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REGULAR ARTICLE

ASSESSING AGRICULTURAL PRODUCTION SYSTEMS FROM A SUSTAINABILITY PERSPECTIVE: SOME FINDINGS FROM AGRO-ECOLOGICAL ZONES OF AFRICA

Kalu Ukpai IFEGWU

Address:
Department of Economics and Business Studies College of Management Sciences Redeemer's University P.M.B. 230 Ede, Nigeria; e-mail: pstkay@yahoo.com

ABSTRACT

The paper assessed agricultural production systems from a sustainability perspective defined in terms of relatively homogeneous agro-ecological zones of Africa, using the framework of a production function. Data used were drawn from FAOSTAT, the National Centre for Atmospheric Research and World Bank Indicators respectively for the period 1961-2009. The data were separated into three sub periods, namely: entire period (1961-2009), the pre-Structural Adjustment Period (SAP) reform period (1961-1985) and the post SAP reform period (1986-2009). This was necessitated by the need to examine whether production systems may have been shifted out of the overall trajectory of system evolution by shocks e.g. policy (SAP) among others. To investigate whether there has been a degradation of the quality of the natural resource base across the diverse agro-ecological zones; the estimated TFP trends were related to changes in selected resource quality variables over time. The results showed that the Northern and Southern agro-ecological zones had non-negative trends in TFP, indicating sustainability of production systems. However, the result indicated that the policy instrument (structural adjustment programme) may have shifted farming or production systems out of the overall trajectory of system evolution in three out of the five agro-ecological zones studied which showed negative TFP trends. A degradation of resource quality over time was noted during the pre-SAP reform period, but was maintained during the post-SAP period.

Keywords: Agricultural Production Systems, Sustainability, Agro-Ecological Zones, Africa.
JEL: R52, R58, H41

INTRODUCTION

Agricultural production systems level within agro-ecological zones are likely to be similar in relevant factors, such as, the types of new technologies that are available, the stock of natural resources, and policy instruments which are particularly important for sustainability analysis. **Hayati, Ranjar, and Karami (2010)** defined a sustainable production system as that which achieves production combined with conservation of the resources on which that production depends, thereby permitting the maintenance of productivity. What is generally meant by productivity is the increase in output that cannot be attributed to corresponding increase in input use. In other words, it is the increase in output over and above the increase that can be achieved by an equivalent raise in the factor of production. This is often referred as total factor productivity (TFP), which is closely associated with innovation or technological change.

According to **Lynam and Herdt (1989),** sustainability can be measured by examining the trends in total factor productivity. For the past half-century, Africa's population has been growing at an annual rate of nearly 2.7 percent, and it is projected to increase another 1.3 times between 2010 and 2050 **(UN, 2010).** Thus, the challenge faced by decision makers in many nations in the continent is how to feed an increasing population without irreparably damaging the natural resource base on which agricultural production depends **(Ehui and Spencer, 1993).** The age-old farming system based on shifting cultivation practices made it possible for farmers to fell and burn the fallow vegetation to cultivate the cleared land (typically 1 to 3 years) and then abandon the site (from 4 to 20 years) to forest or bush cover. This production system was known to be stable and biologically efficient and operated effectively when there was sufficient land to allow a long fallow period to restore soil productivity **(Ehui and Spencer, 1993).**

Today, however, most of the best quality farmlands in Africa have already been used for agriculture, which means further area expansion would occur on marginal land that is unlikely to sustain high yields and is vulnerable to production systems' degradation **(Cassman, 1999). Young (1999)** maintains that marginal lands once used for grazing are being cultivated, the remaining grazing areas and woodlands are over-exploited, and this results in the degradation of the natural resource base. Thus, the agricultural production systems can no longer meet the demands of the present populations, let alone those of future generations. For agriculture to respond to this and future challenges, innovation will not only need to improve the efficiency with which inputs are turned into outputs, but also conserve scarce natural resources and reduce waste **(OECD, 2011).** This implies that agriculture's growth has to be productivity-led (as against being resource-led). If agricultural growth is primarily caused by greater exploitation of natural resources, the prospects of sustaining the growth over the long-run are limited. Yield growth resulting from incremental improvements to innovation can be sustained over the long run **(Byerlee and Murgai, 2001).**

The trends in levels of total factor productivity growth used as measures of sustainability of production systems do not reflect the degradation of the resource base. For the agricultural sector which utilizes natural resources, changes in the stock of these resources need to be accounted for in sustainability measures **(Ehui and Spencer, 1993).** In particular, Africa is characterised by resource-poor small agricultural systems across a range of agro-ecological zones. Farmers' agricultural practices may contribute to environmental degradation, as short-term survival considerations can lead them to pursue strategies that ensure short-run food supplies but degrade the environment and reduce longer run production potential e.g., resource-poor households being forced to cultivate marginal soils to meet their subsistence needs or to intensify cropping systems without the means to purchase the inputs necessary for soil fertility maintenance **(Young, 1999)**.

Also, African agricultural production is predominantly dependent upon rain-fed production systems. Water resource is transient both in space and time. This makes drought a recurrent feature in the continent's agricultural landscape. In fact, it is increasingly unusual for drought not to occur somewhere in Africa each year **(Sear, 1995).** Crop and livestock failures caused by unreliable rains and limited water are becoming the norm, leading to worsening food insecurity. Farmers' health and changes in average life expectancy associated with increasing imbalance between nutrient intake and nutrient needs for an active, healthy life make the availability of quality farm labour difficult and may be depressing agricultural productivity **(Rasul and Thapa 2003).**

Other constraints include government economic policies (such as structural adjustment) among others which may constitute shocks on agricultural production activities leading to an unsustainable production system **(Nin-Pratt and Yu (2012).** The paper examined changes in economic policies, farmers' health, and water scarcity that can either sustain and improve productivity over time, or degrade the natural resource base and therefore lower production potential over time. The production system level was defined in terms of a relatively homogeneous agro-ecological resource base, given that sustainability is likely to relate to underlying agro-ecological, resource quality characteristics of the farming or production system that leads to similar choices of crop and livestock outputs and inputs.

Previous studies on sustainability have been based on aggregation across heterogeneous regions **(Byerlee and Murgai, 2001; Barnes, 2002).** But **Rasul and Thapa (2003)** have noted that due to variation in biophysical and socioeconomic conditions, aggregation across heterogeneous regions may be fraught with problems as indicators used at the regional levels are not necessarily applicable to the other countries. Indicators should be location specific, constructed within the context of contemporary socioeconomic situation, since similar land management decisions are made for somewhat similar conditions. Also sustainability is a dynamic and a time-dependent entity because agricultural production systems are constantly changing due to changing demands of the population that develops these for meeting its needs.

To estimate a TFP trend with some degree of statistical confidence, a sufficient time period of analysis is required. According to **Hayati, Ranjar and Karami (2010),** the number of years required to estimate a statistically valid trend may be as high as 30 years in a variable rain-fed environment with a low growth rate in TFP. But some studies only covered the medium term, thus, presented the problem of not defining the necessary number of years to estimate TFP trends. Other studies **(Lynam and Herdt 1989; Tiongco and Dawe, 2000)** which observed the trends in levels of total factor productivity growth as measures of sustainability of production systems did not consider issues of degradation of the resource base.

The objective of this paper was to assess agricultural production systems from a sustainability perspective defined in terms of a relatively homogeneous agro-ecological resource base that leads to similar choices of crop and livestock activities and inputs. The agro-ecological zones of Africa selected included, Northern, Sudan-Sahelian, Eastern, Gulf of Guinea and Southern agro-ecological zones. This was pursued by employing a production function framework to estimate TFP trends for a sufficiently disaggregated panel data in the above five location-specific agro-ecological zones.

In order to allow for spatial and temporal variability inherent in agricultural production, a sufficient time period of 49 years was analysed. Given that government economic policy (such as structural adjustment), may cause production systems to be shifted out of the overall trajectory of system evolution, the time period was separated into different reform periods to examine whether production systems have been shifted out of trajectory of system evolution.

Since sustainability is likely to relate to resource quality characteristics of the production system; estimated productivity trends were related to changes in resource quality. This was done in order to determine whether there has been degradation of resource quality over time. By assessing Africa's agricultural production systems from a sustainability perspective, it may be possible to incorporate into the production system practices, technologies, etc., which will prevent adverse resource quality changes that threaten sustainability. In developing countries that face rapid population growth, optimizing productivity while conserving the natural resource base that support agricultural production is an essential requirement for farmers to increase global food supplies on a sustainable basis **(Batie, 1998).** In the light of food security crisis in Africa, the issue of maintenance of resource quality is clearly critical to agricultural development strategies and sustainability **(Byerlee and Murgai, 2001).**

The specific objectives were to: (i) to examine whether the productivity of production systems have been shifted out of trajectory of system evolution by the policy instrument (SAP) across the agro-ecological zones (ii) to determine whether there has been degradation of resource quality over time across the agro-ecological zones of Africa. To guide research, the following hypotheses were stated (i) the productivity of production systems have not been shifted out of the overall trajectory of system evolution by the policy instrument (SAP) across the agro-ecological zones (ii) there is no degradation of the resource quality base over time across the agro-ecological zones. The rest of the paper is organized as follows. The next section highlights the data and methods used. This is followed by the section that presents the results and discussion. The last section concludes.

DATA AND METHODS

Output and input quantities data

TFP measures the total conventional inputs used for producing economic outputs. A panel data on output and input quantities involved in African agricultural production were obtained from the United Nations (UN) Food and Agriculture Organization (FAO) between 1961 and 2009. The time period of 49 years was analysed so as to estimate a TFP trend with some degree of statistical confidence. It also provided a sufficient time period of analysis required to capture the effect of the Structural Adjustment Programmes (SAP) on agricultural total factor productivity before and after its implementation by most African countries.

The resource quality variables considered in this paper included; annual rainfall as proxy for land quality, average life expectancy as a proxy for labour quality. These were obtained from the National Centre for Atmospheric Research (NCAR) and the Word Bank Indicators published by the World Bank respectively. For sustainable agriculture, sustainable management of land is a major requirement, which is a function of quality farm labour. A summary of the sample data on the different variables in the production frontier function, expressed in natural logarithms (ln), and those of the resource quality model, used in this paper, is presented in Table 1.

Estimation method

The production function framework is a set of possible relationships between inputs and output at a particular technological level and can be used for the modelling and measuring total factor productivity **(Capalbo and Antle, 1988).** It describes the way factors of production are combined in order to produce the final output.

Generally, it is the combination of these three factors and the way in which they are organized and managed within the industry which determines the extent of productivity growth. The transcendental logarithmic function (translog) which is a flexible form of the production function has been employed to estimate total factor productivity (TFP) trend **(Christensen, Jorgensen and Lau 1973).** Following **Beatie and Taylor (1985)** this paper used the translog functional form to model productivity. The underlying stochastic production frontier function based on the generalized Cob-Douglas in this paper is given as (Eq. 1).

$$lnY_{it} = \alpha_0 + \sum_{k=1}^{5} \alpha_k lnX_{kit} + 0.5\sum_{k=1}^{5}\sum_{j=1}^{5} \alpha_{kj} lnX_{kit} lnX_{jit} + v_{it} - u_{it} \quad (1)$$

Where:
i represents an agro-ecological zone,
t represents the year of observation (1961 =1),
Y_{it} denotes the gross output at constant prices (million US $) in the i[th] zone in year t,
x_{kit} (A_{it} , $L_{it,}$ $T_{rit,}$ F_{it} , S_{it}) denote the land area (1,000 hectares), the total labour used (in thousands), the total agricultural tractors in use (numbers) the total quantity of fertilizer used (metric tons) and the total livestock (in 1000's) respectively.

Table 1 Summary Statistics for Variables in the Production Function and Resource Quality Model

Variable	Sample mean	Std. deviation	minimum	maximum
ln(output)	6.096	0.504	4.769	7.453
ln(land)	3.570	0.454	2.083	4.597
ln(labour)	3.393	0.479	1.964	4.253
ln(tractor)	3.453	1.040	0.301	5.244
ln (fertilizer)	4.197	1.074	1.322	6.262
ln (livestock)	6.145	0.510	4.888	7.463
Rainfall	877.677	500.861	48.2	3035.7
Life expectancy	51.068	8.755	32.453	74.546

Note: Output unit was expressed in Million USD (1999-2001) price. The conventional inputs were expressed as follow: land in 1000 hectares, labour in 1000 persons, tractor in pieces, and fertilizer in metric tons and livestock in 1000 heads. The variables in the resource quality model: annual rainfall and average life expectancy rate were in in millimetres (volume/area) and in percentages respectively.

The output production function can be expressed by Eq. 2, which could be viewed as a strongly separable-inputs translog production frontier function.

$$lnY_{it} = \alpha_0 + \alpha_h lnH_{it} + \alpha_l lnL_{it} + \alpha_k lnK_{it} + \alpha_f lnF_{it} + \alpha_s lnS_{it} + 0.5\alpha_n t^2 + \alpha_{ht}(lnH_{it}) + \alpha_l(lnL_{it}) + \alpha_k(lnK_{it}) + \alpha_f(lnF_{it}) + \alpha_s(lnS_{it}) + (V_{it} - U_{it}) \quad (2)$$

where,
Y_{it} the gross output at constant prices (million US $) in the i[th] zone in year t,
A_{it} hectares of the land area,
$L_{it,}$ the total labour used (persons),
K_{it} the total agricultural tractors in use (numbers),
F_{it} the total quantity of fertilizer used(tons),
S_{it} the total livestock (numbers) respectively,
$\alpha's$ parameters to be estimated,

V_{it} s are iid N$(0, \sigma_v^2,)$ white noise error terms that follow normal distribution,

$U_{it}s$ are non-negative error terms that capture technical inefficiency and follow a truncated normal distribution ($U_{it} \sim N^+(\mu, \sigma_\mu^2)$.

Both error terms are assumed to be independent and identically distributed. In addition, U_{it} is modelled under the assumption of time-varying technical inefficiency by employing the functional form proposed by Battese and Coelli (1992) $U_{it} = (\exp(\eta - (t - T)))_{\mu i}$

A simultaneous equations model was estimated to empirically investigate the effect of resource quality on TFP trends. The effects of resource quality are assumed to be defined by Equation (3)

$$U_{it} = \delta_0 + \delta_1 (RF_{it}) + \delta_2 (LIFE_{it}) + \delta_3 (Time) + W_{it} \quad (3)$$

Where:

RF_{it} the weighted annual rainfall for country i at time t,

$LIFE_{it}$ the life expectancy rate at birth in country i at time t,

$Time_{it}$ the time-varying resource quality effects,

W_{it} symmetric error term,

$\delta's$ the resource quality effects.

RESULTS AND DISCUSSION

TFP Trends Estimates within Agro-Ecological Zones

The total factor productivity (TFP) trends were estimated in terms of the production systems for each of the selected five agro-ecological zones of Africa. This was used as basis for tracking the sustainability of agricultural production systems. A sustainable system has a non-negative trend in total factor productivity over the period of concern. A non-negative TFP growth implies that output is increasing at least as fast as inputs. The results presented in Table 2 showed that the Northern and Southern agro-ecological zones experienced a better and positive TFP trends for the period of study than the Sudan-Sahelian, Eastern and Gulf of Guinea agro-ecological zones which experienced negative TFP trends.

For the Northern agro-ecological zone, it had 6.50% TFP growth for the entire period, 2.80% during the pre-SAP reform period and 15.40% during the post-SAP reform period respectively. The Southern agro-ecological zone had 4.10% TFP growth rate for the entire period, 7.50% during the pre- SAP reform period, and 3.40% during the post- SAP reform period. Despite these positive TFP trends, the other three agro-ecological zones of Sudan- Sahelian, Eastern and Gulf of Guinea experienced lags between the various time periods. While the reforms transformed the negative TFP growth rates in Gulf of Guinea from 1.10% to a non- negative trend of 4.10%. The study failed to find the same trends of TFP for the Sahelian – Sudan and Eastern agro- ecological zones, with the former having a negative trends of 7.90% and 1.80% for the pre-SAP and post- SAP periods respectively and the latter having negative trends of 0.10% and 2.80% for the same periods. These developments could be driven by the level of innovations and technological advances that generate changes and opportunities for improved TFP growth rates in the respective agro-ecological zones.

A direct comparison of TFP trends across the agro-ecological zones suggests that productivity lags could be associated with particular production systems and ecologies. The production systems of the Northern and Southern agro-ecological zones are shown to be sustainable as revealed by their non-negative trends of TFP trend. Production systems high in sustainability can be taken as those that aim to make the best use of natural resource base, while not degrading it.

The policy instrument (structural adjustment programme) may have shift farming or production systems out of the overall trajectory of system evolution in the three agro-ecological zones of Sudan-Sahelian, Eastern, and Gulf of Guinea as they showed negative TFP trends. This finding is corroborated by **Barnes (2002),** who observed that although, there has been a remarkable emergence of innovations and technological advances that are generating promising changes and opportunities for sustainable agriculture, these new agricultural technologies are hardly successful in Sub-Saharan Africa.

Table 2: Total Factor Productivity Trends within the Agro-Ecological Zones

AEZ	YEAR	TEC	TC	TFP
Northern	1961-2009	1.20	5.20	6.50
	1961-1985	2.40	0.40	2.80
	1986-2009	2.50	2.60	15.40
S/Sahelian	1961-2009	1.20	-2.50	-1.30
	1961-1985	2.20	-9.90	-7.90
	1986-2009	0.20	-2.00	-1.80
Eastern	1961-2009	1.10	-1.00	-0.10
	1961-1985	2.20	-2.10	-0.10
	1986-2009	2.30	-4.90	-2.80
G/Guinea	1961-2009	1.30	-0.20	-1.10
	1961-1985	2.50	-1.50	-1.00
	1986-2009	2.10	-3.10	-1.10
Southern	1961-2009	0.70	3.40	4.10
	1961-1985	1.50	5.90	7.50
	1986-2009	2.40	1.10	3.40
Africa	1961-2009	0.90	-1.70	-0.80
	1961-1985	0.20	3.20	3.40
	1986-2009	0.00	3.10	3.10

Note: Northern includes Algeria, Egypt, Libya, Morocco and Tunisia. Sudano- Sahelian: Burkina Faso, Cape Verde, Djibouti, Eritrea, The Gambia, Mali, Mauritania, Niger, Senegal, Somalia, and Sudan. Eastern: Burundi, Ethiopia, Kenya, Tanzania, Uganda, and Rwanda. Gulf of Guinea: Benin, Coted'Ivoire, Ghana, Guinea, Guinea Bissau, Liberia, Nigeria, Sierra- Leone, and Togo. Southern: Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe.

Relationships between Estimated TFP Trends and Changes in Resource Quality Variables

To investigate whether there has been a degradation of the quality of the natural resource base across the diverse agro-ecological zones; two quality resource variables were selected. The choice of amount of rainfall and life expectancy rates were for two reasons: African production system is rain-fed and drought is widespread, with direct impact on land quality. Life expectancy rates affect labour quality. TFP trends were related to changes in the selected resource quality variables over time. This was investigated for both the pre-SAP and post SAP reform periods.

The result of the model estimation for the pre-SAP period was presented in Table 3. The result showed that the land quality variable (proxied by annual rainfall) had positive and significant effects on productivity trend both in the Gulf of Guinea and Southern agro-ecological zones during the period. But it had negative effects on productivity trends in the Northern, Sudan-Sahelian and Eastern agro-ecological zones, suggesting that land quality was being degraded over time. It may be supposed that excessive rainfall which makes agricultural lands prone to losses over time could have caused the observed degradation.

Labour quality (proxied by life expectancy) showed a negative effect on productivity in all but one of the five agro-ecological zones during the pre-SAP period. This may not be unconnected with the suggestion that changes in average life expectancy that affect the availability of quality farm labour may depress agricultural productivity. Also the aged are known to be risk- averse to the introduction to changes, including various kinds of innovations, which does not favour productivity improvement. The effect of time on total factor productivity trend was significantly negative in three out of the five agro-ecological zones, implying a degradation of resource quality over time during the pre-SAP reform period.

Meanwhile Table 4 depicting the post-SAP reform period show that land quality had a positive significant effects on productivity trends in the three agro-ecological zones of Northern, Gulf of Guinea and Southern. That is, agro-ecological zones with higher levels of rainfall achieved higher levels of productivity growth. But land quality had negative significant effects on productivity in the Sudano-Sahelian and Eastern agro-ecological zones, probably due to the incessant droughts in the two agro-ecological zones.

Labour quality had significant negative effects on productivity growth in the three agro-ecological zones of Northern, Gulf of Guinea and Southern. This may possibly be due to nutritional and health status of farm labour. Ill- health in a farming community can reduce agricultural productivity and the ability to deploy appropriate technology. This result agrees with the findings of **Rasul and Thapa (2003)** who observed that when people are healthier, they are likely to have a higher quality of labour inputs and increased productivity. Unlike in the pre-SAP reform, period, time variable was positive and significant in its effects on productivity trends in three of the five agro- ecological zones, implying that resource quality was positively maintained over time during the post reform period.

CONCLUSION

Agricultural production systems level within agro-ecological zones are likely to be similar in relevant factors, such as, the types of new technologies that are available, the stock of natural resources, and policy instruments which are particularly important for sustainability analysis.

Table 3 Parameter Estimates of the Model for the Pre-Sap Period.

Variable	Para.	North	Sudano	Eastern	Gulf	South
Constant	δ_0	13.914	2.687	2.561	0.330	-11.059
		(7.15)	(4.38)	(4.89)	(1.14)	(-7.83)
Rainfall	δ_1	-3.725	-0.345	-0.325	0.236	1.129
		(-0.86)	(-7.01)***	(-4.08)***	(3.75)***	(7.83)***
Life expectancy	δ_2	-7.381	-0.863	-0.906	-0.841	4.821
		(-6.86)***	(-3.15)***	(-2.73)***	(-11.61)***	(14.16)***
Time	δ_3	-0.148	-0.109	0.335	0.359	-0.197
		(-2.39) ***	(-10.61)***	(3.97)***	(6.44)***	(-1.67)*

*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Table 4 Parameter Estimates of the Model for the Post SAP Period.

Variable	Parameter	North	Sudano	Eastern	Gulf	Southern
Constant	δ_0	3.193	-0.722	-1.043	0.371	3.009
		(1.329)	(-0.938)	(1.174)	(0.363)	(2.859)
Rainfall	δ_1	0.419	-1.341	-0.552	1.094	0.890
		(2.57)***	(-3.86)***	(-5.28)***	(5.82)***	(4.25)***
Life Expectancy	δ_2	-2.618	0.127	-0.295	-3.331	-3.772
		(-1.51)*	(0.16)	(-0.70)	(-6.84)***	(6.17)***
Time	δ_3	0.414	2.002	2.063	1.299	0.511
		(1.12)	(3.67)***	(6.76)***	(7.63)***	(0.98)

*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level

Using the framework of a production function, this paper assessed the sustainability of agricultural production systems from a sustainability perspective, defined in terms of relatively homogenous agro-ecological zones, namely, Northern, Sudan-Sahelian, Eastern, Gulf of Guinea and Southern agro-ecological zones of Africa. To estimate a TFP trend with some degree of statistical confidence, a sufficient time period of 49 years was analysed with data drawn from FAOSTAT. Additional data on rainfall and life expectancy were obtained from National Centre from Atmospheric Research and World Bank Indicators respectively. The data was separated into three sub periods, namely: entire period (1961-2009), the pre-Structural Adjustment Period (SAP) reform period (1961-1985) and the post SAP reform period (1986-2009).

This was necessary because farm systems may be shifted out of the overall trajectory of system evolution by shocks e.g. policy (such as structural adjustment) among others. In order to examine whether the natural resource base has been degraded over time, TFP trends were related to changes in resource quality variables. The results show that the Northern and Southern agro-ecological zones had non-negative trends in TFP, indicating sustainability of production systems. The policy instrument (structural adjustment programme) may have shifted farming or production systems out of the overall trajectory of system evolution in the three agro-ecological zones of Sudan-Sahelian, Eastern, and Gulf of Guinea. A degradation of resource quality over time was noted during the pre-SAP reform period, but was maintained during the post-SAP period. In the light of food security crisis in Africa, the issue of maintenance of resource quality is clearly critical to agricultural development strategies and sustainability (**Byerlee and Murgai, 2001**). This calls for policy options that follow specific locations experiences over the longer-term period to arrest the degradation of resources in the identified locations.

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