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Climate Variability and Crop Yields in Northern Ghana: What Role for Crop-Livestock Integration

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Abstract

Climate variability, the short-term fluctuations in average weather conditions and agriculture affect each other. Climate variability affects the agro ecological and growing conditions of crops and livestock, and is 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 agro ecology'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, we provide some insight into the long run relationship between inter-annual variations in temperature and rainfall versus annual yields of the most important staple food crops in Northern Ghana. Applying pooled panel data of rainfall, temperature and yields of selected crops from 1976 to 2010 to co-integration and Granger causality models, there is cogent evidence of co-integration 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 planting season rainfall. Temperature variability over the study period is however stationary, and is expected to have minimal effect if any on crop yields. Overall, the results confirm the fitness of our model of long-term relationships between climate and crop yield variables, and have implications for production decisions on crop-livestock integration by smallholder farming systems.

Introduction

Climate variability – the short term changes in the average weather patterns and agriculture affect each other. On the one hand, climate variability affects the agro ecological conditions of crops and livestock. On the other, agriculture, by emitting greenhouse gases and reducing the agro ecology's potential for carbon sequestration, is a major contributor to climate variability and change. Climate variability and change are believed to be the greatest impediments to the realisation of the first Millennium Development Goal (MDG) of reducing poverty and food insecurity via increased agricultural production in developing countries.

Climate variability is largely caused by human use of energy, but its impact is manifested through changes in agro ecological 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). This is because, unlike in the industrialised regions of the world, a majority of SSA's largely smallholder farmers lack yield-improving techniques like greenhouses 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 agro-climatic conditions.

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 have been common phenomena. Thus climate variability entails risks in Ghana, especially in the dryer northern part of Ghana.

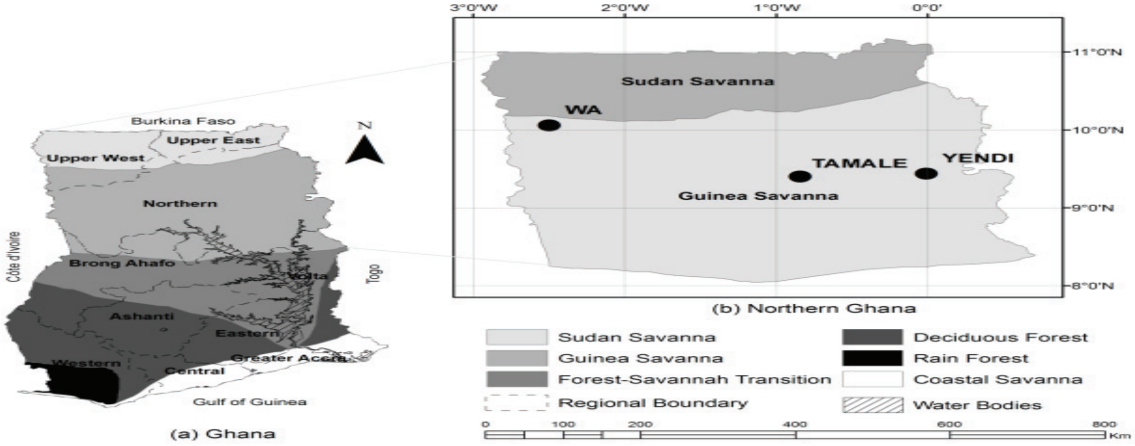
Study Area and Data Description

Northern Ghana comprises three administrative regions - the Northern, Upper East and Upper West regions. Northern Ghana's ecology comprises a sub-humid to semi-arid Guinea Savannah and arid Sudan Savannah zones with an annual precipitation ranging between 400 and 1200 mm, and largely subsistence agriculture that is about 95% rain-fed and employs about 70% of the population. Northern Ghana is chosen as the study area because it is sensitive to climate variability especially erratic rainfall. In addition, the high poverty rate in this part of Ghana is attributed to its vulnerability to climate change and precarious climatic conditions like long dry season of about seven months followed by just a five-month rainy season with recurrent, intermittent droughts and/or floods.

Analyses of Northern Ghana's 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 (Kranjac-Brisavljevic et al, 1999). Whereas irrigated agriculture is seen as the most important means for coping with the effects of climate change and variability in Ghana, just about 3% of Ghana's farmers practise irrigated agriculture (Kurukulasuriya and Mendelsohn, 2008).

The data used for the study includes temperature and rainfall 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, 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 where annual total rainfall ranges from 400-1000mm; and Bole, Tamale and Yendi in the sub-humid/semi-arid Guinea Savannah (GS) zone with annual total rainfall of about 1200mm. The rainfall and temperature figures are those collected within the Rainy Season.

Fig 1: The savannah agro-ecological zones of northern Ghana



Source: Yengoh, et al, 2010

Methodology

I use two statistical time series models – co-integration and Granger causality models to simulate yield sensitivity of the selected major staple crops of Northern Ghana to variations in rainfall and temperature. Co-integration analysis help determine the existence of long run, dynamic relationship between two or more variables. Johansen's (1991) Variance Autoregressive (VAR) co-integration approach is used to simulate the dynamic relationship between crop yields and average annual total rainfall[1] in the selected locations.

Since proof of co-integration between Q_t^c and W_t^i implies Granger causality (Granger, 1987), and since co-integration between variables does not automatically imply causality between them, the evidence of causality between the variables must be provided by Granger causality analysis.

Let the yield per Ha 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 co-integrated if there is an equilibrium, long run relationship between them (Prakash, 1997) or if β is such that $Q_t^c + \beta W_t^i \ \square\ I(0)$. Johansen's approach can be applied to test for the existence of a co-integration relationship between Q_t^c and W_t^i as follows:

$$\mathbf{y_t = \mu + A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + \varepsilon_t} \tag{1}$$

Where $\mathbf{y_t}$ = (Q_c^t and W_i^t) is an n x 1 vector of variables (Q_t^c and W_t^i) and is assumed to follow a VAR process, **ì** 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 *n* x 1 vector of error terms. The VAR process in (1) is rewritten as:

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

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

$\Pi = \sum_{i=1}^{p} A_i - I$ 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 existence of cointegration between Q_t^c and W_t^i implies Granger causality (Granger, 1987), which may be specified as follows:

$$Q_t^c = \sum_{k=1}^{n} a_k Q_{t-1}^c + \sum_{k=1}^{n} b_k W_{t-1}^i + \varepsilon_{1t} \tag{4}$$

Where (4) postulates that, Q_t^c is dependent on Q_{t-1}^c and, W_{t-1}^c, is the error term. 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 study period.

Results and Discussion

Rainfall and Temperature Variability in Northern Ghana

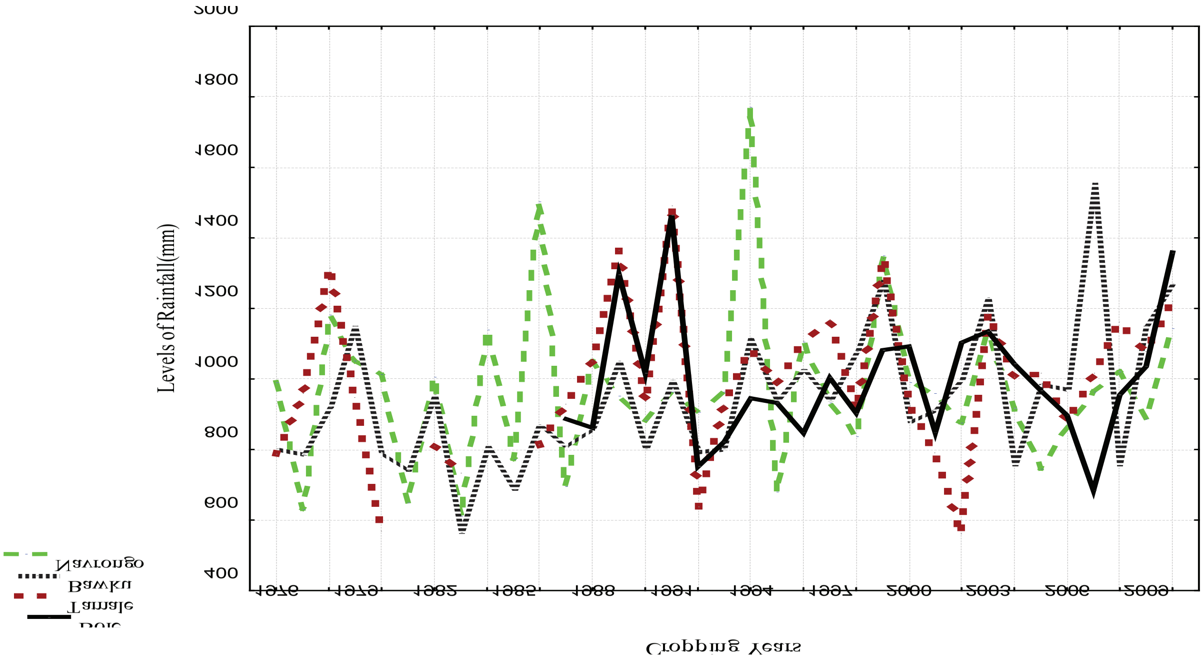
Variability in the level and distribution of rainfall is often reported as the most important determinant of crop yields in smallholder, resource-poor farming systems in arid and semi-arid areas, where farmers lack sufficient yield improving technology. Thus, analysing the rainfall regime is a prerequisite 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.

The seasonal variability in the pattern of rainfall over the study period is quite stark, exhibiting a near-cyclical pattern with rainfall levels alternating 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 from as low as 600mm 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.

With a total mean of rainfall per production season from 1976 to 2010 being 958.84mm, 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.

Figure 2: Seasonal patterns of rainfall in northern Ghana (1976-2010)



Source: Own Plots from GMS Data

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, we performed unit root tests using the ADF and KPSS approaches to determine the stationarity properties of the series[2]. The stationarity results revealed that all the series are non-stationary and integrated of the order 1. In Table 1 where results of the SGS zone are presented, the test statistics of cointegration, signifying the existence and nature of the long run relationships between rainfall and crop yields provide evidence in favour of co-integration between rainfall and crop yields for all cases under the three locations except for millet, and Sorghum in Bolgatanga. The H_0 of $r = 0$, implying an absence of a co-integration relationship between rainfall and yields of the given crops is rejected for all the cases except those mentioned above. We cannot however reject the null hypothesis of one co-integrating relation, i.e. $r = 1$ in all cases.

The findings suggest that, there exists at least one equilibrium co-integration 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 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 between rainfall and crop yields in the SGS zone

Est. Equation (Rainfall --)	Coint. Test Statistics		No. of Lags	Normalised Coint. Coefficients (β)	Granger Causality
	$r_0 = 0$	$r_1 = 1$			
<u>Bawku</u>					
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**

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[2] *Results not presented here for lack of space but are available on request from the authour*

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 co-integration elasticity coefficients, estimated for only the cases with significant co-integration 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 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 (above the mean) will cause a 1.27% upward shock in sorghum yield. Positive and negative signs of the elasticity coefficients are expected since only rainfall within the suitable thresholds may be yield-improving, while both flood and drought events, *ceteris paribus,* exert downward shocks on crop yield.

The Granger causality test (results in last column of Table 1) to check whether significant causal, equilibrium relationships from rainfall to the crop yields in the chosen locations exist is unidirectional; it only examines shocks of rainfall variability on crop yields and not vice versa. H_0 imply that "there is no causality from rainfall to crop yields in the SGS zone." 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 SGS zone, there is a significant unidirectional causal relationship from rainfall to their yields (Ha^{-1}/per annum); meaning recorded planting season rainfall levels can be used to predict the yields of the selected crops. Similar results for the SG zone are presented in Table 2.

Table 2: Cointegration and causality between rainfall and crop yields in the GS zone

Est. Equation (Rainfall --)	Coint. Test Statistics		No. of Lags	Normalised Coint. Coefficients (β)	Causality (Test Stat.)
	$r_0 = 0$	$r_0 = 1$			
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

Here, we find strong evidence of co-integration between rainfall and yields of the four major staple crops. The estimated elasticity coefficients are significant in all cases except three and show that crop yields appear to be less responsive to rainfall in the GS zone 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 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 all crops in Tamale.

Conclusion and Recommendation

This paper examines long-term co-integration and causality between rainfall and yields of major staple crops in two agro ecological zones in Northern Ghana using pooled panel data of rainfall and crop yields over the period 1991 to 2010. Applying the data to the Johansen VAR and Granger causality techniques, we find evidence of co-integration and causality between rainfall and crop yields in the selected locations. This means crop yields have been influenced by levels of planting season rainfall in the study area. 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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