The Moroccan Association of Agricultural Economics (AMAECO)

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Climatic constraints play a predominant role in the performance of national agricultures and their capacity to support economic growth and assure food security for the population. With the climate changes and projected inter and intra annual fluctuations, management of the agricultural sector takes a particular dimension including management of risks inherent in the sector and searching for sustainable growth for the sector. Agricultural policies must permit a continual adaption of the processes of agricultural production and a reduction of negative effects of climate change in order to assure food security for the population.

In the face of climate change, the adaptation strategies can generate important development opportunities. Also, governments have need for pertinent evaluations of the impacts of climate change.

Considering the importance of this problem; to permit an exchange of ideas among professional staff, researchers, and specialists in the domain of development; to contribute to a richer understanding of methods and analytical tools ; and to contribute to better preparation of decision making in this domain – the Moroccan Association of Agricultural Economics (AMAEco) in collaboration with the International Association of Agricultural Economics (IAAE) and the World Institute For Development Economics Research of the United Nations University (UNU-WIDER) are organizing an international conference 6-7 December in Rabat, Morocco under the theme:

« Impacts of climate change on agriculture »
Rabat, Morocco   December 6-7, 2011

The principal themes proposed are the following::

1. Analysis of the impacts of climate change on agriculture: simulations and projections

2. **Climate change and sustainability of agricultural production systems**

3. **Adaption strategies for agriculture in the face of climate change: systems of production, risks in agriculture, and policies for food security**

4. **Water management in the context of climate change**

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Implications of Climate Variability for Yields of Major Staple Food Crops in Northern Ghana:

Some Empirical Evidence

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Abstract

Climate variability, the short-term fluctuations in the weather and agriculture affect each other. Climate variability affects the agroecological and growing conditions of crops and livestock, and is recently believed to be the greatest impediment to the realisation of the first Millennium Development Goal of reducing poverty and food insecurity in arid and semi-arid regions of developing countries. Conversely, agriculture is a major contributor to climate variability and change by emitting greenhouse gases and reducing the agroecology's potential for carbon sequestration. What however, is the empirical evidence of this inter-dependence of climate variability and agriculture in Sub-Sahara Africa? In this paper, I provide some insight into the long run relationship between inter-annual variations in temperature and rainfall, and annual yields of the most important staple food crops in Northern Ghana. Applying pooled panel data of rainfall, temperature and yields of the selected crops from 1976 to 2010 to cointegration and Granger causality models, there is cogent evidence of cointegration between seasonal, total rainfall and crop yields; and causality from rainfall to crop yields in the Sudano-Guinea Savannah and Guinea Savannah zones of Northern Ghana. This suggests that inter-annual yields of the crops have been influenced by the total mounts of rainfall in the planting season. Temperature variability over the study period is however stationary, and is suspected to have minimal if any effect on crop yields. Overall, the results confirm the appropriateness of my attempt in modelling long-term relationships between the climate and crop yield variables.

 Key words: Climate variability, rainfall, yield, cointegration, causality

JEL Classification Codes: L25, Q12, Q51, Q54

1. Introduction

Climate variability – the short term changes in weather patterns and agriculture affect each other. On the one hand, climate variability affects agroecological, growing conditions of crops and livestock. Climate variability and change are believed to be the greatest impediment to the realisation of the first Millennium Development Goal of reducing poverty and food insecurity globally via increased agricultural production in developing countries.

Climate variability results from our use of energy, but its impact is manifested through changes in agroecological conditions and climatic factors, particularly precipitation and temperature. Precipitation, especially rainfall and atmospheric temperature, the most important weather variables affected by climate change, play a crucial role in agricultural production in Sub-Sahara Africa (SSA). Having no glaciers to melt, it is believed that the most profound and direct impacts of climate variability over the next few decades in Africa will be on agriculture. This is because, unlike in the industrialised regions of the world, a majority of SSA's largely smallholder farmers lack yield-improving techniques like greenhouse and irrigation facilities for crop production. In addition, the usually self-bred crop varieties of SSA's subsistent farmers have a more limited genetic diversity and resilience to unfavourable weather conditions than those of developed countries where crops are virtually bred to withstand changes in climatic factors.

Although SSA, like other developing regions of the world, contributes the least to climate change and variability, it is known that semi-arid countries in SSA will be the most affected by the phenomenon in terms of agricultural production. Africa is expected to be the continent where the impact of global warming on agriculturally-relevant climatic variables and production will be greatest (IWRM, 200). Prevailing evidence already show that in semi-arid regions of Africa, rainfall distribution over the past few years is low and highly variable spatially and inter-temporally.

Few empirical climate science studies in Ghana have revealed distinctive inter-annual and inter-decadal variability in climatic variables like precipitation and temperature. For instance, high resolution regional climate simulation using explicit dynamic downscaling of global climate scenario indicates a slight increase in total annual precipitation of 5%, but also a significant decrease (up to 70%) of precipitation in April, the traditional month for land preparation and commencement of crop productions in Northern Ghana. The total duration of the rainy season is also revealed to have shortened, while Dry Season and Rainy Season temperature increased around 1°C and 2°C respectively (Kunstmann and Jung, 2005).

High climatic variability e.g. low and variable distribution of rainfall represents a delicate balance between agricultural production and food security[1]. Studies show that the changes in the agriculturally-relevant variables of climate e.g. increasing temperatures and declining levels and distribution of rainfall, are likely to reduce yields of maize, rice, wheat and other food crops in semi-arid regions (Lobell *et al.,* 2009). The amount and distribution of rainfall affects many other aspects of agricultural production among smallholder farmers in SSA, namely farm sizes, crop enterprises, cropping calendars, incidence and growth of weeds, crop pests and diseases (Yengoh *et al,* 2010).

In Ghana, the variability of rainfall is a threat to the livelihood of smallholder farmers. Over the past few years, rainfall-related crop failure due to episodes of late rains for planting, variability in the pattern and levels of rainfall, and intermittent droughts and floods in Northern Ghana are common phenomena. Thus climate variability entails risks in Ghana, especially in the dryer Northern part of Ghana.

The objective of this study is to assess quantitatively how climate variability affects yields (Ha^{-1}/per annum) of major staple crops, viz. millet, maize, sorghum, rice, groundnuts and yam in Northern Ghana. The motivation is to contribute to the knowledge dearth on the effects of changes in temperature and rainfall in the planting season on the production of major staple crops in Northern Ghana. To the best of my knowledge, there has not been any study on climate variability impacts on crop yields in Northern Ghana. Describing the consequences of climate variability on the yield of major food crops in Northern Ghana will help institute policy measures[2] to improve upon the resilience of subsistence agriculture to covariate, weather shocks, and in predicting long-run economic impacts of climate change on smallholder agriculture. This is particularly important because smallholder agriculture contributes about 70% to livelihood in Northern Ghana.

2. Study Area and Data Description

The northern, Savannah region of Ghana lies between latitudes 8° and H°10'N and has a land area of 97702 km². Northern Ghana's rainfall is characterised by a long dry period of about seven months from October/November to April/May called the Dry Season with no appreciable rainfall level, and a Rainy Season from May to October with adequate levels of rainfall for agricultural production.

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[1] The current hunger crises in Horn of Africa attest to this fact.
[2] Perhaps under Ghana's Government Savannah Accelerated Development Authority (SADA) for poverty alleviation in Northern Ghana

Fig 1: The Savannah Agro-Ecological Zones of Northern Ghana
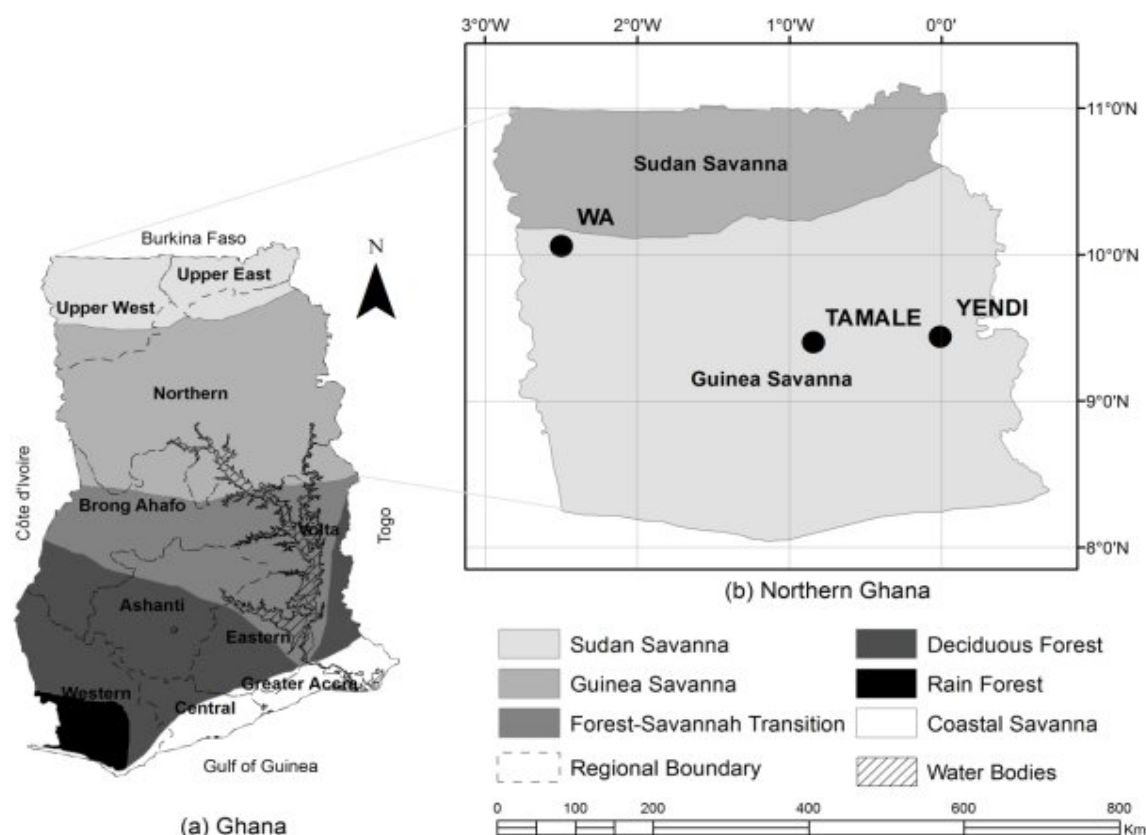
Source: Yengoh, et al, 2010

Northern Ghana, comprising the Northern, Upper East and Upper West regions is located in the sub-humid to semi-arid Guinea Savannah and arid Sudan Savannah zones of Ghana, where the annual precipitation ranges between 400 and 1200 mm, and agriculture, which employs about 70% of the population, is around 95% purely rain-fed. Since colonial times, Northern Ghana has been the poorest part of the country because of its precarious climatic conditions like the long dry season of about seven months followed by just a five-month rainy season with recurrent, intermittent droughts and/or floods in the planting season.

Apart from land degradation and intensification of agriculture leading to declining farm sizes, continuous cropping and unsustainable farming practices causing declining output from crop and livestock systems in this part of Ghana, analyses of climate patterns in the last 60 years have shown that precipitation has

slightly decreased, while temperatures and evapotranspiration have increased. In addition, the onset of the rainy season has shifted forward[3] (Kranjac-Brisavljevic et al, 1999).

Northern Ghana is chosen as the study area because it is sensitive to climate variability especially erratic rainfall. The region is also the most agricultural part of Ghana with a high percentage of subsistent, food crop farmers, and rural poverty incidence of about 52%. Many manifestations of climatic instability in the last two decades are floods causing extensive gully erosion and devastating large areas of farmlands and crops; and several cases of late rains before and persistent droughts during the planting season. Irrigated agriculture is seen as the most important means for coping with the effects of climate change and variability in Ghana, but just about 3% of Ghana's farmers practise irrigated agricultural (Kurukulasuriya and Mendelsohn, 2008).

The data used for the analysis includes temperature and precipitation time series from 1976 – 2010 collected from the Ghana Meteorological Services (GMS), and crop yield (MT/Ha) data from 1991 – 2010 for maize, millet, rice, sorghum, groundnuts and yam[4], obtained from Ghana's Ministry of Food and Agriculture (MoFA). These dataset were collected for six climatically-unique geographical locations viz. Bawku, Bolgatanga and Navrongo in the arid Sudano-Guinean Savannah (SGS) zone with rainfall ranging from 400-1000mm in the Upper East Region (UER); and the sub-humid/semi-arid Guinea Savannah (GS) zone with an annual rainfall of about 1200mm in the Northern Region (NR). The rainfall and temperature figures are those collected within the Rainy Season. Likewise, the yields are average yields per Ha of the selected crops cultivated within the Rainy Season[5]. All analyses are done in the natural log values of the variables.

3. Methodology

Many models exist in the climate impact assessment literature. Some of these include computable general or partial equilibrium models, production functions, and Ricardian-type statistical or process-based models, which are modified and applied in analysing the impact of changes in precipitation, temperature and carbon on agricultural production. A recurring concern however in using these models to estimate potential impacts of climate change on agriculture is whether or not they are able to capture real climate variability scenarios among smallholder crop farmers in rain-fed farming systems in dry lands.

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[3] From April to June

[4] The NR cropping system is cereal- and root and tuber-based with major staple crops like maize, rice, yam and cassava. The UER produces both cereals – millet, maize and rice, and legumes – groundnuts and cowpea as the major staple crops.

[5] Since there is only one crop production season in Ghana from April/May to October/November, temperature and rainfall values measured only within this period are useful here.

To address this concern, I move beyond the usual IPCC modelling techniques of climate change impact analysis to using time series models to simulate the long run and causality relationships between rainfall and crop yield variables. I use two time series modelling techniques - cointegration and Granger causality to simulate the impact of changes in the total levels of seasonal rainfall and average, seasonal minimum and maximum temperature on average, annual yields of the selected major staple crops of Northern Ghana. The models I apply are in the class of statistical crop modelling approaches used in estimating yield sensitivity to variations in rainfall and temperature.

Cointegration analysis help determine the long run, dynamic relationship between two or more variables. I use Johansen's (1991) Variance Autoregressive (VAR) approach to simulate the dynamic relationship between crop yields and average annual total rainfall[6] in the selected locations. Let the level of output of a given crop be Q_t^c and the seasonal average level of the climate variable (e.g. seasonal total rainfall or average temperature) be W_i^t ($i = precipitation\ or\ temperature$) with t denoting time. If Q_t^c and W_i^t are time series variables containing stochastic trends, then they are said to be cointegrated if there is an equilibrium, long run relationship between them (Prakash, 1997). Alternatively, Q_t^c and W_t^i are cointegrated if β is such that $Q_t^c + \beta W_t^i \ \Box\ I(0)$.

Johansen's approach can be applied to test for the existence of a cointegration relationship between Q_t^c and W_t^i as follows:

$$\mathbf{y_t} = \boldsymbol{\mu} + \mathbf{A_1 y_{t-1}} + \mathbf{A_2 y_{t-2}} + ... + \mathbf{A_p y_{t-p}} + \boldsymbol{\varepsilon_t} \qquad (1)$$

Where $\mathbf{y_t} = (Q_c^t\ and\ W_i^t)$ is an nx1 vector of variables ($Q_t^c\ and\ W_i^t$) and is assumed to follow a VAR process, $\boldsymbol{\mu}$ is a vector of intercept terms, $\mathbf{y_{t-i}}$ are the lagged values of $\mathbf{y_t}$, A_i are vector coefficient matrices and ε_t is an nx1 vector of error terms. The VAR process in (1) is rewritten as:

$$\mathbf{\Delta y_t} = \boldsymbol{\mu} + \mathbf{\Pi y_{t-1}} + \sum_{i=1}^{p-1} \mathbf{\Gamma_i \Delta y_{t-i}} + \boldsymbol{\varepsilon_t} \qquad (2)$$

$\Pi = \sum_{i=1}^{p} A_i - I$ is the coefficient matrix denoted as $\Pi = \alpha\beta'$ and $\Gamma_i = -\sum_{j=i+1}^{p} A_j$ is a matrix of short run coefficients

The test for the existence of a cointegration relationship between Q_t^c and W_t^i is based on two likelihood ratio tests – the trace and maximum eigen value tests specified as follows:

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[6] Temperature was found to be fairly stable over the period of the study and thus dropped from the impact analysis

$$\lambda_{trace(r)} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}) \text{ and } \lambda_{max(r)} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}_{r+1}) \text{ respectively}$$

(3)

Where T is the sample size and λ_i is the ith largest canonical correlation. In this study we run the trace test which evaluates the null hypothesis (H_0) that there are at "r" cointegrating relationships between the rainfall/yield variables in the selected locations. In addition, I estimate and test for significance of the long run cointegration coefficient β which indicates the sensitivity of yield to variability of rainfall.

The existence of cointegration between Q_t^c and W_t^i implies Granger causality (Granger, 1987). Furthermore, since cointegration between variables does not automatically imply causality between them, the evidence of causality between the variables must be provided by Granger causality analysis. The Granger causality models applied in this study are specified in equations (4) and (5).

$$Q_t^c = \sum_{k=1}^{n} a_k Q_{t-1}^c + \sum_{k=1}^{n} b_k W_{t-1}^i + \varepsilon_{1t}$$

(4)

$$W_t^i = \sum_{k=1}^{m} c_k Q_{t-1}^c + \sum_{k=1}^{m} d_k W_{t-1}^i + \varepsilon_{2t}$$

(5)

The equation (4) postulates that, Q_t^c is dependent on Q_{t-1}^c and W_{t-1}^c; conversely, equation (5) postulates the same (theoretically) for W_t^c. The ε_{1t} and ε_{2t} are uncorrelated error terms. A proof of causality between rainfall and yield implies that the variability of yield overtime can be explained by varying episodes of rainfall and temperature over the same period of time. The variant of the Granger causality tests run in this paper is based on the vector error correction model (VECM).

4. Results and Discussion

This section reports the results of the analysis. First graphical plots of the variability and patterns in total rainfall and seasonal average minimum and maximum temperature within the farming season, and yields (MT/Ha^{-1}) of the selected major staple crops cultivated in the Rainy Season at the six locations within both agroecological zones of Northern Ghana are presented. The data for the analysis is a pooled panel data of temperature and rainfall figures of the GMS from 1976 to 2010, and crop yields data of MoFA from 1991 to 2010.

4.1 Rainfall and Temperature Variability in Northern Ghana

Variability in the level and distribution of rainfall is the most important determinant of crop yields in smallholder, resource-poor farming systems in arid and semi-arid areas, where farmers often lack sufficient yield improving inputs or technology. Thus, analysing the rainfall regime is a prerequisite for examining climate variability effects on crop yields in the arid and semi-arid zones of Ghana. In figure 2, we illustrate the pattern of rainfall in four locations within the study area, namely Navrongo and Bawku in the arid SGS zone, and Tamale and Bole in the semi-arid GS zone.

Figure 2: Seasonal Patterns of Rainfall in Northern Ghana (1976-2010)
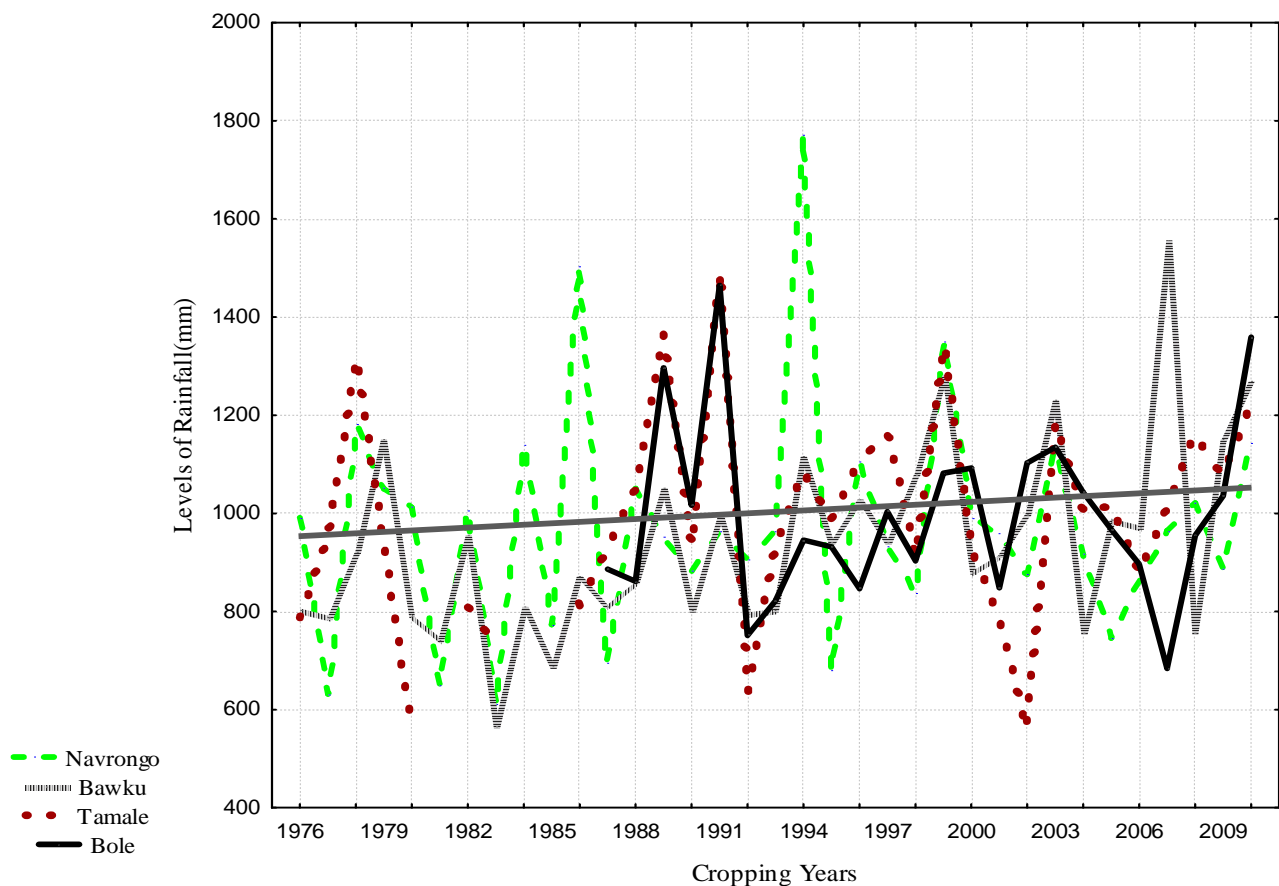
Source: Own Plots from GMS Data

The seasonal variability in the pattern of rainfall over the study period is quite stark, exhibiting a near-cyclical pattern with the rainfall levels alternating quite regularly between peaks and troughs above the mean rainfall level of 958.84mm almost triennially. Within the period of the analysis, several episodes of rainfall levels as low as about 600mm or up to 1800mm can be seen. These represent periods of droughts

and floods, hence risk for crop yields. Furthermore, the overall trend in rainfall, as demonstrated by the trend line appears to have slightly increased over the whole period of study.

The total mean of rainfall per Rainy Season from 1976 to 2010 is 958.84mm, and the cumulative change in the seasonal total rainfall over the period is 11.41mm.This supports Boko (2007) and Nicholson (2005) who recorded slight increases in rainfall over recent years following declining trends and frequent dry spells between the 1960s and 1980s in Ghana. It is also evidence that climate change does cause changes in the rainfall pattern of Northern Ghana. Even though the study did not record the number of rainy days, these, together with lengths of planting periods, are believed to be declining over time (Yengoh *et al,* 2010). The question here is whether or not these variations in the levels and distribution of rainfall affect the yield performance of crops in the study area?

Threshold levels of environmental temperature also affect crop production activities and yields in semi-arid and arid areas (Kunstmann and Jung, 2005; Kurukulasuriya et al, 2006). There is a suitable temperature range for optimal yields in every crop. Therefore, examining the variability of temperature in climate-related studies in crop production is necessary. The study examined the pattern of seasonal, average minimum and maximum temperatures from 1991 to 2010 in the study area. The temperature curve is presented in figure 3.

Fig. 3: Seasonal Average Minimum and Maximum Temperatures in the Two Agroecological Zones of Northern Ghana (1987-2010)
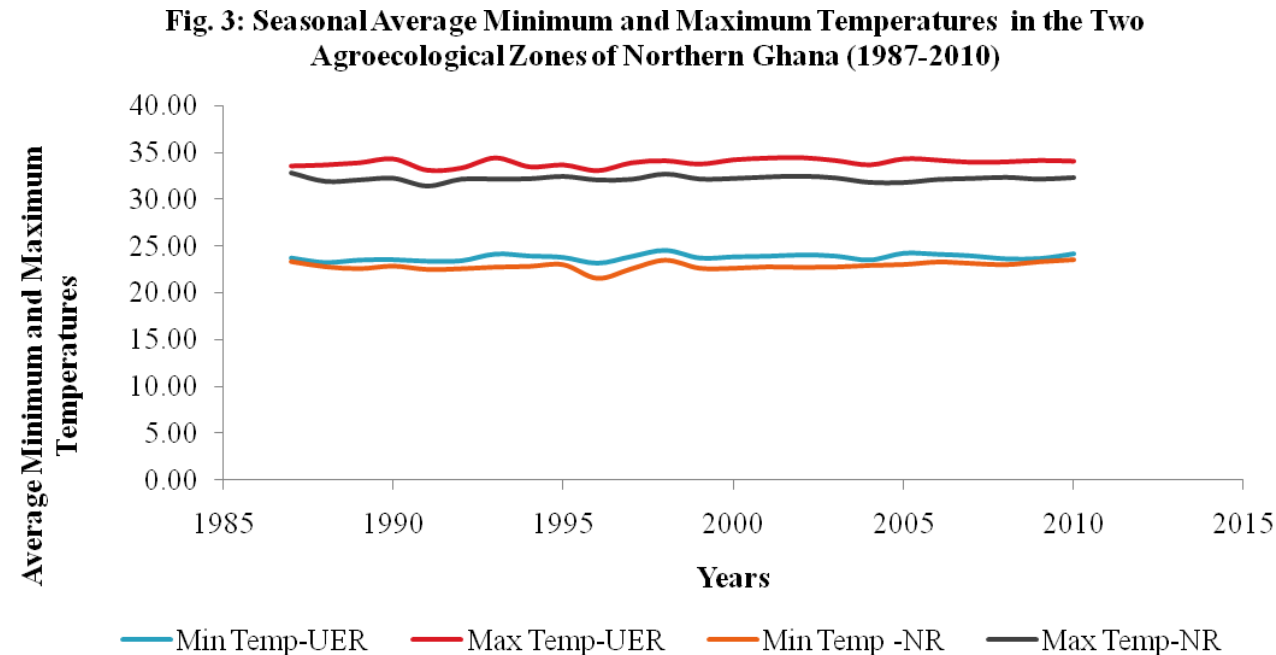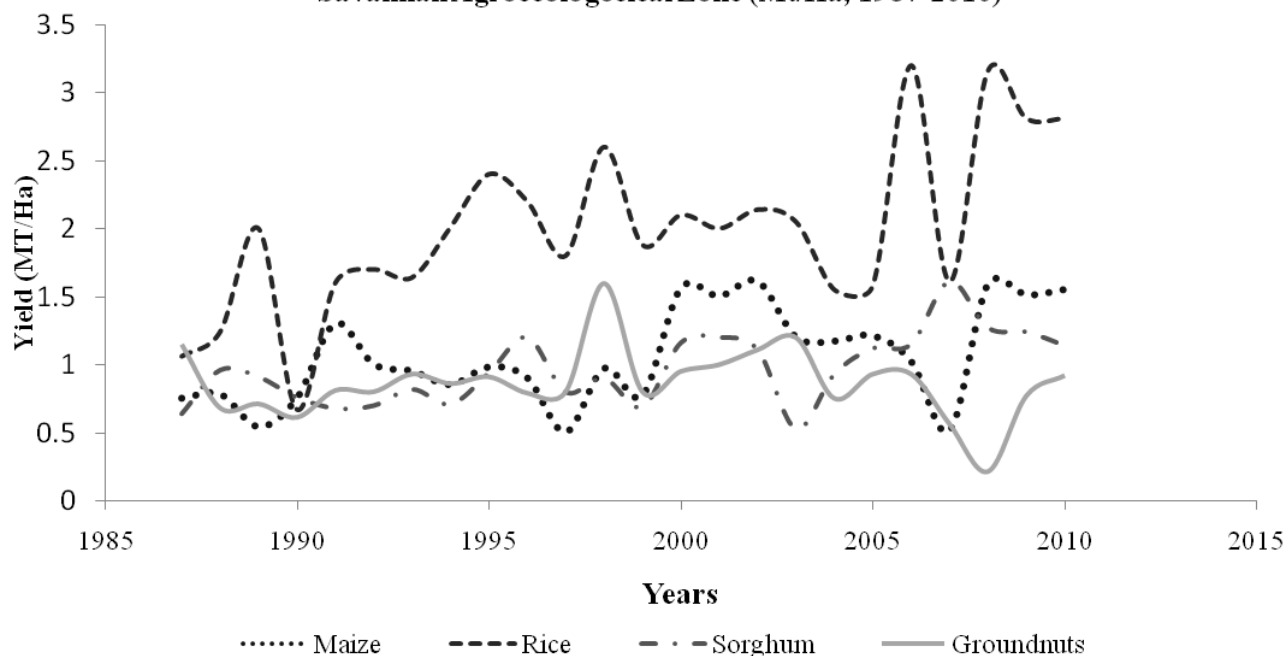
Source: Own Plots from GMS Data

The figure shows a stationary variation in temperature over the study period. Unlike the rainfall series, there are no explosive temperature fluctuations above mean minimum or maximum temperature. The strong 1997/1998 El Nino effect caused just a slight increase in average minimum and maximum temperature, but this increase was not significant enough to affect the long term trend in the observed temperatures in the area. As expected, the average minimum and maximum temperatures of the SGS zone (UER) are about $0.9^{o}C$ and $1.54^{o}C$ respectively higher than the corresponding values in the GS zone (NR).

This finding suggests that Northern Ghana has not experienced notable temperature increases over the study period. The absence of significant varying temperature trends or fluctuations above mean minimum or maximum temperature implies that no fundamental causal relationship should be expected between temperature variability and yields of the selected staple crops in Northern Ghana. For this reason, I drop the temperature variable in the cointegration and causality analysis.

4.2 Crop Yield Variability in Northern Ghana

In the figures 4 and 5, I plot the yield levels and variability of four (4) major staple crops viz. maize, rice, sorghum and groundnut for each zone. Like the rainfall series, the graphical analysis of the yield data shows high and non-stationary variability in the yields of the selected crops over the period of study.
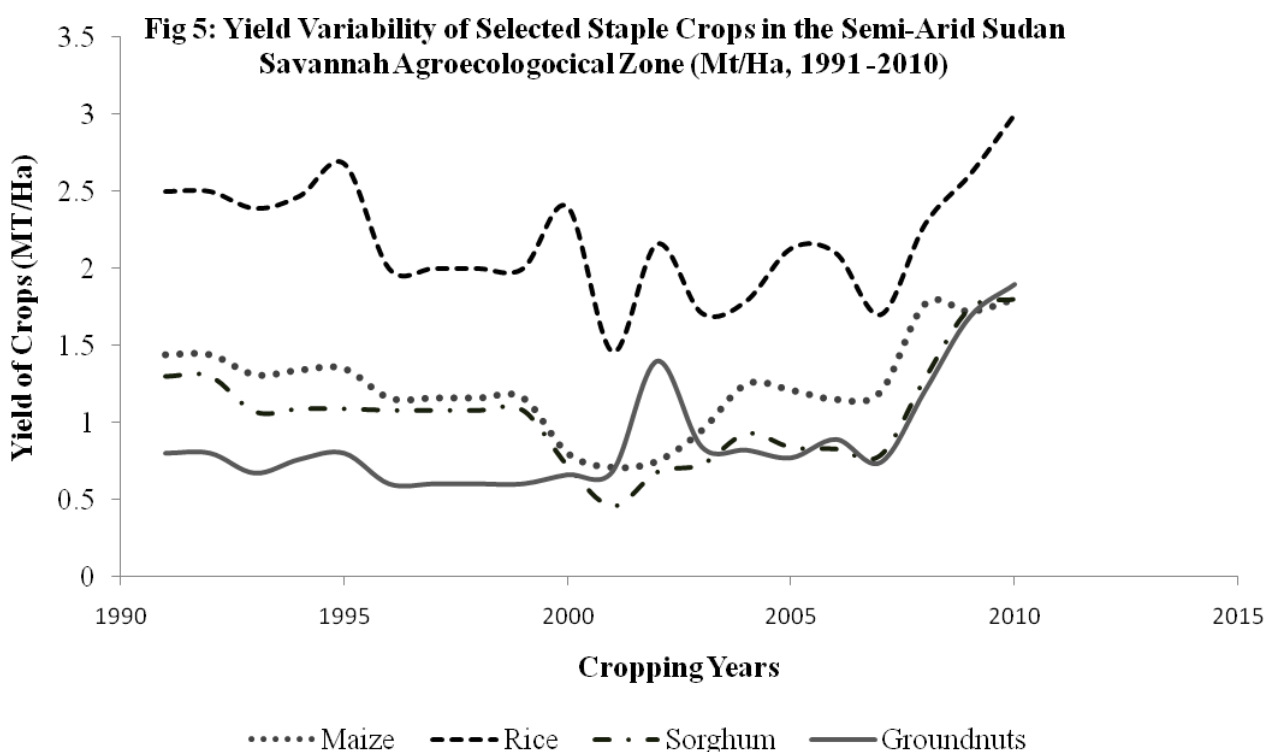

Fig 4: Yield Variability of Selected Staple Crops in the Dry Sudano-Guinean Savannah Agroecologocical Zone (Mt/Ha, 1987-2010)

Source: Own Plots from MoFA Data

First, the average yields the crops in the arid, SGS zone (Fig. 4) show an expected inter-annual variability. It can be seen that whereas the yields of the indigenous crops - maize, sorghum and groundnut - which are purely rain-fed appear much related (turning upward and downward together) over time and giving an insight of the existence of a long run equilibrium relationship, the yield of rice, partly rain-fed (upland rice) and partly irrigated (lowland rice), tends to largely lead the yields of the indigenous crops over the entire period of the analysis. This is expected because irrigation is available for some rice farms in the SGS zone to safeguard yield losses during dry spells in the planting season. In addition, high yielding varieties of rice have been consistently released by different rice improvement research programmes within the period of study.

The yield patterns of the crops in the semi-arid GS zone are similar to that in the arid zone (Figure 5).

Fig 5: Yield Variability of Selected Staple Crops in the Semi-Arid Sudan Savannah Agroecologocical Zone (Mt/Ha, 1991-2010)

Even though the output per Ha of groundnut in the first decade of the analysis lags behind that of the other two indigenous crops, the yield levels of the three indigenuous crops appear again to comove over the study period, while that of rice, also partly rain-fed and irrigated in this zone, again leads the other yield curves over the entire period.

In both figures, yield levels for all the crops appear to be rising in the last five years. This suggests that agro-climatic conditions, especially rainfall, in the last few years are yield-improving. As noted above, favourable weather especially rainfall is the predominant underlying factor affecting the output of most

crops in the arid and semi-arid zones of Northern Ghana, where farmers lack insufficient inputs and improved technology. It appears that as rainfall increased slightly over the last few years, yield levels and variability rose as well. Further analysis is however required to reveal the nature of the empirical linkage between rainfall and the yield performance of the crops. This is the tasks of the next section.

4.3 Testing Cointegration and Causality between Crop Yields and Rainfall in Northern Ghana

This section presents the cointegration and causality analyses results. Since the data used is time series, I performed unit root tests using the ADF and KPSS approaches to determine the stationarity properties of the series. Testing the null hypothesis (H_0) that the individual series contain unit root with a drift and trend but without structural breaks, the results revealed that all the series are non-stationary and integrated of the order 1.

Tables 1and 2 contain the three different categories of estimation results of the analyses. These are: 1) results of the test for cointegration relationships between rainfall and crop yields in the chosen locations, 2) estimated elasticity coefficients of cointegration obtained from a LS estimation of the long-run cointegration equation $Q_t^c + \beta W_t^i \ \square \ I(0)$, and 3) uni-directional Granger causality test statistics of the causal relationship between rainfall and crop yields. The Akaike Information Criteria (AIC) recommended lag values of the cointegartion test are also reported.

Table 1 presents the etimated results for the staple crops of the SGS zone - millet, maize, rice and groundnuts. The test statistics of cointegration, signifying the existence and nature of the long run relationships between rainfall and crop yields (prsented in the column 2), provide evidence in favour of cointegration between rainfall and crop yields for all cases under the three locations except for millet in all the locations and Sorghum in Bolgatanga. The H_0 of $r = 0$, implying an absence of a cointegration relationship between rainfall and yields of the given crops is rejected[7] for all the cases except those mentioned above. We cannot however reject the null hypothesis of one cointegrating relation, i.e. $r = 1$ in all cases.

The findings suggest that, there exists at least one equilibrium cointegration relationship ($r = 1$) between the amount of rainfall in the planting period and the corresponding yields of maize, rice and sorghum over the period of the analysis. Millet yield in the long-run however appears to be insensitive to rainfall. This

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[7] The null hypotheses for all the estimations are tested at the 1%, 5% and 10% levels.

segmentation between rainfall and millet yield may be because millet is drought-tolerant and as such, low levels of precipitation are not necessarily yield-reducing.

Table 1: Cointegration and Causality Tests Statistics and Cointegration Elasticity Coefficients in the Sudano-Guinean Savannah Zone

Est. Equation (Rainfall --)	Coint. Test Statistics $r_0 = 0$	$r_1 = 1$	No. of Lags	Normalised Coint. Coefficients (β)	Granger Causality
Bawku					
Maize	27.53**	8.18	4	-0.954***	7.033***
Millet	31.79	8.05	4	-	
Sorghum	27.39**	10.65	4	1.271***	5.539**
Groundnuts	26.52**	10.30	4	1.476	3.193*
Bolgatanga					
Maize	26.04**	8.36	4	0.115**	1.592
Millet	13.21	3.51	4	-	-
Sorghum	23.90	4.91	4	-	
Groundnuts	25.94**	10.13	4	0.519***	3.959**
Navrongo					
Maize	24.74*	9.85	3	-1.710***	12.472***
Millet	15.76	3.29	4	-	-
Sorghum	26.99**	8.26	4	-0.701	0.850
Groundnuts	26.62**	9.35	3	-3.077***	4.901**

Source: Own Estimation

The cointegration elasticity[8] coefficients, estimated for only the cases with significant cointegration relationships, are the long run responsiveness of the crop yields to rainfall variability. These are significant in all the included cases except for groundnut under Bawku and Sorghum under Navrongo. There is especially a high sensitivity of the yields of sorghum in Bawku ($\beta = 1.27$), and of maize and

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[8] Since the rainfall and yield variables are estimated in their logarithm values.

groundnuts ($\beta = 1.7$ and $\beta = 3.08$ respectively) in Navrongo, with estimated elasticity coefficients above 1. The estimated elasticity of 1.27 for sorghum yield in Bawku implies that a 1% increase in rainfall (within the suitable range) will cause a 1.27% upward shock in yield. Positive and negative signs of the elasticity coefficients are expected since only rainfall within the suitable range is yield-improving, while both flood and drought events, *ceteris paribus,* exert downward shocks on crop yield.

Having determined the cointegration relationships and elasticity coefficients, I performed the Granger causality test to check whether significant casual, equilibrium relationships from rainfall to the crop yields in the chosen locations exist. The test is unidirectional; it only examines shocks of rainfall variability on crop yields and not vice versa[9]. The H_0 is that "there is no causality from rainfall to crop yields in the SGS zone". The results are presented in the last column of Table 1.

For the vast majority of the cases tested, we establish the existence of causality by rejecting H_0. Thus, for most of the staple crops cultivated in the zone, there is a significant unidirectional causal relationship from rainfall to their yields (Ha^{-1}/per annum). Therefore, recorded planting season rainfall levels can be used to predict the yields of the selected crops. Rainfall especially has a strong predictive power for maize and sorghum in Bawku, groundnuts in Bolgatanga, and maize and groundnuts in Navrongo where the estimated test statistics are high and highly significant. The independencies of the yields of maize in Bolgatanga and sorghum in Navrongo cannot be empirically explained.

The results of the SG zone are presented in Table 2. Similar to those of the SGS zone, we find strong evidence of cointegration between rainfall and yields of the four major staple crops – maize, rice, yam and groundnuts. The cases in which we cannot establish cointegration are rice and yam in Tamale and Yendi respectively. The indigenous crops – maize, yam and groundnuts particularly show strong evidence of cointegration with rainfall. This confirms the results of the graphical analysis in figure 4 where the yields of these crops are shown to drift together over the period of the analysis.

The estimated elasticity coefficients are significant in all cases except three. In all significant cases, crop yields appear to be less responsiv to rainfall in the GS zone (all elasticity coefficients < 1) with more negative sign than is the case under the GSG zone. It is expected that yield sensitivity to rainfall in the semi-arid zone where latent soil moisture content is higher should be less than that of crops in arid areas with lower soil moisture content. The negative signs of the elasticity coefficients is an insight to the effect of drought but particularly floods on crop yields. This is because, having a higher level of soil moisture

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[9] While doing the reverse is theoretically possible, it will be practically only artificial.

content and subsoil hard pan, the effects of extremely high rainfall is more yield-reducing here than will be the case in the SGS zone with arid conditions, low hard pan and well drained farmlands.

Table 2: Cointegration and Causality Tests Statistics and Cointegration Elasticity Coefficients in the Guinea Savannah Zone

Est. Equation (Rainfall --)	Coint. Test Statistics $r_0 = 0$	$r_0 = 1$	No. of Lags	Normalised Coint. Coefficients (β)	Causality (Test Stat.)
Bole					
Maize	35.52***	8.98	4	0.541***	19.212***
Rice	18.03*	5.07	4	0.318***	3.758*
Groundnuts	28.09**	6.99	4	-0.135	1.8626
Yam	27.87**	8.16	2	0.060	0.944
Tamale					
Maize	26.64**	6.28	4	-0.213*	1.121
Rice	19.00	4.37	4	-	-
Groundnuts	38.46***	5.66	4	-0.212***	0.048
Yam	18.33	2.36	4	-	-
Yendi					
Maize	35.54***	13.46**	4	-0.942***	37.865***
Rice	34.99**	11.66*		-0.569***	21.260***
Groundnuts	25.04*	7.87		-0.048	2.210
Yam	40.70	3.3	2	-0.299***	3.450**

Source: Own Estimation

The causality test statistics are significant in five out of the ten cases analysed. There is particularly a strong causation of yields of maize and rice in Bole and Yendi, while no empirical evidence of causality exists from rainfall to the yields of the all crops in Tamale. This suggests that rainfall does not have a long-term causal impact on the yield of staple crops in Tamale .Tamale is a big meteropolitan city and the yields of even smallholders here unlike in the rural locations may not be solely climate-forcing e.g. determined solely by rainfall, but also by the use of yield-improving external inputs, seed and technology.

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5. Conclusion and Recommendation

The object of this paper is to examine long-term cointegration and causality between rainfall and yields of the most important staple crops in two distinct the agroecological zones in Northern Ghana. The analysis was conducted using pooled panel data of total rainfall and annual yields of the selected crops over the period 1991 to 2010. The data was applied to the Johansen VAR and Granger causality techniques.

High seasonal variability in rainfall with cyclical fluctuations above the mean of about 959 mm, coupled with several episodes of floods and droughts over the study period, were revealed. The cumulative average increase in rainfall from 1976 to 2010 was 11 mm. In contrast, no notable variability in minimum and maximum temperature was seen. In the core analysis, I found evidence of cointegration and causality between total rainfall and crop yields in the selected locations, meaning yields of the selected staple crops have been influenced by the total mounts of rainfall in the planting season. Overall, the results confirm the appropriateness of my attempt in modelling long-term relationships between the climate and crop yield variables.

The core limitation of this paper is the unavailability of long time series data. Ideally much longer time series is required in capturing seasonal trends and ensuring both the consistency and efficiency of the estimated parameters. However, a longer complete series for both the weather and agricultural data do not exist at the moment in Northern Ghana. The paper strengths lie in being able to use the available data to provide evidence of the long run and causal link of crop yields to variability in rainfall by running Granger causality tests based on a VECM, having established long run equilibrium relationships and estimated elasticity coefficients between the variables. In this way, the paper links long-term causality and cointegration more logically than previous studies in Ghana.

An interesting extension of this paper in future research would be to broaden the scope of the study to encompass other possible climate variables such as CO2, and their interactions with other environmental variables (e.g. nutrient availability, farmers resource endowments etc). Policy measures to counteract yield variability such as encouraging flexible land use and crop insurance should be implemented to protect farmers from exposure to increasingly climate-related risks.

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Appendix A: Individual Plots of the Rainfall Time Series for Four selected Locations