

**Socio-Economic and Environmental  
Consequences of Agricultural  
Technology: A Comparative Study of  
Small Scale Surface Irrigation  
Technology in Nigeria and Swaziland**

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## Abbreviations

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ARIP	Adarice Irrigation Project
ATRBDA	Anambra - Imo River Basin Development Authorities
ATs	Appropriate technologies
BCR	benefit - cost ratios
CV	contingent variation
CVM	contingent variation method
DRF	Dose response functions
EIAs	Environmental Impact Assessments
ESADEP	Enugu State Agricultural Development Project
FAO	Food and Agriculture Organization
FEPA	Federal Environmental Protection Agency
FSR	Farming systems research
GDP	gross national product
ISRIC	International Soil Reference and Information Centre
LAIP	Lower Anambra Irrigation Project
LCDs	Less developing countries
MB	Marginal benefits
MSC	Marginal social costs
NOAA	National Oceanic Atmospheric Administration
OLS	Ordinary least square
PPS	probability proportional to size
RBDAs	River Basin Development Authorities
SRS	simple random sampling
TEA	Total exchangeable acidity
TEB	Total exchangeable bases
TDL	Title Deed Land
UNEP	United Nations Environmental Programme
USA	United States of America
WAI	War against indiscipline
WRDP	Water Resource (Irrigation) Development Programme

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## **Abstract**

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This study compares the socio-economic and environmental consequences of small scale surface irrigation (SSSI) technology in Nigeria and Swaziland. Its major thrust is to identify and compare the economic and environmental externalities of the technology in the two countries. The broad premise is that even as technological innovation is seen as the engine of modern agricultural productivity improvements, international trade competitiveness and general economic growth, and the externalities of the technology may, in the long-run, be inimical to sustainable agricultural/economic development.

Specifically, the SSSI technology is a major World Bank assisted technological thrust for increased productivity and international competitiveness of agriculture in most African countries. In many developing countries, this World Bank assisted technological innovation has received several empirical evaluations of its socio-economic and environmental impacts. Such studies have often uncovered some deleterious effects of the technology and thus provided basis for remedial actions. Unfortunately, despite the increasing proliferation of the technology in sub-Saharan Africa (especially in Nigeria and Swaziland), it has hardly been subjected to any rigorous socio-economic and environmental impacts' assessment. This study is designed to address this research gap.

The study therefore, investigated the consequences of surface irrigation technology on the socio-economic life of farmers and their environment in Nigeria and Swaziland, and identifies the techno-environmental mismatches that exist. It suggests possible mitigation measures to the socio-economic and environmental problems observed in both countries.

The findings show that surface irrigation has had diverse but subtle consequences for social, economic and environmental sustainability in both countries. In general, it has reduced the productive capacity of river flood plains, while creating the illusion of increased crop productivity in the project areas. It has marginally increased crop productivity in both countries, while increasing factor costs significantly. Its environmental impact so far is largely reflected in degraded soils and increased health risks to farm households in both countries. Generally, water resource extraction for irrigation has been high, unregulated and incorrectly priced in both countries. There is need for proper water resource pricing and management, and adequate monitoring of the schemes in both countries. It is important to track these subtle changes in soils and water quality for effective control of the social and environmental problems that have been observed so far. Providing adequate production resources to upland farmers is also critical to improving productivity in the unirrigated farms in Nigeria, while improved agricultural extension services are critical in Swaziland.

# Chapter One

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## Introduction

This study compares the socio-economic and environmental consequences of small scale surface irrigation (SSSI) technology in Nigeria and Swaziland. The broad premise of the study is that even though technological innovation is seen as the engine of modern agricultural productivity improvements, international trade competitiveness and general economic growth, the externalities of the technology may, in the long-run, be inimical to sustainable agricultural/economic development.

Specifically, the SSSI technology is a major World Bank assisted technology for increased productivity and international competitiveness of agriculture in most African countries. In many developing countries, the socio-economic and environmental impacts of this World Bank assisted technology have been empirically evaluated. Such studies have often uncovered some deleterious effects of the technology and thus provided basis for remedial actions. Unfortunately, despite the increasing proliferation of the technology in sub-Saharan Africa (especially in Nigeria and Swaziland), it has hardly been subjected to any rigorous socio-economic and environmental impacts' assessment. This current study sought to fill this research gap.

Available evidence in the literature shows that surface irrigation has affected the environment in diverse ways: ranging from "on-site" edaphic affects to "off-site" effects on bio-diversity and climate change, and on various forms of human welfare. However, its "on-site" effects on soil fertility, salinization and water logging, and its impact on both human and livestock health and water quality, dominate the reviewed literature on the subject. Its effects on the global environments (climate change, green house effects), are however also documented. Like most environmental issues, no boundaries can be put on the effects of irrigation on the environment.

Some key findings in the analysis of data collected from farm surveys in Nigeria and Swaziland in 1998/1999 show that the productivity gains of irrigation in the Nigerian project have been very marginal, when compared with adjacent upland counterparts. The true welfare gain of this productivity increase is yet to be identified since full environmental costs and benefits of the system are yet to be factored into the analysis. Farmers' access to agricultural extension services in Nigeria increased significantly with the introduction of irrigation in the study area. This has lead to an apparent parity in productivity of factors in both systems, and may serve to explain the apparent increase in rice output since irrigation was adopted. Improving extension services may be a better policy option than further development of irrigation in the study area. In Swaziland, there is need for improving extension services to the farmers in both categories. Access to extension by farmers in Swaziland is still poor.

There has been significant degradation (deleterious changes in some chemical and physical properties of soils) in irrigated farms, relative to soils in upland farms in the study area. These changes have been subtle but significant. There has been significant increase in bulk density and



decrease in water infiltration rates in the study area. These trends do suggest that the prospects for the sustainability of crop production on soils in the irrigation projects studied, is bleak. There is therefore the need for regular soil surveys in project areas to monitor trends of the different chemical and physical properties of soils between the two systems, for proper fertility management.

A major environmental health consequence of irrigation development in both countries as reported by respondents is mosquito infestation causing malaria epidemic in farm households, and other water related diseases. Farmers in Swaziland also reported few cases of bilhazia in project areas. There is, therefore, need for a systematic monitoring of the incidence of these diseases in irrigated areas for proper prevention and/or treatment.

### **Statement of the problem**

The impressive degree of technological dynamism has been a constant source of economic development (Wright, 1995) and technological change is seen as the engine of growth (Kayode et al., 1995). Wise management of natural resources and the global environment are essential to achieve sustainable economic development for alleviating poverty, improving human conditions and preserving the biological systems on which all life depends (Heaton et al., 1991, pp. 5-7). Sustainable development means economic development that does not degrade the quality of the environment or world's natural resource base and that "sustain(s)" human progress not just in a few places for a few years (WCEA, 1987). Hence, technological change becomes more dynamic only when it has an incremental value, transforms existing values and systems, and modernizes them by enriching, rather than disrupting, replacing or displacing them (Zahlan, 1991).

A consensus is emerging in literature, that widely replicated present technology packages and practices, if unchecked, would choke the world in wastes and pollutants. The only fundamental changes in technology and economic activities of people are the only realistic strategies that would arrest this trend (Heaton, et al., 1991, pp. 5-7); Krause, 1993; Pearce and Turner, 1990). Building the technological capacity of societies to monitor and mitigate these socio-economic and environmental externalities of technologization, thus becomes pertinent as an important long term strategy (The World Bank, 1989, p. 185). In the words of the Japanese Minister of International Trade and Industry (1991), "the goal of zero production of wastes and/or emission of pollutants for example, would work as well as a goal of zero defects in technology packaging".

Surprisingly, however, in Africa's technologization process, many countries have sought access to western technology, the very technology which many observers blame for the prevailing environmental threats facing humanity, with little attention given to its environmental impact. Over the last three decades, for instance, professional and policy debates surrounding technology transfer in Africa, have centered largely on the issue of locational appropriateness, since advanced capital-intensive technologies, are ill-suited to the needs and resource endowments of developing countries (Eremie & Chheda, 1991).

More recently, however, the issue of increasing the domestic content of agricultural technology packages through indigenization, in order to increase their "appropriateness", has received little treatment (Agboola, 1991). Nevertheless, the issue of ecological friendliness and/or socio-economic

and environmental consequences of technology transfer or indigenization process has either been ignored completely or addressed only fleetingly.

Reports abound of the extension of "appropriate" technologies (ATs) to various rural communities in developing countries (Carr, 1988). In Nigeria, for instance, the National Science and Technology Policy (1986) stipulate *inter alia* the "initiating, promoting, and supporting of relevant and appropriate technology diffusion to her rural areas" (FRN, 1986). Obibuaku, (1974) and Obasanjo and Mabogunje (1991), report extensive extension of appropriate agricultural technologies to Nigerian farmers through her ADP extension programmes. Aina and Soetan (1991) share similar views. The case of Swaziland is not different.

It may thus appear that various forms of agricultural technologies have been transferred to African farmers and may also be in use in some parts of the continent. What is not evident is to what extent these technologies are influencing farmer's cultural, social, economic and environmental conditions. Olukosi et al. (1991), thus recommends that diagnostic surveys be conducted, in order to gather, among other things, the socio-economic and cultural consequences of agricultural technologies on farmers. Eremie and Chheda (1991) also share similar views, adding that greater attention should be given to the social systems within which the generated technologies would operate and/or impact. The recent inauguration of Federal Environmental Protection Agency (FEPA) by the Federal Government of Nigeria in 1995, further amplifies the need for environmental impact assessments (EIA) of technological innovations in Nigeria. It is on this platform that this research is conceived with special reference to SSSI technologies in Nigeria and Swaziland, as case studies.

This SSSI technology recently received a boost from a World Bank assisted National Fadama Development Project for increased productivity and international competitiveness of Nigerian agriculture. In many countries (both developed and developing), the socio-economic and environmental impacts of this World Bank assisted technology have uncovered some of its deleterious effects and thus provided the basis for remedial actions (see Joshi et al., 1990 for India; Hawercamp et al., 1985 for Washington DC; WHO, 1990 for Asia; UNEP, 1991 for North Africa and Middle East; Science Council of Canada, 1986 for Canada).

A study of an irrigation district in eastern Uttar Pradesh in India found that 78% of the farmers reported problems with soil degradation (alkalinity, salinity or water-logging), that forced 29% of their cropland out of production, reduced rice and wheat yields by more than 50% and 80%, respectively, and caused run-off of fertilizers into rivers and estuaries that significantly caused water pollution in India. Soil salinization, primarily caused by faulty irrigation, also lowered crop yields and ultimately made land unsuitable for cultivation in some parts of Canada (Science Council of Canada, 1986). Unintentional pesticide poisoning, occurring mainly in developing countries, was also reported by the World Health Organization to have caused 20,000 deaths and 1 million illnesses per year (WHO, 1990). While over 86% of fresh water withdrawals in Asia, North Africa and other parts of the Middle East are due to irrigation process (UNEP, 1991), other off-farm impacts of the technology are described as more expensive (Chapman et al., 1985; Myers et al., 1985). SSSI technology in Nigeria and Swaziland are no exceptions. According to Mabogunje (1988):

The call to increase agricultural productivity has already induced government (in Nigeria), to embark on irrigation projects in different parts of the country, with the

risk of heightened salinization and toxicity. Private sector operators are also now concerned with large mechanization of cultivation as well as the extensive use of fertilizers, herbicides, pesticides and insecticides, for increased yield. Such developments if not well monitored and managed can be costly in environmental terms. They could in fact compromise the legacy of usable agricultural lands that we bequeath to coming generations of Nigerians.

Sustainable irrigation technology must be seen to be consistent with the preservation of the environment and also promote the socio-economic well-being of both current and future generations. An environmental impact assessment (EIA) of the project is therefore, pertinent in countries where they exist. Unfortunately, Africa's irrigation technology policy has largely ignored and/or addressed the socio-economic and environmental impacts of the irrigation process only fleetingly. Thus, despite the increased proliferation of the technology in Nigeria and Swaziland; it has hardly been subjected to any rigorous socio-economic and environmental impact assessment. This current study seeks to fill this research gap.

### **Objectives of the research**

The principal objective of this research is to investigate the socio-economic and environmental consequences of surface irrigation technology in Sub-Saharan Africa agriculture, with special reference to selected SSSI Project areas in Nigeria and Swaziland as case studies.

The specific objectives are to:

1. Describe the type(s) of surface irrigation technology being used by participant farmers in the project areas.
2. Determine the impact of the irrigation facility on crop productivity of participants compared to non-participants in the same ecological zone.
3. Review the incidence of water-logging, soil salinity, soil erosion and leaching of soil nutrients within the project areas, compared to non-irrigated areas within the same ecological zone and relating these to the productivity of the land.
4. Survey the incidence of water-borne diseases and pests within the project areas, compared to non-irrigated areas within the same ecological zone.
5. Suggest, based on findings, remedial measures for the problems that exist and their implications for irrigation technology policy in sub-Saharan Africa.

### **Outline of the report**

The report is divided into five chapters. Chapter one introduces the core research problems, questions and objectives, and the justification of the study is also presented in chapter one. Chapter two presents the research methodology employed for the case study, discussing the study area and population, sampling methods, data collection and analysis. Chapter three comprises the literature

review, discussing the definition of concepts, conceptual framework, the secondary evidence on environmental impacts of surface irrigation, and explores the potentials of available methods for evaluating these effects in Nigeria and Swaziland. Chapter four presents and discusses the types of irrigation practiced in Nigeria and Swaziland, the research findings and the limitations of the analysis. Finally, chapter five presents the summary of findings, their implications for further research, and the conclusions of the study.

## **Chapter Two**

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### **Research Methodology**

A combination of desk studies, experimental techniques and survey methodology were used in collecting both primary and secondary data relevant to the analysis.

The first stage of this methodology consists of the selection of respondents and, the design and administration of survey instruments. This was implemented in three phases:

1. a pilot survey for sample frame construction;
2. design and administration of structured questionnaires/collection of samples (specimen) for relevant laboratory test. Necessary data/information from the questionnaires and laboratory results were collated, coded and analyzed using a combination of qualitative descriptions and relevant statistical techniques; and
3. a follow-up informal survey for data validation and updating.

### **The study area**

Two case study projects were selected from Nigeria and Swaziland. The two countries are located in the Western and Southern region of Africa and span about 3.07% and 0.058% (91, 077000 and 1,720,000 ha), respectively of Africa's total land area (2,964,138 ha). Out of Nigeria's total cropland (31,335,000 ha, i.e. 34% of total land area), about 3% or 940050 ha are currently irrigated. Similarly, of Swaziland's total crop land (164,000 ha, i.e. 9.5% of her total land area), 38% or 62320 ha are currently irrigated (FAO, 1991). According to World Resources Institute (WRI, 1992/1993: 328), 54% and 93% of the annual internal renewable water resources in Nigeria and Swaziland, respectively are used for irrigated agriculture. The choice of Swaziland as the collaborating country is therefore representative due to this preponderance of irrigation technology in the country (she is second to Egypt where 99% of cropland is irrigated with over 88% of total animal renewable water resources WRI, 1992/93: 328)<sup>1</sup>

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<sup>1</sup> Egypt may not be a good collaborating country since the selection of the control group of farmers (the non-participant farmers) may not be found.

In Nigeria, the Lower Anambra Irrigation Project (LAIP) and Adarice Irrigation Project (ARIP) that span parts of Anambra and Enugu States of Nigeria were selected for the study. The choice of these projects was based on the presence of adjacent upland rice farms, which would serve as the control groups for the study<sup>2</sup>. The long duration of continuous irrigated and upland rice production in both sites (10 years), is also expected to affect soils and productivity in the area.

The project locations have two distinct seasons: the wet and dry seasons. The former lasts approximately from April/May to October/November of each calendar year. The mean annual rainfall is approximately 1,730mm and is bi-modally distributed, with peaks in July and September. The mean annual maximum temperature is about 38°C and that of minimum temperature is 22°C. The entire landform is generally undulating and underlain by the Imo clay shales of the tertiary period (Asadu et al., 1996). The residuum of this shale formation is the parent material of the soils.

The Kingdom of Swaziland lies between latitudes 25° and 28° south and 30° and 33° east in the southeastern part of Africa. The country has an area of about 17,364 km<sup>2</sup>. It is surrounded to the east by Mozambique and the Republic of South Africa to the north, west and south. The population is just over 930,000 people with an average growth rate of 2.7% per annum (Swaziland Government, 1998a). The country has historically been divided into four regions (Highveld, Middleveld, Lowveld, and Lubombo). It has now been appropriately reclassified into six physiographic zones, based on elevation, landforms, geology, soils and vegetation (Van Waveren and Nhlengetfwa, 1992; and Remmelzwaal, 1993). The main characteristics of the physiographic zones are summarized in Table 2.1.

**Table 2.1:** Area and percentage of total land area, total and dependable rainfall, temperature, and altitude of the physiographic zones of Swaziland

Physiographic zone	Area		Rainfall		Mean temp. (°C)	Altitude Above mean sea level (m)
	(Km <sup>2</sup> )	As %	Mean Annual (mm)	Dependable (%)		
Highveld	5,680	33	800-1400	700-1200	17	900-1400
Upper Middleveld	2,420	14	800-1000	650-850	20	600-800
Lower Middleveld	2,420	14	650-800	500-700	21	400-600
Western Lowveld	3,410	20	625-725	425-550	22	250-400
Eastern Lowveld	1,960	11	550-625	400-500	22	200-300
Lubombo Range	1,480	8	700-825	500-750	21	250-600

Source: van Waveren and Nhlengetfwa (1992) and Remmelzvaal (1993).

<sup>2</sup> Both projects are run by the Anambra Imo River Basin Development, Authority in the rice growing villages of eastern Nigeria. Local farmers are participants in the project, but still remain some adjacent plots for upland rice production using the same varieties. Both farms therefore share similar soils, management and natural uncertainties that fraughts agriculture in developing countries. Observed differences in yield are therefore mainly due to changes in the cropping system adopted.

The soils of the Lower Middleveld and Lowveld are characteristically gray or red light-textured soils, derived from granite or gneiss. They are generally shallow, between 40–70cm in depth. They have low moisture-holding capacity due to the shallowness and light texture. They have low fertility and high erodibility.

The eastern Lowveld zone is underlain by basalt, which gives rise to an association of red, brown and black clays. About 45% of the areas have shallow soils (20-40cm). The fertility of the soils is good, except for a shortage of phosphorous. The poor drainage of the black clays and their high alkalinity and salinity in low-lying areas, limit their use for irrigation.

The mean annual rainfall ranges from 1450 mm in the Highveld to 550mm in the Lowveld, with considerable variations from year to year. Years with lower rainfall than normal occur frequently, especially in the Lowveld, leading to drought. Highest temperatures are recorded in January, while lowest temperatures are recorded in July. The highest mean maximum temperature is recorded in the Eastern Lowveld (34°C for Lavumisa at 200 m above mean sea level), and lowest in the Highveld (22°C for Usutu at 1450 m above mean sea level). The lowest mean minimum temperature of 5°C occurs at Usutu in the Highveld, while the highest mean minimum of 10°C occurs at Lavumisa in the Lowveld. Frost occurs in all physiographic zones, but most frequently in the Highveld.

Swaziland relies largely on surface water for its agricultural development and other uses. There are four main rivers in the country. Komati River and its tributary, the Lomati, flow from the Republic of South Africa (RSA) through the north of Swaziland and back into the RSA before entering Mozambique. The Komati has a catchment area of 7,423 km<sup>2</sup> and the Lomati has 740 km<sup>2</sup> within Swaziland. The Mbuluzi River originates in Swaziland and flows into Mozambique, with a catchment area of 3,065 km<sup>2</sup>. The Usuthu River, which, together with a number of tributaries, rises from the RSA and flows out of Swaziland into Mozambique, has a catchment area of 15,876 km<sup>2</sup>. The Ngwavuma, which originates in Swaziland and flows into the RSA before entering Mozambique, has a catchment area of 1,305 km<sup>2</sup>.

Agriculture plays a very important role in national development of both Nigeria and Swaziland and is one of the leading sectors in its contribution to gross national product (GNP). For example, in 1992/1993 financial year, the agricultural sector accounted for E109.7 million or 10.2% of Swaziland's GNP at 1985 factor prices (Swaziland Government, 1995a).

### **Research design and data sources**

*Research design:* The whole research and its questionnaire designs were designed by the principal researcher in collaboration with the management of the selected projects and some resource persons from relevant disciplines in the University of Nigeria. The pre-test of the research instruments were also carried out by the Principal Researcher in Nigeria, and later sent to the collaborator in Swaziland.

*Data sources:* Both primary and secondary data were sourced for relevant analysis. While the primary data was generated through experimental and field survey methods, the secondary data were generated through literature search (desk study). Data were collected on the productivity and soil changes in the irrigated farms (treatment) and their adjacent rain-fed "upland" counterparts (control),

before and after the introduction of the irrigation schemes. In other words, the study adopts the classical experimental design for social research (i.e. combining both the "before" and "after" approach with the counterfactual ("with" and "without" technique)<sup>3</sup>. This was necessary in order to control the effect of climate change and other ecological risks and uncertainties that may affect agricultural yields in developing countries<sup>4</sup>.

Questionnaires were administered by personal interviews in order to collate responses with on-the-spot observations and measurements. Specifically, data on crop output for 1997/1998 crop year were collected through field measurements using the crop cutting technique (Poate and Daplyn, 1993, p. 102). The historical soil and crop output data (from 1986-1996/1997), were collected from the annual reports, and official publications of the Anambra-Imo River Basin Development Authorities (AIRBDA), which are in charge of the selected projects in Nigeria.

### ***Population for the study***

The population of the study comprises all farmers in the selected project areas. This was stratified into two groups:

1. Rice farmers who have participated in the selected irrigation projects continuously for over ten years (from 1986 - 1997).
2. Adjacent farmers who have grown rice on upland conditions continuously within the same period. This group serves as the control group and a benchmark for relevant impact assessment.

### ***Samples for the study***

Sample selection was accomplished in two stages. Firstly, pilot surveys of the selected project areas were carried out to identify and list the two groups of farmers specified. These lists served as the sampling frame. Secondly, equal numbers of farmers in each group were selected using a simple random sampling (SRS) technique. The labour intensity involved in data collection, required minimization of logistic problems that would be caused by large samples, especially, when selected from very distant, highly dispersed projects. As an exploratory baseline study, the samples for the study were limited to small numbers: 40 irrigated farms and 40 upland farms in Nigeria; and 229 irrigated and 42 upland farms in Swaziland. This baseline study would latter be followed up by more detailed ex-post study of the externalities of irrigation in both countries.

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<sup>3</sup> This is the sum of the two irrigation crops (*i.e.* both dry and rainy season crops).

<sup>4</sup> 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).



### ***Design and administration of questionnaires and interview instruments***

This stage involved a careful and detailed design of structured questionnaires and unstructured (informal) interview instruments, to elicit information relevant to the analysis. This was done by the principal researcher, in collaboration with the management staff of the irrigation projects being studied and in dialogue with key informants in the study areas. The focus of the structured questionnaires is to elicit baseline information on:

1. the on-farm impact of the irrigation and its influence on the social and economic life of participant farmers;
2. the off-farm impact of the irrigation process on non-participant neighboring farmers and other users of the irrigation facility; and
3. the socio-economic, productivity and environmental differentials between the participant and non-participant farmers in the project areas.

The unstructured (informal) interviews are designed as a follow-up to the structured questionnaire administration to seek clarifications on certain responses, or elicit other information not captured in the questionnaires. In order to elicit information on the edaphic impact of the irrigation process, soil samples were collected from each farm plot surveyed for suitable laboratory tests and analysis. The same set of data collection instruments was administered in both countries.

### ***Data collection technique***

Personal administration of structured questionnaires, interviews, field observations and focus group discussion techniques, were used for primary data collection. In Nigeria, this was carried out by the Principal Researcher, one Research Assistant (selected from Enugu State Agricultural Development Project, ESADEP), and a team of ten enumerators (selected from Graduate Students of Soil Science, Agronomy, and Agricultural Economics in the University of Nigeria). Four of these enumerators were selected from among the indigenes of the selected project areas to enhance access to farmers and to assist in interpretation of questions to respondents.

### ***Data analysis methods***

The data collected was analyzed with relevant statistical tools, econometric techniques and laboratory tests. Specifically, the first objective was realized by suitable descriptions and review of literature on irrigation development in both countries. Parts of objective 2, 3, 4 and 5 were achieved through suitable descriptive statistics (means, modes, frequency tables, charts and graphs). The remaining part of objective 2, the ordinary least square (OLS) multiple regression technique was employed explicitly, for comparing factor productivity between the two systems using the Cobb-Douglas production function.

We compared the marginal productivity of factors between the irrigated crops (treatment)<sup>5</sup> and upland rain-fed crop (control) using the Cobb Douglas production function. The goal was to test for differences in returns to factors while controlling for the potential effects of other general changes such as in climate or ecology<sup>6</sup>.

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

$$Y = AX_1^{b_1} X_2^{b_2} X_3^{b_3} e^m \quad [1]$$

Where:

$Y$  = Rice output (000'kg per hectare per year)

$A$  = Scale factor<sup>7</sup> (level of technology)

$X_1$  = Amount of farm labour (000'N per hectare per year) measured as the value of the number of mandays employed per hectare per year

$X_2$  = Cost of land and water resources (land and water charges '000'N per hectare per year)

$X_3$  = Variable capital costs (machinery hiring costs, fertilizers, herbicides, and insecticides, etc.) used ('000'N per hectare per year)

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

$e$  = Base of natural logarithm.

The exponents,  $b_1, \dots, b_3$ , represent the relative proportion of rice output contributed by the various inputs  $X_1$  through  $X_3$  defined above and indicate the elasticity of output with respect to changes in the input variables through. The Cobb-Douglas Production function provided the 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).

Despite the restricted econometric model assumed in the Cobb Douglas production function (Kidsom 2003, p. 14), this approach utilises 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

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<sup>5</sup> To control for scale effects of farm size, the model was estimated on a per hectare basis.

<sup>6</sup> Molnar, (1965); Bernnet and Murphy, (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.

<sup>7</sup> To control for scale effects of farm size, the model was estimated on a per hectare basis.

and convenience, the Cobb Douglas production function has been widely used in agricultural economic research (Molnar, 1965; Luck and Martin, 1988; Marcours and Swinnen 1997; and Smale *et al.*, 1998)<sup>8</sup>.

The difference in marginal output between the two systems computed from the production function was regarded as the rough estimate of the physical effect of the irrigation project on the soil. This will be a cost if negative and a benefit if otherwise. In addition, the cost and returns of production and productivity of the two systems (with- and without-irrigation), are determined. Statistical tests of differences between means are also employed in comparing the participant and non-participant farmers' statistic on crop productivity, production costs and returns per hectare.

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<sup>8</sup> Molnar, (1965); Bernnet and Murphy, (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.

## Chapter Three

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### Literature Review

#### Introduction

This chapter reviews literature on some of the basic concepts underpinning the study and integrates empirical evidence on the environmental impacts of irrigation technology<sup>9</sup> in countries where they exist. This aims to inform the methodological and analytical focus of the case studies in Nigeria and Swaziland.

#### *Definition of concepts*

*The concept of technology:* Technology as defined by Banjo (1988) is the application of scientific knowledge, including the skill necessary to deploy principles, procedures and processes that can be used to modify, manipulate and otherwise produce changes in the specific features and behaviour of the physical world, to serve human or social purposes. In other words, technology connotes scientific knowledge and skills, whose application leads to the solution to practical problems existing in society.

Ernst et al. (1994) further emphasizes that technology is not all machines, but rather the knowledge, partly embodied in machines, and otherwise embodied in organizational structures and processes, an interplay of machines, skill and processes through which organizations adapt means to ends. However defined, the distinguishing feature of technology is that it refers to stock:

1. the stock of the ways of doing things;
2. the stock of the knowledge partly embodied in machines, organizational structures and processes; and
3. the stock of physical capital, depository of practical and tacit knowledge.

More importantly the technology debate in Africa centers not on the definition of the term, but rather on the “appropriateness” of the available technologies to the socio-economic conditions of African

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<sup>9</sup> Technology as defined by Banjo (1988), is the application of knowledge, including the skills necessary to deploy principles, procedures, and processes that can be used to modify, manipulate and otherwise produce changes in the specific features of the physical world to serve human or social purposes.

agriculture. In this connection, Agboola, (1991) opines that the potentials of most agricultural technology (e.g. tractorization), are indeterminate. As the definitions of what appropriate technology is continue to grow, all terms used in describing an appropriate agricultural technology are often person, institution, regional and sometimes country specific. However defined the appropriateness of technologies are always assessed based on the following development principles: productivity, profitability, stability, suitability, sustainability, and equitability (Agboola et al., 1991). Okigbo, (1989) and McNamara, (1990), consider appropriate "an agricultural technology in which resources are utilised in such a way as to provide increasingly cost effective level of productivity with minimum adverse effects on the resource base. Obakin, (1991), consider appropriate an agricultural technology, only if it satisfies the criteria for optimum adoption.

*The concept of agricultural sustainability:* There are many definitions of sustainable development in literature. Pezzy (1989) for instance lists almost sixty definitions of the term, while the Pearce Report exhibits thirty in its gallery of definitions (Pearce et al., 1989). However, despite the divergent views on the specific boundaries of the term, recent definitions seem to have crystallized around the Brundtland Commission's definition that:

development is sustainable when it meets the needs of the present without compromising the ability of the future to meet their own needs (WCED, 1987, p. 43).

After the report, and subsequent definitions of the term (Tisdell, 1988; Babier, 1987; Perace et al., 1990; Lele, 1991; Pearce, 1993), the theoretical and operational significance of sustainability have centered on two basic concepts underpinning the management of human activities: one concentrating on development goals and the other on limiting the harmful impact of human activities on the natural environment. The basic consensus has therefore been that, while development projects should meet the current basic needs of man, it should also secure the availability of natural resources for future generations, rather than "asset-stripping" them for growth today. There are, however, many problems associated with the interpretation and application of the sustainability concept in practical terms (Dasgupta and Maler 1990, p. 16).

In this study, we define a project as sustainable its patterns of production and consumption can be reproduced indefinitely without depleting essential natural resources and ecosystems, on which future productivity depends. Attempts to translate sustainability concepts into the language of economics are not often very easy, because mainstream neo-classical economists have had little to

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<sup>10</sup> Some notable exceptions include the pioneering work of A.C. Pigou (1920) and Hotelling (1931).

say about it<sup>10</sup>. The paper therefore adopts the characterization of sustainable agricultural systems of Serageldin, (1993, p. 9):

An agricultural system is sustainable if it protects fish stocks from irreplaceable depletion, aquifers from irreplaceable depletion and pollution, fertility of soils from depletion, erosion and waterlogging, the atmosphere from excessive accumulation of greenhouse gasses and ozone layer depletion, and encourages forest ecosystems.

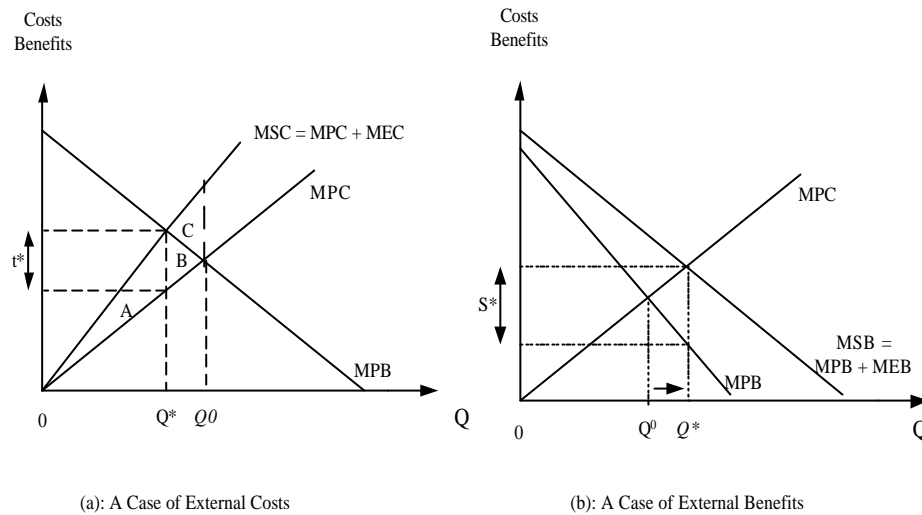
Sustainable agriculture is therefore not only a matter of short-term increases in output, it is also a matter of conserving the natural resource base on which future productivity depends, (i.e. non-declining physical resource flows from natural environment)<sup>11</sup>.

A simple attempt to operationalize this model of sustainability is that of the neo-classical school: an essential extension of optimal growth and capital accumulation concepts to include natural capital. Integrating concerns for exhaustible natural resources depletion and/or pollution externalities into the traditional growth models is therefore a neo-classical concept. A statistical fraction of requirements for sustainability is most often ensured by assuming a secular improvement over time in factor productivity; but the validity of such a hypothesis is still controversial. Many other models of sustainable development are discussed in the literature: Evolutionary models, ecological economic models, Neo-Ricardian models (see Faucheux et al., 1996, pp. 3-7), but the current study restricts its concept of sustainability to the basic neo-classical model. It therefore seeks to internalize the environmental effects "externalities" of development into the traditional neo-classical economic production models, to balance the trade-off between output growth (material throughput), and environmental quality and inter-temporal equity. Sustainable agriculture is therefore simply defined as an agricultural system that ensures a non-declining physical flow of resources from the agro-ecosystem and in per capita social welfare. This could serve as a paradigm for environmental choice and policy in agrarian economies.

*The concept of externality.* Externalities are simply defined as costs and benefits of production or consumption, which are not reflected in market prices (Babier, 1995, p. 3). This is the basic concept that underpins evaluation of environmental effects of projects. It is the primary cause of the divergence of private cost from social costs of projects (Koutsoyiannis, 1991, p. 542). Social welfare is therefore often not maximized due to project externalities (Figure 3.1).

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<sup>11</sup> Bogo *et al* (1996, page 14) also opine that "Economic development in a specified area (region, nation, the globe) is sustainable if the total stock of resources does not decrease over time".



**Figure 3.1:** Divergence of market from private optimum due to externality costs.

The triangle  $A + B$  represent the loss of social welfare due to the marginal externality costs (MEC). Attaining social optimum, thus requires internalisation of project externalities either by a quantitative restriction of output at  $Q^*$ , or imposing a pigouvian tax  $t^*$  on the production activity that lead to the MEC. In cases where marginal external benefits exists, and marginal social benefits exceeds the marginal private benefits (Figure 2.3b), social welfare maximisation requires encouragement of the production activity up to  $Q^*$ , for instance by means of production incentives, like Pigouvian subsidization  $S^*$ <sup>12</sup>. In order words, social welfare can be optimised if the net externalities of the project are fully internalized. By definition, internalization of an external effect involves the removal of its external character, making it 'internal to the economic process' (Mishan, 1971, p. 3). In order words, an externality is internalized if a market for the effect comes into being (Verhoef, 1999, p. 205).

The presence of externalities, therefore make the difference in the results that emerge from standard classical production functions. Models which ignore these externalities will no doubt

<sup>12</sup> It is important to consider both MSC and MSB in agricultural project valuation studies especially due to the multi-functionality of agriculture (see: Hodge 2000).

produce high, but unsustainable benefit forecasts that might be misleading to policy. The conflicts between environmental sustainability and conventional economic optimality should therefore be central to policy. Internalizing the externalities (socio-economic and environmental consequences of irrigation) into the main frame of its cost benefit analysis, may thus offer a good framework for considering the real economic trade-off in agriculture.

*The concept of the environmental effects:* The term environment has been defined by the New Collegiate Dictionary as “the aggregate of all the external conditions and influences affecting the life and development of organisms”. It is, however, more relevant for environmental economists to conceive the environment as systems within which living organisms interact with the physical elements of nature (see Sada, 1988; Abrams, 1971). These external physical factors of interaction could be biological, social or cultural (Keller, 1976). In recent literature of the developing discipline of ecological economics, the environment is often alluded to as natural capital, which is conceived to comprise of renewable and non-renewable resources. Thus defined, the environment is considered as degraded, when injurious substances (pollutants) are introduced, which, by fouling it, reduce the satisfaction or utility derivable from it, by organisms growing in, developing and interacting with it.

These definitions make the conceptualization of “environmental effects” controversial. For ecological economists, of the infinite consequences of present actions, processes or projects, on both intergenerational equities and intra-generational/inter-temporal distribution of natural capital is indeterminate due to irreversibility and non-substitutability of impacts. Conceived as such, measurement of the effects of projects on the environment is constrained by ontological and epistemological ignorance as well as the chaotic patterns of environmental change — “a low probability high risk event”. Monetization of effects of projects on the environment and internalizing them into policies, are therefore necessary but not sufficient conditions for sustainable environmental management.

On the other hand, environmental economics, as a paradigm on which the current study is conceived, perceives environmental effects of projects as an ‘externality concept’. These are measurable in terms of the neo-classical models of optimal resources allocation (the Pareto Criterion). ‘Environmental effect’ is therefore a social welfare concept.

### **Theoretical background to technology-environment nexus: the sustainability debate**

The last two decades have witnessed prolific growth in the literature on the relationship between technological innovations and environmental sustainability. These concerns are however not new in economic literature. Malthus (1834) stressed the importance of capital as a vehicle of economic growth, Engels (1959) argued for the significance of technological progress, in his trenchant attack on the Malthusian theory of limits to growth. Ricardo (1817), on the other hand describes labour and capital as paramount in the production process. Subsequently, most economic growth theories of the mid Twentieth Century seemed to favour only capital and labour as the main determinants of production. In 1959, technological change was explicitly included as an exogenous variable in production functions (see Solow Swan Model, 1956, 1957). The neo-classical theorists paid increasing attention to natural resources as a factor of production, but it was generally believed that



such factors are unlikely to pose limits to growth (Solow 1974, 1986). There was a general optimism about the role of technological innovations on the growth-environment nexus (see for example, Johnston and Cownie, 1969; Ruttan and Binswanger, 1978).

In the early 1970s, endogenous growth theories incorporated human capital (such as production and transmission of knowledge) into production models and allowed for possible effects of external economies on output growth (see Romer, 1986 and 1994). The possibility of environmental and natural resources diminution limiting growth and productivity of factors, were, however, not well defined.

This technology driven economic growth model immediately came under criticism within the same period (1970s), mainly by ecologists and environmental economists, based on the idea that continued exploitation of the natural resource base will eventually undermine the sustainability of the world economy (see for example, Maler, 1974; Pearce et al., 1990, 1993; Pearce and Turner, 1990; Pearce and Warford, 1993; Perrings, 1995; Turner et al., 1993). Yet these views also vary amongst the different proponents of the precautionary principle to growth. To date, the argument is best described as inconclusive. Tietenberg (1996), however, identifies two extreme models: the pessimist and the optimist models.

*The pessimist model:* Drawing on the basic assumptions of Malthusian theory, the pessimists perceive the environment as a fixed stock of resources that is inversely correlated with output growth. Economic growth can therefore not go on indefinitely due to environmental constraints and externalities. Raising the levels of output through technological growth will therefore, not only deplete the stock of capital, but, will also exacerbate discharge of "production residuals" (pollutants) and inevitably disrupt the natural ecosystem on which economic growth depends.

These views are typified in the statement of the United States Ecologist Commissioner at the 13th National Conference of the US Commission for UNESCO in 1969:

"The ecological facts of life are grim. The survival of living things, including man, depends on the integrity of the complex web of biological processes which comprise the earth's ecosystem. However, what man is now doing on earth, violates the fundamental requisite of human existence... Modern technologies act on the ecosystem which supports us in ways that threaten its stability: with tragic perversity we have linked much of our productive economy to precisely those features of technology which are ecologically destructive".

Other publications which called into question the feasibility and sustainability of technological growth on environmental grounds were Ehrlich and Ehrlich, (1970); and Goldsmith et al., (1973). Subsequently, the pessimist model assumed a central position in growth modeling with the "doomsday message" of the 1970s typified in the limits to growth published by Meadows et al., (1972).

Using historical values from 1900 and 1970, the model shows that food, industrial output and population, grow exponentially until the rapidly depleting resource base forces a slow-down in industrial technological process. These views were relatively ignored until 1970s and more recently when the OECD, in their Paris Summit re-iterated that:

Widely replicated present technologies and practices would choke the world in waste and pollutants... A significant increase in these wastes as developing economies expand would severely exacerbate waste disposal and health problems in urban areas, increase pollution damage to crops and forests and the potential for global warming. These cannot be sustained indefinitely (OECD, 1991, p. 33).

This shifted the emphasis from resource depletion to pollution problems that are associated with technology packages. Since then, the limits to growth thesis have spawned an immense literature.

Summarily, the extreme views of the pessimists are essentially Malthusian, with the basic argument that the fixed environmental resource base would limit growth in the near future. Attempts to increase output through technological innovations would instead exacerbate pollution and natural resource degradation, which in turn, limits growth. This is therefore not sustainable.

*The optimist model:* Contrary to the pessimists, the optimists view technological innovations as the engine of economic growth, agricultural productivity improvement and international competitiveness, especially in less developing countries (LDCs) (Kahn, 1976; David, 1992; Kayode, et al., 1995; Wright, 1995).

The basic assumption of the optimist is mainly that continuing technological evolution would serve to push back the natural limits to growth, envisioned by the pessimists, until they are no longer limiting (Tietenberg, 1996, p. 8). Painting a scenario for America and the world, Kahn et al. (1976) proposed an S-shaped logistic curve for growth of the world economy. The basic conclusion of the model is summarized in Kahn, (1976, p. 1):

...200 years ago, almost everywhere human beings were comparatively few, poor and at the mercy of the forces of nature, and 200 years from now, we expect, almost everywhere they will be numerous, rich and in control of the forces of nature.

He therefore argues that natural resources would not limit growth, since the availability of physical resources can be expanded through the use of better technologies, such as irrigation. If soils become depleted or scarce, food production can be raised with hydroponics and single cell protein technologies.

The set of arguments has been summarized by Tietenberg (1996, page 9):

Substantial increases can be expected in conventional food produced by conventional means, conventional food produced by unconventional means, unconventional food produced by conventional means, and unconventional food produced by unconventional means.

In 1981, Professor Zschau further buttressed the optimists' views by referring to Professor R. Solow's model. The optimists therefore believe that the depletion effect of natural resource exploitation would be controlled by technical change, which will augment the quality of capital and labour, and allow for, among other things, the extraction of lower quality non-renewable resources (Pearce and Turner, 1990, p. 13).

From the foregoing, it is clear that controversies surrounding theories on technology-environment nexus are best described as inconclusive. In the 1870s to 1970s, mainstream economists (with some exceptions) believed that economic growth was indefinitely sustainable due to the “buffering effect” of technological innovations on natural resources diminution. A number of views in the 1970s, 1980s, and 1990s have crystallized with environmentalism providing the background for emerging contradictions to these theories. Even in Ricardo’s model, economic growth peters out in the long-run, because of the relative scarcity of natural resources. He acknowledges the fact that diminishing returns to production sets in not so much, because of lack of technical progress, but rather a necessary outcome of production. On balance, it is now widely recognized that technology-environment relationships can be very delicate, and that ruthless pursuit of growth can cause substantial irreversible damage to the environment. While the “Malthusian pessimists” see a global system of diminishing returns as imminent, the “technological optimists” are convinced that this will be overcome by new technologies that will maintain the momentum of ever greater productivity of all (classical) factors of production (land, labour, and capital). Building the capacity of societies to monitor and/or mitigate the externalities of specific technologies is therefore an important long term strategy to sustainable development.

### **Irrigation process and environmental degradation: evidence from other countries**

Like most projects, irrigation has a wide range of beneficial and harmful effects on the environment. The beneficial effects are often reflected on the welfare gains by farmers due to increased crop output and the multiplier effect of this on national incomes and food security. On the other hand, its numerous deleterious effects have been documented as either “on-site” and “off-site” effects (WRI 1992). For the purpose of this paper, the environmental impacts of irrigation are classified as:

- On-site edaphic impact including soil salinization, leaching, erosion and water logging, which reduces soil fertility and the carrying capacity of arable land.
- Off-site aquatic impacts including effects on water flow and water quality, fish stock and other aquatic resources and pharmaceuticals. These are reported in form of varying degrees of nitrate pollution and run-off of fertilizers and agrochemicals into aquifers and water courses. They impose external costs on water users and damage ecosystems.
- Off-site biotic effects including impacts on human and livestock health. These are reported in form of pesticide pollution of air and domestic water sources, pesticide residues on crops and livestock and breeding of water borne disease vectors. All these cause varying levels of illness and disease epidemics in irrigated areas.
- Off-site effect on bio-diversity including effect on wildlife and genetic diversity of crops. These occur in form of desiccation and pollution of available water sources, causing depletion in the stock and species of aquatic life (fish, algae).
- Off-site climatic effects including greenhouse effects at local and regional levels.

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*On-site effect on soils:* Since irrigation permits growth of two or three annual crops on the same piece of land, such an intensive cropping regime will necessarily deplete soils. Shrivastava (1994, p.

52) for instance, argues that such an intensive cultivation of land would ultimately lead to springing up of deserts. Salts contained in surface water also become concentrated on irrigated land through evaporation and seepage, thus causing soil salinity.

Empirical evidence on this has been documented in many case studies. Yudelman (1989) for instance, reports cases of salinity affecting crop yields in irrigated zones of the Indus River (Pakistan), the Nile Delta in Egypt, parts of Iraq, Peru, Mexico and the interior communities of North East Brazil. Mustapha and Pingali (1995, pages 733-750) also report similar productivity trends in irrigated areas of Pakistan, due to soil salinity and water logging. In India, over 87% of irrigated farms were reported to be water logged and saline, forcing 29% of cropland out of production and reducing rice and wheat yields by over 50% and 78%, respectively (Joshi and Dayanatha (1990). The Science Council of Canada (1986) also reports cases of salinization that lowered crop yields and made land unsuitable for cultivation in Canada. On the basis of this evidence on salinizing effects of irrigation, ISRIC (1990) defines salinization as increase in the salt content of soils due to poorly managed irrigation schemes in semi-arid zones, salt-water intrusion into the ground water and the accumulation of salt from saline ground water or parent rock, because of high moisture evaporation in intensively irrigated areas.

### ***Off-site effects***

#### (1) Impact on water flow and water quality, fish stock and other aquatic resources

Irrigation schemes inherently divert water flows and interfere with the previous flow patterns through the catchment area. Irrigation is reported to account for over 86% of water withdrawals in Asia and in many countries of North Africa and the Middle East, occurring at unsustainable rates (UNEP 1991, p. 176-177). This has various effects on aquatic life (fish stocks for example), and leaching and/or return waters from irrigated farms also pollute surface and ground water bodies with agro-chemicals. Various upstream irrigation dams in the Euphrates are reported to have increased the salinity of the rivers downstream and also reduced their volumes (Winpenny, 1995, p. 26). The use of fertilizers and pesticides also contaminated drinking water in Egypt (Yudelman, 1989). In a study of 26 zones of the United States, Engberg and Feltz (1998) report higher concentrations of trace elements and pesticide residuals in irrigated areas of the study. Irrigation return water in the upper Euphrates catchment of Turkey and Syria as also reported to be highly saline up to twice the concentrations found in the river's natural flow (Beaumont 1996). In comparison, the salinity of the water courses in this study area before irrigation, were significantly lower (Beaumont 1996). According to Myers et al. (1985, p.10):

public water quality related effects including run-off of fertilizers and pesticides into surface waters and leaching of these into ground water, constitutes a very significant effect of irrigation on human welfare.

These appear to be even more costly than the on-farm impacts on soils and crop productivity (Chapman et al., 1985, p. 7).

## (2) Impact on human and livestock health

Irrigation has both positive and negative effects on human and livestock health. The positive effect is the derived benefit of increased supply of food for human nutrition and livestock feed, farm income for health expenditures accruing from the effect of irrigation on crop productivity and employment opportunities as irrigated farming intensifies (Winpenny, 1995, p. 28). However, the negative risks to public health of irrigation seem to dominate the literature on the health impacts of irrigation. These are documented under three broad categories:

### *(a) The effect of chemical residues on soils, crops, water bodies and atmosphere*

Residues on soils and crops can enter the food chain and cause different levels of debilitation and diseases for both man and livestock, but polluted air and water bodies have caused respiratory diseases in many places. It is estimated that over 10,000 people die and 400,000 suffer acutely from pesticide poisoning caused by irrigation every year (Repetto, 1985)<sup>16</sup>. According to the WHO (1990, p. 86):

“the incidence of pesticide poisoning is poorly documented, but is considerably significant, causing 20,000 deaths and one million illnesses per year in irrigated areas world-wide”.

Vanderhoek et al., (1998) also identifies pesticide poisoning as a major health problem in irrigated areas of Sri-Lanka.

### *(b) The effect of water-related tropical diseases/pests encouraged by the anthropic environment in irrigated areas*

This is the most widely documented of the health impact of irrigation (Winpenny, 1995; Tiffen, 1990; Cifuentes et al., 1993; Forattini et al., 1993a, 1993b, 1994). The first type of health risk arises from water borne diseases and pests, whose growth and development is encouraged by the anthropic environments associated with irrigated agriculture. Cifuentes' study in Mexico, shows that irrigating farmers had more problems with diarrhoea diseases and parasitic infections like ascarids and lumbricoides than farmers in unirrigated areas (Watts et al., 1998, pp. 755-765; Cifuentes et al., 1993, pp. 614-619). Wild (1997, p. 1252) also identifies irrigation as a hydrokinetic factor causing urinary catheter disease in the United States of America (USA).

The second type of health risk comprises diseases passed to humans by insects (vectors) that breed on water surfaces. Malaria and schistosomiasis (bilharzia) are the most widespread of this category (Winpenny, 1995, pp. 29). In certain places, lymphatic filariasis (elephantiasis), onchoceroiasis (river blindness) and Japanese encephalitis are reported as the main dangers (Tiffen 1990). Forattini et al. (1993b, pp. 316-325) also reports cases of increased breeding of mosquitoes (*Diptera culicidae*) and *Anopheles albitarsis* species in flooded rice fields in south eastern Brazil. The findings of the study suggest a hypothesis that the development of irrigation schemes may be a factor in the emergence of *Anopheles albitarsis* species (a primary causative agent for malaria), some other mosquito species and the cause of increased transmission of mosquito

borne diseases in Sri-Lanka. Forattini et al. (1993a, pp. 227-236) also established a linear relationship between a rice irrigated system and mosquito breeding in Riberia valley, Brazil. Compared with unirrigated areas of the valley, the study shows that most disease vectors, especially *Anopheles nyssorhynchus* and *Culex melanoconion*, show high degrees of adaptation to anthropic environments of the irrigated zones.

(c) *Disease infestation risks caused by overcrowding and multiple use of irrigation waters*

The third source of health risk arises from overcrowding of people and livestock in irrigated areas, causing epidemics of contagious and zoonotic diseases in project areas (Carruthers, 1968, p. 7).

(3) Effect on wildlife and genetic diversity

The creation of irrigation canal networks involves river diversion and flooding, and destroys previous habitats, to create new ones (Edo and Compadre, 1995, p. 61). The diffusion of new, genetically uniform, high yielding crop varieties, also reduces crop diversity over large areas. This makes crops more susceptible to disease. Irrigated agriculture was reported to have contributed significantly to deforestation, adversely affecting flow velocity of rivers and indigenous fish species and replacing 200,000 ha of natural wildlife habitat in Sri-Lanka (see Imbulana et al., 1996, pp. 1 and 11). This aspect has not been empirically evaluated in most countries. What is found in literature are reports of biodemographic alterations, caused by irrigation in some countries (see Edo and Compadre, 1995, pp. 61-70; Parasuraman, 1995, pp. 227-242; Shettima, 1997, p. 66-70) for Northern Spain, Karnataka and Nigeria, respectively.

(4) Effects on climate

Like other schemes that entail the creation of extensive new surface water bodies, irrigation can temper local climates through the cooling effect of water. The vegetation associated with irrigation also provides welcome shade in arid conditions and its green house effect is also minimal. According to Winpenny (1995, p. 30):

on the global scale, methane production from irrigated fields is believed to be a minor contributor to green house effect (adding only 5% or less to green house gas emissions)

Like the impact of irrigation on biodiversity, its contribution to climate change is mentioned only fleetingly.

**Discussion**

From the foregoing, it is evident that irrigation projects have affected the environment in many deleterious ways. However, the on-site effects on soil fertility, salinization and waterlogging, and its impact on human health and water quality, dominate available literature on the subject. Several other problems may also emerge from the technology that is yet to be documented. Observed effects also varied with the types and location of projects. The long-term prognosis for the sustainability of irrigated agriculture is not clear.

## **Chapter Four**

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### **Irrigation Technology in Nigeria and Swaziland: Research Findings and Limitations**

#### **Presentation of results and findings**

This section presents the results and findings of this research project.

#### *Irrigation systems in Nigeria*

The major types of irrigation technology that presently benefits small farmers in Nigeria comprises the small scale surface irrigation types (see Erhabor, 1977; Erhabor and Miller, 1981; Palmer - Jones, 1977a; Abalu and D'silva, 1980; Norman, 1972; Nigeria's Second and Third Development Plans 1970-1974, and 1975-1980). According to Erhabor, (1982):

Irrigation development in Nigeria has largely been on small scale basis. From 1956-1965, the focus of irrigation development shifted from large schemes in Sokoto and Middle Belt Provinces to small schemes. Throughout the 1960s, the eastern division concentrated on small scale rice projects in the Niger valleys. Between 1955 and 1960 about 500,000 pounds, out of the total 1,863,000,000 pounds capital expenditure, was allocated to these (small scale irrigation) schemes.

This buttresses the Federal government's commitment to small scale irrigation technology for the overwhelming majority of her farmer population - the small holder farmers.

The large scale irrigation schemes which were developed in the northern part of the country in line with the Food Agriculture Organization (FAO) recommendation (see First National Development Plan, 1962 -1968), were variously criticised in the 1970s and 1980s (see Patrick et al., 1975; Palmer -Jones, 1977a; Erhabor, 1982), and hence, the present emphasis on small schemes. Such studies uncovered that the large schemes were not suitable to Nigeria's small farmers due to its cost intensity, unsuitability to farmers' small land holdings and the general farming systems, and other deleterious externalities accruing from its scale and the socio-demographic features of the small farmers. Commenting on the weakness of the large scale irrigation projects, Abalu and D'silva (1980) noted that:



even if the country could afford the heavy investment that would be involved, the tendency would be to create a landless class by displacing original owners of land and replacing them with more wealthy individuals. In the absence of alternative employment opportunities, the result would be abject poverty in rural areas and urban areas, which would experience heavy migration from the rural areas.

Norman (1972) opines that the persistence of small scale irrigation technology among African farmers over the years is best summed up in their farming system - which reflects the attempts of farmers to adapt to their environment over periods of time. Since they have low levels of farm resources, the level of technology they prefer has been biased towards the low risk and low productivity traditional technologies that have been used by their ancestors for generations. There are, however, very sound reasons for the system of production they have adopted. Erhabor (1982) opines that this is because the small scale schemes are relatively inexpensive, require little foreign investment and operation with local resources and labour. His preliminary assessment of the northern states of Nigeria (1982), thus underscores the dominance of the small scale traditional lift devices (with rivers, streams and wells as water sources).

Evidence from the survey shows similar trends. Rivers, lakes, streams and wells are the dominant irrigation water sources in Nigerian small scale farms (Uguru, 1996). As enlisted by Uguru (1996), the major types of small scale surface irrigation technology used by Nigerian small farmers include:

1. *Basin irrigation* is the simplest and most common of the surface irrigation technology. The farmland is divided into two or more basins using earth bunds, and water that enters the basin is retained until it infiltrates. The size and shape of a basin vary, depending on the type of crop, soil and farming system. Every basin is usually level land.
2. *Border irrigation* involves splitting the land into strips, which slope uniformly away from the water entry points or farm channels, in the direction of the water flow. They are long and narrow shaped. Border irrigation can be adapted to suit many field crops, soils and farming systems.
3. *Furrow irrigation* involves the making of small channels, known as furrows, through which water flows and infiltrates into the root zone of the crops that are planted in ridges.
4. *Pressurised irrigation methods*, unlike the other surface irrigation methods, are characterized by the single factor that they apply water at the points where water is needed. There are two main types, namely: sprinkler irrigation and trickle or drip irrigation.

The sprinklers are of three types, viz.: the rotating or rotary sprinklers, the spray-type nozzles, and the perforated pipes. The rotary sprinklers are most common in developing countries, but because of the low level of technology in Africa, they are still being used sparingly.

The selected irrigation project in Nigeria uses only the basin irrigation technique with rivers serving as the primary irrigation water source.. The project area is organized in 4 zones: north east (NE), north west (NW), south east (SE), and south west (SW) zones, respectively. The irrigation water is drawn from the Anambra and Obina rivers, Omor and Adani of Anambra and Enugu States, respectively, by means of two giant pumping engines located at the bank of each river. The water

from the rivers is pumped into the main canal where it is distributed by gravity to the cropping zones of each project. The zones are plotted out into units of 10 ha, which are further divided into fields of 0.5 ha, that are allocated to participant farmers on annual basis.

The major components of the irrigation infrastructure in both projects are:

- The pumping station consisting of five pumps and an engine and an intake structure located 16.5 km upstream on both rivers.
- A head race canal measuring 16.7 km long, which bifurcates into the east and west main canals with a total length of 23 km.
- Irrigation canals made up of 12 km secondary canals, 50.6 km tertiary canals and 270.6 distribution canals, and drainage canals, totaling 450 km.

The RBDA does not engage in direct rice production, but in addition to providing irrigation water, helps the farmers to obtain machinery, fertilizers, herbicides, and necessary advice on rice cultivation under irrigation. Evidently, this type of irrigation if adopted will make its effects evident on the environment.

### ***Irrigation systems in Swaziland***

The systems of irrigation in Swaziland can be considered from the point of view of the scale of operation and the method of water application used. Irrigation systems largely follow the duality of the land tenure system in Swaziland, namely, those operated on SNL and TDL. Much of the large scale irrigation takes place on large TDL company estates, and private TDL farms that are engaged in large scale production of sugar-cane, citrus, cotton, pineapples and trees for pulp and lumber production. The farmers on this land, use surface, sprinkler and buried pipeline, with orchard valve and drip irrigation systems.

*Irrigation on TDL:* Much of the large scale irrigation takes place on large TDL company estates and private TDL farms that are engaged in large scale production of sugar-cane, citrus, cotton, pineapples and trees for pulp and lumber production. The farmers on this land use surface sprinkler and buried pipelines with orchard valves, and drip irrigation systems.

*Irrigation on SNL:* Irrigation on SNL is generally at a small scale level and often takes the form of a scheme, either a cooperative, government run, or privately run (Sithole and Testerink, 1983). There are basically three major methods of irrigation in use on farms on SNL, namely, furrow, sprinkler and hand watering. Flood or basin irrigation is also used on SNL farms, but most farmers use one of the three methods mentioned earlier. Furrow irrigation is the common method in use on SNL, particularly on association/cooperative farms. Most of the individual and some of the cooperative farms are irrigated using sprinkler systems. Hand watering is used on individual farms where the method of water application varies from use of simple watering cans or buckets, to use of flexible hose-pipes

carried from plant to plant. Irrigation on SNL is under four irrigation schemes, namely, RDA programme, cooperative or association of farmers, private SNL farmers, and Swaziland irrigation schemes.

*RDA programme:* RDAs are located in the SNL to develop agriculture and improve the rural infrastructure (such as roads, social services and markets). There are 13 RDAs with 29 sub-areas of potentially good land for irrigation, all over the SNL. Most of these areas have suitable land for irrigation. The government of Swaziland has established irrigation projects serving 10 to 25 small scale farmers with farm sizes of 1 to 3 ha (Richardson, 1985). Most of the schemes are furrow-irrigated, with a typical system consisting of a diesel or electric pumping plant, a reservoir, unlined canals and land leveling. Canals and irrigated areas are normally fenced to keep animals away. There is no rent or water charge in any of the schemes. The irrigation systems are designed and constructed with the help of the Ministry of Agriculture and Cooperatives (MOAC), but the farmers do the maintenance of the canals themselves.

There are five irrigation methods commonly used in Swaziland (Booker Tate, 1997), namely, furrow, dragline sprinkler, floppy sprinkler, centre pivot and drip irrigation:

*Furrow irrigation* is a simple, low energy method used by many smallholder irrigators in the country (Atkins, 1998). However, while it is relatively simple to manage, the system is comparatively inefficient and thirsty, and is not a suitable option for difficult or shallow soils, and has the disadvantage of being labour intensive.

*Dragline sprinkler* method is relatively low cost option used by many new small holder irrigation farmers. Application efficiencies are quite low and operating costs high to ensure water is pumped to moderately high pressure nozzles. The major disadvantage is the need to move the sprinkler frequently, especially on shallow soils.

*Floppy sprinkler* method is a solid set design that has undergone considerable refinement during the last few years. Due to its low nozzle pressures, the method uses less energy than the dragline and conventional solid set methods. A floppy sprinkler is simple and easy to maintain. It is easy, with low labour requirements and high water efficiency. However, the system has relatively high capital and installation costs and is untested, albeit on small areas in Swaziland (Atkins, 1998).

*Centre pivot irrigation* method is popular in Swaziland, but expensive. It is automated and has a high efficiency rating, with low energy and labour requirements. It is, however, difficult to maintain. Since it irrigates along circular routes, land on field corners is left out. It is estimated that some 22% to 25% of the potential irrigable land area can be excluded from the installed system (Atkins, 1998).

*Drip irrigation* method is used mainly on tree crops. It provides high water use efficiency, but is expensive to install and very difficult to manage, especially with buried system where leaks and crop intrusions can remain undetected for some time. Another problem is that the

system demands high quality water, and frequent flushing and chemigation to avoid system malfunction.

*Furrow irrigation on SNL:* Furrow irrigation is the common method in use on SNL (Dunn, 1986), probably owing to the fact that it is an effective, relatively inexpensive and simple method of water delivery. Furrow irrigation is the sole method of water delivery for the associations/cooperatives (with the exception of rice schemes) and is also used on many of the individual irrigated farms. The current study focuses on furrow irrigation as a surface irrigation technology used by small scale farmers on SNL.

During his irrigation research in Swaziland, Dunn (1986) observed that furrow irrigation systems on SNL have five unique, but important characteristics that influence the performance of the system and the level of crop production. The first characteristic is the common practice by farmers to irrigate only one furrow at a time, using all of the water available for the one furrow. After the furrow has filled to certain level, the farmer shifts the water to the next furrow. The second feature is that furrows are blocked at the end to prevent run-off of water. Essentially, this makes the furrow a long narrow basin, which is filled with water to a certain level before the in-flow of water is shifted to the next furrow. This is an important aspect of the system since the amount of water which infiltrates the soil and fills the root zone to field capacity, depends on how long water is in contact with the surface. With this system, water infiltration is insignificant and total volume of water applied is equal to the storage capacity of the furrow. There is no run-off, hence, the delivery efficiency is close to 100%. However, because the contact time and hence the infiltration time is insignificant, the crop water use efficiency may be very low. The third feature is that farmers on many individual irrigated farms and all associations/cooperatives break the irrigated field into crop/management blocks. These blocks are perpendicular to the length of the field and, hence, establish the furrow length. The blocks vary in length according to the number of crops, planting dates, resources and field length. It is not uncommon to find a 100m long field broken into five blocks, each approximately 20m long. The fourth feature is that furrow lengths are relatively short and variable, ranging from 5m to 150m. This characteristic, coupled with the practice of irrigating one furrow at a time and lack of run-off, accounts for lower water use efficiency by crops. The fifth feature is the tendency of farmers with furrow irrigation to plant on the sides or bottom of the furrow, rather than at the centre of the bed. This affects cultivation, fertilization, and crop quality.

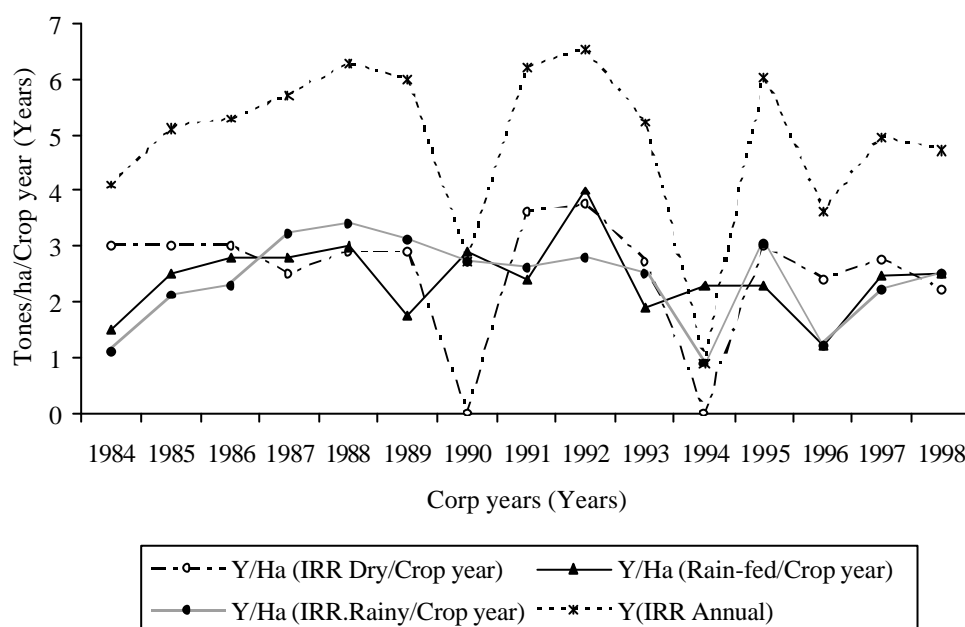
### **The impact of irrigation on crop productivity in the case study areas**

Only a preliminary analysis is presented at this stage of the project. This is because during the follow up surveys, it was observed that the present institutional framework in both countries does not warrant adequate costing of factor inputs in both systems. However, since this institutional distortion of data is consistent in both systems and across the countries, we still reason that the results obtained from this analysis will not be affected in absolute terms. The accuracy of particular monetary estimates used for the analysis is constrained by the present institutional framework. Subsequent research on the subject should attempt to factor in these institutional variables into the analysis, in order to create an updated database for detailed analysis as is necessary. This limits the scope of current analysis

and hence the level of conclusions reached from the available data. Nevertheless, this does not hamper the policy implications of the current research. As a baseline study, the aim of the analysis is to explore the subject area, and possibly generate hypotheses that would direct further inquiry on the subject. The present institutional framework: the irrigation land ownership/annual rental system, the subsidization of other irrigation facilities, leaves the farmers blindsided as to the real cost of the irrigation facility, and prevents proper cost-benefit analysis of the system. As typical in most developing countries, the farmers perceive that developed resource(s) are free goods and hence attribute no personal cost to them. This affects resource use and stewardship in Africa.

#### *Crop productivity trends in both systems in Nigeria*

The trends in crop productivity in the Nigerian irrigated and upland farms sampled are presented in Figure 4.1.



**Figure 4.1:** Trends in Output per Hectare in both Systems (1984 -1998)

Source: Historical yield data (1984 -98)

On a crop year basis, the figure shows that the output of rice paddy per hectare has been more stable in the upland systems than in the irrigated counterparts. A 5-year moving average of the annual yields across the systems also confirms this claim (Table 4.1).

**Table 4.1:** A 5-year Moving Average of Annual Yields in both Systems

Crop Years Irrigation.	Annual Yield (Tones per Hectare)		% Change due to
	Irrigated	Upland	
1984 - 88	2.88	2.46	+17.07
1989 -92	2.04	2.59	-21.08
1993 -97	2.03	2.0	-1.33
Mean	2.60	2.39	+8.74
% Growth Rate between 1984 & 97	- 29.25	-16.05	

(-) represents a decrease; and (+) represents an increase.

Source: Historical data collected from annual reports of the RBDAs studied.

Table 4.1 shows that average yield in both systems have declined over the years, but the rate of decline has been more in irrigated farms by about 13%. There was a 17% increase in crop yield due to irrigation in the first 5 years of introduction, but this trend has continuously declined thereafter. On the aggregate, irrigation has only increased output by 8.74% in the study area. This suggests that the irrigation scheme studied does not have a significant influence on crop yield. Based on the trend lines, crop productivity in the study area is predicted to rise by 13.34 % in the rain-fed farms each decade, while decreasing by 19.15% in the irrigated farms. This represents a predicted crop loss of about 0.4813 tons per ha in irrigated farms and a gain of about 0.303 tons per ha of the upland farms within the next decade. These results diverge strictly from the findings of Asadu et al. (1996), reporting about 450% increase in rice output due to irrigation in the study area. There was a significant increase in rice output (as reported in the study), due to introduction of irrigation at the onset of the project life, but this may have been due to the external economies of the government presence (access to improved production inputs), brought about by the irrigation project location in the area, rather than by the technology per se. This hypothesis is explored further studies.

It is, however, acknowledged that the project is still young for conclusive claims to be made, but other studies have also reported similar trends. Based on his findings, Carruthers (1968: p. 14), concluded that there has been little or no general yield increase in the irrigated regions of Indo-Pakistan over the centuries. In a more detailed analysis of yield trends in more than fifty countries, Collin Clerk (1960) reports that yield stagnation is fairly general in poor countries. Even in countries obtaining high yield (Egypt and Japan), sustained yield increases were extremely rare. It is, however, not very expedient to transfer such claims to the Nigerian case. A more detailed country-wide study is therefore necessary to explore the real effects of the irrigation schemes on crop productivity, especially in the rain forest regions like Nigeria.

***Comparing the productivity of factors between the systems.***

The Cobb-Douglas production function was used to measure the effects of labour costs ( $X_1$ ), irrigation land rents and water charges ( $X_2$ ), and the cost of other variable inputs, including seeds and agro-chemicals (fertilizers, herbicides, and insecticides), used ( $X_3$ ), on output. The following results were obtained from the baseline data collected from our survey of eastern Nigeria and Swaziland, conducted in 1998:

For irrigated farms in Nigeria:

$$\begin{aligned} \ln Y_{(IRRIG)} &= 5.51 + 0.04 \ln X_1 + 0.18 \ln X_2 + 0.39 \ln X_3 \\ &\quad (2.23)^* (0.17) \quad (0.28) \quad (0.08)^* \\ R^2 &= 45\%, \quad N = 40, \quad F = 9.98^* \end{aligned} \quad [1.1]$$

For upland farms in Nigeria:

$$\begin{aligned} \ln Y_{(UPL)} &= 8.85 + 0.34 \ln X_1 - 1.04 \ln X_2 + 0.62 \ln X_3 \\ &\quad (3.39)^* (0.11) \quad (0.55) \quad (0.10)^* \\ R^2 &= 80\%, \quad N = 40, \quad F = 47.09^* \end{aligned} \quad [1.2]$$

For irrigated farms in Swaziland:

$$\begin{aligned} \ln Y_{(IRRIG)} &= 8.67 + 0.17 \ln X_1 + 0.23 \ln X_2 + 0.63 \ln X_3 \\ &\quad (3.46)^* (0.33) \quad (0.22) \quad (0.11)^* \\ R^2 &= 48\%, \quad N = 229, \quad F = 17.23^* \end{aligned} \quad [1.3]$$

For upland farms in Swaziland:

$$\begin{aligned} \ln Y_{(UPL)} &= 6.85 + 0.24 \ln X_1 + 0.96 \ln X_2 + 0.28 \ln X_3 \\ &\quad (3.17)^* (0.09)^* \quad (0.31)^* \quad (0.07)^* \\ R^2 &= 74\%, \quad N = 42, \quad F = 27.44^* \end{aligned} \quad [1.4]$$

where (\*) = Significant at 5%, ( ) = Standard error estimates.

The parameter estimates represent the relative proportion of rice output contributed by unit increases in the respective variables.

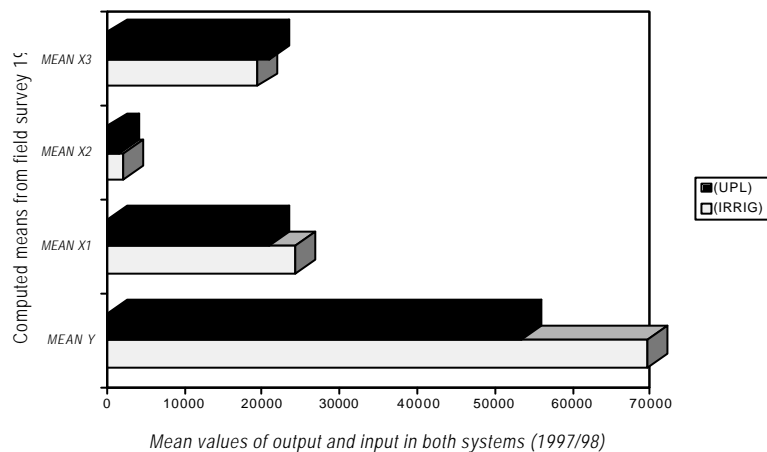
These results show that for Nigeria, only variable capital costs have significant contribution to output, at 5% significance level, with a production elasticity of 0.39. This implies that a percentage increase in investment on variable inputs, like improved seeds and agro-chemicals (fertilizers, herbicides and insecticides) in the irrigated farms, would increase farm output by 39%, respectively. The returns to labour, land and water resource use in the irrigated farms, are rather low and statistically insignificant. In the upland farms, all three variables are statistically significant and their relative elasticity of production, increase tremendously. The pattern of significance of variables is similar for Swaziland, but the return to variable costs is higher in irrigated farms than in their upland counterparts. These findings are of crucial importance to farm credit policy targeting and other farm management policies in the affected projects. Increasing access to variable inputs (fertilizers, insecticides, fungicides and improved seed varieties), is central to improved crop productivity in both irrigated and upland rice producing farms in both Nigeria and Swaziland.

However, this has to be done with caution: the exogenous variables of the standard models specified ( $X_1 - X_3$ ) can only explain 45% and 80% of the variation in the endogenous variable (output Y), in the irrigated and upland farms in Nigeria, respectively. About 55% and 20% of the variations are therefore subsumed in the stochastic variable ( $\mu$ ) in the irrigated and upland systems, respectively. The exogenous variables of the models specified ( $X_1 - X_3$ ) for Swaziland, can only explain 48% and 74% of the variation in the endogenous variable (output Y), in the irrigated and upland farms, respectively. About 52% and 26% of the variations are therefore subsumed in the stochastic variable ( $\mu$ ) in the irrigated and upland systems, respectively. This suggests that the models are either not completely specified or that the data collected are not robust, especially for the irrigated farms. A look at the moments (mean, mode and median) of the output data in both systems, does however, suggest that the sample is normally distributed, thus shifting the hypothesis to the former. The implication is that there is still more to the productivity problems that cannot be explained in the present analysis.

Nevertheless, one clear result of the present analysis is that the influence of labour costs ( $X_1$ ) and irrigation facility [land and water charges ( $X_2$ )] on irrigated farms in Nigeria, were not significant even at 10%; on upland farms, they were significant at 5% and 10%, respectively. This may be due to the management system of the project studied. Plots of land are developed by government and rented out to participant farmers at highly subsidized rates. The cost of land and mechanized labour are therefore, not fully internalized in the private farmer's cost streams, as included in the Cobb-Douglas model. On the other hand, the upland systems are more often personally run by local farmers. The latter is therefore more amenable to the profit maximizing production scenario assumed in the Cobb-Douglas model. The influence of other variable costs ( $X_3$ ) is positively significant at 5% in both systems and countries. One imminent policy intervention that could boost productivity in both countries, would therefore, be improving the access to variable inputs (improved seeds, fertilizers, insecticides and fungicides), by farmers. Government involvement in the development of irrigation facilities may not be as crucial to improving productivity as presently perceived.



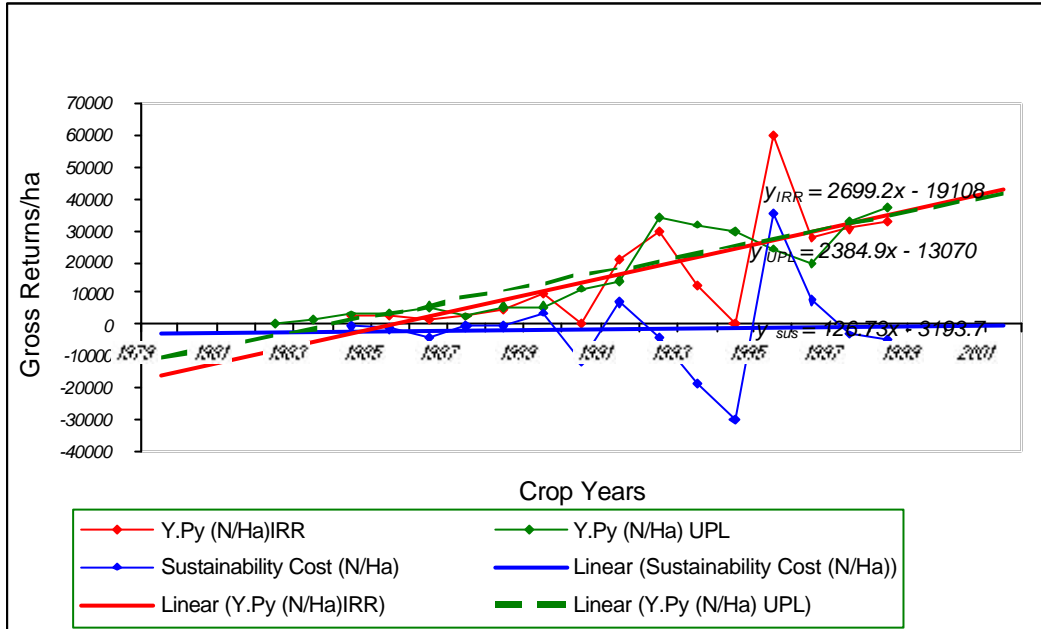
*Tests for differences in means:* The null hypotheses of zero difference in mean output and variable inputs used between the two systems were tested using the Z-tests, since  $n > 30$  in each case. The results show that there is significant difference in crop output realized from the irrigated farms and the upland farms, but that the cost of labour and land/water inputs were also significantly higher in the irrigated systems at 5% levels of significance. The difference in the cost of land and water charges is, however, significant at 1% level. This may have implications for water use efficiency in irrigated farms, especially when viewed in the context of the marginal difference in output. The non-significant difference in the use of other variable inputs like fertilizers and agro-chemicals between the systems is also critical to understanding the impact of irrigation on crop productivity in the study area. This is a possible explanation for the close nominal parity in yields observed since the introduction of irrigation in eastern Nigeria in 1984 (Figure 4.2).



**Figure 4.2:** Mean Values of Input and Output in both Systems (1997/98)

Source: Survey data 1998.

The figure shows that irrigation in Nigeria increased rice yield by only about 30% at over 38% differential cost of land and water withdrawals in the study area. This already suggests that the sustainability cost of irrigated agriculture is negative (Figure 4.3).



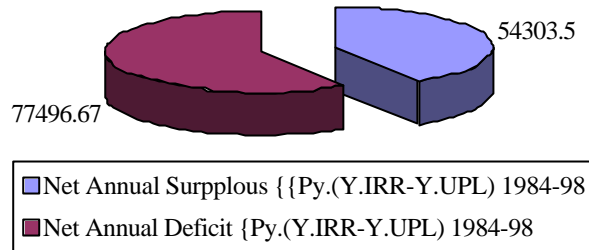
**Figure 4.3:** Sustainability Cost of Irrigated Rice Production (1984-98)

Source: Historical Yield Data

Sustainability cost, as used in this context, is defined as the opportunity cost of not embarking on the irrigation project. What the country would lose if they chose to revert to upland rice production only. In this study, this was measured as the value of crop output that would have to be forgone by the farmers if irrigation projects are abandoned for the traditional system of upland rice production, excluding the environmental externalities.

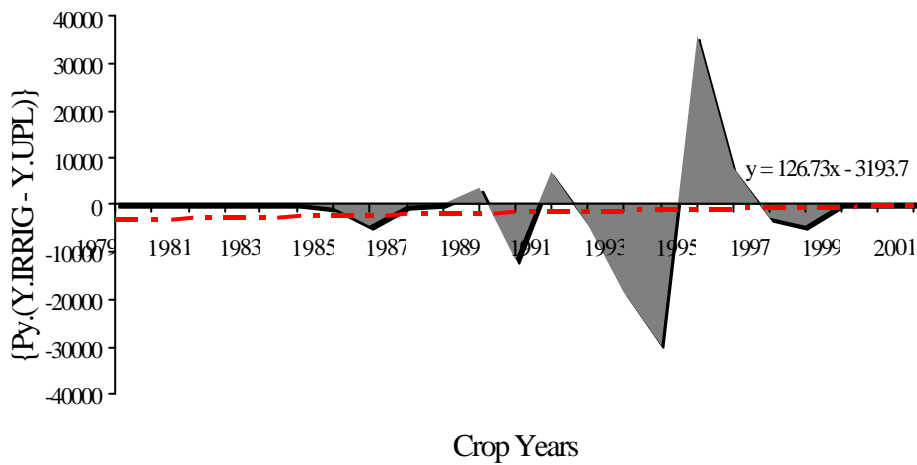
$$\sum_{i=1}^n \{P_y(Y_{IRRIG} - Y_{UPL})\} \quad [2]$$

Where  $P_y$  is the farm gate price of crop output;  $Y_{IRRIG}$  is the annual crop yield in irrigated farms,  $Y_{UPL}$  is the annual crop yield in the rain-fed farms; and n is the number of years under consideration. The computed figure above does suggest that the farmers stand to regain over 8% of their output which has been lost to irrigation between 1984 and 1998. However, the respondents' assessment of the performance of irrigation has been only on annual basis, thus leading to the current "misguided" perception of irrigation as increasing productivity in the study area. To explore this hypothesis further, we looked at the computed value of output (Gross returns per hectare of cropped land) at Lower Anambra irrigation project for the specified period in a counterfactual framework (See Figure 4.4).



**Figure 4.4:** Net Annual Differences in Gross Returns between the Systems 1984-98

Figure 4.4 shows that between 1984 and 1998, the Lower Anambra Irrigation project had a net annual deficit of ₦77,498.67 and net annual surplus of ₦54,303.50. This represents a cumulative loss of ₦23,193.17 over the period of 14 years<sup>13</sup>. A graphical analysis of the above shows that irrigated farms in the study area yielded gross returns per hectare more than their upland counterparts only in 1989/90, 1991/92, 1994/95 and 1996/96 crop years, while the Upland farms yielded more gross returns per hectare for the rest of the period (See Figure 4.5).



**Figure 4.5:** Computed Differentials Gross Returns per Hectare between Irrigated and Upland farms (1984-98).

Source: Computed from historical data 1984-1998.

<sup>13</sup> Computed from the operation performance reports of the Lower Anambra Irrigation Project (1998).

This does suggest that the farmers stand to gain if they focused on proper management of traditional rain-fed cropping system instead of embark on irrigation. It is however still necessary to internalize other externalities of irrigation into the main frame of its Cost Benefit Analysis in order to guide policy simulations in these directions. Subsequent inquiries on the subject should seek to balance the trade-offs and provide conclusive evidence that can be submitted in verification or refutation of the ensuing hypotheses.

Despite these costs, irrigation plays a role in increasing food supply to rural households in both countries. The adoption of irrigation enabled farmers to access other productivity boosting farm inputs like fertilizers, improved varieties, agro-chemicals, and contact with extension services. The introduction of irrigation enhanced access of farmers to improved production facilities using frequency of access to extension services by respondents, as a proxy. Only about 24% and 17% of upland and irrigating farmers in Swaziland had very frequent access to agricultural extension services, but the corresponding figure for Nigeria was 100% and 79%, respectively. On the other hand, 57% and 49% of upland and irrigated farmers had no access to such facilities, while all farmers in the irrigation project zone studied in Nigeria (both participant and non-participants), have had access to extension services at least once a year. This enhanced access by farmers to other productivity boosting inputs like improved production practices and varieties of seeds, and agro-chemicals. This may serve to explain the rise in output of rice in both systems in Nigeria, after the introduction of irrigation. What may be needed to boost productivity in Nigerian rice farms may therefore be improving the availability of these productivity boosting inputs and land-saving technologies, rather than irrigation. The sustainability cost of water abstraction for irrigation may be a waste, after all its deleterious environmental implications notwithstanding. This though, is an issue that requires further research.

### **Environmental problems encountered in both countries**

The major impacts of irrigation are classified as on-farm and off farm impacts below:

The on-farm environmental impacts documented from these exploratory surveys in both countries are in Tables 4.2. As shown in Table 4.2, the major environmental problems observed in Nigeria were waterlogging (91.25%), transboundary conflicts with pastoralists and other neighbouring farmers (86.25%) and decreased crop productivity (60.00%). Swaziland had a slightly different scenario with soil erosion (69.50%) and decreased crop productivity (68.00%) taking the highest percentage of the reported problems. The case of recording a higher rate of soil erosion in Swaziland (69.50%) than that of Nigeria, (31.25%) may be explained by the differences in topography of the two countries. While most irrigated areas in Swaziland are often sloppy hill sides that of Eastern Nigeria were located on flat terrains of Uzouwani and Ayamelum Local Government Areas of Anambra and Enugu States, respectively. Much of the reported erosion cases in Nigeria are still restricted to canal beds, side slopes and embankments.

Of greater relevance to this study is the fact that the rates of decrease in productivity in irrigated areas of both countries were substantial. A 68% decrease for Swaziland, and 60% decrease for Nigeria are significant enough to justify further statistical enquiry on the purported productivity boosting role of irrigation, in both countries. In Nigeria, over 58% of the respondents also report desiccation of

water sources due to the irrigation development as major environmental problems that threaten the very sustainability of irrigation in the area.

: On-Farm Environmental Problems Documented from the survey

Environmental Problems	Lowveld (Swaziland)		Lower Middleveld (Swaziland)		Highveld (Swaziland)		Upper Middleveld (Swaziland)		Swazi Nation		Nigeria	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Water logging	33	37	31	53	12	39	13	26	89	38.75	73	91.25
Soil erosion	30	33	53	91	29	94	30	60	142	69.50	25	31.25
Decreased crop Productivity	65	72	8	14	31	100	45	86	149	68.00	48	60.00
Soil salinity	11	12	10	17			3	6	24	8.75	31	38.75
Transboundary conflicts											69	86.25
Drowning of farm animals	21	23			26	84			47	26.75	4	5.00
Desiccation of water resources											47	58.75

Source: Survey data 1998. Multiple responses recorded

Table 4.3 presents the off farm impacts. It is evident that the dominant environmental externality of irrigation in both countries was mosquito infestation in the households. However, this problem was more pronounced in the Nigerian case (97.50%), than in Swaziland (39.00%). This disparity may also be explained by the weather differentials in the two countries. While Nigeria is typically tropical, thus favouring mosquito growth, Swaziland often experiences cold winter seasons, which suppress mosquito growth. Other household externalities are generally more pronounced in Nigeria than in Swaziland. This was however, clustered in the Lowveld and Upper Middleveld regions of Swaziland.

Over 86% of Nigerian respondents reported various degrees of malaria, and 42% of Swaziland farmers suffered malaria, and 43.5% reported cases of bilhazia. In Nigeria, over 90% of the farmers also use the canal water for drinking and other domestic needs, and this made such diseases as dysentery, exzema and typhoid commonplace in the project areas. Over 80% of such diseases was recorded among farmers at the Omor project zone of the LAIP.

### **Limitations of the Analysis and Areas for Further Research**

The study was conducted as a baseline study to identify potential research on the social, economic and environmental impacts of irrigation in developing countries. Resource limitations meant that the samples for the study were small. This limits the level of conclusions that can be reached based on current data. Other technical problems that are always associated with farm production and environmental studies in developing countries were also observed. The value of farm output obtained from the survey can at best be as reliable as the farmer respondents are, and their ability to report farm output in measurable units. Subsistent consumption, illiteracy and lack of farm records are expected to have affected the reported output figure, significantly. We do, however, reason that this would not impair the results of our analysis, since we are comparing two systems within the same socio-economic setting, hence the errors of measurement may cancel out. Further research is required in this area.

The prevailing institutional framework where irrigation facilities are indirectly subsidized by government made appropriate costing of irrigation inputs difficult. Most irrigation facilities like water are not priced by respondents, since they pay only a fixed subscription fee for its use per plot, irrespective of volumes consumed. We therefore believe that the  $X_2$  variable in our production function is an underestimate of the real cost of land and water extracted for irrigation. The impacts of irrigation on soil and water quality and the contingent values of the observed irrigation externalities are not reported in this working paper. We strongly recommend follow-up studies to carry out full cost-benefit analysis of the impacts of irrigation technology in both countries.

**Table 4.3: Off-Farm Environmental Problems Documented from the survey**

Environmental Problems	Lowveld (Swaziland)		Lower Middleveld (Swaziland)		Highveld (Swaziland)		Upper Middleveld (Swaziland)		Swazi Nation		Nigeria	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Water logging	1	1.10							1	0.44	53	66.25
Soil erosion	6	6.67							6	2.62	12	15.00
Chemical food poisoning	23	25.56					1	2.00	28	12.23	37	46.25
Mosquito												
Infestation	68	75.55	6	10.34			20	40.00	94	41.05	78	97.50
Income switing									0	0.00	13	16.25
Water pollution	2	2.0					4	8.0	6	2.62	56	70.00
Descication of water resources											43	53.75
Malaria	48	53.33					7	14.00	55	24.02	69	86.25
Bilhazia			4	6.70			30	60.00	34	14.85		

Source: Survey data 1998. Multiple responses recorded

## Chapter Five

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### Summary of Findings, Recommendations and Conclusions

#### Summary of Findings

The study has reviewed the literature on the effects of irrigation technology on the environment and the available methods that can be used to evaluate these effects. A clear framework for further research on the subject is also developed and case study surveys conducted in Nigeria and Swaziland.

Available evidence in the literature shows that surface irrigation has affected the environment in diverse ways: ranging from "on-site" edaphic affects to "off-site" effects on biodiversity and climate change, and on various forms of human welfare. However its "on-site" effects on soil fertility, salinization and water logging, and its impact on both human and livestock health and water quality, dominate the reviewed literature on the subject. Its effects on the global environments (climate change, green house effects), are however, also documented. Like most environmental issues, no boundaries can be put on the effects of irrigation on the environment.

"Sustainability" has been a watchword for much of recent work in environmental economics, but there remains considerable disagreement in the conceptual and operational content of the term. This has been largely due to diverse disciplinary perspectives, and the axiomatic foundations of the dynamic models within which the concept has been explored. The net result is a debate in which the fundamental points at issue remain obscure. This study adopts the simple neo-classical operational definition of the term: non-declining physical flow of resources, in an agro-ecosystem and in per capita social welfare of farmers.

The empirical findings from the survey are summarized as follows:

- The major type of irrigation practiced in the LAIP studied in Nigeria was of the basin type, and furrow, dragline sprinkler, floppy sprinklers and centre pivot irrigation were practiced in Swaziland. Furrow irrigation was, however, dominant.
- The productivity gains of irrigation in the Nigerian project has been very marginal when compared with adjacent upland counterparts, however, the true welfare gain of this productivity increase is yet to be identified. Full environmental costs and benefits of the system are yet to be factored into the analysis. The trend of crop productivity is increasing by 13.34 % in the upland systems and decreasing by 19.15% in the irrigated systems each decade. This represents a predicted opportunity cost (crop loss) of about 0.7843 tons of paddy to the farmers, for adopting irrigated agriculture for every decade.



- There is a strong hypothesis that there are yet some factors influencing productivity of factors in the irrigated farms in both countries that are yet to be captured in the classical Cobb-Douglas production function. This may be the environmental variables. Further research is required in this area.
- The sustainability cost of irrigation in the Nigerian project is negative. Eight percentage of total value of crop output has been lost to irrigation since its inception in the study area. This represents ₦23, 193.17 over the past 14 years of irrigation in the project areas. This implies that the rain-fed system is even more economic in classical terms even if irrigation has no negative externalities on the environment. Proper management of the traditional rain-fed cropping system may be a better investment option.
- Farmers' access to agricultural extension services in Nigeria increased with the introduction of irrigation in the study area. This has led to the apparent parity in productivity of factors in both systems and may serve to explain the apparent increase in rice output since irrigation was adopted. Improving extension services may be a better policy option than further development of irrigation in the study area. In Swaziland, there is strong need for improving extension services to the farmers in both categories. Access to extension by farmers in Swaziland is still poor.
- The major environmental consequence of irrigation development in both countries, as reported by respondents is mosquito infestation, causing malaria epidemic in farm households, and other water related diseases. Farmers in Swaziland also reported few cases of bilhazia in project areas. There is, therefore, need for a systematic monitoring of the incidence of these diseases in irrigated areas for proper prevention and/or treatment.

### **Recommendations**

This analysis provides empirical evidence from Nigeria and Swaziland, which corroborates the evidence in literature to underscore the deleterious effects of irrigation in areas where they exist. However, it does not reach definite conclusions as to the total economic value of irrigation in the study areas. It is also considered valuable in identifying areas for further inquiries on the subject:

- Irrigation water resources have been valued at a "zero" or "near zero price" in both countries. What is often built into available "ex-ante" appraisals and "ex-post" analysis of the projects is the "water-provision charges". At the micro levels, this constitutes only the cost of maintaining the irrigation infrastructures. Irrigation water is therefore, undervalued (treated as a non-traded public good). Further research is therefore needed to estimate the real cost of the irrigation water in the study area. It is hoped that this would improve the efficiency of water use in irrigated agriculture. Babier and Thompson (1998) in their study of large scale irrigation projects in the Hadejia-Jama'are River Basin of northern Nigeria, opine that the prevailing assumption that water is essentially "free" is a hypothesis that ought to be empirically verified. Evidence from this study show that the irrigation river sources in Nigeria are currently being desiccated and cases of water poisoning is also recorded.

We recommend that proper water resources management (the complex of measures and facilities, which ensure the necessary quality and quantity of water for the whole economy), should be incorporated into irrigation planning and implementation in both countries. This is necessary, especially in Nigeria where the rivers serve as a major source of water for both farm and household uses in the surrounding communities. Such a management strategy should comprise:

- routine data collection and evaluation on the quality and flow levels of water sources;
- appropriate fiscal management research and development, to assess the cost and benefits of alternative water uses;
- meteorological data collection and management, to forecast water shortfall periods and irrigation demand in project areas; and
- proper water pricing, regulatory and enforcement activities to ensure rational water use in project areas. This would reduce the overflooding and consequent water logging problems encountered in the study.

The following approaches tried out in Czechoslovakia, may be considered for policy in respective countries:

- Setting an order of priority for surface water use and abstraction. In economic terms, this can be achieved by comparing the costs and benefits of all alternative uses of surface water to see which water demand alternative is most beneficial to society.
- Introducing appropriate water pricing policy for both farm and domestic water uses. Effective pricing of irrigation water is considered as the most effective way of saving water and preventing overflooding of irrigation farms, because it will "*ceteris paribus*" increase water use efficiency in project areas. This will no doubt reduce the mosquito infestation and other water related environmental problems reported during the survey.
- Estimating and adopting minimum acceptable flow levels in irrigation river sources and in the main canals. Pressurized irrigation systems should be adopted instead of the canal systems presently adopted in the LAIP, where they can be afforded.
- Establishing and/or improving registration systems for surface water withdrawals than is presently available in the study areas.

## Conclusions

The findings of the study corroborate Rees' argument that modern technologies reduce the carrying capacities of ecosystems, while creating the illusion of increasing it (see Rees, 1996, p. 6):

We often use technology to increase the short-term energy and material flux through exploited ecosystems. This seems to enhance systems productivity, while actually permanently eroding the resource base...energy-subsidized intensive agriculture may

be more productive than low input practices in the short term, but it also increases the rate of soil and water depletion.

The presupposed productivity gains of irrigation technology in Nigeria and Swaziland may therefore be illusory. However, the confines of this study prevent a complete analysis. The data collected from the survey could only allow a preliminary analysis, and as such, the propositions generated are at best primary hypothesis, subject to further verification.

The conclusion of the study is therefore an identification of research gaps with respect to the costs and benefits of irrigated agriculture in the study areas. The dominant assumptions in the economic analysis of projects also need re-assessment. The Cobb-Douglas model explains only 45% and 48% of the functional input-output relationships in Nigeria's and Swaziland's irrigated agriculture. In the traditional upland systems, it still explained about 80% and 74% of the variations in Nigeria and Swaziland, respectively. It is therefore hypothesized that environmental externalities may be the missing factor(s). This may serve as a good framework for understanding the real trade-offs between the perceived productivity gains of irrigation and its deleterious effects on the environment. Further research on the subject is highly recommended. The on-farm and off-farm impacts of irrigation in both countries have also been documented and mitigation measures recommended. The productivity gains of irrigation have been marginal, but its impact on water availability and quality, health of farmers and farm animals and on irrigated soils are considerably significant. Land and water resources used for irrigation are also under-estimated in both countries.

We therefore hypothesize that the increase in productivity of irrigated agriculture depends on the underestimation of environmental resource inputs and the low value given to its environmental externalities. This is, however, a subject for further research. In the interim, the current policy for intensifying smallholder irrigation development in Nigeria and SNL should be supported by soil and water conservation programmes to mitigate observed environmental externalities of these projects. In the Nigerian case, the sustainability cost of the irrigation projects studied is negative. Given the substantial financial loss incurred by the irrigation projects in comparison to adjacent upland (rain-fed) plots, the prognosis for the sustainability of agricultural production of irrigated farms is bleak. The opportunity cost of irrigation in the Nigerian case study, is highly significant and exceeds the net production benefits gained from these projects.

## Bibliography

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- Abalu, G.O.I. and B. D'silva (1979). "Socio-Economic Analysis of Existing Farming Systems and Practices in Northern Nigeria", Paper Presented at the Workshop on Socio-Economic Constraints to the Development of Semi-Arid Tropical Agriculture, ICRISAT, February 19 - 23, pp. 14.
- Abalu G.O.I. and B. D'silva (1980). "Nigeria's Food Situation: Problems and Prospects". *Food Policy*, February, 1980, pp. 49-60.
- Adams, W.M. (1991). *Wasting the Rain: Rivers, People and Planning in Africa*. Earthscan, London, UK.
- Adeboye, T. O. Beganehwa, M.S.D. and Bamiro, O.A. (1995). "Effects of Reforms on Technology Capability in Sub Saharan Africa: A Conceptual Framework". ATPS Working Paper No. 1.
- Agboola A.A. and H. Tijani-Eniola (1991). "Appropriate Technology Generation for Small-Scale Farmers in Nigeria", In *Appropriate Agricultural Technologies for Resource-Poor Farmer*, J.O. Olukosi, A.O. Ogungbile and B.A. Kalu eds., NFSM Workshop, Calabar.
- Ahmaed, I. and Doelman, J.A. eds. (1995). *Beyond Rio: Environmental Crisis and Sustainable Livelihoods in the Third World*. Macmillan, London, UK.
- Ahmed A.U. and Sampath, R.K. (1992). "The Effects Of Irrigation Induced Technology Change" In *Bangladesh Rice Production*, American Agricultural Economics Association.
- Aina, O.I. and Soetan (1991). "Sap, Gender, Technology: The African Experience". A Paper Presented at the International Conference of West African Technology Policy Studies Network, 9 - 10 December, Federal Palace Hotel, Lagos, Nigeria.
- Allan, L. (1986). "On-Farm Research and Household Economics", In *Understanding Africa's Rural Households and Farming Systems*. Moock J.L., ed., Westview Press/Boulder and London, UK.
- Allauddin, M and Tisdell, C.A. (1986). "Market Analysis, Technical Change and Income Distribution in a Semi-Subsistence Agriculture: The Case of Bangladesh", *Agricultural Economics* 1 (1), pp. 1-18.
- Arrow, K., Solow, R., Portney, P., Leamer, E., Radner, R. and Schuman, H. (1993). *Report of the NOAA Panel on Contingent Valuation*. Fed. Regist. 58 (10), 4602-4614.
- Asadu C.L.A., (1996). "Soil Management for Conservation and Sustainable Rice Production in an Irrigated Area of Eastern Nigeria", *Outlook on Agriculture*, 25 (3) P.151-56.
- Asano, T. and Pettygrove, G.S. (1988). Using reclaimed municipal wastewater for irrigation. In *Developing World Water*. Grosvenor Press International, Hong Kong, pp. 242-246.
- Asian Development Bank (1996). *Economic Evaluation of Environmental Impacts: A Workbook, Parts I and II*, The Environment Division, Office of Environment and Social Development, ADB Manila, Phillippines.

- Atkins, S.L. (1998). *The economics of smallholder irrigation systems in Swaziland*. Paper presented at the International Association of Agricultural Economists Inter-Conference Symposium, August 10-16, 1998, Badplass, South Africa.
- Ayoola, G.B. (1990). "Technological Progress in Agriculture: Some Issues". Proceedings of 1990 Annual Conference, Nigerian Economic Society, May 23 (1990).
- Babier, E.B. (1987). "The Concept of Sustainable Economic Development", *Environmental Conservation*, 14 (2), pp. 101-10.
- Babier, E.B. (1995). "The Economics of Soil Erosion: Theory, Methodology and Examples", IDRC, Research Paper Presented to the Fifth Biannual Workshop of Economy and Environment in South Asia, Singapore. November 28-30, 1995.
- Babier, E.B. and Thompson, J.R. (1998). The Value of Water: Floodplain Versus Large Scale Irrigation Benefits in Northern Nigeria. *Ambio*, Vol 27 No. 6. Sept. 1998.
- Babu, S.C., B.T. Nivas and G.J. Traxeer (1996). *Irrigation Development and Environment Degradation in Developing Countries - A Dynamic Model of Investment Decisions and Policy Options*. IFPRI, No. 337.
- Baker, R. (1993). *Environmental Management in the Tropics. An Historical Perspective*. CRC Press, Tokyo, Japan.
- Balogun, E.D. and E.U. Ukeje (1986). "The Impact of River Basin Development Authorities on Nigerian Agriculture: A Case Study of Niger River Basin Development Authority. *Economics and Financial Review*. Vol. 24 No. 2.
- Banjo, A. (1988). "The Form and Concept of Policy". A Paper Delivered at the Institute of Strategic Studies, Kuru.
- Bartick, T.J. and V.K. Smith (1987). "Urban Amenities and Public Policy." In *Handbook of Regional and Urban Economics*. E.S. Mills, ed., New Amsterdam: Elsevier Press, The Netherlands.
- Bergman H. (1973). *Guide to the Economic Evaluation of Irrigation Projects*. OECD, Paris, France.
- Bernnet, R. and Murphy, S. (1991). "Occupational Noise: Cost-Benefit Analysis of a Reduction in Standard" Research Paper No.1, Bureau of Industry Economics, Canberra, Australia.
- Bernett, J.W. (1991). Alternative Resource management Options for Fraser Island and the Great Sandy Region: Aspects of an Economic Evaluation., In: *Commission of Inquiry Into the Conservation. Management and Use of Fraser Island and the Great Sandy Region*, pp. 53-58.
- Blake G.R. (1965). "Bulk Density"; In *Methods of Soil Analysis, Agronomy* No. 9. Part 2, American Society of Agronomy, C. A. Black ed., Madison, Wisconsin, USA.
- Bishop J. and J. Allen (1989). "The On-Site Costs of Soil Erosion in Mali" Working Paper 21., World Bank, Environment Department, Washington D.C., USA.
- Biswas, A.K. (1993). Water for Agricultural Development: Opportunities and Constraints. *International Journal of Water Resources Development* 9, 3-12.
- Bogo J., K.G. Maler, and L. Umeno (1996). *Environment and Development: An Economic Approach*, 2nd ed. Kluwer Academic Publishers, London, UK.
- Bouyoucos G.H. (1951). A Calibration of the Hydrometer for Making Analysis of Soils. *Argon.J.* (43) pp. 434-38.
- Bray, R.H. and Kurtz, L.T. (1945). Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science* (59), pp. 39 -45.

- Bremner, J.M. (1965). "Total Nitrogen" In *Methods of Soil Analysis*, American Society of Agronomy No. 9. Part 2, C. A. Black ed., Madison, Wisconsin, USA.
- Brookshire, D., W. Schultze and M. Thayer (1985). "Some Usual Aspects of Valuing A Unique Natural Resource", Mimeo, University of Wyoming.
- Brookshire, D.L. Eubanks, and A. Randall (1983). "Estimating Option Prices and Existence Values for Wildlife Resources", In *Land Economics*, February.
- Brown, L.R. and E. Wolf (1984) "Soil Erosion: Quiet Crisis in the World Economy", Worldwatch Paper No. 60, Washington D.C., USA.
- Brundtland Commission (World Commission on Environment and Development) (1987). *Our Common Future*, Jim McNeil, New York, USA.
- Buzdugan, S. and Carroll, F. (1983). *Environmental Assessment: Small Farmer Pilot Irrigation Project*. Ronco Consulting Corporation, Washington D.C., USA.
- Caircross, S. and R.G. Feachem (1983). *Environmental Health Engineering in the Tropics: An Introductory Text*. John Wiley & Sons Ltd, Great Britain.
- Caldwell, L.K. (1991). "Globalizing Environmentalism: Threshold of a New Phase in International Relations", *Soc. Nat. Resour.* 4. 259-72.
- Carr, M. (1988). Mass Production or Production by Masses? In *The Greening Aid: Sustainable Livelihood In Practice*, C. Conroy and M. Litvinoff eds., Earthscan Publications Ltd., London, UK.
- Carruthers, I.D. (1968). *Irrigation Development and Planning: Aspects of Pakistan Experience*. Department of Economics, University of London, UK.
- Carson, R. (1991) "Constructed Markets." In *Measuring the Demand for Environmental Quality*. J.B. Barden And C.D Kolstard, Eds. Amsterdam, North Holland.
- Cassam, M. (1983). *An Assessment of the Market for Swazi Nation Land Farmers*. Ronco Consulting Corporation, Washington D.C., USA.
- CGIAR (Consultative Group of International Agricultural Research) (1989). "Sustainable Agricultural Production: Implications for International Agricultural Research". FAO Research and Technology Paper 4, Italy, Rome.
- Chidebelu, A.N. and Nwike I. (1991). "Agricultural Technology Transfer: the Case of Imo State Agricultural Development Area Programme" In *Appropriate Agricultural Technologies for Resource-Poor Farmers*. Olukosi, J.O., Ogungbile A.O. and Kalu, B.A. eds., National Farming Systems Research Network.
- Cifuentes, E., Blumenthal, U., Ruizpalacios, G., Bennett, S., Quigley, M., Pessey, A. and Romeroalvarez, H. (1993). "Health Problems Related to Irrigation With Waste Water in Mexico", *Salud Publica De Mexico*, 35 (6) pp. 614-619.
- Collin, C. (1960). *The Conditions of Economic Progress*. 3ed., Macmillan Press, London, UK.
- Common, M.S. (1996). *Environmental and Resource Economics: An Introduction*. Longman. New York, USA.
- Commoner B. (1963). *Science and Survival*. New York, Ballantine, USA.
- Commoner B. (1972). *The Closing Circle*. Cape, London: Jonathan, UK .
- Commonwealth of Australia (1995). *Techniques to Value Environmental Resources: an Introductory Handbook*. Australian Government Publishing Service, Canberra, Australia.

- Conway G.R. (1986). *Agroecosystem Analysis for Research and Development in Bangkok*. Winrock International.
- Dailey, G. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Covelo, CA, USA.
- Dasgupta, P. and Maler, K.G. (1990). "The Environment and Emerging Development Issues", Proceedings of the World Bank Annual Conference of Development Economics, 1990, World Bank, Washington D.C., USA.
- Dasmann, R.F., J.P. Milton and P.H. Freeman (1978). *Ecological Principles for Economic Development*. John Wiley & Sons Ltd., London, UK.
- David (1992). "Policy Induced Local Sourcing of Raw Materials and Technological Development in Nigerian Industry" Kayode F., A. Oyejide and Afolabi S. eds., Interim Report Submitted to ATPS Network, 1995.
- Dubgaard, A. (1990). "Danish Policy Measures to Control Agricultural Impacts on the Environment" Institute of Agricultural Economics, Copenhagen, Denmark.
- Dunn, G.H. (1986). "Irrigation Research in Swaziland". End of Tour Report: September 1982 to November 1986. Mbabane, Swaziland.
- Economic Commission for Africa (1989). *Role of Technology in Small Farmers' Productivity in Africa*. July, U.N., Addis Ababa, Ethiopia.
- El Serafy, S. (1998). "Pricing the Invaluable". *Ecological Economics* 25 (1), 25-27.
- Enrlich, P.R. and Ehrlich, A.H. (1970). *Population Resources Environment*. W.H. Freeman, San Francisco, USA.
- Eremie, S.W. and H.R. Chheda (1991). "Technology Generation and Transfer in Nigeria: The Farming Systems Research Network and the Agricultural Development Interface". *Journal of the West African Farming Systems Research Network*, Vol. 1 No. 1, 1991.
- Edo, M.A. and Compadre (1995). "Biodemographic Alterations Derived from Reservoir Building in a Rural Settlement in Spain". *Journal of Bioscience*, 27 (1) pp. 61-70.
- EEPSEA (1995). "Valuing the Health Impacts of Pollution" IDRC, Research Paper Presented to the Fifth Biannual Workshop of Economy and Environment in South Asia, Singapore, November 28-30, 1995.
- Ehrlich, P.R. and Ehrlich, A.H. (1970). *Population Resources Environment*. San Francisco: W.H. Freeman.
- Ellis, G.M. and A.C. Fisher (1987). "Valuing the Environment as Input". *Journal of Environmental Management* (25) pp. 149-56.
- Engels, F. (1959) "Outlines of a Critique of Political Economy", In *Economic and Philosophic Manuscripts of 1844*. K. Marx ed., Foreign Languages Publishing House, Moscow, Russia.
- Erhabor, P.O. (1982). "Efficiency of Resource Use Under Small Scale Irrigation Technology in Nigeria." Indiana Technical Report No. 148, Purdue University Water Resources Research Centre, West Lafayette, Indiana.
- Erhabor, P.O. and W. Miller, (1981). *The Adoption of Small Scale Irrigation Technology in Nigeria*. Department of Agricultural Economics, Purdue University Water Resources Research Centre, West Lafayette, Indiana.

- Ernst, D., Mytelka, L. and Ganiatsos, T. (1994). " *Technological Capabilities - A Conceptual Framework*" Chapter 1 of the Draft UNCTAD Six Country Research Project on Technological Development in Smith and East Asia.
- FAO/ICA, (1980). *Agricultural Development in Nigeria 1965 - 1980*. Rome, Italy.
- Faucheux, S., Pearce, D., and Proops, J. (1996). *Models of Sustainable Development: New Horizon in Environmental Economics*. Edward Elgar Publishing Ltd. Chetenham, UK.
- Federal Ministry of Science and Technological (1986). *National Policy on Science and Technology*. Federal Republic of Nigeria, Lagos, Nigeria.
- Field, B.C. (1994). *Environmental Economics: An Introduction*. Mcgraw-Hill Inc., Singapore.
- Food and Agriculture Organization of the United Nations (FAO) (1990). " *Socio-Economic Aspects of Environmental Policies in European Agriculture*. Rome, Italy.
- Forattini, O.P., Kakitani, I., Massad, E. and Marucci, D. (1993a). "Studies on Mosquito (Ditera, Culicidae) and Anthropic Environment. 2. Immature Stages Research at a Rice Irrigation System Location in South Eastern Brazil", *Revista Sao De Saude Publica* 27(4) pp. 227-36.
- Forattini, O.P., Kakitani, I., Massad, E. and Marucci, D. (1993b). "Studies on Mosquito (Ditera, Culicidae) and Anthropic Environment. 3-Survey of Adult Stages at a Rice Irrigation System and the Emergence of Anopheles Albitarsis in South Eastern Brazil". *Revista Sao De Saude Publica* 27 (5) pp. 313-25.
- Forattini, O.P., Kakitani, I., Massad, E. and Marucci, D. (1994). "Studies on Mosquito (Ditera, Culicidae) and Anthropic Environment. 5-Breeding of Anopheles-Albitarsis in Flooded Rice Fields in South Eastern Brazil", *Revista Sao De Saude Publica* 28 (5) pp. 329-33.
- Fowler, (1983). " *Vegetable marketing in Swaziland*". A Paper Presented at Vegetable Production and Marketing Seminar. MOAC, Lobamba, Swaziland.
- Frederick, K.D. (1992). "Managing Water for Economic, Environmental, and Human Health", In: *Global Development and the Environmental Perspectives on Sustainability, Resources for the Future*. J. Darmstadter ed., Washington D.C, USA.
- Gillen E.F (1974). "Social Indicators and Economic Welfare" *Economic Papers* 45 pp. 45-82.
- Graves, P.E. and G. Fishelson (1982). "Estimation of Damage Coefficients: The Sulphur Dioxide Example." In *Environmental Policy: Air Quality, Vol. 2*. D.S. Tolley, P.E. Graves, and A.S Cohen, eds., Mass.: Ballinger, Cambridge, USA.
- Greig, P.J and Devonshire, P.G. (1981). "Tree Removals and Saline Seepage in Victorain Catchments: Some Hydrologic and Economic Results", *Australian Journal of Agricultural Economics* 25 (2) pp. 134-48.
- Gold Smith, E., Allen, R., Allaby, M., Davoll, J. and Lawrence, S. (1973). *The Blueprint for Survival*. Tom Stacey.
- Haile, T. (1988). Socio-economic Aspects of Small Scale Irrigation in Ethiopia. In *Irrigated Agriculture in Africa. Vol. 2*. P.N. G. van Steekelenburg ed., Conference Proceedings, 25-29 April 1988, Harare Zimbabwe, CTA and ILRI.
- Hanemann, M. (1984). "Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses". *American Journal of Agricultural Economics* 67 (3) 332 -341.
- Hanemann, M. (1989). Welfare Evaluations in Contingent Valuation Experiments with Discrete Response Data: Reply. *American Journal of Agricultural Economics* 71 (3) 1057-1061.



- Hanley, N. and C.L. Spash (1998). *Cost Benefit Analysis and the Environment*. Edward Elgar, England, UK.
- Hanley, N., Shogren, J.F. and White, B. (1997). *Environmental Economics in Theory and Practice*. Macmillan Press, London, UK.
- Hawercamp, A.J., E.H. Clark, li and W. Chapman (1985). *Eroding Soils: The Off-Farm Impacts*. The Conservation Foundation. Washington, D.C., USA.
- Heaton, G., Repetto, R. and Sobin R. (1991). *Transforming Technology: An Agenda For Environmentally Sustainable Growth in the 21st Century*, World Resources Institute, Washington D.C, USA.
- Hillel, D. (1990). *Irrigation Development*. In *Irrigation of Agricultural Crops*. Agronomy Stewart, B.A and D.R. Nielsen eds., No. 30, ASA, CSSA, and SSSA. Madison, USA.
- Hodge, Ian (1998a). "Agri-Environment Policy in the United Kingdom: Progress Evaluation and Potential". Department of Land Economy, University of Cambridge, UK, June 1998.
- Hoehn, J.P., Berger, M.C. and Blomquist, G.C. (1987). "A Hedonic Model of Interregional Wages, Rents, and Amenity Values." *Journal of Regional Science* 27: pp. 605-619.
- Hornsby, A.G. (1990). Pollution and public health problems related to irrigation. In *Irrigation of Agricultural Crops*. Agronomy Stewart, B.A. and D.R. Nielsen eds., No. 30, ASA-CSSA-SSSA, Madison, WI 53711 USA. Chap. 38 pp. 1173-1188.
- Hottelling, H. (1931). "The Economics of Exhaustible Resources", *Journal of Political Economy* 39 pp. 137-75.
- Hren, J. and R.F. Herman (1998). "Effects of Irrigation on the Environment of Selected Areas of Western United States and Implications to World Population Growth and Food Production" *Journal of Environmental Management* 52, (Ev980182.), pp. 353.360.
- Hufschmidt, M.M., James, D.E., Meister, A.D., Bower, B.T. and Dixon, J.A. (1993). *Environment, Natural Systems and Development: An Economic Valuation Guide*. Johns Hopkins University Press Baltimore.
- Igbal, Muhammad (1975). *Irrigation Projects of the Northern States of Nigeria, Vol. I*. Iar/Abu Zaria, August 3.
- Igbozurike, U.M. (1983). *Agriculture at the Cross Roads. A Comment on Agricultural Ecology*. University of Ife Press, Ile-Ife, Nigeria.
- Imbulana, K, Kouradsen, F. and Steele, P. (1996). "Irrigation Development in Srilanca: Some Health and Environmental Impacts". *Marga*, 14 (1) pp. 1-15.
- International Monetary Fund (1989). "Balancing Development and the Environment". *Finance & Development* 26:4.
- International Soil Reference and Information Centre (1991). *Wageningen*. The Netherlands. Nov. 1991.
- James, D. (1991). *The Application of Economic Techniques in Environmental Impact Assessment: Guide to Analysis and Procedures*. David James Ecoservers Pty Ltd.
- Japanese Ministry of International Trade and Industry (1991). "The New Earth 21" Action Paper Presented at the U.S-Japan Conference on Global Warning. Atlanta, UK, June 3.
- Johnston, B.F. and Cownie, J. (1969). "The Seed-Fertiliser Revolution and Labour Force Absorption", *American Economic Review* 59 (4), pp59-82.

- Jones, C.N. (1986). "Intra - Household Bargaining in Response to the Introduction of New Crops: A Case Study of North Cameroon", In *Understanding Africa's Rural Households and Farming Systems*. Moock J.L. eds., Westview Press Inc.
- Joshin, P.K. and Dayanatha, Jha (1990). "Environmental Externalities in Surface Irrigation Systems in India", In *Environmental Aspects of Agricultural Development*, International Food Policy Research Institute, Washington D.C., USA.
- Jules, N.P. and G.R. Conway (1988). *Agriculture as Global Polluter International Institute for Environment and Development*. London, UK.
- Kahn, H., Brown W. and Martel, L. (1976). "The Great Transition" In *The Next 200 Years*. William Morrow & Co Inc. Publishers, New York, USA.
- Kassinis, G.I. (1998). "A Model for Estimating Pollution Emissions for Individual Economic Activities" *Environmental Impact Assessment Review* 18: pp. 417- 438.
- Kayode, F., Oyejide, A. and Afolabi, S. (1995). "Policy Induced Local Sourcing of Raw Materials and Technology Development in Nigerian Industry". Interim Report Submitted to ATPS Network, Sept., 1995.
- Krause, R. (1993). *Agricultural Technology and Environment in the Increasing Mechanization of Agriculture in the Tropics and Subtropics*. National Resource and Development. Institute for Scientific Co-Operation. Tiibingen 37.
- Koutsoyiannis, A. (1991). *Modern Microeconomics* (2nd ed.) Macmillan, London, UK.
- Leitmann, J. (1994). "Rapid Urban Environmental Assessment", *Lessons From Cities in the Developing World*. Vol. 1, Methodology and Preliminary Findings.
- Lele, S. (1991). "Sustainable Development: A Critical Review". *World Development* 19 (6), pp. 603-21.
- Loomis, J., Kent, P., Strange, L., Fausch, K. and Covich, A. (1999). "Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results From a Contingent Valuation Survey". *Ecological Economics* 33 (2000) 103-117.
- Luck, D. and Martin, I. (1988). *Review of Road Cost Recovery*. Occasional Paper 90, Bureau of Transport and Communication Economics, Australian Government Publishing Service, Canberra.
- Lust, R.E., Huet, D.L. and Schmitz, A. (1982). *Applied Welfare Economics and Public Policy*. Englewood Cliffs, Nj: Princeton-Hall.
- Maddox, J. (1992). *The Doomsday Syndrome*. McGraw - Hill, New York, USA.
- Maler, K.G. (1974). *Environmental Economics: A Theoretical Enquiry*. Baltimore, John Hopkins University Press, USA.
- Marx, K. (1956). *Capital*. Mosco: Progress Publishers.
- Masuku, M.B. (1992). "Evaluation of the International Fund for Agricultural Development (IFAD) Irrigation Schemes in Swaziland". B.Sc. Dissertation, Faculty of Agriculture, University of Swaziland, Luyengo, Swaziland.
- Mcleans, E.O. (1965). "Aluminium" In *Methods of Soil Analysis*. Agronomy, C. A. Black ed., No. 9. Part 2, American Society of Agronomy, Madson, Wiscosin.

- McNamra, R.S. (1990). *African Development Crisis: Agricultural Stagnation, Population Explosion and Environmental Degradation*. An Address to the African Leadership Forum, Lagos, Nigeria, June 21.
- Meadows, D.H., Meadows, D.L. and Randers, J. (1992). *Beyond the Limits: Global Collapse or A Sustainable Future*. Earthscan, London, UK.
- Meadows, D.H., Randers, J. and Behaerens, W. (1992). *The Limits of Growth: A Report of the Club of Rome's Projection on the Predicament of Mankind*. Universe Books, New York, USA.
- Molnar, I. (1965). "Production in Relation to Rainfall, Superphosphate and Erosion". *Australian Journal of Agricultural Economics* Vol.9., No.2, Pp. 169-175.
- Murdoch, G. (1968). *Soils and Land Capability in Swaziland*. Mbabane.
- Mushala, H. (1989). "Small Scale Irrigation Farming in Swaziland: Status and Outlook". Draft Paper, CODESRIA Research Network, Swaziland.
- Mustapha, U. and Pingali, P.L. (1995) "Intensification-Induced Degradation of Irrigated Infrastructure: the Case of Waterlogging and Salinity in Pakistan". *Pakistan Development Review* 34 (4) pp. 733-750.
- Myers, C.F., Meek, J. and Stuart, T. (1985). "Non-point Sources of Water Pollution". *Journal of Soil and Water Conservation* Vol. 40, No. 1.
- Mytelka, L.K. eds. (1994). *South - South Cooperation in a Global Perspective*. Paris: OECD, France.
- Nairn, R.J. (1971). "Community Involvement in the Noarlunga Freeway Review". Paper Presented to the Second Conference of Economists, Sidney.
- Nigeria, Federal Ministry of Economic Development (1963). *National Development Plan 1962 - 1968*. Federal Government Printer, Lagos, Nigeria.
- Nigeria, Federal Ministry of Economic Development (1970). *Third National Development Plan 1970 - 1974*. Federal Government Printer, Lagos, Nigeria.
- Nigeria, Federal Ministry of Information, (1971). *Second National Development Plan 1970 - 1974*. Federal Government Printer, Lagos, Nigeria.
- Nkambule, S.V. and Ndlovu, L.S. (1988). "The Impact of Agriculture on the Environment: the Case Study of Swaziland". Paper presented to United Nations Environment Programme (UNEP), Mbabane, Swaziland.
- Norman, D.W. (1972). "An Economic Survey of Three Villages in Zaria Province". Samara Miscellaneous Paper No. 37. Zaria, Nigeria.
- Norman, D.N. and D.C. Baker (1983). *Components of Framing Systems Research: Credibility and Experience in Bostswana*.
- Obakin, F.O. (1991). "Appropriate Food Processing Technology Generation for Resource-Poor Farmers in Nigeria: The Case of Small Scale Brown Sugar Processing Technology" In *Appropriate Agricultural Technologies for Resource-Poor Farmers, Proceedings of the National Farming Systems Research Network Workshop*. J.O. Olukosi, A.O. Ogungbile and B.A. Kalu, eds., Calabar, August, 14-16.
- Obasanjo, O. and A. Mabogunje eds. (1991). *Elements of Development. African Leadership Forum*. Nigeria.
- Obibuaku, L.O. and G.D. Hursh (1974). "Farm Practice Adoption in Eastern States of Nigeria". *Agricultural Administration* 12 (2).

- OECD (1991). *The Economics of Sustainable Development: A Progress Report*. Organisation for Economic Cooperation and Development, Paris, France.
- OECD (1992). *Benefit Estimates and Environmental Decision Making*. OECD, Paris, France.
- Oguntoyinbo, J.S. (1970). "Irrigation and Land Reclamation Projects in Nigeria". *Nigerian Agricultural Journal* 7(1).
- Okereke, O. (1991). "Increasing Rice Output Through Tractor Use in Anambra State, Nigeria". In *Issues in African Rural Development*. C.R., Doss and C. Olson, eds., International Institute for Agricultural Development, Arlington, Va: Winrock.
- Okigbo, B.N. (1979). *Cropping Systems and Related Research*. African Association for the Advancement of Agriculture and Science in Africa. Addis Ababa (Occasional Publication Serriesoti).
- Okigbo, B.N. (1981). "Technical and Environmental Problems of Irrigation and Mechanization with Some Possible Solutions in Nigeria's Green Revolution Programme", In *The Green Revolution in Nigeria (Proceedings of a National Seminar)*. G.O.I. Abalu, J. Abdullahi and A. Iman eds., Zaria: Ahmadu Bello University, Nigeria.
- Oldeman, L.R. ed. (1988). *Guidelines for General Assessment of the Status of Human-Induced Soil Degradation*. International Soil Reference and Information Centre, Wageningen, The Netherlands.
- Olson, R. V. (1984). "Iron Solubility": In Soils as Affected by pH and Free Iron Oxide Content. Soil Science. *American Proceedings* (12), pp. 153-54.
- Olukosi, J.O., Elemo, Kumar, K.V. and Ogungbile, A.O. (1989). "Contribution of Farming Systems Research to the Development of Improved Crop Mixture in the Nigerian Savanna". Paper Presented at the 2nd Conference of West African Farming Systems Network, Accra, Ghana.
- Olukosi, J.O., Ogungbile, A.O. and Kalu, B.A. (1991), "Appropriate Agricultural Technologies for Resource-Poor Farmers". Proceedings of the National Farming Systems Research Network Workshop, Calabar, Nigeria. 14-16 August.
- Oomen, J.M.V., Wolf, J. de and Jobin, W.R. (1990). "Health and Irrigation". ILRI Publication 45, Volume 1, Wageningen, The Netherlands.
- Owusu, K.T. (1988). *An Analysis of Buyer and Producer Constraint in the Fresh Produce Sector in Swaziland: A Basis for Formulating Policies to Achieve Increased Market Penetration and Production*. Social Science Research Unit. University of Swaziland, Kwaluseni, Swaziland.
- Oyaibevwen (1988). "A Conceptual Framework for an Environmental Management Policy". In *Environmental Issues and Management in Nigerian Development*. P.O. Sada and F.O. Odemerho eds., Evan's Brothers Ltd., Ibadan.
- Palmer-Jones, R.W. (1977a). *Irrigation Development and Irrigation Planning in the North of Nigeria*. Abu, Zaria, Nigeria.
- Palmer-Jones, R.W. (1977b). "The Impact of Small Scale Irrigation on Small Farmers at Kano River Project, Kaduna". Progress Report for the Irrigation Cropping Scheme, Abu, Zaria, Nigeria.
- Parasuraman, S. (1994). "Economic and Social Marginalisation of Irrigation Project Displaced People". *Journal of Rural Development* 13 (2) pp. 227-42.
- Pearce, D. (1993). *Blueprints 3: Measuring Sustainable Development*. Earthscan, London, UK.
- Pearce, D.W. Markandaya, A. and Babier, E.B. (1989). *Blueprint for a Green Economy*. Earthscan, London, UK.

- Pearce, D.W. and K.G. Maler (1991). "Environmental Economics and the Developing World". *Ambio* 20 (2) pp. 52-54.
- Pearce, D.W. and Turner R.K. (1990). *Economics of Natural Resources and the Environment*. BPC Wheaton Ltd, Exeter, UK.
- Pearce, D., Babier, E. and Markandaya, A. (1990). *Sustainable Development Economics and Environment in the Third World*. Earthscan, London, UK.
- Pearce, D.W. and Warford J.J. (1993). *World Without End: Economics, Environment and Development*. Oxford, Oxford University Press, UK.
- Perrings, C. (1995). *Incentives for Sustainable Development in Sub-Saharan Africa*. In Ahmed and Doeleman eds., pp. 95-132.
- Pezzy, J. (1992) "Sustainable Development Concepts: an Economic Analysis". Environment Paper No. 2, World Bank, Washington D.C., USA.
- Pigou, A.C. (1920). *The Economics of Welfare*. Mcmillan & Co, London, UK.
- Pinstrupp-Andersen, P. (1994). "Socio-Economic and Policy Considerations for Sustainable Agricultural Development". In *Agriculture and Environmental Challenge*. Proceedings of the Thirteenth Agricultural Sector Symposium, Shricastava J.P. and Alderman, H. The World Bank, Washington D.C., UK.
- Poate, C. D. and Daplyn, P.F. (1993). *Data for Agrarian Development*. Cambridge University Press, UK.
- Rommelzvaal, A. (1993). *Physiographic Map of Swaziland. FAO/UNDP/GOS Land Use Planning for Rational Utilization of Land and Water Resources Project SWA/89/001*. Field Doc. 41 Mbabane, Swaziland.
- Repetto, R. (1985 ed). *The Global Possible*. University Press, Newhaven, Yale.
- Repetto, R., Margrath, W., Wells, M., Beer, C. and Rossini, F. (1989). *Wasting Resources: Natural Resources in National Income Accounts*. World Resources Institute, Washington D.C., USA.
- Richardson, E.V. (1985). *Water Management Synthesis II Project: Swaziland Activity Irrigation priorities*. Appraisal Report. Colorado State University, Fort Collins, Colorado, USA.
- Romer, P.M. (1986). "Increasing Returns and Long-Run Growth". *Journal of Political Economy* 94 (5) pp. 1002-1037.
- Romer, P.M. (1994). "The Origins of Endogenous Growth". *Journal of Economic Perspectives* 8 (1), pp. 3-24.
- Rosegrant, M.W. and M. Svendsen. (1993). "Asian Food Production in the 1990s" Irrigation Investment and Management Policy Research Reprints, Vol. 18 No. 1, Feb., 1993.
- Rukuni, M. (1988). Economic and Financial Aspects of Small Holder Irrigation in Zimbabwe. In *Irrigated Agriculture in Africa. Vol. 1*. Conference Proceedings, P.N. G. van Steekelenburg, ed., 25-29 April 1988, CTA and ILRI. Harare, Zimbabwe.
- Ruttan, V.M. and Binswanger H.P. (1978). "Induced Innovation and the Green Revolution". In *Induced Innovation, Technology, Institutions and Development*. Binswanger and Ruttan eds., Baltimore, Md: John Hopkins University Press, USA.
- Schramm, G. and Wartford, J.J. (1989). *Environmental Management and Economic Development*. eds., Baltimore Md: Johns Hopkins/World Bank.

- Science Council of Canada (1986). *A Growing Concern: Soil Degradation in Canada*. SCC, Ottawa, Canada.
- Serageldin, I. (1993). "Agriculture and Environmentally Sustainable Development". In *Agriculture and Environmental Challenge*. Proceeding of the Thirteenth Agricultural Sector Symposium, J.P. Shrivastava and H. Alderman, The World Bank, Washington D.C., USA.
- Shettima, K.A. (1997). "Ecology, Identity, Developmentalism and Displacement in Northern Nigeria". *Journal of Asian and African Studies* [Leiden], Xxxii (1-2), pp. 66-80.
- Shrivastava, M.M.P. (1994). "Sustainable Development With Special Reference to Agriculture". *Journal of Rural Development* 13 (1), pp. 47-55.
- Sithole, V.M. and J. Testerink. (1983). "*Irrigation and food security in Swaziland: current status and research priorities*". Paper presented at the 4th Annual University of Zimbabwe/Michigan State University Conference on Food Security in Southern Africa, 31 October – 4 November, 1983. Social Science Research Unit, University of Swaziland, Swaziland.
- Solow, M. R. (1974). "Intergenerational Equity and Exhaustible Resources". *Review of Economic Studies* 41, pp. 29-46.
- Solow, M.R. (1986). "On Intertemporal Allocation of Natural Resources". *Scandinavian Journal of Economics* 88(1), pp. 141-49.
- Solow, M.R. (1956). "A Contribution to the Theory of Economic Growth". *Quarterly Journal of Economics* 70 pp. 65-94.
- Solow, M.R. (1957). "Technical Change and the Aggregate Production Function". *Review of Economics and Statistics* 39, pp. 312-20.
- Spash, C. and Hanley (1995). "Preferences, Information and Biodiversity Preservation". *Ecological Economics* 12, pp. 191-208.
- Spiegel, M.R. (1972). *Theory and Problems of Statistics: Schaum's Outline Series*. Mcgraw-Hill Co. New York, USA.
- Stark, L. (1990). *Signs of the Hope: Working Towards Our Common Future*. Oxford University Press, New York, USA.
- Stern, P.H. (1988). *Operation and Maintenance of Small Irrigation Schemes*. Intermediate Technology Publications Ltd, London, UK.
- Strand, J. (1981). "*Valuing Fresh Water Fish as a Public Good in Norway*". Mimeo, University of Oslo, Department of Economics, Oslo, Norway.
- Strand, J. (1981). "*Valuation of Freshwater Fish as a Public Good in Norway*". Mimeo, University of Oslo, Department of Economics, Oslo, Norway.
- Sturgess, R. (1992). *Socio-Economic Study of Central Highlands*. Kew.
- Swaziland Government (1983). *The Fourth National Development Plan 1983/1984 – 1987/1988*. Ministry of Economic Planning and Development, Mbabane, Swaziland.
- Swaziland Government (1994). *Swaziland Annual Agriculture Survey 1993/1994 – Phase II*. Central Statistics Office, Mbabane, Swaziland.
- Swaziland Government (1995a). *Development Plan 1995/1996 – 1997/1998*. Ministry of Economic Planning and Development, Mbabane, Swaziland.
- Swaziland Government (1995b). *Swaziland Annual Agriculture Survey 1994/1995 – Phase II*. Central Statistics Office, Mbabane, Swaziland.

- Swaziland Government (1996a). *Development Plan 1996/97 – 1998/1999*. Ministry of Economic Planning and Development, Mbabane, Swaziland.
- Swaziland Government (1996b). *Swaziland Annual Agriculture Survey 1995/1996 – Phase II*. Central Statistics Office, Mbabane, Swaziland.
- Swaziland Government (1997a). *Economic and Social Reform Agenda (ESRA)*. Ministry of Economic Planning and Development, Mbabane, Swaziland.
- Swaziland Government (1997b). *National Development Strategy (NDS): A Twenty-five year vision*. Ministry of Economic Planning and Development, Mbabane, Swaziland.
- Swaziland Government (1997c). *Swaziland Environment Action Plan: Volume I* Swaziland Environment Authority, Ministry of Tourism, Environment and Communications, Swaziland.
- Swaziland Government (1997d). *Swaziland Environment Action Plan: Volume II*. Swaziland Environment Authority, Ministry of Tourism, Environment and Communications, Swaziland.
- Swaziland Government (1998a). *Annual Statistical Bulletin*. Central Statistical Office, Mbabane, Swaziland
- Swaziland Government (1998b). *Small-holder Agricultural Development Project, Appraisal Report*. Working Paper VI. Small-scale Irrigation Development. Ministry of Agricultural Economics Section, Agriculture and Cooperatives, Mbabane, Swaziland.
- Tanji, K.K. and Hanson, B.R. (1990). Drainage and Return Flows in Relation to Irrigation Management. In *Irrigation of Agricultural Crops*. Stewart, B.A. and Nielsen, D.R. eds., No. 30, ASA-CSSA-SSSA, Madison, WI 53711 USA. Chap. 35, pp. 1057-1087.
- Thaler, R., and Rosen, S. (1976). "The Value of Saving a Life: Evidence from the Labour Market", In *Household Production and Consumption*. 40, Nelson T. ed., National Bureau of Economic Research, Washington D.C., USA.
- Thampapillai, D.J. (1988). "The Value of Natural Environments", The Extraction of Finite Energy Resources — A Method of Valuation. *International Journal of Energy Research* 12 pp. 527 - 38.
- Tietenberg T. (1996). *Environmental and Natural Resource Economics-4th ed*. Harper Collins College Publishers.
- Tiffen, M. (1990). *Guidelines for Inter-sectoral Cooperation to Improve Health Aspects of Irrigation*. World Health Organisation, Geneva, Switzerland.
- Tillman, G. (1981). *Environmentally Sound Small-scale Water Projects: Guidelines for Planning*. CODEL VITA Publication, USA.
- Tisdell, C.A. (1988). "Sustainable Development: Differing Perspectives of Ecologists and Economists, and Relevance to the LDCs". *World Development*. 16 (3), pp. 373-84.
- Turner R.K. Pearce, D. and Bateman, I. (1993). *Environmental Economics*. John Hopkins University Press; Baltimore, USA.
- Uguru M.I. (1981). *Crop Production: Tools Technologies and Practice*. Falladu Publishing Company, Nsukka, Nigeria.
- Ugwu, M.I. (1996). *Crop Production: Tools, Techniques and Practice*. Fulladu Publishing Company, Nsukka, Nigeria.
- United Nations Environmental Programme (1991). *Environmental Data Report*. 3rd Edition, Prepared for UNEP by the Gems Monitoring and Assessment Research Centre in Collaboration With the World Resources Institute and the U.K. Dept of Environments. Basil Blackwell, Oxford, UK.

- United Nations Conference on Environment Development (UNCED) (1991). *"Conservation And Development of Forests: Options for Agenda 21"*, Third Draft, October 29 1991.
- U.S. Environmental Protection Agency (1990). *Environmental Investment: The Cost of a Clean Environment*. US.EPA Washington D.C., USA.
- U.S. Congress Office of Technology Assessment (OTA) (1989). *Serious Reduction of Hazardous Waste: for Pollution Prevention and Industrial Efficiency*. U.S. Govt. Printing Office, Washington D.C., USA.
- Vanderhoek, W., Konradsen F., Athukorala, K. and Wanigadewa, T. (1998). *"Pesticide Poisoning: A Major Problem in Sri-Lanka."* Social Science and Medicine, Feb.-March, 46 (4-5) pp. 495-504.
- VanWaveren, E. and Nhlengetfwa, J.V. (1992). *Agro-climatic Characterization of Swaziland. FAO/ UNDP/GOS Land Use Planning for Rational Utilization of Land and Water Resources Project SWA/89/001*. Field Doc. 1. Mbabane, Swaziland.
- Walkley, A. and Black, I.A. (1934). Determination of Organic Carbon in Soils. *Soil Science* (37), pp. 29-38.
- Watts, S ., Khallaayonne, K., Bensefia, R., Laamrani, H. and Gryseels, B. (1998). "The Study of Human Behaviour and Schistosomiasis Transmission in an Irrigated Area of Morrocco". *Social Science and Medicine* 46 (6) pp. 755-765.
- WCED (1987). *Our Common Future*. World Commission on Environment and Development. Oxford, Oxford University Press, UK.
- Willig, R.D. (1976). "Consumer Surplus Without Apology". *The American Economic Review* 66 (4), pp. 589-91.
- Winpenny, J.T. (1991). *Values for the Environment: A Guide to Economic Appraisal*. London HmsO, UK.
- Woodhouse, P. (1992). "Environmental Degradation and Sustainability". In *Poverty and Development in the 1990s*. T. Allen, and A. Thomas eds., Oxford University Press, Oxford, UK.
- World Health Organisation (1990). *Public Health Impacts of Pesticides Used in Agriculture*. Geneva, Switzerland.
- World Bank (1984). *"Sub-Saharan Africa: from Crisis to Sustainable Growth"*. Washington, D.C., USA.
- World Bank (1992). *Development And The Environment*, World Bank Report, New York, Oxford University Press, USA.
- World Resources Institute (1992). *World Resources 1990-1991*. New York, Oxford University Press, USA.
- Wright (1995). *"Policy Induced Local Sourcing of Raw Materials and Technology Development in Nigerian Industry"*. Interim Report Submitted to ATPS Network, F. Kayode, A.O. Oyejide and S. Afolabi.
- Yaap, T.P. (1989). "The Cost of Degradation to the Community: Issues and Estimates". *Australian Journal of Soil and Water Conservation*. 2 (3) pp. 389-393.
- Young, M.D. (1988). "Some Step in Other Countries". *EPA Journal* April.
- Yudelman, M. (1989). "Sustainable and Equitable Development in Irrigated Environments". In Leonard H.J (1989). *Pollution and the Struggles for the World Product: Multinational Corporations, Environment and Comparative Advantage*. Cambridge University Press, Cambridge.



- Zahlan, A.B. (1991). *Acquiring Technological Capacity: A Study of Arab Consulting and Contracting Firms*. Macmillan, London, UK.
- Zschau, E. (1991). Advancing Technology Innovation through Tax Policy. *Technology in Society* 30 Nos. 1 and 2.

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