) (tcom2)	1008	19.72414	1.251792	17.57925	22.13305
Mean temperature (March-April) (tcom3)	1008	19.52797	1.193852	17.48295	21.81078
Mean wetness index (November-December) (wcom1)	1008	1.384871	.9449548	.33275	5.381725
Mean wetness index (January-February) (wcom2)	1008	1.432622	.9649444	.384875	5.544375
Mean wetness index (March-April) (wcom3)	1008	1.74015	.9509898	.669375	5.3485

Table 4: Soil type – Chromic luvisols (perc1cMFU)

Proportion of plot area covered by soil Perc1cMFU	**Household plots**	**Percent**
0	647	66.70
.1	62	6.39
.2	142	14.64
.3	66	6.80
.6	20	2.06
.7	33	3.40
Total	970	100

Table 5: Soil type – Orthic ferralsols (percfoFU)

Proportion of plot area covered by soil PercfoFU	**Household plots**	**Percent**
0	342	35.26
.1	30	3.09
.2	65	6.70
.3	64	6.60
.4	34	3.51
.5	116	11.96
.6	30	3.09
.7	210	21.65
.8	27	2.78
.9	34	3.51
1	18	1.86
Total	970	100

Table 6: Soil type – Lithosols (percilqHS)

Proportion of plot area covered by soil percilqHS	Household plots	Percent
0	621	64.02
.1	51	5.26
.2	173	17.84
.3	41	4.23
.4	32	3.30
.5	20	2.06
.6	32	3.30
Total	970	100.00

Table 7: Mean annual runoff (in cm)

Variable	Observations	Mean	Std dev	Min	Max
roff_mean	1008	30.0301	13.32263	11.14925	50.56691

Table 8: Variables distpmktkm and distsmktkm

Variable	Observations	Mean	Std dev	Min	Max
Distant to input market in km (distpmktkm)	959	23.7122	31.49476	0	360
Distant to output market in km (distsmktkm)	950	20.82	32.91	0	595

Table 9: Variables extc and inc1

Value of the variable	Received public extension for crop production (extc)	Borrowed money (inc1)
Yes: 1	370	86
No: 2	631	911
Total households	1001	997

Table 10: Household labor

Variable	Obser-vations	Mean	Std dev	Min	Max
Child household labor (landhhcd1)	764	9.626963	19.48931	0	288
Adult female household labor (landhhfd1)	942	28.92675	27.52775	0	240
Adult male household labor (landhhmd1)	951	29.9653	29.07663	0	240

Table 11: Socio-economic variables included in the regression

Variable name	Description
Farm type	Small, medium, large farm
Hhhdocc1	Primary occupation of head of household: farming or non-farming
Hhsize	Size of the household
Transport	Means of transport used to carry farm produce for selling in the market. Possible values: walk, animal, cart, truck or other.

Table 12: Variables representing planting and harvesting months

Variable name	Description
plantoct,plantnov	planting month
	(October, November)
harvmar, harvapr, harvmay, harvjune, harvjuly	harvesting month
	(March, April, May, June and July)

Table 13: Estimated regression coefficients of net farm revenue per hectare (nr1_3)

Net crop revenue per hectare (nr1_3)	Estimated coefficients	t-statistic	Significance level
Mean temperature (November-December): (**tcom1)**	**-4282.98**	**-2.34**	**0.019**
Mean temperature (January-February): **(tcom2)**	**6232.428**	**3.09**	**0.002**
Mean temperature (March-April): (tcom3)	-1594.81	-0.96	0.338
Mean wetness index (November-December): (wcom1)	-99.2666	-0.17	0.864
Mean wetness index (January-February): (wcom2)	242.6801	0.64	0.522
Mean wetness index (March-April): (wcom3)	12.12254	0.09	0.929
Mean temperature squared (November-December): **(tcom1sq)**	**91.16825**	**2.26**	**0.024**
Mean temperature squared (January-February): **(tcom2sq)**	**-150.018**	**-3.16**	**0.002**
Mean temperature squared (March-April): (tcom3sq)	45.31013	1.08	0.281
Mean wetness index squared (November-December): (wcom1sq)	387.3936	1.25	0.211
Mean wetness index squared (January-February): **(wcom2sq)**	**-201.871**	**-2.35**	**0.019**
Mean wetness index squared (March-April): (wcom3sq)	-39.7648	-1.17	0.242
Mean annual runoff**: (roff_mean)**	**44.23606**	**2.14**	**0.033**
Mean annual runoff squared**: (roff_mean2)**	**-0.68425**	**-2.35**	**0.019**
Soil type – Chromic Luvisols: (percfoFU)	-46.6943	-0.6	0.552
Soil type – Orthic Ferralsols: (**perclcMFU**)	**-503.654**	**-2.91**	**0.004**
Soil type - Lithosols: (**percilqHS**)	**-242.336**	**-2.39**	**0.017**
Distance to input market in km: (distpmktkm)	0.001513	0.01	0.995
Distance to output market in km (distsmktkm)	-0.10097	-0.61	0.544
Received public extension services: (extc)	-20.1031	-1.37	0.17
Farm type: (**farmtype)**	**32.42927**	**1.93**	**0.054**
Household size: (hhsize)	5.080366	1.58	0.114
Borrowed money: (inc1)	34.2957	1.76	0.079
Primary occupation of household head (farming/non-farming): (hhhdocc1)	0.89528	0.38	0.704
Child household labour: (landhhcd1)	-0.88024	-1.45	0.148
Adult female household labour: (landhhfd1)	-0.03874	-0.18	0.854
Adult male household labour: (landhhmd1)	0.037366	0.18	0.854
Transportation to output market: (transport)	-1.76893	-0.55	0.584
Planting month (October): (plantoct)	-65.4114	-1.55	0.123
Harvesting month (March): (harvmar)	15.55523	0.13	0.893
Harvesting month (April): (harvapr)	-89.4216	-1.63	0.103
Harvesting month (May): (harvmay)	-8.38	-0.12	0.903
Harvesting monthe (June): **(harvjune)**	**-291.951**	**-2.04**	**0.042**
Constant	-1480.57	-0.15	0.883

R-Squared = 0.2663

Table 14: Change in marginal net revenue in US$ with respect to unit change in mean temperature, precipitation and runoff

Climate scenario	Marginal net revenue per hectare (US$)
1℃ increase in mean temperature (November–December) (tcom1)	-322.62
1℃ increase in mean temperature (January–February) (tcom2)	315.70
20% reduction in mean precipitation (January–February) (wcom2)	-334.67
1cm increase in mean annual runoff (roff_mean)	3.39

Table 15: Change in marginal net revenue as % of mean net revenue

Climate scenario	Marginal net revenue per hectare expressed as % of the observed mean net revenue per hectare
1℃ increase in mean temperature (November–December) (tcom1)	Loss of 243%
1℃ increase in mean temperature (January–February) (tcom2)	Gain of 237%
20% reduction in mean precipitation (January–February) (wcom2)	Loss of 252 %
1cm increase in mean annual runoff (roff_mean)	Gain of 2.5 %

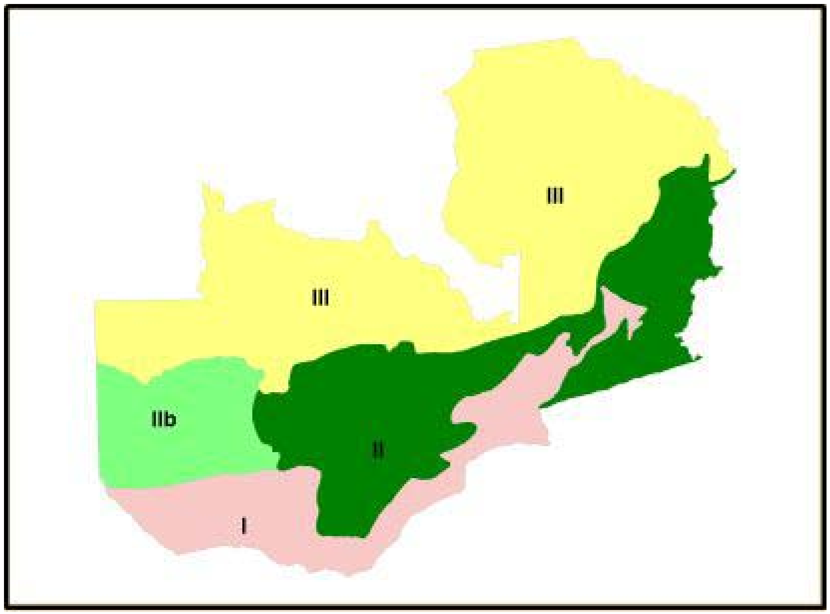

Figure 1: Agro-ecological zones of Zambia

Note: See text for explanation on Zone characteristics

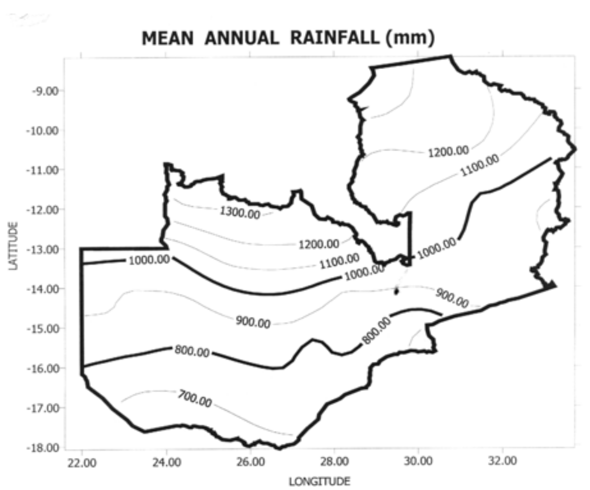

Figure 2: Mean annual rainfall

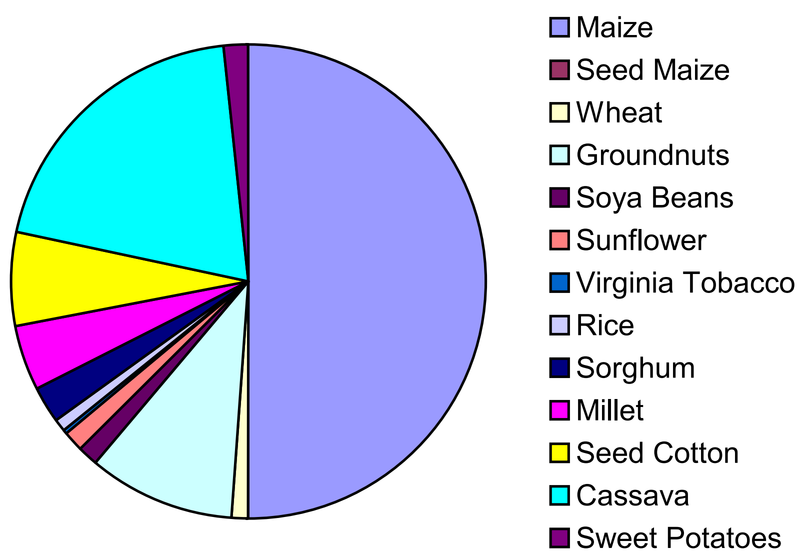

Figure 3: Crop area planted in season 2001/02

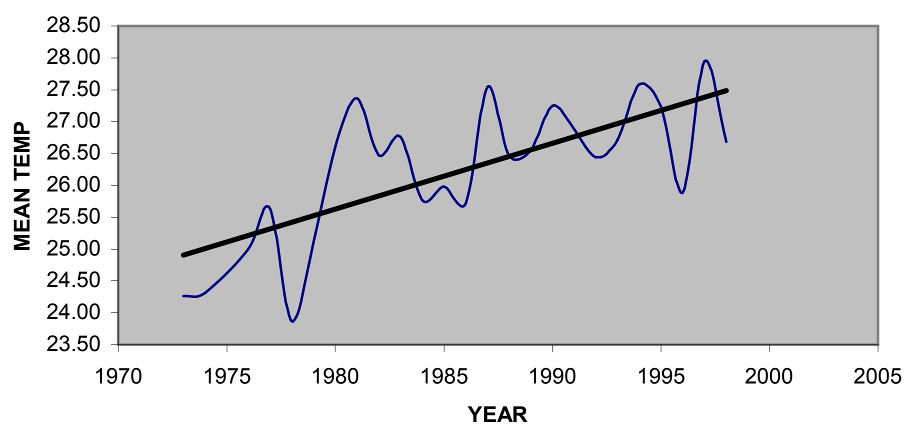

Figure 4: November–December mean temperature in Zone I

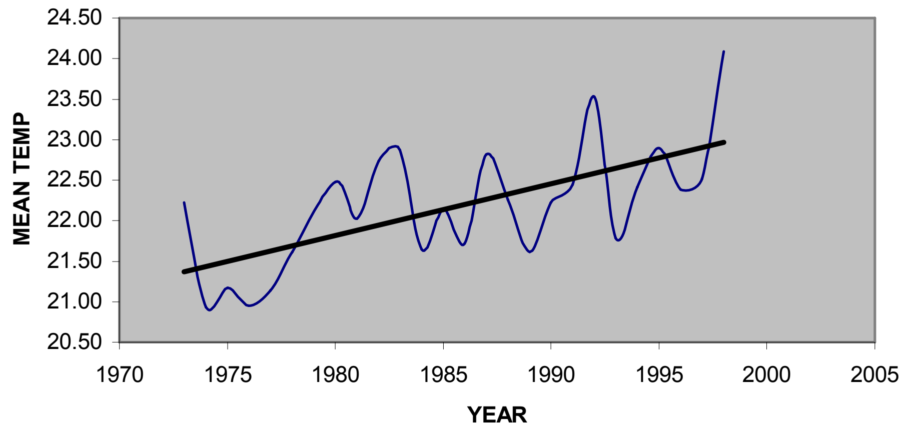

Figure 5: January–February mean temperature in Zone I

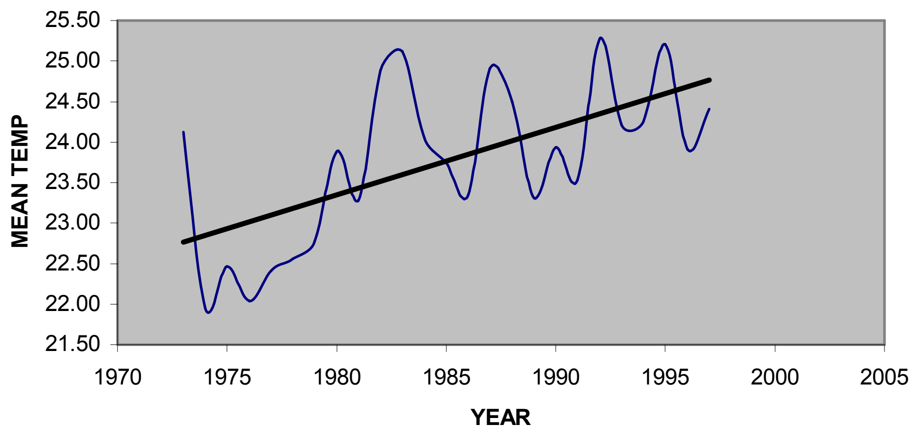

Figure 6: March–April mean temperature in Zone I

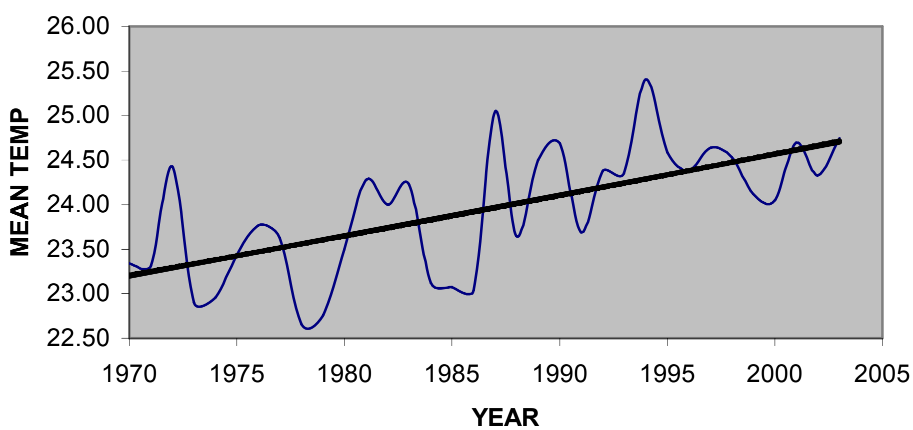

Figure 7: November–December mean temperature in Zone II

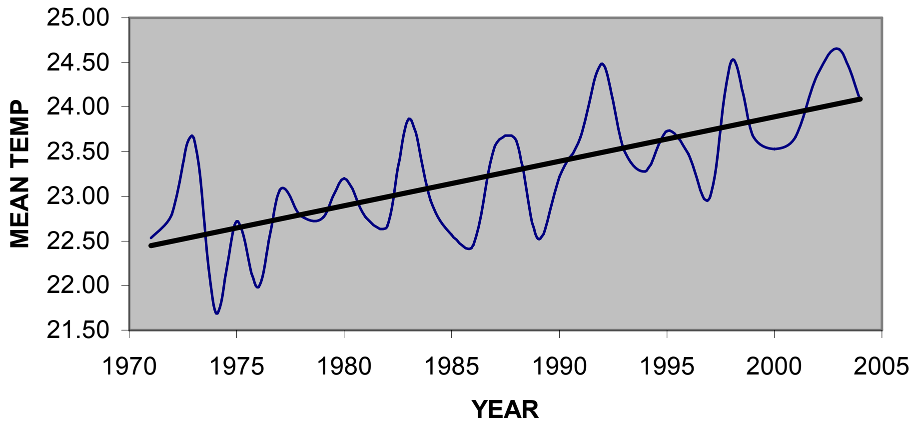

Figure 8: January–February mean temperature in Zone II

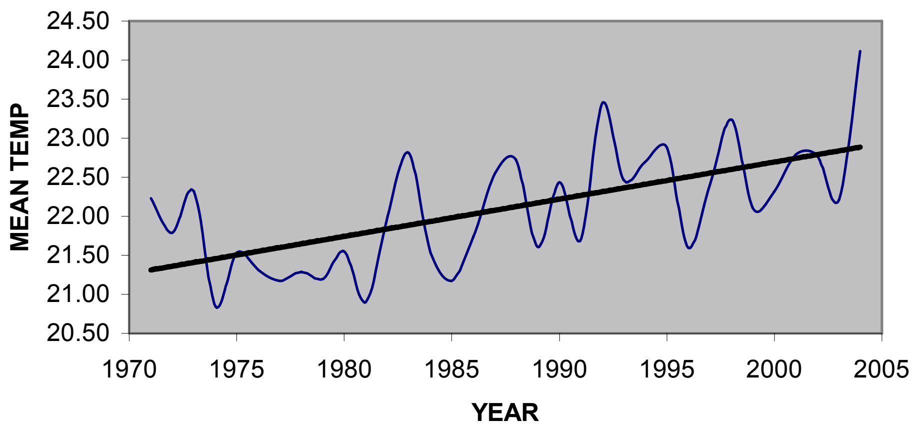

Figure 9: March–April mean temperature in Zone II

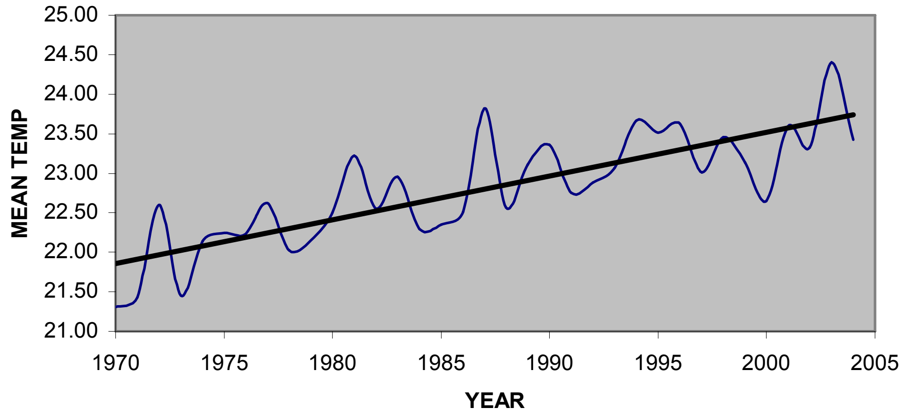

Figure10: November–December mean temperature in Zone III

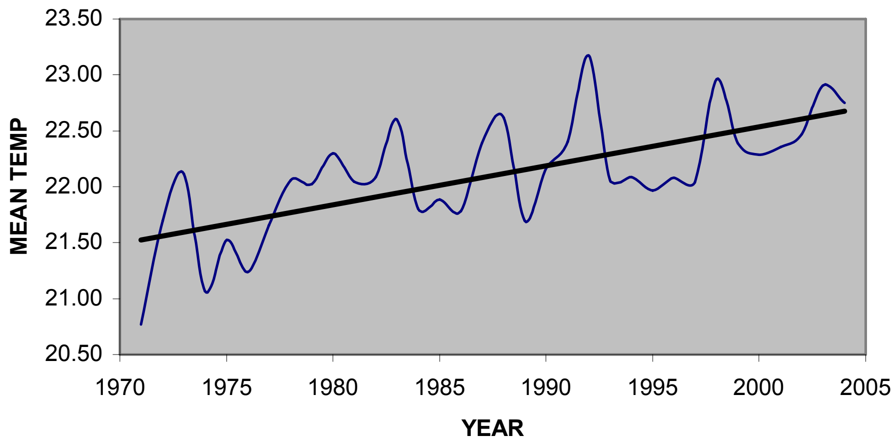

Figure 11: January–February mean temperature in Zone III

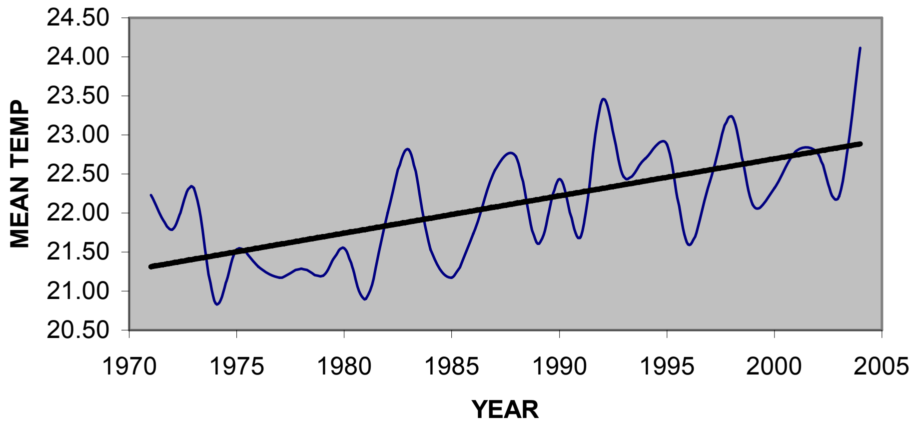

Figure 12: March–April mean temperature in Zone III

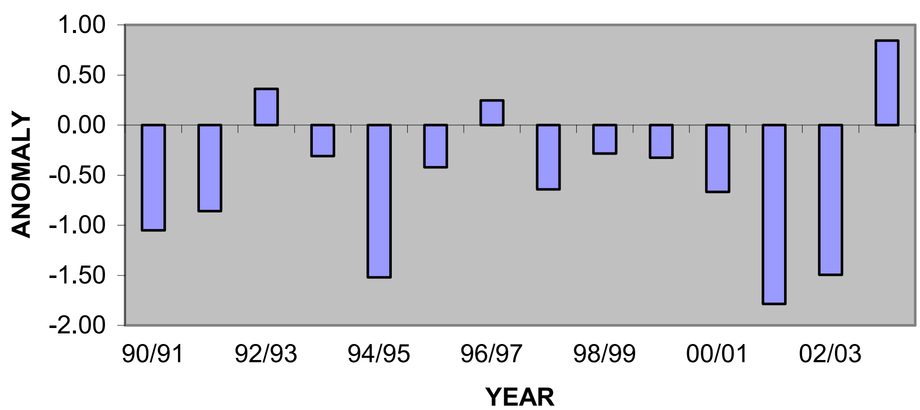

Figure 13: Annual rainfall anomalies in agro-ecological Zone I from 1970–2000 annual average rainfall

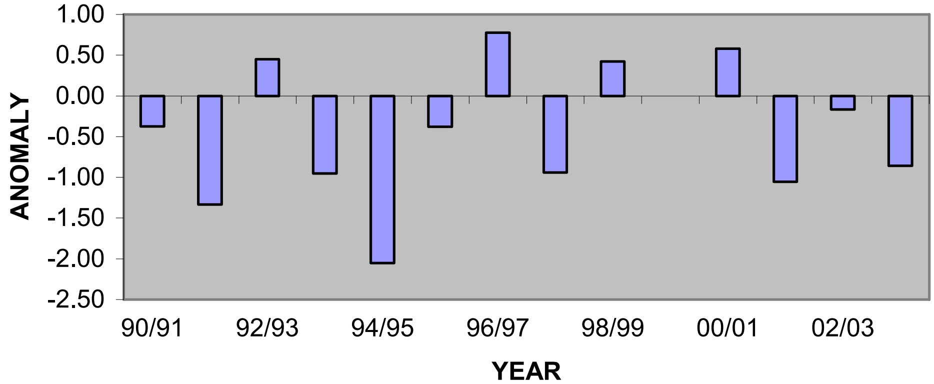

Figure 14: Annual rainfall anomalies in agro-ecological Zone II from 1970-2000 annual average rainfall

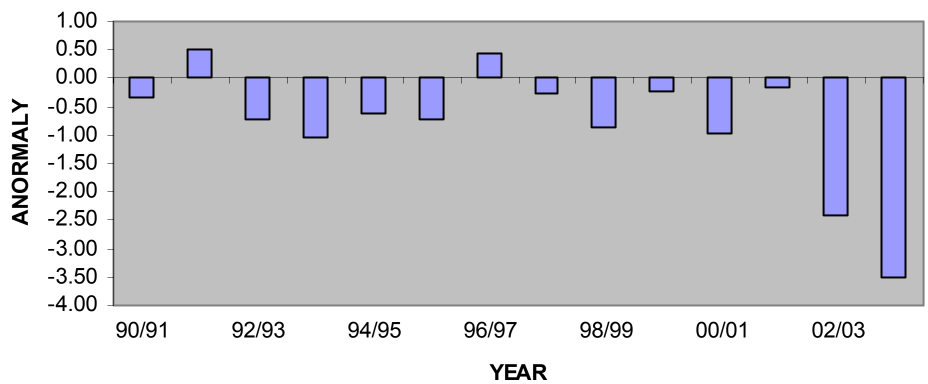

Figure 15: Annual rainfall anomalies in agro-ecological Zone III from 1970-2000 annual average rainfall

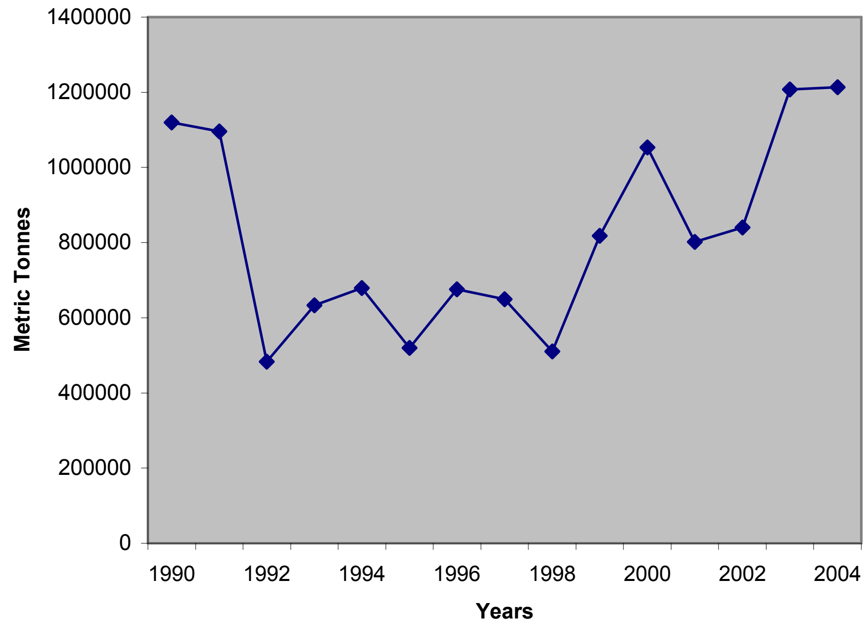

Figure 16: Maize production

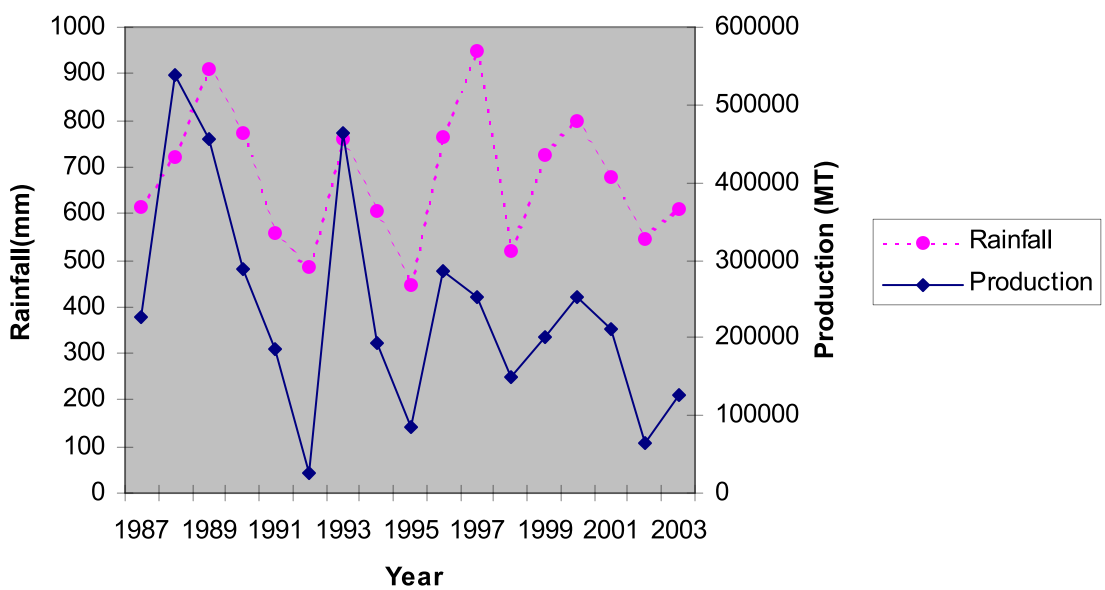

Figure 17: Rainfall and maize production for Southern Province

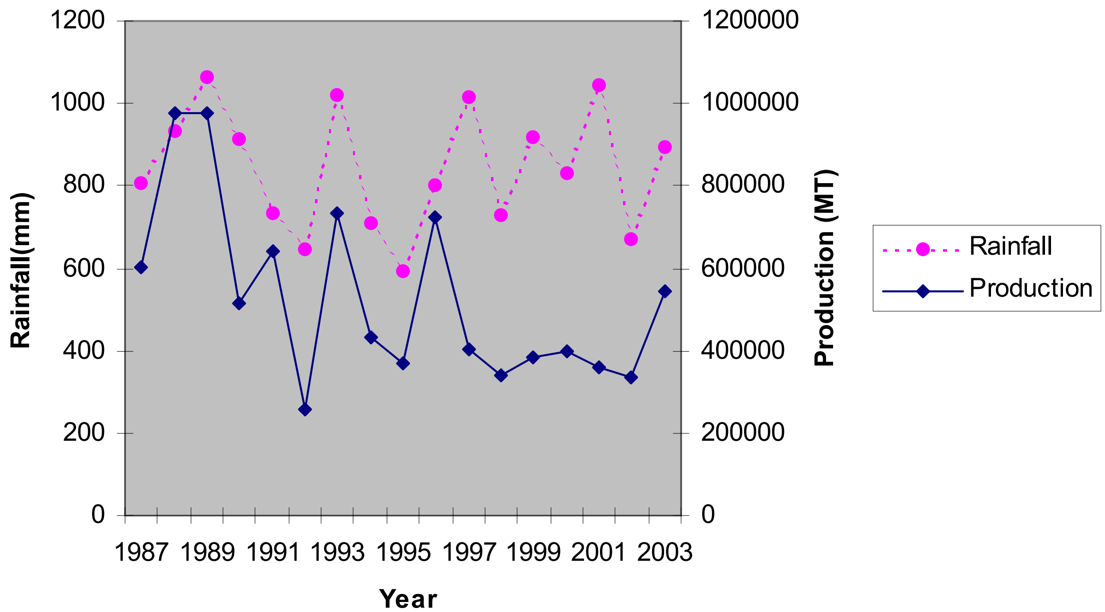

Figure 18: Rainfall and maize production for Central and Eastern Provinces

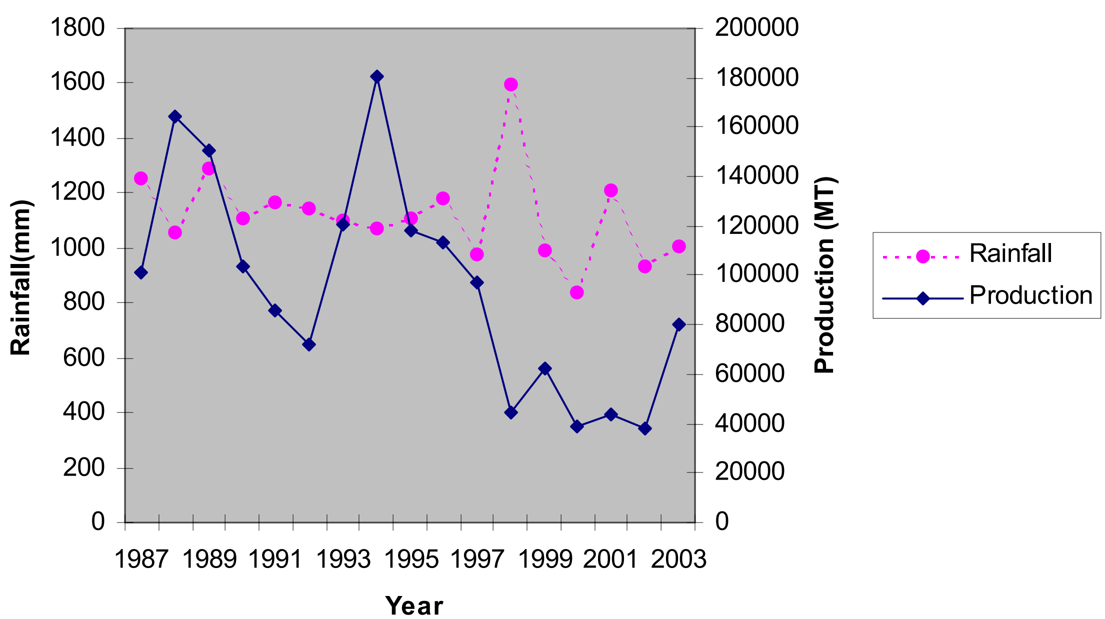

Figure 19: Rainfall and maize production for Northern Province

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