Assessing Environment in Agriculture in Sub-Saharan Africa (SSA): A Time Series Estimation

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INTRODUCTION

The interrelated role of agriculture and environment in explaining agricultural performance in sub-Saharan Africa (SSA) cannot be stressed enough given that agriculture is central to economic growth and dependent on natural resources (fertile soil, bio-diversity, fresh water, etc) under serious threat. Agriculture plays multifunctional roles in relation to the environment. Each of the farming systems generates both positive and negative environmental externalities. In addition to producing tangible products (crops, livestock) traded in markets, agriculture also produces environmental externalities that are not accounted for or transmitted by market price.

Subsistence agriculture as a widespread agricultural practice in SSA has huge implications to environment mainly due to its low and declining labour productivity leading to increased but unsustainable exploitation of the environment. Soil erosion and deforestation are the major environmental externalities caused mainly by these agricultural practices leading to the inability of the sector to provide livelihood for the increased rural population. For instance, land degradation has contributed to high depletion of soil nutrients conducive to the continued low level of productivity thereby reinforcing the cycle of low productivity, poverty and environmental degradation. Africa is therefore caught up in a vicious circle: - *destruction of the environment by man with its attended distortion of the hydrological cycle, poor agricultural performance and further degradation of the environment-*

Though the interrelated role of agriculture and environment is recognized in explaining agricultural performance, the complex ways by which environmental factors affect agriculture and vice versa are not thoroughly investigated. A close scrutiny of agricultural economics literature in the past fifty years reveals that most of estimation of production functions has been based on neo-classical growth models that emphasized **physical and human capital** accumulation. These models have shown their limits against environmental issues. In fact, as production is itself dependent on natural resources, the physical and labour productivity decrease with the exhaustion of natural resources (Gillis et al., 1998). The consideration of **natural capital** refocuses the theoretical debate on sustainable development (WCED, 1987; Colby, 1989; Batie, 1991; CCE, 1992; Piriou, 1997) Thus, the **natural capital (the environmental factors)** must be considered in the explanation of agricultural production just like the physical and human capital in sub-Saharan Africa.

1 STATE OF ART

Though it is recognized that environmental factors play an important role in determining agricultural productivity, only few agricultural economists have investigated the issues. To prove this, about 227 articles of the Journal of the International Association of Agricultural Economists between 1991 and 2003 were consulted. Of these publications, only 30 publications (13%) dealt with environment issues in general and 14 publications (6%) with water issues. This implies that about 81% of publications were devoted to non environmental issues in the fields. More surprisingly, 6 of the total number of publications (< 3%) concern Africa, and only 4 of these publications published by Africans (table 1 below).

Table 1: Status of series/publications of Agricultural Economics consulted between 1991and 2003

Environment Issues		Non environment & Water	Geographical coverage		Nationality of authors		Total publications Consulted
Water	Water & environment		African	Non African	African	Non African	
14	30	197	6 (<3%)	24 (11%)	4	26	227

Source: Author's calculation

Moreover, out of the 227 publications, only one article has attempted to model environment (land fertility level) and agricultural production of small-scale farmers in western Kenya in sub-Saharan Africa. (Odulaja and Kirios, 1996).

In few cases where environment factors (climatic conditions) are investigated, agricultural economists use either ordinal scales (good/bad; high/average/weak) or average rainfall as a summative environmental indicator in estimating agricultural production function. (Odulaja and Kiros, 1996; Frisvold and Ingram, 1995). Thus, the literature relating production to environmental factors is very scanty in SSA.

The present study built on these assets, conceptualises the relationships and shows the case of rainfall as a crucial environmental factor in SSA. The methodology proposed is an attempt to improve the measurement of rainfall in the estimation of agricultural production function based on time series data in SSA.

The main hypothesis is that the agriculture growth is less associated with more associated with rainfall distribution in the explanation of agricultural performance, and that environment factors compared with other factors are not significant in explaining agricultural growth in SSA.

2 MODEL SPECIFICATION AND DATA SOURCES

2.1 CONCEPTUAL FRAMEWORK

An improved and adapted specification of production in sub-Saharan Africa will draw from the works of Odulaja and Kirios (1996) in a case study in Western Kenya. They defined the small-scale Sub-Saharan Africa production function (Y) as a function of land (or herd size), L, environment effect, E, and management effect, M, represented as

Y= f(L)g(E)h(M)...(2)

where f, g, h are functions relating L, E, and M, respectively to Y.

The generalized model was written as:

$Y=aL^{b}\exp(cE+dM)+\varepsilon$……………………….(3)

where a, b, c and d are positive constants and ε the residual

Environment (E) includes factors such as rainfall, soil type, humidity, temperature, erosion and vegetation. As specific location factors, these factors are often represented in most surveys as good, bad, high, medium, low etc (Lomperis, 1991; Yanaihara, 1993; Flaherty and Jenglalern, 1995.). For more meaningful modelling, the above scales are transformed to continuous scales using the uniform ranking transform method. The **mean** of the uniform-ranks is then obtained for each sample to represent the environment index. Hence the environmental index, E, is distributed in the interval [0,1].

In time series studies, the situation is different and such environmental parameters such as rainfall, temperature, soil fertility (N,P,K) may be quantified and the **mean** of these environmental indices may be calculated.

A close scrutiny of agricultural practices/agronomic sciences reveals that agricultural output is more determined by rainfall distribution **(standard deviation)** than rainfall's **mean.**

This relationship is explored in the Togolese context for, like SSA, the state of the natural environment continues to suffer from physical degradation. All these put high pressures on the country's natural resources.

The methodology is the following:

The first step is to gather a comprehensive daily rainfall data in the country over many years;

The second step is to calculate the mean of daily rainfall of a given year;

The mathematical computation of the mean of this rainfall is as follows:

Suppose in a given country, there are r agro-ecological zones Z_i, with i = 1,….,r ; S_{ij} seasons in given zone j= 1,……ki ,it may be demonstrated that

The mean of daily rainfall of r zones in a given growing year in a given country is:

$$\overline{m} = \sum_{i=1}^{r} \frac{m_i}{r}$$ where m_i is the mean of all the zones Z_i, i = 1,…,r,

but $$m_i = \sum_{j=1}^{k} \frac{m_{ij}}{k_i}$$ where m_i is the mean of the given season S_j^i (k_i seasons) in the zone Z_i

with $$m_{ij} = \frac{\sum_{l=1}^{n_{ij}} R_l^{ij}}{\left|S_j^i\right|}$$ where m_{ij} the total number of rainfall during the season S_j^i in the zone

Z and $\left|S_j^i\right|$ is the total length of the season S_j^i expressed in number of days.

By replacing the above expressions in the equation, it follows that the mean of rainfall in the country during a growing year is:

$$\overline{m} = \sum_{i=1}^{r} \frac{\sum_{j=1}^{k_i} \frac{m_{ij}}{k_i}}{r} = \sum_{i=1}^{r} \frac{1}{r} \left(\sum_{j=1}^{k_i} \frac{1}{k_i} \frac{\sum_{l=1}^{n_{ij}} R_l^{ij}}{\left|S_j^i\right|} \right)$$

$$= \sum_{i=1}^{r} \frac{1}{r} \sum_{j=1}^{k_i} \frac{1}{k_i \left|S_j^i\right|} \sum_{l=1}^{n_{ij}} R_l^{ij}$$

$$\overline{m} = \sum_{i=1}^{r} \sum_{j=1}^{k_i} \sum_{l=1}^{n_{ij}} \frac{R_l^{ij}}{r k_i \left|S_j^i\right|}$$

The third step is to calculate the intra-annual variation of the rainfall within a given year represented by the standard deviation of rainfall as follows:

The mean of variance of daily rainfall (V_i) of r zones Z_i in a given growing year in a given country is:

$$v = \sum_{i=1}^{r} \frac{V_i}{r}$$ with $Z_i = Z_1\ Z_2, \ldots\ldots. Z_r$ and given V_i = V1, V2 …..Vr

The variance of daily rainfall (V_i) in the zone Z_i r is computed as follows:

Given k_i seasons in the zone Z_i, if v_j^i is the variance of rainfall computed over one season

S^i_j in the zone Z_i, then: $V_i = \sum_{j=1}^{ki} \frac{V_{ij}}{k_i}$

Vi is therefore the mean of rainfall variances of k_i seasons $S^i_1, S^i_2, \ldots S^i_k$ in the zone Z_i.

To compute v^i_j (variance of rainfall over the season S^i_j of the zone Z_i),.

Let us consider m_{ij} as the rainfall mean computed over the season v^i_j .

With n_{ij} , $|S^i_j|$, R^{ij}_l , the total number of rainfall days of the season S^i_j, the length of the season in days S^i_j and the quantity of rainfall of the l-th day during the season S^i_j

$$V^i_j = \sum_{l=1}^{n_{ij}} \frac{(R^{ij}_l - m_{ij})^2}{|S^i_j|} \quad \text{Or} \quad m_{ij} = \sum_{q=1}^{n_{ij}} \frac{R^{ij}_q}{|S^i_j|}$$

It follows that:

$$V^i_j = \sum_{l=1}^{n_{ij}} \frac{\left(R^{ij}_l - \sum_{q=1}^{n_{ij}} \frac{R^{ij}_q}{|S^i_j|}\right)^2}{|s^i_j|}$$

It can be demonstrated that:

$$V^i_j = \frac{1}{|S^i_j|^3} \sum_{l=1}^{nij} \left(R^{ij}_l \cdot |S^i_j| - \sum_{q=1}^{nij} R^{ij}_q\right)^2$$

Thus :

$$v = \sum_{l=1}^{r} \frac{1}{r} \sum_{j=1}^{k_i} \frac{1}{k_i} \cdot \frac{1}{|S^i_j|^3} \sum_{l=1}^{n_{ij}} \left(R^{ij}_l \cdot |S^i_j| - \sum_{q=1}^{n_{ij}} R^{ij}_q\right)^2$$

$$v=\frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{n_{ij}}\frac{\left(R_l^{ij}\cdot\left|s_j^i\right|-\sum_{q=1}^{n_{ij}}R_q^{ij}\right)^2}{k_i\cdot\left|s_j^i\right|^3}$$

The standard deviation of rainfall as the index of rainfall variability in a given growing year in a given country is: $IDPLU=\sqrt{v}$

2.2 EMPIRICAL MODEL

The theoretical model is a production function of three sets of variables: **physical capital** **(K_p,), human capital** (K_h) **and environmental capital (**K_E) as follows:

$Y_t=f(K_p,K_h,K_E,\varepsilon_h)$……………………………………………………………..(4)

The empirical model is expressed as follows:

$Y=\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\beta_4 H+\beta_5 SAN+\beta_6 NUT+IDPLU+\varepsilon$……………...(5)

where,

Y = food production index per capita (%);

H = the literacy rate index for people more than 15 years old (%), it is used as proxy as this latter is not available for the agricultural sector; (%)

X_1 = index of cultivated area in km² per capita (%);

X_2 = index of irrigated agricultural area in % of the total of agricultural areas – It represents the level of investment in rural infrastructures;

X_3 = quantity of fertilizers index per acres (%); it is a proxy of the level of agricultural technology;

SAN = index of health expenditures share in total national budget;

NUT = index of food availability per capita in kilocalories, a proxy of the nutritional status;

IDPLU= index of the rainfall variability; standard deviation (%)

ε, is the usual error term.

All the variables being expressed in natural logs, the coefficients obtained are elasticities.

2.3 DATA

2.3.1 Descriptive statistics

Secondary data cover the period 1965-1992. First, the data on production, real income (IR) as explanatory variables originate from the World Bank. Second, data on food security and availability (NU) are from FAO. Data on the literacy rate come from the national reports on sustainable human development published regularly by UNDP.

Monthly rainfall data were collected from the national Meteorology office. These disaggregated data enable the computation of intra-annual standard of deviation of the rainfall (IDPLU). Data on health indicator, SAN (share of health in national budget) come from Health Statistical Directory between 1965 and 1996.All the data were transformed into indices (base 100 in 1987). Table 2 summarizes the descriptive statistics of variables.

Table 2: Statistics summary for dependent and independent variables

	Mean	Median	Maximum	Minimum	Standard deviation
X1	4,84	4,84	5,25	4,46	0,23
X_2	4,36	4,47	4,62	3,39	0,33
X_3	2,82	3,14	4,72	0,00	1,57
SAN	4,83	4,78	5,33	4,42	0,26
H	3,94	3,66	4,65	3,19	0,53
Y	4,77	4,77	4,98	4,58	0,13
NUT	4,62	4,63	4,75	4,56	0,06
IDPLU	4,36	4,31	5,09	3,59	0,39

Source: Author's calculation

2.3.2 VALIDITY TESTS

a) Unit root tests

The unit root tests show that the hypothesis of non-stationarity is accepted in level for all variables with trend and constant. In the first difference form, the tests show that non-stationarity is rejected at level $\alpha = 5\%$ for all variables included in the model (table 3).

Table 3: Results of unit root tests

Variables	In Level	In 1st Difference
SAN	-0,57 [4]	-3,98* [1]
H	-2,07 [4]	-3,64* [2]
X_2	-1,90 [1]	-3,82* [1]
X_3	-1,92 [4]	-4,00* [1]
NUT	-2,66 [2]	-2,55* [3]
Y	-2,16 [4]	-3,63* [3]
IDPLU	-2,17 [3]	-7,03* [1]
X_1	-2,44 [4]	-3,41* [3]

The values in brackets are the lags number introduced in the model. The sign (*) means that the hypothesis Ho of non-stationarity is rejected at level α=5%. The AIC statistics was used to determine the number of lags.

Source: Computation of the author

b) Cointegration tests

The unit roots tests (Dickey-Fuller), applied to residual, show that food production (Y) is co-integrated with individual series H, X_1 et X_3 at $\alpha = 5\%$ which is not the case for SAN, NUT, IDPLU, X_2 series. However, in general all the independent variables series are co-integrated with Y at 5% level.

The unit root (Table 3) and co-integration tests (Table 4) show that the long-term relations are co-integrated. Thus the error correction models (ECM) are therefore their best short-term specifications (Engle and Granger, 1987). The ECM of the long-term model is as follows:

$$\Delta Y_t = \theta_1 \Delta X_{1t} + \theta_2 \Delta X_{2t} + \theta_3 \Delta X_{3t} + \theta_4 \Delta H_t + \theta_5 \Delta SAN_t + \theta_6 \Delta NUT_t + \theta_p \Delta IDPLU + (1-\lambda) ECM_{t-1} + v_t \quad \ldots(5)$$

The coefficient (1-λ) reflects the magnitude of the adjustment taking place in the short run to correct the instability of the past period.

Once the series stationary properties are established, the co-integrated relation is tested (Johansen, 1988). This "normalizes" the co-integration relation through probability techniques. The co-integration techniques verify the existence or not of a long-term equilibrium relation between the variables and is the long-term model.

The ECM is the residual of the estimation of the long-term model (equations 5). The coefficients θ, δ and π represent the short-term elasticity, while the Δ translates the fluctuations between two successive years. Due to the fact that all the variables of the three models are stationary, the error terms $\nu_{t,}$ μ_t, ω_t, are all distributed by the normal centred reduced law.

The long-term model (5) was estimated by generalised least square (GLS) due to the presence of autocorrelations of errors. The introduction of Dum binary variables in the long-term models was made necessary due to the existence of a structural break in the two models estimations, from 1980 as shown by the Chow's test. The reasons for these breaks lie in the economic crisis experienced by the country at the beginning of the 80's. This crisis leads to the country economic setbacks and the implementation of structural adjustment programs (SAP). Moreover, Klein test did not disclose existing multicollinearity between the explanatory variables in the estimations.

The short term model (table 6) being estimated by ordinary least squares (OLS), some explanatory variables such as literacy, irrigated lands, use of fertilisers, health and nutrition index were lagged two years to assess the lagged effects of these investments.

Table 4: Results of co-integration tests or unit roots tests

Co-integration relationships	ADF [lags]
Y on X_1	-2,30* [4]
Y on H	-2,18* [3]
Y on X_2	-1,00 [3]
Y on X_3	-2,05* [3]
Y on SAN	-0.04 [5]
Y on NUT	-0,12 [3]
Y on IDPLU	-1,48 [1]
Y on H, X_1, X_2, X_3, NUT, SAN,IDPLU	-2,73* [3]

The values in brackets are the lags number introduced in the model. The sign (*) means that the hypothesis Ho of non-stationarity is rejected at level α=5%. The AID statistics was used to determine the number of lags.
Source: Author's calculation

3 Environment as a Determinant of Food Production

3.1 The long run model

First, the environment factor (IDPLU) is not significant and is negative which implies that food production has not benefited from rainfall distribution for the period 1965-1992.

Second, with respect to other variables, a distinction must be made between human capital variables and physical capital variables (see table 5).

Table 5: Estimation of long-term model

Variables	Dependent variable Y	
	Coef. (b)	T of Student
Constant	-6,73	-8,77*
X_1	0,96	13,88*
X_2	0,09	3,13*
X_3	0,06	6,63*
H	0,21	8,11*
SAN	0,06	2,10*
NUT	1,12	11,28*
IDPLU	-0,004	-0,35
Dum	1,55	3,93*
Dum $\times$ X_2	-0,38	-8,10*
Dum $\times$ H	-0,21	-8,07*
Dum $\times$ SAN	0,20	3,72*
	R^2 = 0,975	DW = 2,69

* The sign (*) means that the coefficient is significant at 5% level
Source: Author's calculation

3.2 THE SHORT RUN MODEL

The estimations yield the following results.

First, with respect to the environmental indicator, it is important to notice that the result corroborates that of long term i.e. rainfall distribution has not induced favourable food production in Togo for the period 1965-1992.

In conclusion, the results of short and long term models indicate that the environment variable (rainfall distribution) compared to other variables contribute less to the explanation of food production in Togo. In fact since almost four decades, rains are unforeseeable and display low distribution over space and time. The main cause is among others the extensive agricultural and its attending deforestation and continuous degradation of the ecosystems.

Table 6: Estimation of short run model

Variables	Dependent Variable DY Coef. (q)	T Student
ΔX_1	0,72	2,51*
ΔX_2	0,02	0,22
ΔX_3	0,05	3,29*
ΔH	0,06	1,34
ΔSAN	0,06	1,46
ΔNUT	0,63	2,86*
ΔX_2(-2)	-0,08	1,61
ΔIDPLU(-2)	-0,01	-1,42
ΔH(-2)	-0,18	-3,59*
ECM (-1)	-0,55	-2,76*
	R^2 = 0,70 F = 7,99 (0,0002)	
	LM Test = 0,37 (0,70)	
	White= 1,27(0,41)	

* * The sign (*) means that the coefficient is significant at 5% level
Source: Author's calculation

CONCLUSION AND POLICY IMPLICATIONS

The interrelated role of agriculture and environment is widely recognized by scientists. However, agricultural economists despite their strategic position have not played an active role, through investigations, in bringing to the front the strong linkages between the agriculture sector and the degradation of the ecosystems in Africa. Such investigations, if carried out, will provide appropriate information base for greater awareness and more informed decision making and sustainable agricultural policies formulation in SSA. It is therefore recommended that environment issues continue to be top in the current and future research agenda in Africa. Agricultural economists must therefore seize the opportunity, through their research works, to participate more actively in meeting these challenges.

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