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Irrigation Externalities and Agricultural Sustainability: Implications for Food Security in Developing Countries

by

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ABSTRACT

In this paper, we examine the relative sustainability of arable agriculture in irrigated and rain-fed farms in south eastern Nigeria. As agricultural intensification made possible by irrigation is increasingly regarded as the password to solving the growing food security problems in developing countries, traditional (less intensive) rain-fed agriculture is increasingly seen as inimical to food security and international competitiveness in agrarian economies. Mounting empirical evidence in the literature suggest that irrigation externalities are often significantly high to extents that preclude long-term sustainability of agriculture on irrigated land. Characterising the agro-ecosystem as a factor input we examine the implications of irrigation intensification for agricultural sustainability using adjacent rain-fed farms as the counterfactual. We examine the trade-offs in the switch from less intensive farming systems to the intensive irrigation in terms of differentials in marginal returns to factor inputs and yield stability over time. The analyses found mixed results indicating the dilemma that irrigation presents to sustainable agricultural policy and food security in developing countries. While extended duration of land use (i.e. double cropping) increased the annual crop yield per land area cropped, there was no significant differences in marginal productivities of factors between the irrigated and rain-fed farms in the river basin. The fitted production functions for the irrigated and rain-fed farms were coincident. The production elasticity of land was negative and declining (in the irrigated farms) while those of anthropogenic inputs (labour and capital) were positive and increasing. The annual yields recorded in the irrigated farms (1984-98) were also less stable relative to those of their rain-fed counterparts within the same period. The contribution of irrigation to total crop yield per land area in the river basin peaked in the early 1990s and declined progressively afterwards. Conversely, biophysical analyses of local environmental conditions found that the impacts of irrigated on agricultural production support systems were significantly high and often irreversible, thus precluding its long-term sustainability. About 9% of the irrigated land in the study area was irreversibly degraded. In summary, while the overall short term food security implications of the productivity gains of double cropping are uncertain, the prognosis for long-term sustainability of agricultural production in irrigated farms is bleak. We conclude that surface irrigation is not a panacea for sustainable food production in the sub-region. Instead, it increases the rate of resource flows through the exploited ecosystem, thus asset-stripping natural capital of productive energy, while appearing to increase short-term crop productivity. Since, the marginal physical product of land was negative and declining while those of anthropogenic inputs (i.e. labour and capital) were positive and increasing (and not significantly different in both systems), we recommend that focusing agricultural policies on measures to improve farmer's labour productivity and access to improved farm inputs should be given the priority in the study area and perhaps elsewhere, not irrigation.

INTRODUCTION

Irrigated agriculture is a major human use of land and water resources. About 70% of the water drawn from rivers, lakes and aquifers is used in agricultural production (FAO, 2000a, Shortle and Griffin, 2001). By 1900, there were about 40 million hectares of irrigated fields (Field 1990) but by 1998, this had increased to more than 271 million hectares, with much of the increase occurring after the 1950s (FAO 2000b).

The primary reason for this phenomenal growth in irrigated agriculture has been its perceived impact on crop productivity. Constituting only about 17% of global cropland, irrigated agriculture produced approximately 40% of the world's food in 1997 (FAO, 1997). However, mounting empirical evidence in the literature suggest that land-use intensification (e.g. double cropping) made possible by irrigation has had deleterious environmental consequences that ceteris paribus preclude its sustainability (see for example: Joshi and Dayanatha, 1990; WHO, 1990; Hren and Herman 1998, and Shortle and Griffin, 2001, and Urama 2003) to mention just a few. Hence, scientists and environmental groups in developed countries are increasingly calling for the transfer of irrigated land and water resources to other sustainable uses (USDI, 2000). Yet, rapid population growth coupled with the continuing decline in per capita agricultural productivity in sub-Saharan Africa has led to a renewed call for more irrigation development in the sub-region (Oldeman, 1998; and FAO, 1997 and 2001)[1].

Specifically, governments and policy makers in sub-Saharan Africa have continued to support transfer of prime agricultural land from less intensive rain-fed traditional cropping systems to intensive irrigation systems. Such decisions have been driven by two popular assumptions:

I. That irrigation increases total crop output per hectare via double cropping (i.e. more food from the same piece of land per annum). In other words, irrigation is perceived to have a *spatial advantage* over the rain-fed cropping systems by enabling the growth of crops on the same piece of

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[1] While the aggregate global food supply/demand picture is relatively good, FAO, (1997) predicted that there will be a worsening in food security problems in sub-Saharan Africa.

land twice each year. This is expected to double the amount of food produced from each plot of land each year.

That irrigation improves marginal productivity of factor inputs (i.e. more food per unit input per hectare per season). In other words, irrigation would have a temporal advantage over the rain-fed cropping system by increasing the returns per unit of input used per cropping season. In this way, irrigation would not only double crop yield per land area cropped per annum, but also reduce the amount of farm inputs required[2].

These perceived temporal and spatial advantages of irrigation over the traditional rain-fed cropping system are considered as the sine qua non for increasing and sustaining crop yield to abate the food security problems in the sub-region.

Previous economic analysis of irrigation in south eastern Nigeria has focused on the total productivity gains from irrigated farms due to the opportunity to grow crops during the dry season, ignoring its environmental externalities that may preclude its sustainability (see: Okereke 1991, Asadu et al, 1996). The opportunity cost of alternative use of resources (i.e. land and water resources, labour and capital assets) during the dry season under the less intensive rain-fed cropping systems are also not factored into the analyses.

In this paper, we examine the relative sustainability of crop production in the irrigated and rain-fed farms in Anambra Imo river basin of south eastern Nigeria from both temporal and spatial perspectives (see Table 1)[3]. To account for the duration of resource use, we distinguish between the ‘seasonal’ and ‘annual’ yield gains per hectare in the irrigated and rain-fed farms and examine the marginal productivity of factors in both systems as well as the trends in yield/ha/cropping season over time. To account for the spatial advantage of irrigation, we also compare the yield trends in

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[2] This second objective is considered crucial to enhancing food security among farmers in developing countries where access to farm inputs is limited and more constraining than availability of arable land.

[3] See Appendix 1 for details on the comparative analysis framework applied in the study. In this way we compare crop yield between the irrigated and rain-fed farms by duration of land use (i.e. temporal scale) and by physical land area cropped (i.e. spatial scale). Using yields in the rain-fed farms as the benchmark we compute changes in yield/ha per cropping season as the temporal contribution of irrigation to the food need of the region, and total changes per calendar year as its spatial contribution.

the rain-fed farms with the sum of the yields from the rainy and dry season irrigated farms.

Table 1: The Comparative Analysis Framework

	Rain-fed farms	**Irrigated farms**		
	(Single crop)	Full irrigation (dry season) crop (Single crop)	Supplementary irrigation (rainy season crop) (Single crop)	Dry + Rainy season crops
Temporal scale	(6 months)	(6 months)	(6 months)	(12 months)
Spatial scale	(1 hectare)	(1 hectare)	(1 hectare)	(1 hectare)
	Control	Treatment (i)		
	Control		Treatment (ii)	
	Control			AT1

Key: Control = Benchmark crop yield; Treatment (i – ii) = irrigated cropping systems whose impacts are being examined within cropping seasons, AT1 = Annual irrigation treatment defined as the sum of the rainy and dry season crops (i.e. ignoring the duration of land use).

Specifically, the comparative analyses are presented in the following temporal scales. First, we compare the rain-fed crop data with the full irrigation (dry season) crop data, then with the supplementary irrigation (rainy season) crop data and finally with the sum of the rainy season and dry season irrigated crop data, respectively.

In general we examined the differences in marginal productivities of factors, the differences in means, and the relative stability of yield trends over time (1984-98) between the irrigated and rain-fed rice farms in the river basin. Based on findings, we draw conclusions regarding the sustainability of irrigated farming in the study area using the rain-fed farms as a benchmark. Following Rees (1996); Reardon, et al., (1999), and Barrett et al., (2002), we argue that the observed increase in total output per land area cropped per annum (made possible by intensified land use i.e. double cropping) is unsustainable. Unlike the less intensive traditional rain-fed cropping systems, land-use intensification in the irrigated farms lead to significant degradation of the environmental source and sink functions on which sustainable productivity depends.

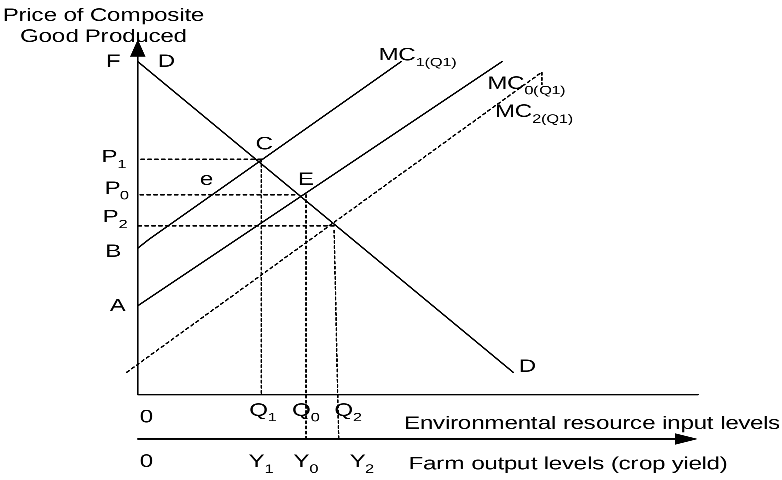
The paper is presented in the following sequence. First we discuss the counterfactual framework, research design and data sources. Second, we present the empirical results regarding the impacts of irrigation on factor productivity, on total output/ha farm and on gross margins. Finally we draw implications for the sustainability of arable agriculture in the sub-region based on findings. Following Martinez-Alier, (1987), we argue that the (perceived) increase in productivity of modern agriculture (in this case, irrigation) depends on the underestimation of energetic inputs it requires and the low value given to its environmental externalities.

CONCEPTUAL FRAMEWORK

The central idea of this study is that the farm (production unit), farm household (consumption unit) and the environment are in a dynamic web of interrelationships that are not mutually exclusive (see: Common 1996, p.14; Pearce and Turner 1990, p. 30; Pearce and Warford 1993, p.190; and Hanley et al., 1997, p.3). In subsistence economies, crop production is heavily dependent on natural capital (e.g. soil and water quality), partly because farmers lack access to artificial fertilisers or because they lack the resources to buy them. Hence, ecosystem degradation often translates directly into food insecurity through reduced factor productivity and hence farm output.

In this paper, we characterise the agro-ecosystem as a farm production factor and model the welfare impacts of its degradation in a counterfactual framework. An increase in the environmental quality variable 'Q' (e.g. soil fertility) is assumed to increase attainable output given any vector of anthropogenic variable inputs (X1 + X2 +, …, + Xn). For single product farms, deterioration in environmental quality would either increase factor prices, or reduce farm gross margins attainable from a given set of anthropogenic inputs. In other words, a change in environmental quality reflects in the value of the marginal physical product (and cost) of factors derived from relevant production (and cost) functions. For instance, the number (and quality) of wetland acres available as a habitat for fish influence the unit cost of harvesting commercially valuable fish (Ellis and Fisher 1987, p.149). Likewise, irrigation induced changes in soil and water quality affects crop growth, productivity of factors, production costs and, hence the welfare of farmers. These changes can be represented as parametric shifts in the marginal costs of production, due to changes in the supply of the environmental resource input (i.e. the supply of water and soil nutrients) along the given demand curve “DD” (see Figure 1).

Figure 1: Deriving Changes in Welfare from Environmental Input Costs



The basic assumption here is that there is proportional dose-response relationship between environmental resource inputs (soil and water quality) and marginal productivities of other anthropogenic factors (Faucheux et al., 1996, p.346). Changes in environmental quality are therefore shown as shifts in the marginal costs of production along a farmer’s environmental resource demand curve DD from MC0 at Q0 to MC1 at Q1 (in the case of a degradation in environmental quality), and to MC2 at Q2 (in the case of an improvement). In the case of degradation, the consumers are invariably worse off, but the net social welfare effect of degradation (dSW) is the sum of its effects on the consumers and producers in the society:

$$dSW = \{(AEP_0 - BCP_1) + P_0ECP_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

If the product market is competitive (such as in agricultural product markets), the net welfare effects of marginal changes in environmental resource input(s) can therefore be measured directly in terms of the corresponding marginal input costs and marginal physical output changes, holding other farm factors constant.

For computational simplicity, we estimate the aggregate welfare change (dSWQ) due to the effects of irrigation on environmental quality, say from Q0 – Q1, by comparing the production and cost functions of irrigated and rain-fed farms in the project area (Urama 2003, p.100).

Methodological Framework

We compared the marginal productivity of factors between the fully irrigated (treatment) and rain-fed (control) farms in the study area using the Cobb Douglas production function. The difference in marginal productivity of factors between the two crops was regarded as the “within season” (temporal) effect of irrigation. The goal was to establish the counterfactual while controlling for the potential effects of other general changes such as in climate or ecology[4].

The stochastic form of the Cobb Douglas production function employed is as specified below:

$$Y = AX1\beta1X2\beta2X3\beta3e\mu i........................(2.1)$$

Where:

Y = Rice output (000’kg/ha/cropping season),

A = Scale factor (level of technology),

X_1 = Amount of farm labour (000’₦/ha/cropping season) measured as the value of the number of man-days employed per hectare per cropping season,

X_2 = Cost of irrigation facility (land and water charges (‘000₦/ha/cropping season),

X_3 = Variable capital costs (machinery hiring costs, fertilizers, herbicides, and insecticides, etc.) used ('000₦/ha/cropping season),

μ = Stochastic error term, which takes account of unexplained factors affecting rice production in both systems,

e = Base of natural logarithm.

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[4] In assessing the effects of irrigation schemes, the likely consequences of not building them should also be considered. The 'without project' scenario, contains its own possible environmental effects (Winpenny, 1991, p. 26).

The exponents, $\beta1...\beta3$, represent the relative proportion of rice output contributed by the various inputs X1 through X3 defined above and indicate the elasticity of output with respect to changes in the input variables X1 through X3.

Justification for the Choice of Model

The Cobb-Douglas Production function provided basis for estimating a multiple-log linear model, in which the parameter estimates of the explanatory variables were their partial production elasticity coefficients, holding other variables constant (Gujarati 1995, p. 247, Kidsom 2003, p. 4). Thus, it enabled us to compare the impact of irrigation on partial productivity of factors with those of rain-fed farms in the study area. By introducing the additive and multiplicative forms of a dummy variable (D = 1, if irrigated; and D = 0 if rain-fed), the differential intercept and the differential slope coefficients of a pooled production function were estimated[5].

The explicit functional form of the base model estimated is specified below:

$$\ln Y = \beta0 + \beta1\ln X1 + \beta2\ln X2 + \beta3\ln X3 + \beta4D + \beta5\ln X1D + \beta6\ln X2\,D + \beta7\ln X3\,D + \mu \qquad (2.2)$$

The differential intercept coefficient ($\beta4$) shows the percentage change in farm output in the study area, due to irrigation[6], while the differential slope coefficients ($\beta5$, $\beta6$ and, $\beta7$) show by how much the partial elasticity of output with respect to labour costs X1, land/water charges X2, and other variable costs X3 in the irrigated farms differ from those of the rain-fed farms respectively.

From the estimated model, significance of the effects of irrigation on crop productivity as well as its impacts on partial productivity of factors were tested in terms of standard t-tests while the general significance of the model was tested in terms of F-tests, all at 5% level.

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[5] By convention, the coefficient of the dummy variable '$\beta4$' tells by how much the value of the intercept term of the category that receives the value 1 differs from the intercept coefficient of the base category, while the differential slope coefficients ($\beta5$, $\beta6$, …, βn) show the differentials in the partial elasticities of output with respect factors (X1,…,n) (Gujarati, 1995).

[6] The partial differentials of output variable 'Y' with respect to the labour variable 'X1' = $(\partial Y/\partial X1)(X1/Y) = \beta1$ which by definition, is the elasticity of Y with respect to X1, etc.

This approach also has a number of advantages: First, the individual production functions for the irrigated and the rain-fed farms can be deduced from the model. By assuming that $E(\mu) = 0$, the production function for the irrigated and the rain-fed farms were given by equations 2.2.1 and 2.2.2 respectively and the responses of output with respect to specific production factors were easily examined.

$$E(Yi\backslash Di =1, XI) = (\beta0 + \beta4) + (\beta1 + \beta5)\ln X1 + (\beta2 + \beta6)\ln X2 + (\beta3 + \beta7)\ln X3 \quad (2.2.1)$$

$$E(Yi\backslash Di = 0, XI) = \beta0 + \beta1\ln X1 + \beta2\ln X2 + \beta3\ln X3 \quad (2.2.2)$$

Second, it enabled us to test the main hypothesis specified for the study: the statistical significance of the difference in partial productivity of factors; and on the overall production functions. The Chow test would for instance test for statistical difference in the irrigated and the rain-fed production functions, if estimated separately, but would not indicate the source(s) of the difference. The advantage of this approach therefore lies in the ability not only to test for statistical difference in crop productivity between the irrigated and rain-fed farms studied, but also test for the source(s) of the difference. The knowledge of the source(s) of difference in productivity was central to the present analysis[7]. Furthermore, since the multiplicative form of the dummy variable technically increased the degrees of freedom of the production function (relative to individual models for each system), it was also expected to improve the precision of the parameter estimates (see Gujarati, 1999).

Despite the restricted econometric model assumed in the Cobb Douglas production function (Kidsom 2003, p. 14), this approach utilizes the basic framework that has been applied in similar studies (Okereke 1991) and provides a basis for comparability of empirical results. Due to its simplicity and convenience, the Cobb Douglas production function has been widely used in agricultural economic research (Molar, 1965: Luck and Martin, 1988: Marcours and Swinnen 1997; and Smale *et al.*, 1998)[8].

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[7] The difference in (partial) productivities of inputs between the two systems computed from the production functions are regarded as the differential effect of the irrigation project on factor productivity in the study area.

[8] Molnar, (1965); Bennet and Murray, (1991); and Luck and Martin, (1988) for instance have used a similar technique to measure cost of land degradation in Victoria, the benefits of lower noise levels in factories, and the cost of road congestion respectively.

Data Sources

Two main data types were applied in the analyses: cross sectional data generated from a farm survey conducted in Anambra Imo river basin of south-eastern Nigeria in the 1999/2000 crop year, and time series data collated from secondary sources.

The survey questionnaire was duly pre-tested on a randomly selected sample of 20 respondents, (11 irrigation farm owners and 9 rain-fed farm owners) in June 1998. This was subsequently followed up by a pilot survey of 80 farmers (40 from each group) exploring the potentials and limitations of the study. The results of the pre-test and pilot study (see Urama, 1999) informed the re-designing of the survey questionnaire, the survey coverage and timing, and questionnaire administration techniques adopted.

Primary data were collected by personal interviews, on-the-spot field observations and field measurements. Specifically, data on crop output for the 1999/2000 crop year were collected through field measurement using the Crop Cutting Technique[9].

Based on empirical evidence provided by Sukhatme (1954) and subsequent recommendations by FAO (1982), a 5m2 subplot was chosen due to the observed homogeneity in cropping density across the farms sampled[10]. The harvested crop was then weighed in kilogrammes and scaled up to standard measurements (metric tones/hectare).

Historical crop output data (from 1984-1998) were collected from the annual reports and official publications of the Anambra-Imo River Basin Development Authority (AIRBDA) and relevant databases held in the University of Nigeria Nsukka.

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[9] Measurement of crop output in developing countries is the subject of a number of guides and manuals (FAO 1982, Poate and Casely, 1985, Poate 1988 and Poate and Daplyn, 1993), ranging from farmer estimates of output, whole plot harvest, sampling harvest units, crop cutting, and marketing records, but the CCT was considered most appropriate in the current case study (see Poate and Daplyn 1993, p. 110 for our rationale for choosing the CCT). Crop cutting involved the measurement of output from one or more Yield Subplots (YSP) laid in the farm plot under study (see: Poate and Daplyn 1993, p. 102 for details).

[10] Two random numbers were selected from the random number table, such that they lay between zero and half the perimeter distance around each sampled farm. The first number prescribed the distance around the perimeter from a starting point A. The second number chosen, prescribed the distance into the farm from the entry point to the centre of where the subplot was laid. Each plot was entered at right angles to the perimeter at the entry point. In cases where the YSP location

Population for the Study

The population for the study comprised all rice farmers in the selected project areas, stratified into two groups in order to establish the counterfactual:

Rice farmers who have participated in the selected irrigation projects continuously (using the same plots) for over ten years (from 1986-1999);

Adjacent farmers who have grown rice on rain-fed conditions continuously (using the same plots) within the same period.

Samples for the Study

Sample selection was done in two stages. Firstly, a census survey of the selected project area was carried out in 1998 to identify and list the two groups of farmers specified above. These lists comprising 367 farmers in category (i) and 312 farmers in category (ii) respectively served as the sampling frame. Secondly, equal ratios of farmers in each group (30%) were selected using a Simple Random Sampling (SRS) technique. The numbers of farms and farmers sampled in each project area are therefore specified through the Probability Proportional to Size (PPS) sampling technique. This was necessary to make the data self-weighted in order to enhance comparison (see Poate and Daplyn, 1993, p.62)[11]. This gave a total of 110 irrigated farms and 93 non-irrigated farms and their farm owners respectively.

The sampling percentage of 30% (of each group) was chosen because of the intensity of survey and resource constraints. The pilot survey indicated that respondents were relatively homogenous and intensive survey of a randomly selected sample can produce unbiased results (see: Urama, 1999).

DESCRIPTION OF THE CASE STUDY AREA

The Lower Anambra Irrigation Project (LAIP) covering a net area of about 3,850 hectares (original area: 5,000 hectares) located in the southern corner of the Do-

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point was close to the farm boundary such that part of the YSP fell outside the farm plot, the YSP was shifted forward, backwards or sideways until it was fully inside the farm plot.

[11] This ensures equal representation of both systems relative to population size, thus eliminating probabilities of sample size effects on data analysis eliminating probabilities of sample size effects on data analysis.

Anambra river basin on the western border of former Anambra state (see Appendix 2), was purposively selected for the case study.

The choice of Lower Anambra river basin for the case study was informed by a number of factors. First, the presence of irrigated and adjacent rain-fed rice farms in the river basin provided effective treatment and control groups in the same ecosystem. Second, the local farmers that participated in the irrigation projects retained some adjacent plots for rain-fed rice production using the same crop varieties. The local farmers pay an annual subscription fee for allocated plots in the irrigation project area each crop year.

The RBDA does not engage in direct rice production, but in addition to allocating land to subscribing farmers, provided irrigation water and helped the farmers to access machinery, fertilisers, herbicides, and necessary advice on improved crop management practices[12]. It was therefore possible to identify treatment and control farms that share similar soils, management and ecology in the river basin. Also, paired production of rice in irrigated and rain-fed cropping systems has been going on in the river basin since 1984. This relatively long duration of irrigated and adjacent rain-fed rice production in both sites (>15 years) was also expected to have affected productivity as well as soil and water quality in the study area.

Meteorology and Hydrology in the Project Area

The location has two distinct seasons: the rainy season lasting for about 7-8 months of the year (from April/May to October/November) and the dry season lasting for about 4 -5 months of the year (from October/November to March/May).

The mean annual rainfall is approximately 1,730mm and is bi-modally distributed with peaks in July and September. The mean annual maximum and minimum temperatures are about 38°C and 22°C respectively. The Do-Anambra river on the western border of Anambra state, and Obina river in northern border of Enugu state are the major sources of irrigation water for the two project sites at Omor (Anambra state) and Adani (Enugu state) respectively.

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[12] Most of the farmers in the area had no access to fertilisers and other production boosting inputs prior to the irrigation introduction in the area. A major role of the project is sourcing of improved

Soils and Pedology

The entire landform in the project area is generally undulating and underlain by the Imo clay shales of the tertiary period (Asadu et al., 1996, p. 4). The residuum of this shale formation is the parent material of the soils. The soils in the area are therefore remarkably homogeneous. They generally have deep solum depth (≥ 1 meter), medium to fine texture commonly classified as clay loam to silty clay, medium to low permeability, massive granular structure, are slightly sticky and plastic in consistency, and have medium to high in water retention capacity, which is about 30 to 40% by volume.

Cropping Patterns, Farm Operations and Farm Structures in the Project Area

Traditionally, crops were grown only during the rainy season and the soil is left to recover over the dry season. Only skeletal farming activities went on during the dry season normally comprising clearing of new farm sites, manuring of existing farms using crop residues, forest leaves and different types of compost/animal manure. Livestock were allowed to graze on harvested crop fields and in that process manure the farms with their droppings. This traditional farming system is often refereed to as ‘rain-fed farming’. Irrigation intensified arable cropping in the river basin by enhancing the growing of crops during the dry season. This act of growing two crops per calendar year is referred to as 'double cropping' involving supplementary irrigation during the rainy season and full irrigation during the dry season (see Appendix 3)[13].

The rainy season was popularly referred to as the 'cropping season' until dry season cropping became popular in the study area due to irrigation. The duration of each cropping season is hereafter referred to as 'crop year'.

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agricultural inputs for participant farmers. Because the participant farmers keep both irrigated and rain-fed farms, these inputs are shared between the two systems.

[13] The implicit assumption behind this practice was that water supply was the only limiting factor to growing crops during the dry season.

RESULTS AND DISCUSSION

Summary Statistics of the Survey Data

In this sub-section, we describe the general descriptive statistics of the survey data including the gross margin budgets for the dry season irrigated farms and the rain-fed farms based on the cross sectional data for 1999/2000 cropping season. The aim is to provide background information relevant to the production function analysis. Details on the demographic characteristics of the farmers and the gross margin budgets for the irrigated and the rain-fed farms sampled are presented in Appendix 4 and 5 respectively.

Both groups of farmers were mostly middle aged (about 47 years on average) with 77.3% between 40 and 60 years of age; had only primary education (less than 7 years of formal education) with 89.1% below secondary education; and held between 0.5 and 3 hectares of rice field in the river basin. Over 67.3% held either 1 or 2 plots (0.5 or 1.00 hectare only) in the irrigation project area. On average, they were all experienced rice farmers (i.e. have spent between 10 – 25 years as a rice farmer in the project area). About 66.4% of the sample were married and about 80% earned an annual gross income below N100,000.00 (US $743.34). Farming was the primary source of livelihood among the respondents.

The main difference observed between the irrigated and rain-fed farms relate to the farm inputs and cultural practices. The mean cost of inputs/ha in the rain-fed farms was N43,602.54 (N1,519.25 for land charges; N20,982.17 for labour costs; and N21,101.12 for other variable costs) while that of the irrigated farms was N53,587.11 (N 2,097.00 for land and water charges; N22,670.63 for labour costs; and N28,819.48 for other variable costs) for the dry season crop. On the other hand, the mean value of rice output (and gross margins) per hectare recorded in the rain-fed and dry season irrigated farms were N53,708.20 (and N10,105.66) and N 67,678.76 (and N14,091.65), respectively. The gross margins for the irrigated and dry season rain-fed farms for the 1999/2000 crop year were not significantly different at 5% level (P = 0.0000).

The Results of the Production Function

A pooled regression function of the form specified in equation 2.2 above was estimated for the irrigated and rain-fed farms studied and relevant null hypotheses were tested in terms on t-tests and F-tests respectively. The estimated model is summarised in Table 2.

Table 2: The Estimated Production Function

Variables in natural logarithms	Symbol	Estimated Coefficients ($\beta 1 \ldots \beta 7$)	t-statistics	P >¦t¦	[95% Confidence Interval]	
Constant	($\beta 0$)	8.5130 (3.4494)*	2.47	0.0140	1.7102	15.3159
Labour costs	X1	0.4996 (0.0967)**	5.17	0.0000	0.3089	0.6903
Land and water charges	X2	-0.9246 (0.4765)*	-1.94	0.0540	-1.8644	0.0151
Other variable inputs	X3	0.4196 (0.0845) **	4.96	0.0000	0.2529	0.5863
Dummy variable (1= irrigated; 0 = Rain-fed)	D	-5.2562 (3.7326)	-1.41	0.1600	-12.6265	2.0962
Labour dummy	X1D	-0.1875 (0.1346)	-1.39	0.1650	-0.4530	0.0779
Land/water dummy	X2D	0.9556 (0.5102)	1.87	0.0630	-0.0506	1.9618
Other variable costs dummy	X3D	0.0384 (0.0991)	0.39	0.6980	-0.1570	0.2339
Number of Observations	203					
F(7,195)	69.11**					
Adjusted R2	0.7024					

* = Significant at 5 percent level; ** = Significant at 1 percent level, ( ) = Standard error.

Overall, the estimated production function is statistically significant at 1% (F7, 195 = 69.1100, P = 0.0000)[14]. The estimated R2 of 0.7127 indicates that about 71% of the

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[14] By convention, one could infer that since the computed F value is highly significant, the probability of committing type 1 error (i.e. , the level of significance) is very low- 1 in 100.

variation in output is statistically explained by the explanatory factors in the model. There was no evidence of multi-collinearity or hetroschedasticity in the model.

The analysis find that the partial regression coefficients for the individual production factors (βI) and (β3) for labour input (X1) and other variable inputs (X3), respectively, were significant at 1% level while that of land/water charges (X2) was significant at 5%. The overall significance of all the explanatory variables is consistent with apriori expectations and with findings elsewhere (see: Olayide and Heady, 1982; Okereke, 1991; Urama, 1999 and 2003). A Cobb Douglas production function estimated for the irrigated farms in the river basin only, found similar results with R2 = 0.88; (see Okereke, 1991, p. 294). As shown in the model, the differential intercept coefficient (β4) is not significant at 5% level (P>|t| = 0.1600). Similarly, the differential slope coefficients (β5, β6 and, β7) with respect to the individual factors of production specified (X1, X2, and X3), respectively were also not statistically significant (P>|t| = 0.1650, 0.0630 and 0.6980 respectively).

In summary, the analyses find that the two production functions are not significantly different[15]. In statistical terms, they are coincident. However, the marginal productivity of labour and variable costs were higher than that of land/water charges.

We therefore conclude that there was no significant difference in factor productivity per hectare per cropping season between the dry-season irrigated crop and rain-fed crop in the study area for the 1999/2000 crop year only. Because the production function analysis was based on cross-sectional data collected from one cropping season only (i.e. the fully irrigated dry season crop and the rain-fed crop only), we do not draw conclusions regarding the total productivity gains from irrigation (i.e. its spatial advantage over rain-fed systems) from the current analysis[16]. Instead, we conclude that the LAIP had no temporal advantage over the rain-fed cropping system in the river basin for the 1999/2000 crop year.

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[15] The same conclusions were reached by using the Chow test multi-step procedure (See Gujarati, 1995).

[16] The current analysis relates only to the impact of irrigation on marginal productivity of factors within cropping seasons. However, the fact that the dry season irrigated crop performed as well as the rain-fed crop strongly suggests that the LAIP did provide favourable conditions for crop production during the dry season in the river basin. This should, ceteris paribus, double the total annual crop harvests per land area cropped in the irrigated farms.

Discussion of Results and Policy Implications of Findings

These findings have mixed (and complex) policy implications. First, consistent with earlier studies in the river basin, the matched performance of the dry-season irrigated farms and the rain-fed farms (implied by the coincident production functions) suggest that the LAIP offered farmers the opportunity to double the amount of crops produced per land area per annum by growing crops during the dry season (see: Okereke, 1991, Asadu et al., 1996). This may have apparent short term implications for food security in the sub-region. However, the full welfare impacts of the LAIP may not be simply defined by the total yield gains made possible by double cropping only. The opportunity cost of forgone alternative resource uses during the dry season in the rain-fed farms (i.e. the dry season comparator) and the avoided abatement costs of potential resource degradation caused by irrigation (i.e. irrigation externalities), defines the real counterfactual and should be factored into the analysis before such conclusions can be reached. As discussed earlier, dry season cropping in the irrigated farms displaced indigenous crop-livestock-soil management techniques and other less intensive micromanagement of farm resources adopted in the rain-fed farms during the dry season. Rain-fed farmers use the harvested rain-fed farms for livestock grazing and other agro-silvopastoral activities as a system of sustainable natural resources management (NRM), and also engage in other welfare yielding activities during the dry season. Studies elsewhere suggest that these traditional practices evolved from farmer experimentation and are often well adapted to their particular ecological, social and economic contexts in ways that are beneficial to agricultural and ecosystem/social sustainability in developing countries (Barrett et al., 2002: 5)[17]. The point being made here is that even though the results corroborate findings elsewhere regarding the positive impact of irrigation on total crop yield per land area per year due to double cropping, its potential impacts on the ecosystem and the opportunity cost of forgone alternative resource uses that it displaces relative to rain-fed farming systems (especially during the dry season) require critical attention.

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[17] The social, economic and environmental contradictions in agricultural intensification made possible by irrigation schemes and improved natural resources management in developing countries are now well documented (see Freudenberger and Freudenberger, 2002).

The second policy implication of the findings derives from the statistically insignificant difference in returns to factor inputs (i.e. marginal productivity of factors) between the two systems. From a long-term sustainability perspective, we argue that since the full irrigation (dry season) crop did not enhance factor productivity growth (and has potentials for degrading the resource structure upon which future productivity depends), its perceived productivity gains should be approached with caution. Assessing irrigation based on total productivity gain per land area per year might mislead policy choices.

Thirdly, the magnitude of the partial production elasticites of factors suggest that holding other farm inputs constant, the responsiveness of farm output to labour input (X1) and to other variable inputs (X3) is higher than the returns to land/water inputs (X2) which constitute the main factor input that is being harnessed more in the irrigated farms than in the rain-fed farms)[18]. In fact, the negative partial regression coefficient with respect to land/water charges implies that at constant levels of labour and variable costs i.e., Y = f(X2¦ X1, X3), the marginal returns to land/water resources in the study area is declining (see: Olayide and Heady, 1982. p. 55; and Gujarati, 1995, p. 242)[19]. In other words, this suggests that the marginal returns to land/water resources is uneconomic (see: Olayide and Heady, 1982, p.56), and lower than the marginal returns to labour and other variable inputs in the study area. The returns to labour and variable costs are positive and increasing. Consistent with the results elsewhere in Sub-Saharan Africa (see: Okereke, 1991, Pretty and Buck, 2002), the highly significant production elasticity coefficients for labour (X1) and variable inputs (X3) suggest that focusing policy measures on improving labour productivity (e.g. farm mechanisation, extension education, etc) and farmers' access to other variable inputs (e.g. fertilisers, pesticides, improved seeds etc) would improve agricultural productivity in the sub-region more than land saving technologies such as irrigation, at least in the short term. We acknowledge the fact that in the long term, diminishing returns to factor inputs and biophysical limits to

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[18] The model indicates a 95% confidence that the partial elasticities of output with respect to labour input (β1) and variable cost input (β3) are positive (lying between 0.31 and 0.69; and 0.25 and 0.57 respectively, while that of land/water charges is negative, lying between (-1.84 and 0.02). This suggests that Y = f(X2¦ X1, X3) is at stage III of production.

[19] The only difference in the X2 variable in the case of irrigation is the extra cost of water abstraction charged by the RBDA in addition to the land rent paid by the farmers (both irrigators and rain-fed farmers) in the river basin to the RBDA.

growth may possibly preclude productivity gains in both systems. However, the balance of evidence from our analysis strongly suggests that improving the traditional rain-fed farming system would do better, in the river basin, for a longer term.

In summary, while the overall short term food security implications of these findings are uncertain, the prospect of long-term sustainability of agricultural production in the river basin is bleak. Targeting agricultural policy on measures to improve labour productivity and access to improved farm inputs is a priority. We will return to the relative sustainability of food supply with respect to yield stability over time in the next sub-sections. So far, we can conclude that the only advantage that the LAIP has had over rain-fed farming system in the river basin is a result of the ability to grow two crops on the same piece of land per year, not a result of any statistically significant improvement in returns to units of inputs per period. Factoring in the welfare and ecosystem sustainability benefits of the less intensive rain-fed farming system (i.e. the opportunity costs of resources used up in the irrigation intensification process and the avoided pollution abatement costs) is crucial to assessing the sustainability of irrigation in the river basin and perhaps elsewhere.

In the next sub-section, we compare the trends and variability (i.e. relative stability) of annual yields recorded in the irrigated and the rain-fed farms to draw implications for the sustainability of each system.

Crop Productivity Trends in the Irrigated and Rain-fed Farms in the River Basin

The term 'sustainability' has been defined in diverse ways but in each definition there is a concept of stability through time. Following the set of weak criteria for assessing the sustainability of natural systems outlined by Conway (1985) and Urama (2003), a crop production system fulfils the weak sustainability criteria if its crop productivity level is high enough to offset the potential abatement costs of its externalities, and stable (i.e. non-declining and non-variable over time). Strong sustainability criterion would require that it still leaves its natural support structures (i.e. the ecosystem) resilient (i.e. able to sustain anthropogenic stress) and non-declining over time (see Appendix 6 for details).

The analysis presented in this sub-section examines the comparative stability of crop yield in the irrigated and rain-fed farms in the study area (1984-98) only.

Comparing Means and Trends of Output/ha in Both Systems (1984-98)

The predominant data sources for the analyses presented here are back issues of annual reports of the Anambra-Imo River Basin Development Authority (AIRBDA) and relevant publications in the project area.

The descriptive statistics of the annual yield data for all the systems over time (1984-98) are presented in Table 3.

Table 3: Descriptive Statistics of the Annual Yields/ha in both Systems over Time (1984-98)

	Cropping Systems			
Statistics	Y/ha (Rain-fed) Per crop year	Y/ha (IRR Dry Season Per crop year)	Y/ha (IRR. Rainy Season Per crop year)	Y/ha(IRR Annual) (Dry + Rainy season crops)
Duration of land use	6 months	6 months	6 months	12 months
Mean	2.42	2.51	2.38	4.89
Median	2.45	2.90	2.50	5.20
Standard Error	0.18	0.28	0.20	0.40
Standard Deviation	0.68	1.09	0.77	1.54
Minimum	1.20	0.00	0.89	0.89
Maximum	4.00	3.74	3.40	6.54
Sum (1984-98)	36.3	37.69	35.64	73.33
Number of Observations (years)	15.00	15.00	15.00	15.00

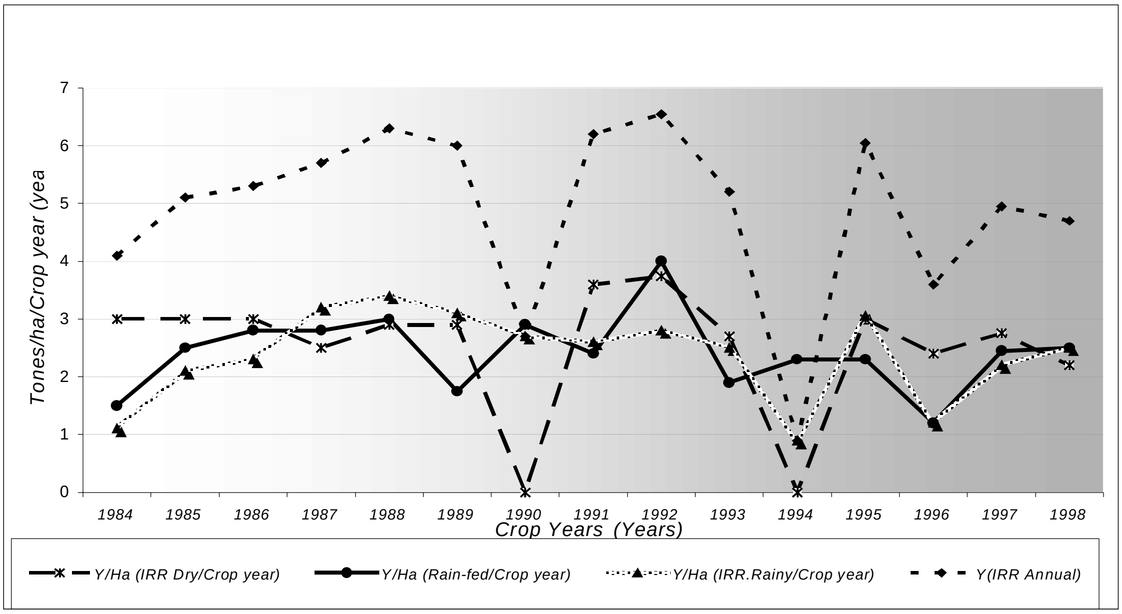
Source: Computed from Historical Yield Data (1984-98).

A test of differences in means show that neither of the mean yields from the irrigated crops (the rainy and dry season crops) was significantly different from those of the rain-fed farms in the study area, at 5% levels. As expected the cumulative mean of the total output per hectare from the rainy and dry season irrigated crops was significantly higher than that of the rain-fed farms, reflecting the spatial advantage of irrigation over the rain-fed farms.

However, field observations reveal that over 8.97% of the developed irrigation plots in Adani have been classified as unsuitable for crop production by the irrigation management in 1998 due to persistent water logging, salininty and other soil degradation problems. This increases the concerns for the sustainability of the annual productivity gains in the irrigated farms in the river basin. In the long-run irrigation induced soil degradation may limit crop production in the river basin.

In Figure 2, we present the trends in yield for both systems disaggregated by temporal and spatial scales. First we compare the rain-fed crop with the rainy season irrigation crop and then to the dry season irrigation crop data. To account for the spatial advantage of irrigation over the rain-fed farms, we also present the trends in total annual yield per hectare in the irrigated farms computed as the sum of the yields from the rainy and the dry- season irrigation crops for each year.

Figure 2: Trends in Output per Hectare in Both Systems



On a crop year basis, the Figure shows that the output of rice per hectare increased by about 100% (1.5 metric tones/ha to 3.0 metric tones/ha) in rain-fed farms during the early years of irrigation adoption (1984-1988). The yields in the irrigated farms (for both dry and rainy season crops) were relatively stable at about 3.0 metric tones/ha within this period. Since the early 1990s, the yields in both systems have been unstable, rising to about 4.00 metric tones/ha in 1992 for the rain-fed and dry season irrigated crops and falling to about 1.2 metric tones/ha in 1996 for the rain-fed crop. On the whole the trends in the rain-fed and the rainy season irrigated crops were similar and more stable than the dry season irrigated crops.

In most of the years, the LAIP doubled the total crop yield per hectare per annum due to double cropping (i.e. planting two crops on the same piece of land in one year). This is an apparent advantage of irrigated farms over the rain-fed farms that informed the adoption of the LAIP. Compared to the rain-fed farms, the trends in total output per hectare in the irrigated farms (both dry and rainy season crops combined) increased from about 4.1 metric tones per hectare in 1984 to about 6.5 metric tonnes per hectare in 1992, but declined to 3.6 metric tonnes per hectare in 1996. On the whole, there seems to be a more downward trend in the total output per hectare in the irrigated farms than there is in the rain-fed farms. However, all the fitted trend lines had low R2 values suggesting that we cannot place much confidence on the fitted trends at 5% levels.

Comparing Yield Stability in Systems (1984-98)

In this sub-section, we examine the variability of yields in terms of deviations from their respective means and the trends in the contribution of irrigation to crop yield within each cropping season and within each calendar year. As shown in Figure 3 the rain-fed crops have been more stable than the irrigated crops in terms of deviations from their respective means within the period[20].

The variation in the yield per hectare per crop year has generally been widest in the dry season irrigated crop compared to the rainy season irrigated crops and rain-fed crops. The extreme case scenarios occurred in 1990 and 1994 when irrigated crops were infected by the Blast (fungus - *Pyricularia grisea*) leading to total crop loss in the irrigated farms. This suggests that the basin type surface irrigation practiced in the LAIP increased crop's vulnerability to diseases by increasing the spread of diseases between farms either due to higher cropping density or flooding.

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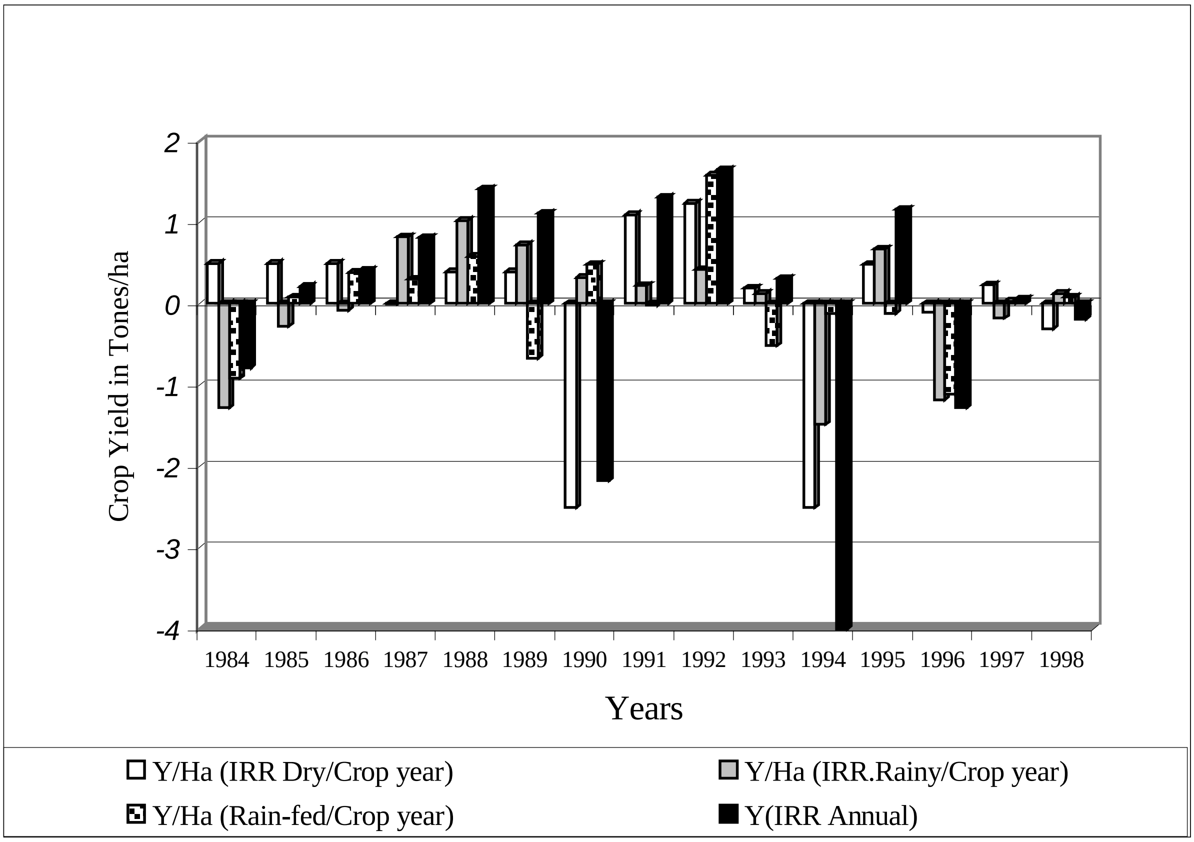
[20] Variations were computed as deviations own mean (Yit – Yi).

Figure 3: The Variability of Crop Yield in both Systems

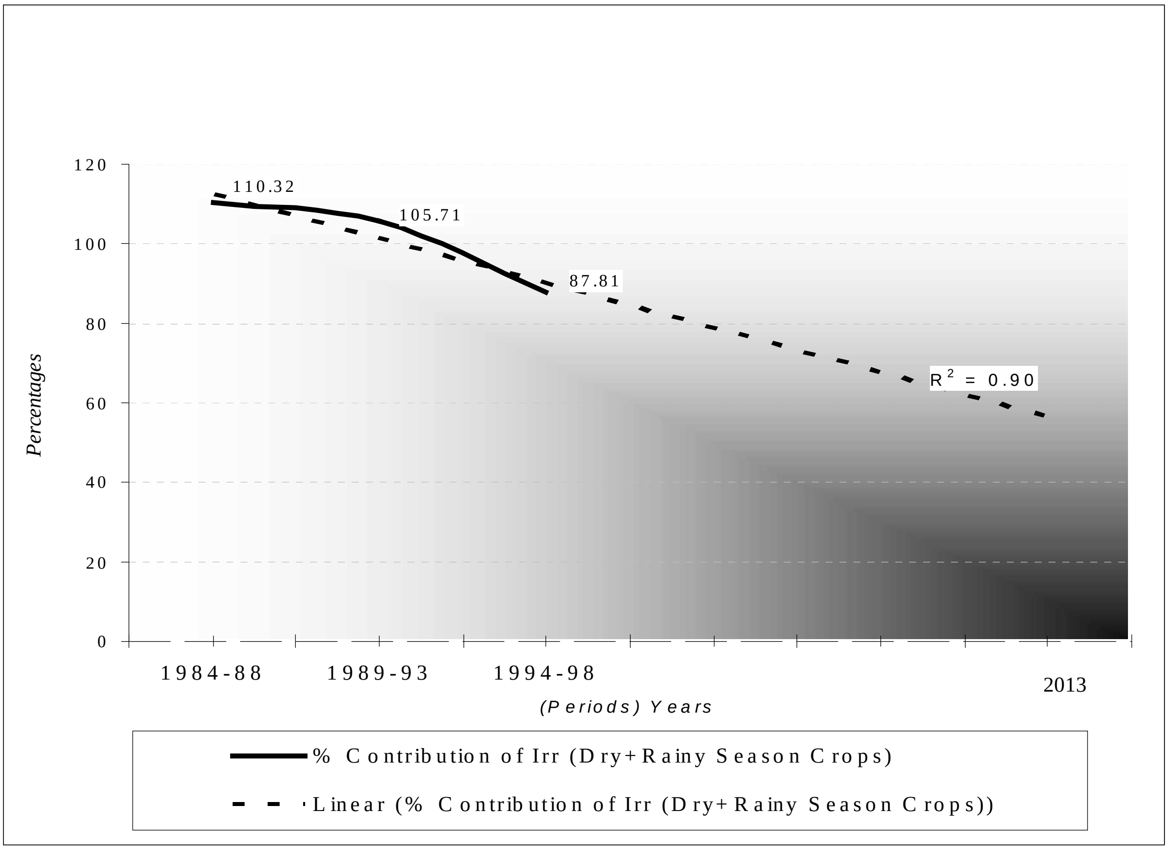


Source: Computed from Historical Yield Data (1984-98).

As defined above, yield stability over time is crucial to the sustainability of food supply (i.e. food security) especially from subsistence farmers' perspective. Empirical studies find that increase in productivity per unit land is not the priority objective of subsistence farmers but stable output either because it is expensive to purchase their own food or because reliable resource supplies do not exist (Urama, 2003). In Nigeria, anthropogenic inputs (e.g. lack of improved varieties, inefficient farm implements, low access to agricultural credit and extension services) are the major factors limiting agricultural productivity (Okereke, 1991) not availability of arable land. One positive impact that farmers in the study area attributed to the LAIP in the river basin was its role in exposing the farmers to these inputs. Prior to the introduction of irrigation in the study area, 77.5% of the sampled farmers had no access to either agricultural extension services or any agrochemical (artificial fertilisers, pesticides etc.). At the time of the survey (1999/2000) all the irrigators and 79% of rain-fed farmers had access to these productivity-boosting inputs. All the farmers sampled identified the enhanced access to improved agricultural inputs as critical to increasing food production in the study area. The production function analysis found that there were higher marginal returns to labour inputs (X1) and to other variable inputs (X3) than there was to land and water resource inputs (X2) in the study area. The wide variation in yield in the irrigated farms was a great concern to the farmers because of increased risk of food insecurity in the farm households. In simple terms, subsistence farmers are risk averse and derive greater welfare from stable output than from higher but more variable output per land area. In this context, the yields from the rain-fed farms were more sustainable than yields from the irrigated farms.

Overall, what is evident from historical yield data is that annual crop yields initially increased slightly in all the systems, peaked in the early 1990s and declined thereafter (Table 4). Using a 5-year moving average and the yields from the rain-fed farms per period as the benchmark, we find that the combined contribution of irrigation (i.e. dry season plus rainy season crops) to total output per hectare per year also peaked in the early 1990s and declined at an increasing rate thereafter (Figure 4).

Figure 4: Percentage Contribution to Output/ha by Irrigation in The LAIP (1984-2013)



Source: Computed from Historical Yield Data, (1984-98).

As shown in Figure 4, a 15-year extrapolation of the impact of irrigation on crop yield suggests an increase downward trend in the contribution of irrigation to total output per land area cropped in each calendar year (R2 = 0.90) at 5% significance level.

In summary, our assessment of the relative potential of the irrigated and rain-fed farms in the study area to meet the ‘weak sustainability’ criteria (analysed both in terms of factor productivity, and productivity trends over time) find that:

The LAIP increased total food produced per given land area (i.e. the total productivity of land resources) in the river basin by offering farmers the opportunity to grow crops during the dry season. However, the trend in total contribution of irrigation to the food basket peaked in the early 1990s and has declined at an increasing rate in the past decade.

There was no significant difference in marginal productivity of factors between the rain-fed and dry season irrigated crops, but while the marginal product of labour and other variable inputs are significantly positive and increasing, the marginal product of land/water inputs is negative and declining. Observed fungibility in the use of modern production inputs associated with the irrigation project may explain the matched trend in productivity in the irrigated and rain-fed farms at the inception stage of the LAIP.

The annual yields of crops in the irrigated farms were less stable than those of the rain-fed farms in the river basin, possibly due to increased susceptibility to diseases.

About 9% of the irrigated land has been (irreversibly) degraded, suggesting the irrigation externalities may preclude sustainable crop production in the LAIP, in a relatively short term.

We argue that increasing marginal returns to resource inputs is more crucial to sustainable food production especially in the context of subsistence farming where the opportunity costs of land and water resources are lower relative to other production factors. In this context, the LAIP had no significant advantage over rain-fed cropping in the study area. Total productivity of land resources (i.e. crop yield per land area) increased at the inception stage of the LAIP but our analysis suggests that this is declining.

Table 4: A 5-Year Moving Average of Annual Yields/ha Data in both Systems (1984 – 98)

Periods in years	**Rain-fed crop**	**Irrigated (dry season crop)**	**Irrigated (rainy season crop)**	**Irrigated (rainy + dry season crop)**	**% Contribution of irrigation (dry season crops) combined**	**% Contribution of irrigation (rainy season crop) only**	**% Contribution of irrigation (rainy + dry season crops) combined**
	(Tones/ha)	(Tones/ha)	(Tones/ha)	(Tones/ha)	[(Yit-Yrt)/Yrt]100	[(Yit-Yrt)/Yrt]100	[(Yit-Yrt)/Yrt]100
1984-88	2.52	2.88	2.42	5.3	14.29	-3.97	110.32
1989-93	2.59	2.588	2.74	5.33	-0.08	5.87	105.71
1994-98	2.15	2.07	1.97	4.04	-3.72	-4.93	87.81
mean yield/ha (1984-98)	2.42	2.51	2.38	4.89	3.50	-1.01	101.28
% Decline in output/ha between (1984-88) and (1994-98)	14.68	28.13	18.68	23.81	na	na	na

Source: Secondary Data collated from LARBDA Annual Reports (1984-98).

Percentage contributions were computed with rain-fed crop yields as the benchmark. Y_{rt} =Average yield in the rain-fed farms per period (t), while Y_{it}= Average yield in the irrigated farms per period (t); na = Not applicable.

Following Rees, (1996) and Barrett et al., (2002), we argue that the observed trend in productivity in the river basin might be an indication of short-term energy and material flux through ecosystems which ceteris paribus increases systems productivity but also exacerbates ecosystem degradation in ways that precludes long term agricultural sustainability. The prospect of sustainable food production under irrigation in the study area is therefore bleak. In the next sub-section, we examine the financial returns to farmers in both systems.

CONCLUSION

The paper examined two “weak sustainability related” research questions. First, does surface irrigation (as practiced in the LAIP) have any significant effect on crop production in the study area? Second, is the productivity gain from irrigation (if any) sustainable (i.e. stable and non-declining over time)?

We have examined the impact of irrigation on marginal productivity of factors (land/water charges, labour cost and other variable costs) and on total yield per land area cropped both within cropping seasons (i.e. temporal scale) and for each calendar year (i.e. spatial scale). The temporal and spatial scales of analyses were adopted to account for the different duration of land use in the two systems. While the temporal scale analyses compared the marginal returns from the irrigated crops with those of the rain-fed crops based on cropping seasons only (i.e. marginal productivity of factors), the spatial scale analyses focused on total returns per land area for the whole calendar year (i.e. the total product of land/water resources).

The productivity analysis find that double cropping in the LAIP increased total amount of food produced per land area per annum by about 110% in the irrigated farms compared to the less intensive rain-fed farms in the river basin during the inception stage of the project. When the duration of resource use (including land and water resources and other anthropogenic inputs) was factored into the analysis, the production functions analyses find no significant difference in marginal factor productivity in the fully irrigated (dry season) farms and rain-fed farms in the river basin. Also, the marginal product of the anthropogenic inputs, (i.e. labour and other variable costs), were positive and increasing while that of land/water resources was negative and decreasing. The use of productivity-boosting variable inputs (e.g.

artificial fertilisers, extension education, agrochemicals, etc.) associated with the LAIP, were fungible, leading to a matched “within season” performance of the irrigated and rain-fed farms.

The trend analysis, assessing the relative yield stability in both systems (1984 - 1998), find that the positive contribution to food production in the river basin by the LAIP peaked in the early 1990s and declined at an increasing rate afterwards. The annual yields in the irrigated farms have also been less stable compared to those of the less intensive rain-fed farms. Furthermore, about 9% of the irrigated land has now been forced out of crop production by irrigation induced soil degradation. The dry season irrigated crops had displaced alternative traditional uses of ecosystem resources and integrated the micro-management of the farm ecosystem in the rain-fed farms.

These findings raise a number of implications relevant to sustainable agricultural policy in the sub-region, and perhaps elsewhere. We argue that the short term food security implication of the total yield gains made possible by “double cropping” in the irrigated farms is complex. Contrary to current popular perceptions, we argue that the apparent increase in total output/ha/year in the river basin at the inception stage of the LAIP was possibly the effect of short-term increase in energy and material flux through the agro-ecosystem due to intensified resource use (e.g. double cropping) which, ceteris paribus, increases the rate of depletion of agricultural support systems in the river basin. This is a form of Goodland’s (1999) oxymoronic growth and cannot be sustainable (i.e. asset-stripping natural capital for growth today). Factoring in the avoided abatement costs of ecosystem degradation associated with irrigation and the opportunity costs of displaced resource uses in the rain-fed farms shifts the balance of evidence in favour of less intensive rain-fed farming systems, even under the “weak sustainability principle” (i.e. Potential Pareto optimality criteria). The complexity of the tradeoffs between dry season cropping in the irrigated farms and the dry season comparator (including the alternative uses of ecosystem and anthropogenic resources during the dry season under rain-fed cropping systems) mean that the contribution of irrigation to farmers’ welfare and food security should not be judged on the basis of dry season harvests of crops in the irrigated farms only. Instead, the choice of competing farming system should depend on considerations for their relative marginal physical products (MPPs) per period; the actual trade-off between alternative resource uses, and their relative potentials to deplete agricultural support systems. Considering that the marginal productivities of labour and variable inputs were higher than that of land/water resources in the estimated farm production function, we recommend that Nigeria's short term agricultural policy for the sub-region should prioritise measures that enhance labour productivity and farmer's access to improved farm inputs and not necessarily on large scale irrigation development.

In the context of strong sustainability criterion, the irreversibility of some irrigation externalities especially on the agricultural support systems (i.e. land and water resources) questions the sustainability of irrigation as a 'land-saving technology' in the river basin, even in a relatively short term. Historical evidence from studies elsewhere and empirical evidence from our survey (see Urama 2003) strongly suggest that it is rather 'land-degrading'.

Even though the LAIP is still relatively young for conclusive claims to be made regarding its long term sustainability, the analyses find a downward trend in the yield gains in the irrigated farms in the study area. Empirical evidence from studies elsewhere (Clark, 1960; Carruthers, 1968; Joshi and Dayanatha, 1990; Oldeman, 1998; Scherr, 1999; and FAO, 2001) corroborate this finding. In his study Oldeman, (1998) estimates an 8 -14% cumulative decline in agricultural productivity in sub-Saharan Africa, while FAO, (2001) reports that per capita agricultural production in the sub-region is down by greater than 16% of what it was in the 1970s. Per capita livestock productivity is also reported to have declined (Barrett et al., 2002), possibly due to displacement of traditional crop-livestock management systems by modern technologies. Overall, about 65% of agricultural cropland and 31% of permanent pasture in Africa is estimated to be degraded with 19% classified as seriously degraded (Scherr, 1999). In a detailed analysis of yield trends in more than fifty countries, Clark (1960) found that yield stagnation was fairly general in irrigated farms in poor countries.

Based on the results of our analyses and empirical evidence from studies elsewhere, we conclude that the irrigated agriculture, as practiced in the Anambra Imo River Basin is not sustainable.

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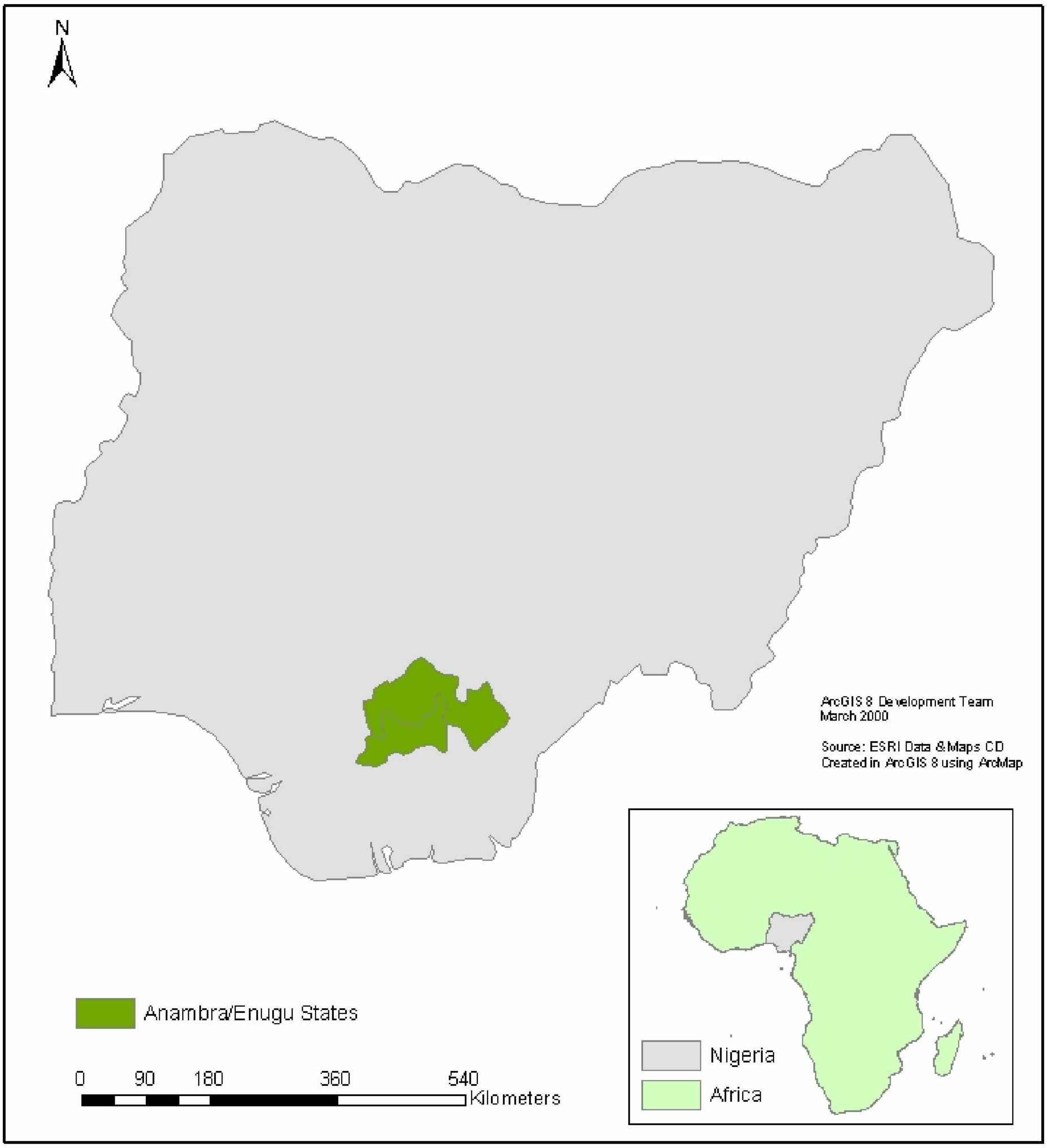
Appendix 1: The Comparative Analysis Framework

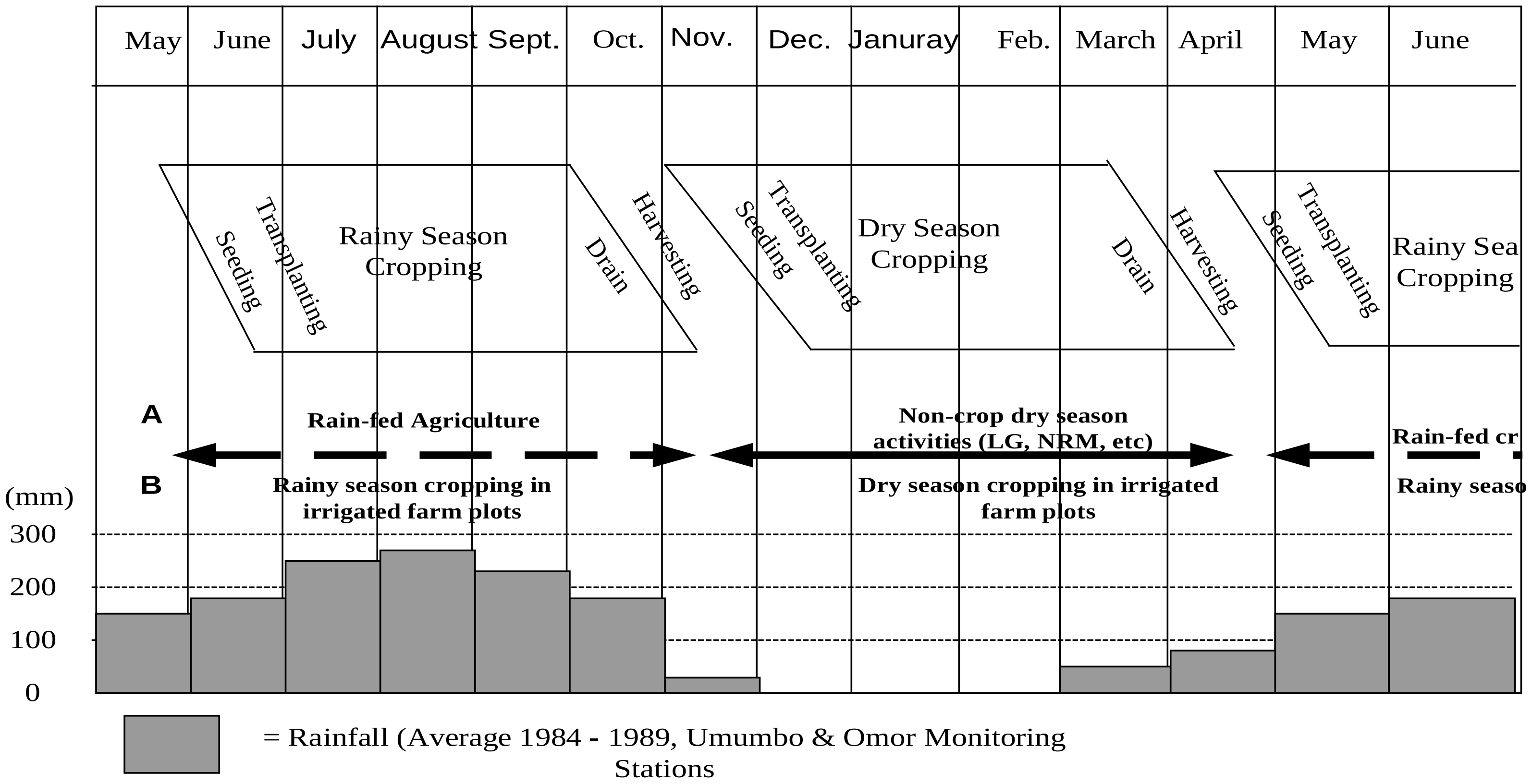
	Activities in the rain-fed farms within cropping seasons		**Activities in the irrigated farms within cropping seasons**		**Activities in the rain-fed farms per annum**	**Activities in the irrigated farms per annum**
	Rain-fed farms (Single crop)	Non- cropping/ NRM activities in rain-fed farms during the dry season	Supplementary irrigation (rainy season crop) (Single crop)	Full irrigation (dry season) crop (Single crop)	Rain-fed crop + dry season non-cropping/ NRM activities	Dry + Rainy season crops
Temporal scale	{6 months}	{6 months}	{6 months}	{6 months}	{12 months}	{12 months}
Spatial scale	[1 hectare]	[1 hectare]	[1 hectare]	[1 hectare]	[1 hectare]	[1 hectare]
	Control/season		Treatment (i)			
	Control/season			**Treatment (ii)**		
	Control/annum				**AC1**	
						AT1

Key: { } = Temporal scale; [ ] = Spatial scale; Control = Benchmark crop yield; Treatment (i – ii) = irrigated cropping systems whose impacts are being examined within cropping seasons, AC_1 = Annual control defined as the sum of welfare gains from the rain-fed crop yield and welfare benefits (and avoided costs) of alternative resource uses by rain-fed farmers during the dry season (i.e. the dry season comparators to dry season cropping in the irrigated farms). AT_1 = the annual treatment in the irrigated farms defined as the sum of the rainy and dry season crops. Because of our focus on crop productivity in this chapter, we compare only the crop production systems (see Table 1). We return to assessing the cumulative effects of the annual treatment and control activities in the next chapter.

Appendix 2: Location of the Lower Anambra Irrigation Project



Appendix 3: The Cropping Pattern in the Lower Anambra Irrigation Project Area



A = Traditional Farming System; LG = Livestock Grazing; NRM = Natural Resources Management

B = Irrigated Farming System (Double Cropping = Dry + Rainy Season Cropping.

Appendix 4: Sample Population Statistics

Statistics	Education irrigated (years of formal schooling)	Education rain-fed (years of formal schooling)	Age irrigated (in years)	Age rain-fed (in years)	Farm experience irrigated (in years)	Farm experience rain-fed (in years)	Farm size irrigated (in plots)	Farm Size rain-fed (in plots)[21]
Maximum	16.00	12.00	65.00	69.00	20.00	25.00	5.00	6.00
Mean	7.61	5.23	46.57	48.61	12.94	15.46	1.84	2.42
Median	6.50	6.00	46.00	48.00	12.00	15.00	2.00	2.00
Mode	6.00	6.00	45.00	46.00	10.00	13.00	1.00	2.00
Minimum	0.00	0.00	31.00	30.00	10.00	10.00	1.00	1.00
Standard error	0.43	0.32	0.79	0.81	0.23	0.36	0.09	0.11
Number of farmers	110.00	93.00	110.00	93.00	110.00	93.00	110.00	93.00

Source: Survey Data 2000.

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[21] I Plot = 0.5 hectares

Appendix 5: The Gross Margin Budgets for the Irrigated and Rain-fed Farms for 1999/2000 Crop Year

A: Gross Margin Budgets for the Dry Season Irrigated Farms in Nigerian Naira (1999/2000)

Statistics	**Output**	**Labour**	**Land/Water**	**OVC**	**TC**	**GM**
Min	38,000.00	14,600.00	1,900.00	18,500.00	36,800.00	-25,543.00
Mean	67,678.76	22,670.63	2,097.00	28,819.48	53,587.11	14,091.65
Median	69,000.00	22,430.00	2,000.00	28,600.00	53,600.00	14,530.00
Max	86,400.00	37,300.00	2,650.00	38,300.00	67,440.00	27,980.00
Sd	10,903.08	3,045.88	148.82	4,211.16	5,902.52	8,120.03
N	110	110	110	110	110	110

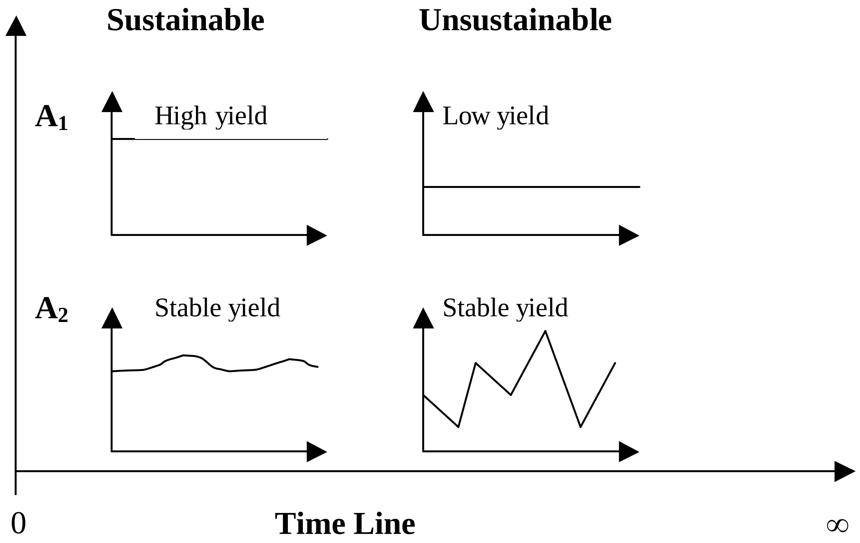
B: Gross Margin Budgets for the Rain-fed Farms in Nigerian Naira (1999/2000)

Statistics	Output	Labour	Land	OVC	TC	GM
Min	28,000.00	10,470.00	1,500.00	10,600.00	22,570.00	-12,170.00
Mean	53,708.20	20982.17	1,519.25	21,101.12	43,602.54	10,105.67
Median	52,000.00	20,520.00	1,500.00	20,800.00	42,700.00	9,895.00
Max	81,050.00	28,400.00	1,700.00	29,800.00	56,730.00	28,148.00
Sd	10,795.12	3,631.81	43.52	4,309.36	7,261.70	6,574.50
N	93	93	93	93	93	93

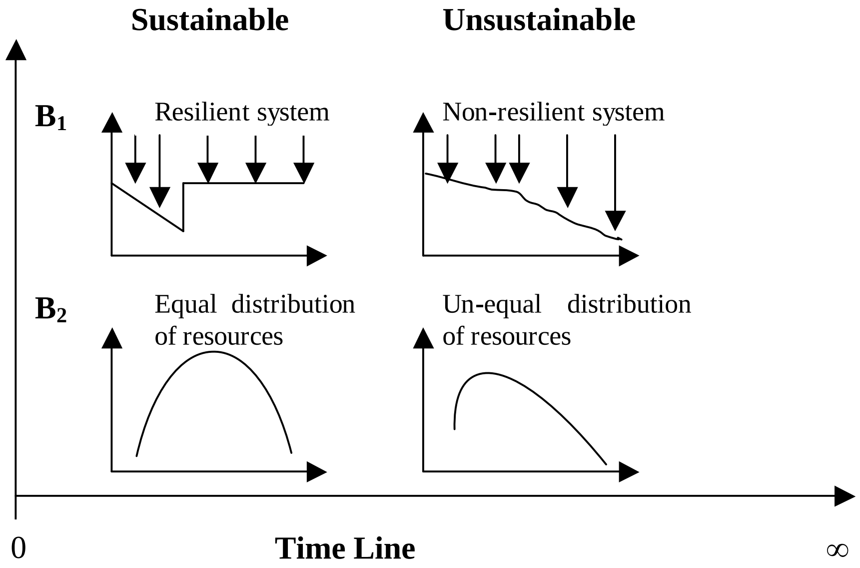
Source: Survey Data 2000. Software used = STATA 7.0.
Key: Cost/revenue items comprised: Output = market value of crop output/ha; Labour = Labour cost/ha; Land/water = land/water charges/ha; OVC = other variable costs/ha; TC = total cost of production computed as land/water +labour + OVC; GM = gross margin per hectare; Min = Minimum value in the sample, Max = Maximum value in the sample; Sd = Standard deviation, and N = Sample size.

Appendix 6: Sustainability Indicators in Agricultural Systems (Adapted from Conway, 1985; Nijnik, 2002 and Urama, 2003)

A: Weak sustainability criterion defined in terms of agricultural output/ha/year



B: Strong sustainability criterion defined in terms of ecosystem stability and intergenerational equity



Key: A_1 = High productivity criterion: -The marginal physical product of factors should be positive and its value high enough to cover production costs plus associated pollution abatement costs.

A_2 = Yield stability criterion: - Output per land area per period should be stable and non-declining over time.

B_1 = Ecosystem resilience- .The agro-ecosystem should be able to sustain its production support functions under the anthropogenic stress associated with the production system over time.

B_2 = Net social welfare associated with the ecosystem resources that support the production system should be equitably distributed both within the current generation and the future generation.