AN INTEGRATED EVALUATION OF AGRICULTURAL RESEARCH IN TROPICAL AFRICA: CASE OF NIGERIAN FOOD CROPS RESEARCH SYSTEM

By

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INTRODUCTION

Problem Statement

Problematic Situation

While the problem of food shortages in the world is sensed with mixed feeling of optimism and pessimism [Poleman, 1975], the specter of hunger is a dramatic reality for most of Sub-Saharan Africa. Data on per capita food production [USDA, 1974] indicate a declining trend since 1969 (see Table I). Though additional conventional resources were used, the resulting increase in total food production was not sufficient to cover total food needs. The qualitative dimension of the food problem may be more serious than the quantitative dimension. Recent provisional food balance sheets [FAO, 1977] indicate that per capita protein supplies as well as total food calories are below needed requirements (see Table II).[1]

This discrepancy between domestic per capita food supply and requirements calls for alleviating what has come to be termed the African food crisis. Alternative policies include population control and food imports. The alternative of population control, although very

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[1] There are certainly an appreciable amount of protein and calories supplies that are not accounted for in reported data, sources of such supplies are game, fishing and fruits gathering.

TABLE I

INDICES OF PER CAPITA FOOD PRODUCTION,
BY COUNTRY, 1965-74
(1961-65 = 100)

Country	1965	1966	1967	1968	1969	1970	1971	1972	1973	Prelim. 1974
ALGERIA	96	67	80	93	81	86	77	85	68	59
ANGOLA	100	100	100	100	104	101	99	94	97	88
BURUNDI	106	107	106	105	105	110	112	109	105	82
CAMEROON	104	106	107	109	108	99	107	102	94	97
DAMOMEY	95	97	96	97	97	96	92	90	91	91
ETHIOPIA	99	100	100	100	100	100	99	98	94	90
GHANA	94	99	99	90	92	86	88	83	84	85
GUINEA	96	94	95	101	104	107	108	103	102	101
IVORY COAST	100	107	108	107	113	113	119	114	119	124
KENYA	93	101	107	100	94	95	87	91	88	87
LIBERIA	103	93	93	90	89	87	87	85	87	87
LIBYA	116	102	115	130	114	98	91	122	142	149
MALAGASY REPUBLIC	100	105	109	111	112	111	111	112	101	105
MALAWI	94	132	160	114	143	112	137	143	149	158
MALI	95	94	94	84	95	90	79	67	60	62
MOROCCO	110	85	94	129	102	105	113	114	94	107
NIGER	93	94	106	81	103	87	72	63	50	56
NIGERIA	98	100	92	89	106	98	96	96	91	95
RHODESIA	95	96	91	71	92	80	94	107	76	110
RWANDA	96	101	120	116	117	121	119	112	115	86
SENEGAL	110	89	107	82	90	67	93	63	73	84
SIERRA LEONE	97	95	95	98	92	95	96	93	88	89
SOUTH AFRICA, REPUBLIC OF	89	94	121	98	99	100	110	114	91	111

TABLE I (Continued)

Country	1965	1966	1967	1968	1969	1970	1971	1972	1973	Prelim. 1974
SUDAN	96	92	105	86	100	104	100	100	91	99
TANZANIA	100	105	101	100	99	102	99	103	92	82
TOGO	100	101	103	102	102	103	103	97	95	96
TUNISIA	103	79	79	85	76	94	117	116	131	128
UGANDA	106	106	104	106	104	101	97	93	85	86
UPPER VOLTA	101	85	95	85	84	81	80	67	62	79
ZAIRE	101	109	110	116	121	118	106	104	107	109
ZAMBIA	97	129	169	116	120	83	159	220	159	194

Source: USDA, Indices of Agricultural Production in Africa and the Near East, 1965-1974.

TABLE II

CALORIES AND PROTEINS SUPPLIED PER CAPITA
AND PER DAY

Commodity	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
	Calories (Number Per Day)										
Grand Total	2088	2105	2113	2106	2120	2138	2148	2155	2123	2095	2116
Vegetable Products	1962	1978	1983	1972	1985	2002	2008	2021	1993	1970	1990
Animal Products	126	127	130	134	135	136	140	134	130	125	125
Grand Total Excl Alcohol	2051	2068	2075	2068	2083	2100	2109	2117	2084	2055	2075
Cereals	1004	1012	1023	1022	1017	1021	1026	1041	1032	1010	1023
Wheat	146	155	165	166	170	176	183	191	197	201	201
Rice	105	106	107	106	106	108	110	112	112	111	113
Maize	264	262	262	263	262	262	265	277	273	267	278
Millet and Sorghum	389	389	393	388	378	375	368	358	350	328	331
Roots and Tubers	465	464	462	460	473	478	460	457	445	445	448
Sugars and Honey	69	73	76	78	79	82	88	91	92	92	92
Fulses	90	93	89	91	92	89	94	91	87	88	89
Nuts and Oilseeds	67	67	67	66	66	65	66	67	66	65	62
Vegetables	18	18	18	18	18	18	18	18	18	17	18
Fruit	90	90	89	87	86	88	89	87	86	86	88
Meat and Offals	58	58	58	60	60	61	61	59	57	55	53
Eggs	3	3	3	3	3	3	4	4	4	4	4
Fish and Seafood	11	11	12	12	12	12	14	13	14	13	13
Milk	38	37	39	39	40	41	42	41	39	36	37
Oils and Fats	131	133	131	124	128	135	141	142	139	138	140
Vegetable Oils and Fats	116	118	115	107	111	118	124	126	124	123	124
Animal Oils and Fats	15	15	16	17	17	17	17	16	16	15	16
Stimulants	1	1	1	1	1	1	1	1	1	1	1
Spices	5	5	6	6	6	6	5	6	6	5	5
Alcoholic Beverages	36	36	38	37	37	38	38	38	39	40	40

TABLE II (Continued)

Commodity	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
						Proteins (Grammes Per Day)					
Grand Total	52.2	52.7	52.9	53.1	53.1	53.2	53.9	53.8	52.9	51.8	52.4
Vegetable Products	42.8	43.2	43.3	43.3	43.3	43.2	43.6	43.9	43.2	42.6	43.1
Animal Products	9.4	9.4	9.6	9.8	9.8	10.0	10.3	9.9	9.7	9.3	9.3
Grand Total Excl Alcohol	51.9	52.3	52.6	52.8	52.8	52.9	53.5	53.4	52.6	51.5	52.0
Cereals	27.1	27.3	27.6	27.6	27.4	27.5	27.6	28.0	27.8	27.2	27.6
Wheat	4.4	4.7	5.0	5.0	5.1	5.3	5.5	5.7	5.9	6.0	6.0
Rice	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.3	2.3	2.4
Maize	6.9	6.8	6.8	6.8	6.8	6.8	6.9	7.2	7.1	6.9	7.2
Millet and Sorghum	10.8	10.8	10.9	10.7	10.4	10.3	10.1	9.8	9.6	9.0	9.1
Roots and Tubers	4.6	4.6	4.6	4.6	4.7	4.8	4.6	4.7	4.6	4.6	4.6
Sugar and Honeys											
Fulses	5.8	6.0	5.8	5.9	6.0	5.8	6.1	5.9	5.6	5.7	5.8
Nuts and Oilseeds	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.4
Vegetables	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.9	.9
Fruit	1.0	1.0	1.0	.9	.9	.9	1.0	.9	.9	.9	.9
Meat and Offals	5.3	5.3	5.4	5.5	5.5	5.5	5.6	5.3	5.1	4.9	4.8
Eggs	.3	.3	.3	.3	.3	.3	.3	.3	.3	.3	.3
Fish and Seafood	1.8	1.8	1.9	2.0	1.9	2.0	2.2	2.1	2.2	2.1	2.2
Milk	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.1	1.9	2.0
Oils and Fats											
Vegetable Oils and Fats											
Animal Oils and Fats											
Stimulants	.2	.2	.2	.2	.2	.2	.2	.2	.2	.1	.2
Spices	.2	.2	.3	.3	.3	.2	.2	.3	.2	.2	.2
Alcoholic Beverages	.3	.3	.4	.3	.3	.4	.4	.4	.4	.4	.4

Source: Provisional Food Balance Sheets, FAO, Rome, 1977.

important and effective in the long-run, is not, however, immediately palatable to the socio-cultural system of African societies. Because of this, its implementation is very hazardous. A policy of food imports, although workable in case of short-run urgency, is not reliable for three reasons. First, commercial imports require capacity to pay, but for most African countries, per capita incomes have been at best stagnating and foreigh exchange has been limiting. Second, the instability of world food production and availability of food imports is a serious concern in the light of experience in the early 1970's [Sanderson, 1975]. The possibility of cushioning the instability has been enhanced by building world food reserves, but the political and economic feasibility of such international reserves is not yet established. Finally, national pride demands self-sufficiency to meet basic nutrition needs. Nations prefer to use scarce foreign exchange for production capital imports which they are unable to supply domestically.

In a recent publication edited by Schultz [1978], a case is made that the underproduction that currently prevails in most developing countries is due to the lack of incentives in the system. At the domestic level, reliance on a high food price policy to induce farmers to produce more is not adequate because shortages are technologically as well as economically determined. For a system to respond to incentives, favorable investment alternatives to increase income output must be available. The response to higher prices along the traditional supply curve requires additional conventional resources for which the supply is highly inelastic. Land is limited due to population pressures and the farm labor is scarce because of erratic value judgments that undervalue agriculture [Schultz, p. 10, 1978].

Thus, the domestic policy needed to break the food supply constraint in Africa is the combined policy of higher food prices and development of an appropriate agricultural technology in the sub-Saharan tropical frontier as well as other areas. In the case of Nigerian agriculture, a sophisticated food crop research network exists that goes back to 1930 and was further strengthened by the funding of the International Institute of Tropical Agriculture (IITA) in 1967. Yet, Table I indicates the per capita food production has been declining. This is a problematic situation that this study intends to analyze.

Problem Specification and Hypotheses

The coexistence of declining food productivity and continuing funding of the food crops research can be a symptom of the lack of input or output by the existing food crops research system. Also, it is warned that low per capita food production might be a symptom of wrong agricultural price, credit and land policies rather than the direct effect of inefficiency of technology generated by research centers [Mosher, 1977].

The ineffectiveness of the research network might be due to the fact that the structure and organization of research are not consistent with identified needs and resources at hand, or that the product of research does not reward the peasant to the extent of compensating him for the risk of innovation. As to the price policy, one can postulate that low producer prices combined with high input prices make it unprofitable to adopt new technologies, despite of their physical superiority over traditional ones. The scarcity of credit in rural areas restrains diffusion of modern technology which requires a higher supporting capital.

All the above hypotheses can be tested, but given the limitations on data and time, this study has chosen to concentrate on the verification of the physical and economic profitability of the research to both farmers and Nigerian society. Other hypotheses need to be tested by other independent studies or by studies relying on the information that private and social returns to research are positive and attractive.

Objectives, Scope and Methods of Analysis

In view of hypotheses formulated earlier, the objectives of this study are the following:

1. to qualitatively describe and analyze the structure and performance of food crops research networks in Nigeria.
2. to determine whether the related varieties produced by the existing Nigerian research systems are physically and economically superior to the traditional cultivars.
3. to estimate rates of return to food crops research expenditures.
4. to suggest a food crops research policy consistent with the Nigeria food economy.

The scope of the study is limited in time and space. Data available on research expenditures extend only back to 1960. However, missing data were derived by making the crude assumption that food crops research expenditures constituted a given percent of total federal expenditures. The chosen ratio of food crops research expenditures to the total federal expenditures was that prevailing from 1968 to 1976.

In space, the study was limited to Nigerian crops for which data were judged to be at least minimally adequate. The crops retained for the study were rice, maize and Cassava. However, in the qualitative description of the research network, an effort was made to account for research programs related to other food crops such as cowpeas, sorghum and millet.

An environmental model of the kind developed by Dr. Hahn [1979] is used to determine whether High Yielding Varieties are adapted to the environment. The analysis requires yield information for various varieties and locations. The same data are used to undertake the stockastic efficiency analysis by comparing different variety distributions.

The environmental model and stochastic efficiency analysis provide the information about the physical performance of improved varieties. To analyze the economic advantage of new technology, a budget analysis is made to determine the profitability of a package of improved technologies at the farmers' level.

To meet objective (3) an aggregate production function is estimated and used to derive marginal returns to research. This analysis requires data not only on yield, acreage, labor and prices of outputs and inputs, but also data on food crop research expenditures.

Review of Literature

Theory and Concepts

In his celebrated book "Getting Agriculture Moving" Mosher [1966] enunciated four necessary conditions for encouraging agricultural development. Those conditions are: 1) modifying the production process; 2) changing the behavior of farmers; 3) changing the nature of individual farms; and 4) changing the relationships between costs and returns in individual businesses. Technological progress affects agricultural development by inducing changes in (1) and (4). The conditions (2) and (3) were considered by Schultz [1964] as already being initiated in most developing countries so that the Schultzian concept of agricultural development emphasized mainly the change of the production process. Neither Schultz nor Mosher explained how technological change is induced in the system. Presumably its demand is given and it is up to the system to supply it.

Taking the Hicksian or neoclassical framework of analysis, Hayami and Ruttan [1971] formulated a theory of induced development with tentative answers as to how the demand for a new technology arises. Specifically, the Hayami-Ruttan model postulates four mechanisms of induced innovation: 1) induced innovation in the private sector; 2) induced innovation in the public sector; 3) institutional innovation, and 4) dynamic sequences. It would appear that apart from mentioning it, Hayami and Ruttan did not really develop a genuine theory of private induced innovation; instead, they relied on the Hicksian theory of technological change where factor-product prices ratios are considered very crucial in determining the technological bias. Hayami and Ruttan apply the Hicksian framework to the public sector for analyzing how it decides on the choice of new technology. Their analysis presents no new theory of demand for new technology in the private nor public sector. Instead, they interpret neoclassical theory of technological progress with an application to the agricultural sector. The Hayami-Ruttan interpretation is that:

> If the demand for agricultural products increases due to growth in population and income, prices of the inputs for which the supply is inelastic will be raised relative to prices of inputs for which the supply is elastic. Likewise, if the supply of particular inputs shifts to the right faster than others, the prices of these inputs will decline relative to the prices of other factors of production. In consequence, technical innovations that save the factors characterized by an inelastic supply or by slower shifts in supply become relatively more profitable for agricultural producers (p. 57).

Implied in the above statement are the usual assumptions of the neoclassical theory of the firm. The relevancy of these assumptions for the analysis of realistic economic problems has been questioned [Cyert and March, 1963]. However, the integration of institutional innovations and dynamic sequences in the private and/or public sector makes the Hayami-Ruttan model more realistic and appealing. Institutional changes are expected to lubricate the system by making it more flexible and by improving the mobility of factors with respect to market signals while dynamic sequences will cause market signals to move toward a static equilibrium by going through a series of successive disequilibria. Among institutional changes contemplated in the Hayami-Ruttan model are land and credit reforms. When these changes are consistent with the technological change, the adoption of the new technology is enhanced. Hayami and Ruttan [1971, p. 275] underscore the importance of extension education in the process of agricultural development. But they note that differences in productivity among farmers are almost the same in systems with a strong extension network and in systems with a weak extension effort [Hayami and Ruttan, 1971, p. 275]. Although factors other than extension influence farm productivity, one can hypothesize that (1) in the early stage of development, extension education plays an important role in explaining productivity differences among farmers and (2) in the late stage of development, when farmers are better trained in management and closer to the technology frontier, the marginal impact of extension effort is low.

In developing countries, publically supported agricultural research and extension education is important for two reasons: (1) technical competency of the traditional peasant cannot be taken for granted and (2) the process by which the new technological change is demanded bypasses the peasant. That is, the producer has not privately demanded the new technology through market signals; instead, the public sector, taking the place of the peasant, responds to social needs expressed through the markets and/or through the political process by supporting agricultural research. In this context, it is the role of government to build or facilitate the mediating function between agricultural research centers and the peasant. Without this function, actual returns to research may be low and diminishing.

The above argument can be illustrated using the concept of meta-production function (MPF) of type described in Figure 1. The curves C_o and C_o are respectively yield response of traditional cultivars and High Yielding Varieties (HYV_s). For the respective price ratios P_o and P_1, levels F_o and F_1 of fertilizer are used. If the traditional farmer does not have access to HYV_s but takes advantage of the lower price of fertilizer by imitating the modern farmer in the input-use pattern, he will find himself in the irrational range of production with declining total output. During the next planting season, he may adopt HYV_s or sink back to his traditional production process at F_o. Given those two choices, the peasant might protect himself by going back to F_o rather

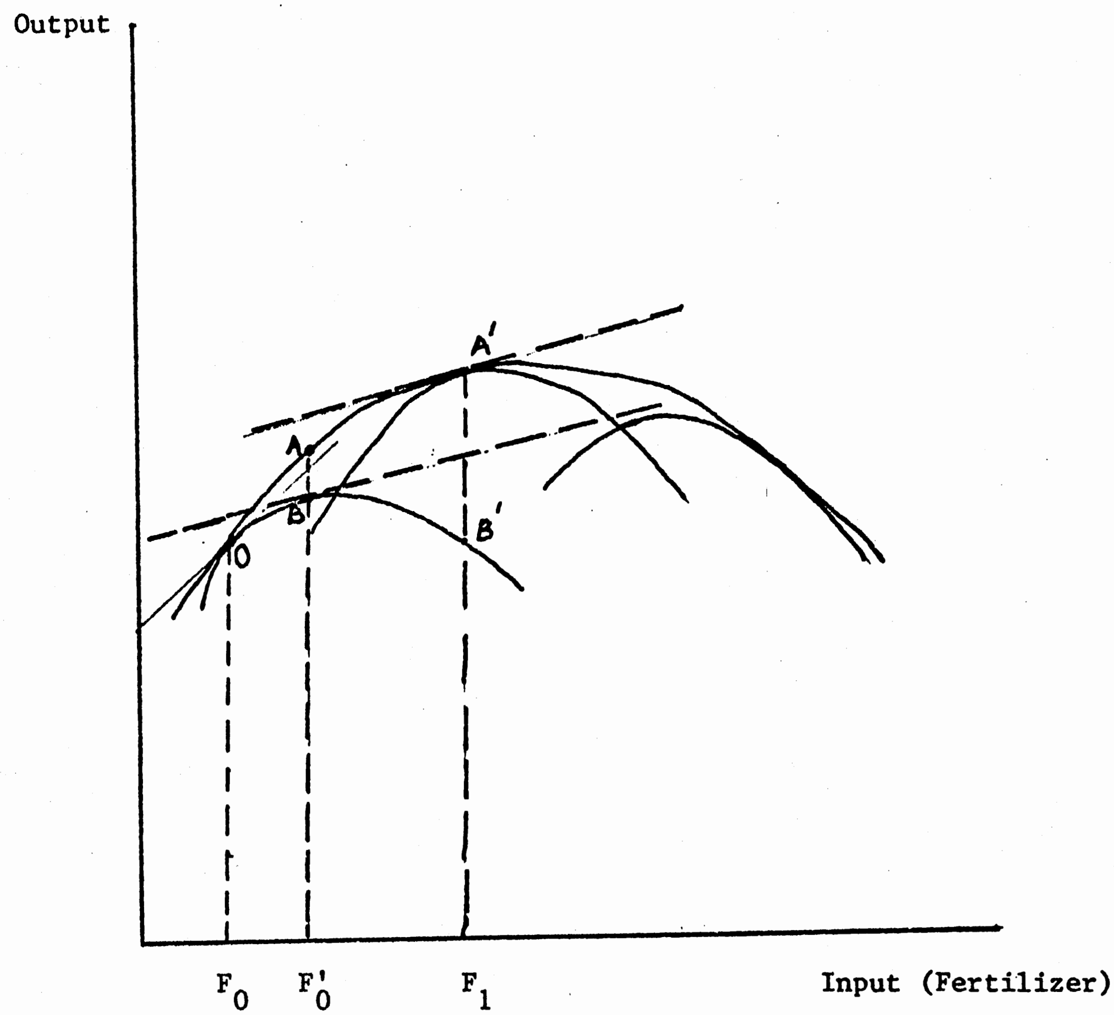

Figure 1. Metaproduction Function of a Hypothetical Crop

than shift to a higher response curve. This is likely to happen if he has high differential evaluation defined as the difference between his apparent and correct perception of HYV_s [Bernhardt and MacKenzie, 1969]. The difference AB and A'B' are losses of output due respectively to traditionalism and temporary ignorance. Those two losses affect actual rates of returns to research. If these two losses are minimized by the majority of peasants moving to the higher response curve, the total agricultural product and returns to research are increased. Thus, the process of agricultural productivity is not only dependent on the availability of superior technology embedded in MPF but also on the efficient use of this technology.

Evenson [1978], contending that most developing countries have overinvested in agricultural extension, provides a framework for distinguishing between research and extension activities [Evenson, 1978]. He specifically recognizes three types of changes in production--potential, optional and actual. Changes in optional production are labeled technological changes and changes in actual production are labeled technical changes. Evenson calls the difference between optional and actual production "economic slack", and calls the difference between potential production and optional production "technological slack" (p. 29).

The reduction of economic slack is thought to be determined by the extent of extension and rural development while the reduction of technological slack depends on the development of research capabilities. Overinvestment in extension programs occurs if rates of return on extension are too low to justify current commitment of resources in this particular activity.

Production Functions

The literature on production functions is vast and only those issues relevant to this analysis will be mentioned. Issues of functional form, specification and aggregation are selected for a brief review.

Johansen [1972, p. 5], in his typology of production functions, distinguishes four types of production functions: (1) the ex ante function at the micro level, (2) the ex post function at the micro level, (3) the short-run (or transient) function at the macro level, and (4) the long-run (or steady-state) function at the macro level. The ex ante function corresponds to the locus of points connecting A and A' in Figure 1 describing the metaproduction function which is an expression of the relevant technological knowledge in the system at a given point in time. The ex post function specifies actual input-output relations taken by the production units from the available MPF or ex ante function. The short-run function at the macro level is an aggregation of ex post functions at the micro level whereas the long-run function at the macro level is a hypothetical construct similar to the ex ante function at the micro level, but now defined in the context of the overall sector.

Before examining the issue of aggregation in the production process, it is well to examine the literature regarding the problem of the functional form. Two types of functional forms are emphasized in the literature, linear and non linear splines. A good discussion of different splines is presented by Poirier [1975] in his analysis of structural change. He distinguishes four important splines which are:

linear, cubic, bilinear, and Cobb-Douglas splines (CDS). The importance of Poirier's analysis is that it challenges the commonly accepted view of constant relationships in a linear function. Particularly, it is indicated that a linear spline might have one or more "knots" so that the marginal product is not continuous but rather is a setp function. Such splines can be estimated with the ordinary regression model. However, if steps in marginal products are unsystematic, the regression model might provide a poor fit. The cubic spline is the so-called polynomial function with a continuous marginal product and estimable through least squares with proper transformation. The knots in this function represent inflection points. To improve the fit, oversampling of data around the knots or inflection points is suggested.

The bilinear spline is a linear spline in two or more variables, but with one or more interaction terms. Again the estimation procedure follows the traditional regression technique with proper transformation of the interaction variable. The Cobb-Couglas spline estimated in logarithmic form reduces to the bilinear spline without an interaction term.

This review now examines the problem of aggregation. The literature records numerous conditions to be met for consistent aggregation. The chain partial derivative of the aggregate function F with respect to the micro input X_{rs} (with macro input $X_r = F(X_{r1} \ldots X_{rn})$) must be equal to the chain partial derivative of F with respect to X_{rs} (with macro output $Y_s = F(X_{r1} \ldots X_{rn})$) [Green, p. 36, 1974]. In mathematical form the condition is

$$\frac{\partial F}{\partial X_r}\frac{\partial X_r}{\partial X_{rs}} = \frac{\partial F}{\partial Y_s}\frac{\partial Y_s}{\partial X_{rs}} \qquad 2.1$$

To this condition is added the **sufficient** condition of linearity.[2] Taking the above criterion as a necessary and sufficient condition, the use of cubic, bilinear and Cobb-Douglas splines to estimate macro-type production functions is quite incorrect. Production functions relating agricultural research inputs to output are estimated with aggregate variables, yet most studies report use of Cobb-Douglas splines (see for instance Evenson, 1971).

In addition to choosing the functional form and the level of data aggregation, other specification problems plague the analyst.[3] One problem arises from the so-called management bias [Griliches, 1957][4].

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[2]This condition can be defined as follows; for any function

$$Y_s = f_s(X_{1s},\ldots X_{rs},\ldots X_{ms})$$

to be aggregated to the form of

$$Y = F(X_1\ldots X_m)$$

there should exist functions G, H, g_r, h_s, G_r, H_s, h_{rs}, h_{rs} such that

$$Y = H[h_1(Y_1)+\ldots+h_n(Y_n)] = G[g_1(X_1)+\ldots+g_m(X_m)]$$

where Y_s $(s = 1\ldots n)$ and X_r $(r = 1\ldots m)$ are respectively

$$Y_s = H_s[h_{1s}(X_{1s})+\ldots+h_{ms}(X_{ms})]$$

and

$$X_r = G_r[g_{r1}(X_{r1})+\ldots+g_{rm}(X_{rn})]$$

[3]Specification is used here in a restricted sense as a process of variables identification; in a broad sense it certainly also covers form and shape of functions to be estimated.

[4]By management bias it is meant that lack of introducing a variable for managerial skill leads to the underestimating of returns to labor (if managerial skill is positively correlated with quantity of labor) or returns to capital (if level of managerial input is correlated with level of capital inputs).

There exist, however, statistical techniques that help eliminate the management bias from the regression equation.

Stochastic Efficiency Analysis

The notion of stochastic dominance was first introduced by Quirk and Saposnik [1962] in their attempt to improve on the Von Neumann-Morgenstern preference orderings. The emerging theory conflicts with the traditional two-moments portfolio analysis based on mean (E) and variance (V) or E-V frontier criterion. Criteria of preference ordering developed by Quirk and Saposnik were based on first and second degree dominance of a set of probability distributions of a stochastic variable such as yield. First degree stochastic dominance (FSD) is a summation or an integral of the probability or density function of a stochastic variable over a given range, while second degree stochastic dominance (SSD) is defined as a summation or an integral of the distribution function over a specified range. The Quirk and Saposnik treatment was later improved by Hader and Russel [1969] who provided evidence for superiority of the method over E-V frontier analysis. It was particularly shown that FSD and SSD were not only necessary and sufficient conditions for determining the ranking of preferences, but that a specification of the form of the utility function was no longer necessary to make statements about preferences of the decision maker either under a monotonic or a concave utility function. This finding is independently confirmed by another study on efficiency analysis [Hanoch and Levy, 1969].

By 1970, an additional criterion in theory of stochastic efficiency analysis was added and called as a third-degree stochastic dominance or

TSD [Whitmore, 1970]. This criterion is obtained by comparison of summations or integrals of SSD over a relevant range. The TSD criterion is shown to be superior to FSD and SSD, but as Whitmore points out it has its own problems in case of some cross-over in the distributions. In 1973, Levy using a more specific distribution, confirms the power of stochastic dominance over the E-V, but discovers that when a stochastic variable has a log-normal distribution, the E-V criterion suffices to make preference orderings. The extension of Quirk and Saposnik [1962], Hadar and Russel [1969], Whitmore and Levy [1970] to the convex combination of probability distributions is rigorously made under generalized theorems elsewhere [Fishburn, 1974].

So far the articles reviewed have dealt only with theoretical aspects of the efficiency analysis. Empirical counterparts are few and are mostly oriented toward portfolio selection in financial management [Porter, 1973]. An exception is the effort by Anderson to use stochastic efficiency in the analysis of the impact of stabilization policy measures [Anderson, 1973].

This study will compare distributions of yield varieties using stochastic dominance criterion. The mathematical model underlying this criterion will be presented in Chapter IV. Before turning to that presentation, methods of evaluating the economics of research systems through calculation of rates of returns are reviewed. Historical rates of returns are reported followed by comments on methodological problems.

Rates of Returns to Agricultural Research

The literature on the economics of agricultural research traces to the pioneering work by Griliches [1958] who estimated the contribution of research workers to the farm productivity in the United States using the case study of hybrid corn. He found rates of return to research ranging from 30 to 40 percent during the 1940-1955 period. Griliches' [1964] first method of computing the rates of returns used the concept of consumers and producers surplus estimated by taking into account shifts in product supply due to the hybrid innovation. In his second study, Griliches formulated an expanded production function where educational research and extension expenditures were introduced as relevant nonconventional inputs. He estimated the impact of the agricultural research and extension by computing their marginal product. This procedure, which the literature terms the sources-of-growth approach [Arndt et al., 1977], is sometimes combined with the so-called productivity index approach to value the productivity of research [Cline, 1975].

Cost-benefit analysis is an alternative to the sources-of-growth or productivity index approach. Economists have interchangeably used one or another depending on specific conditions of research. The sources-of-growth or productivity index approach originated with the study by Tang [1963] dealing with aggregate agricultural research productivity in Japanese agriculture. Rates of return reported are similar to those of Griliches for U.S. hybrid corn. Trying to duplicate Tang's study for aggregate U.S. agriculture, Latimer [1964], found insignificant rates of returns for the entire U.S. agricultural research and extension. Latimer's results are considered to be erratic and as such they have been referred to only incidentally. In 1966, Peterson analyzed the payoff from research in the United States poultry, and reported a moderate rate of return of 21 percent annually for the

1915-1960 period. Evenson [1968] estimated rates of returns for the U.S. aggregate research and extension system to be about 47 percent. Continuing with the same methodology, Evenson [1969] applied the analysis to the case of sugarcane varieties in South Africa, Australia, and United States. He found higher rates of return of 40, 50 and 60 percent, respectively. Recently, popularized methods of sources-of-growth have reported rates of returns to research to be in the neighborhood of 40 percent in India during the 1953-1971 period [Evenson, 1973], 45 to 93 percent in Mexico for the period going from 1943 to 1963 [Ardi-to Barletta, 1970] and 63 percent for India again [Kahlon et al., 1977].

Based on direct cost-benefit analysis, the rates of return range from 16 percent reported by Schmitz and Seckler [1970] for mechanization of tomato harvesting in the U.S. between 1958 and 1969 to 96 percent in Colombian soybean industry during 1960's. Authors mentioned above in the camp of sources-of-growth approach have also tried direct cost-benefit analysis. While results from both methods are comparable, each has serious flaws.

Hertford and Schmitz [1977] contended that the critical element in estimation of rates of return is not the nature of method used but rather finding the change in output attributable to research. In cost-benefit analysis, adequate increases of the contribution of research requires proper determination of shifts in supply and of the demand function for the product. These measures are used to estimate consumers and producers surpluses. The controversy over the relevancy of consumers surplus as a useful economic concept has almost ended with a tacit agreement that the concept is relevant when estimated by means of a compensated demand curve [Hicks, 1959]. However, most studies reported under the direct cost-benefit approach did not adjust for this effect. Use of the compensated demand curve would have reduced consumers surplus and rates of return below those reported.

Basically, the compensated demand takes into account income compensations associated with price changes to keep the consumer's real income constant. Such compensations can be made in two different ways, namely Hicksian [1959] and Slutskyan method. With the Hicksian method, an effort is made to keep the consumer on his original level of satisfaction (indifference curve) while in Slutskyan method, the attempt is made to give the consumer the equivalent basket of goods as before rather than keeping him on the previous indifference curve.

A second conceptual difficulty, as pointed out by Hertford and Schmitz [1977], related to direct cost-benefit analysis and deals with the fact that new technology could be a derived demand rather than a direct demand--for instance, demand for hog feeding induced by corn hybrid. This argument is irrelevant for most developing countries where crops varieties are directly demanded for food consumption. A third problem addresses itself to the question of how to quantify the benefits. Objective quantification of the social value of the research is precluded by lack of a real social welfare function, the probalistic nature of research results and negative externalities [Plaxico, 1962]. Overstating or understating the value of benefits is likely. Conversion of quantities into real output benefits is also complicated by the inappropriateness of market prices. Market failure makes discounting procedures less than straightforward.

Two basic criticisms have been directed at the sources-of-growth approach to rates of return. The first criticism dealing with quality of inputs in aggregate production functions can be remedied in two ways: one is to introduce nonconventional inputs a la Griliches as it is done by many researchers [Evenson, 1968, 1969, 1973; Cline, 1973, and Knutson and Tweeten, 1979]. Another approach is to derive quality component through subtle mathematical operations [Sawada, 1968].[5] The second criticism arises from shortcomings of the residual method of estimating the technological change using the production function [Kahlon, et al., 1977]. The residual depends on the degree of specification of production--how many variables are left out or included. This is a valid criticism because calculating the rate of technological change with a residual approach would give different estimates depending on whether the technological change is embodied or disembodied.[6]

Either a direct cost-benefit analysis or a sources-of-growth approach encounters the problem of estimating rates of return into the presence of uncertainty and risk. The framework similar to the stochastic analysis can be formulated. In fact, the incorporation of risk

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[5]Actually those operations can be basically defined as the decomposition of inputs into two parts, namely quantity component and quality component so that growth in output $\dot{q}$ can be described as

$$\dot{q} = f(\dot{L} + \dot{l}, \dot{K} + \dot{k})$$

where $\dot{L}$ and $\dot{K}$ are quantitative growth rates in labor and capital whereas $\dot{l}$ and $\dot{k}$ are qualitative changes in labor and capital. But subtleties referred to above try to indirectly measure $\dot{l}$ and $\dot{k}$ which are, however, unobservable.

[6]Another criticism is that education and knowledge creation in broad terms (e.g. farm magazines, radio, TV, etc.) is omitted. Also private research contributions are not fully accounted for. It is difficult to separate contribution of education, extension and research.

analysis into the estimation of rates of return was suggested elsewhere [Sprow, 1967] and timidly attempted by the World Bank staff [Pouliquen, 1970]. One of the reasons why reported rates of return to agricultural research are so high is because of a deterministic nature of analysis with reliance on most optimistic outcomes.

CHAPTER II

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

Agro-Ecological Features of Nigeria

Geographical Location and Climate

Located in the gulf of Benin, Nigeria shares its northern boundaries with Niger in the north, Chad in northeast; in the east, it is entirely bordered by Cameroon, while Benin stands up as a sole neighbor in the west. In the south, the Atlantic Ocean stretches from the bight of Benin to the bight of Biafra. The entire Nigerian territory covers 356,699 square miles making it area-wise the thirteenth largest country in Africa. However, on demographic account, Nigeria continues to be the most populated nation on the continent with a population of about 80 million.

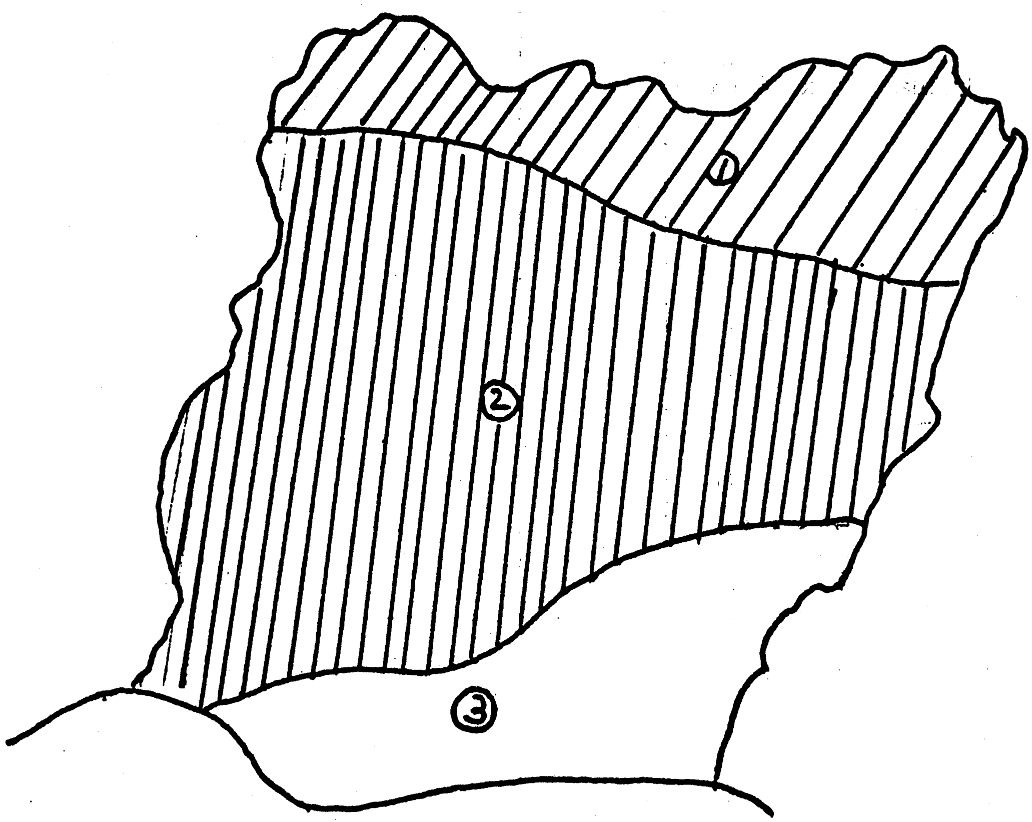
The relief of Nigeria is characterized by a lower plateau rolling downward from south and east to north and west. Its elevations go as high as 4,000 feet above sea level, but in general Nigeria has a flat topography as do most West African countries. Because of this relief and its location between 4° and 14° N, within the equator and the tropic of Cancer, Nigeria is part of the Inter-tropical convergence zone (ITCZ). This zone is formed by the convergence of two systems, namely the southern air masses and the northern air masses. Following previous reports [Des Bouvrie and Rydzewski, 1977], one can distinguish three main agroclimatic zones, namely 1) the Sudano-Sahelian zone, 2) the Sudano-Guinean zone, and 3) the tropical rain forest (Guinean) zone (see Figure 2).

The Sudano-Sahelian zone is succinctly described by water balance diagrams in Figure 3a and 3b. The vegetation in this zone is a Sudanese Savanna with Andropogon gayanus as one of the dominant species. The Sudano-Guinean zone can be represented by a water balance diagram in Figure 4. Because of its large size, this zone has three types of vegetation, namely 1) derived Savanna, 2) guinean Savanna, and 3) lowland forest. Finally, the tropical rain forest zone as its name implies is dominated by the rain forest which in some northern areas gives way to a derived Savanna.

The superimposition of precipitation maps, vegetation maps and soil maps reveals many agro-ecological entities with different agronomic requirements. An effort to cast and catalogue such agro-ecological entities is underway by the Farming Systems Program of the International Institute of Tropical Agriculture. However, four main groups of soil can be recognized: coastal, swamp and alluvial, rain forest, lateritic, and sandy soils.

Origins and Development of Traditional Food Crops

Botanists and experts in plant domestication conclude that African agriculture is noncentric [Harland et al., 1976]. There is no way to assert that a particular plant has originated from a particular region. However, some experts believe that transition from food gathering to regular cultivation occurred between 3000 B.C. and 1000 B.C. in the



1 Sudano-Sahelian zone

2 Sudano-Guinean zone

3 Rain Forest zone

Figure 2. Agroclimatic Zones of Nigeria

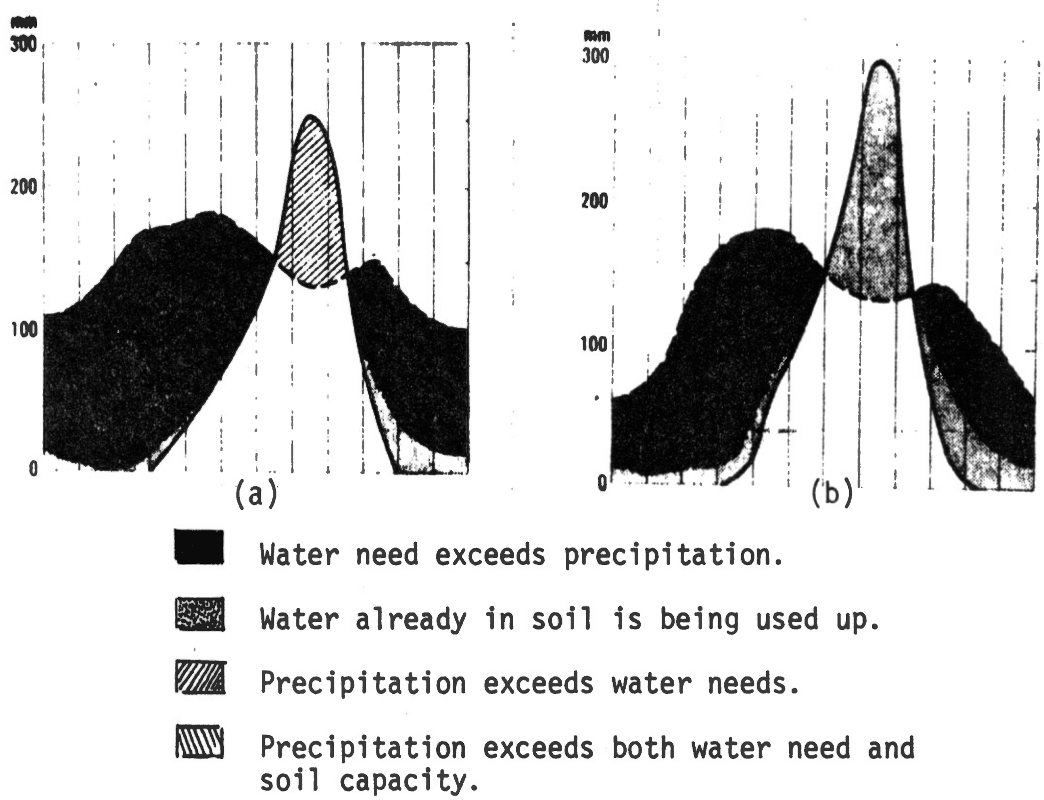
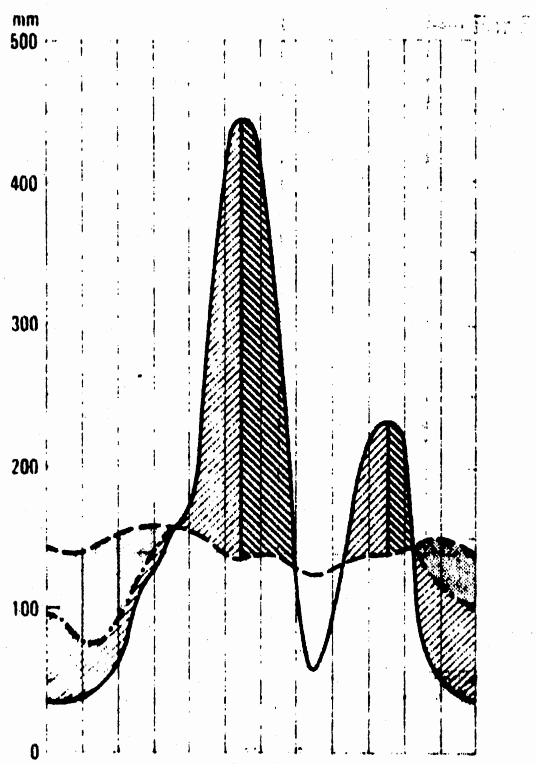


Figure 3. Water Balance in Nigerian Sudano-Sahelian Zone



For legend see Figure 3.

Figure 4. Water Balance in Nigerian Sudano-Guinean Zone

Sahel and northern Sudan zones [Clark, 1976].

Earlier crops connected with the period of cultivation are sorghum. They are believed, somewhat with controversy, to have originated from northeastern Africa, particularly in Ethiopia. Wherever their origin, they are contemporary to the iron age. Second to sorghums are yams. The Yam Belt is thought to stretch from Ethiopian lowlands to the west Africa. The literature of plant domestication shows that the movement of crop colonization is north-south or east-west. At this stage, however, it is important to understand the farming systems which have developed after a given crop has been introduced in the region.

Farming Systems in Nigeria

Once introduced in Nigeria, food crops have adapted to specific environments. Groundnuts have found a favorable climate in thornbush and dry Savannas of the north. Millets and sorghums are adapted to the climatic conditions of Sudano-Sahelian and Sudano-Guinean zones. Cassava and yams do well in derived Savannas, while rice is ambivalent; that is, it can be found in dry Savannas as well as in wet coastal swamps.

The methods of cultivation remain the traditional shifting cultivation or a permanent system of crop rotation. In the context of Nigerian agriculture, the following rotation systems are usually encountered: forest cultivation rotation and Savannas rotation. In the forest systems, the most important crops are cocoyam or taro (Xanthosoma), plantain (Musa paradisiaca) and Cassava (Manihot utilissima). Those crops are usually found side by side in a multiple cropping fashion. But the sequence of cropping is noted to be as follows: cocoyam and plantain are first planted, then in areas where cash crops are not interfering with food crops, maize and/or cassava follow [Ahn, 1970, p. 233].

In savanna systems, one encounters yams, maize, millet and fonio, guinea corn and groundnuts. Dryland rice is also best suited to this system. The normal rotation begins with maize, followed by guinea corn, which is overtaken by millet. This sequence of coarse grains is often preceded by yams.

In both forest and savanna rotation, the need for a development of fallow is crucial to the maintenance of the cultivation system. During fallow periods, soil fertility is regenerated and possible erosion avoided as the new vegetation recovers the area. However, this system of cultivation is no longer possible in Nigeria where population pressures make land a very scarce resource. Also, continuous use of land after reaching the fallow stage reduces yield and causes food shortages. The improvement of cultivation practices and development of high-yielding varieties are basic goals in the development of Nigerial agriculture. Those goals are institutionally operationalized through the food crop research system described in the next section.

Nigerian Food Crop Research System

The Nigerian Food Crop research network is unusually complex for a country in that stage of economic development. There exist, at lower levels, regional research institutes dealing with crop research in specific environments; in the middle are national research establishments dealing with specific crops at the national scale; at the top is the international research component represented by the International Institute of Tropical Agriculture (IITA).

Regional Research Components

Two important research institutes are the Institute of Agricultural Research and Training (IAR&T) headquartered at Moor Plantation in Ibadan and the Institute of Agricultural Research (IAR) located at Samaru-Zaria in the northern part of Nigeria. Figures 5 and 6 describe the structural organization of both institutes. Both institutes are part of the university system and are under the direct authority of their respective vice-chancellors. Research divisions are organized on a crop-wise basis. Supporting fields such as soils and engineering and economics are independent divisions with their own branches.

The functional divisions of the IAR&T can be categorized into three main units: research, training and services. The research units consist of four departments organized according to crop systems. Cereals, grain legumes, industrial crops and vegetables are the current active departments. The maize breeding program has produced the so-called Western Yellow variety believed to outyield the local variety by 60 percent. Research by the grain legumes department produced the celebrated Brown variety. The research activity of IAR&T shows promise as evidenced by varieties produced and by the publication rate.

The services unit is made up of information, soil survey and soil testing, and seed production. It has been estimated that an average of 15, 7.5 and 2.3 tons of improved seeds were produced, respectively, for maize, rice and beans.

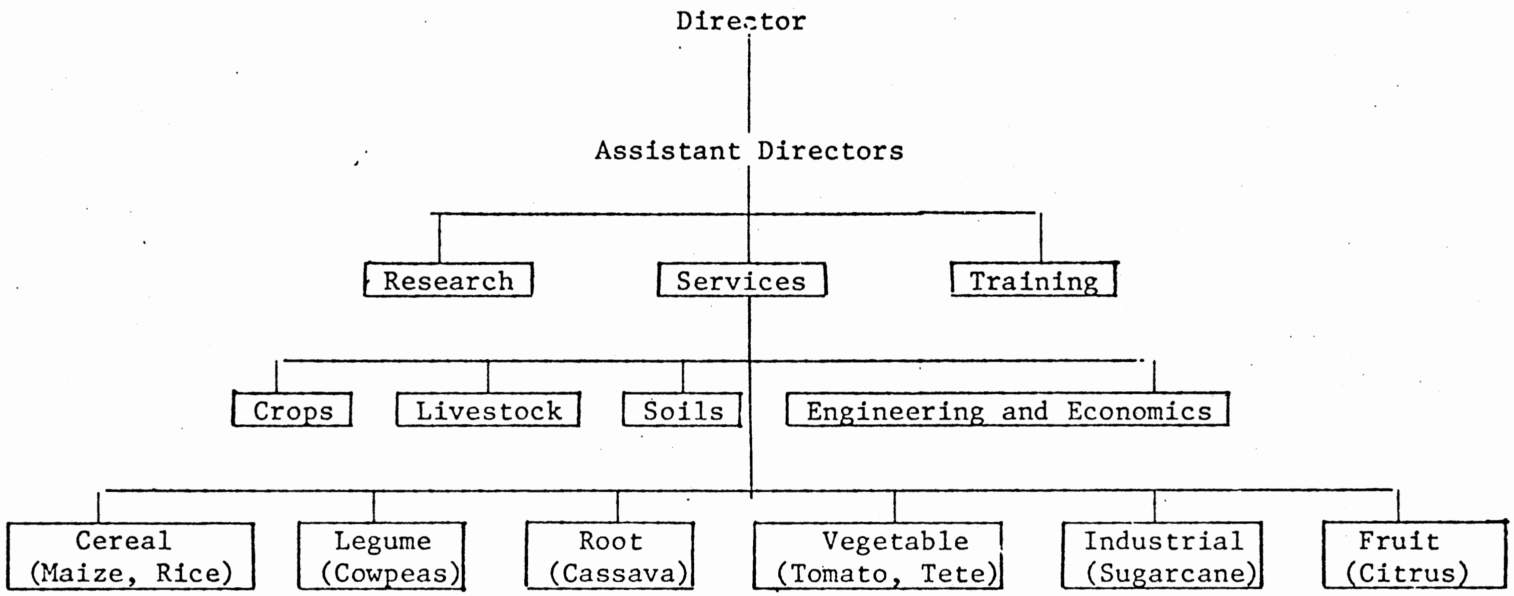


Figure 5. Graphic Illustration of the Research Unit at IAR&T

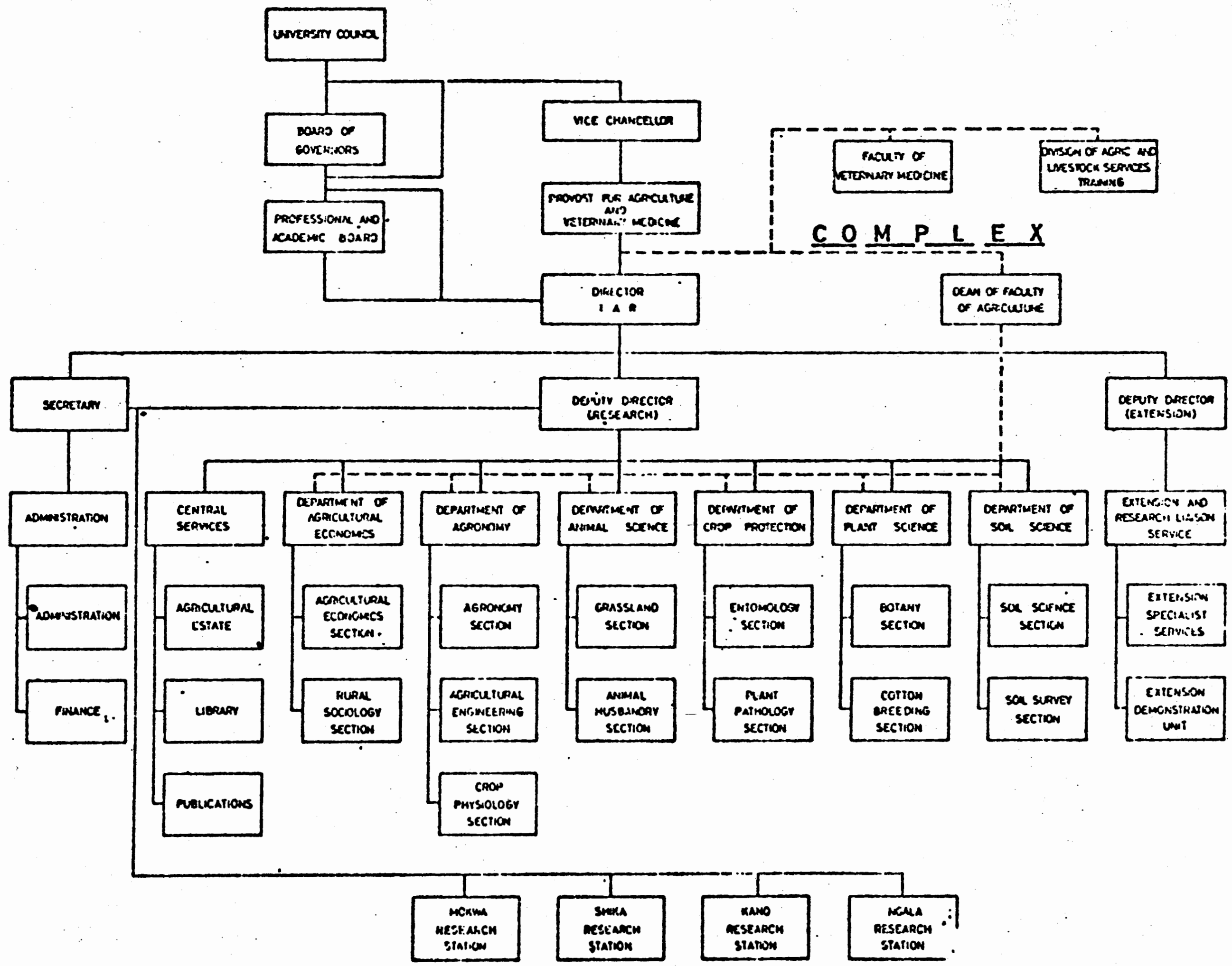


Figure 6. Organization of Research at IAR, Samaru

The training unit is tailored around three schools: the School of Agriculture, located at Akure, offers a two-year certificate program; the School of Animal Health, located at Moore Plantation, also offers a two-year certificate, and the training units produces agricultural superintendents from its School of Agriculture at Moor Plantation. For the years 1974 and 1975 the enrollment has been approximately 50 students.

The same structure and mode of operation was adopted by IAR at Samaru until recently. The research system was subdivided into programs: Cereal Improvement, Grain Legumes Improvement, Farm Mechanization, and Socio-Economic and Extension. This structure is very similar to that of IITA described later.

National Research Institutes

Three national food crop research institutes, completely different in their organizational framework from regional institutes, are part of the Nigerian agricultural research system. These are: 1) National Root Crops Research Institute (NRCRI) at Umudike in Imo State, 2) National Cereals Research Institute (NCRI) at Moore Plantation, and 3) National Vegetable Research Institute (NVRI) in Ibadan. The three institutes are not comprehensive research systems. The NRCRI concentrates its research effort on cassava and yam; the NCRI emphasizes only the research on rice, wheat, maize, sorghum and millet, while the NVRI deals only with vegetables.

Food crop research was recently reorganized and the impact cannot be determined yet. It is argued that by focusing the research effort on specific crops, every food crop can be dealt with efficiently since some scientific resources are allocated to each crop. But potential problems are serious. Scientific manpower is too limited in Nigeria to allow a duplication of effort and utilization of the scientific staff in a specialized structure. Financial and manpower constraints argue against reliance on commodity oriented research for efficient utilization of scarce scientific resources.

The International Institute of Tropical Agriculture (IITA)

The IITA group is organized into four main components: Farming Systems Program, Cereal Improvement Program, Grain Legume Improvement Program and Root and Tuber Improvement Program (see Figure 7). The structure constitutes a balanced organization with no circular flow, that is, no one is his own superior.

The Grain Legume Improvement Program (GLIP) focuses on cowpeas and soybeans research which is structured to allow complementary work with teams of plant breeders, plant pathologists and agronomists. The program organization is aimed at several objectives which are either primarily research based, or structured on a cooperative effort with other institutions outside IITA. The research based activities are plant improvement, crop protection and crop growth and management. The cooperative module is made up of (1) collaborative research projects involving the United Kingdom, University of Gembloux in Belgium and Technical University of Berlin [IITA, 1976], and (2) cooperative activities testing improved lines in tropical environments of Africa. Cooperative activities include the improvement programs in Tanzania and Upper-Volta.

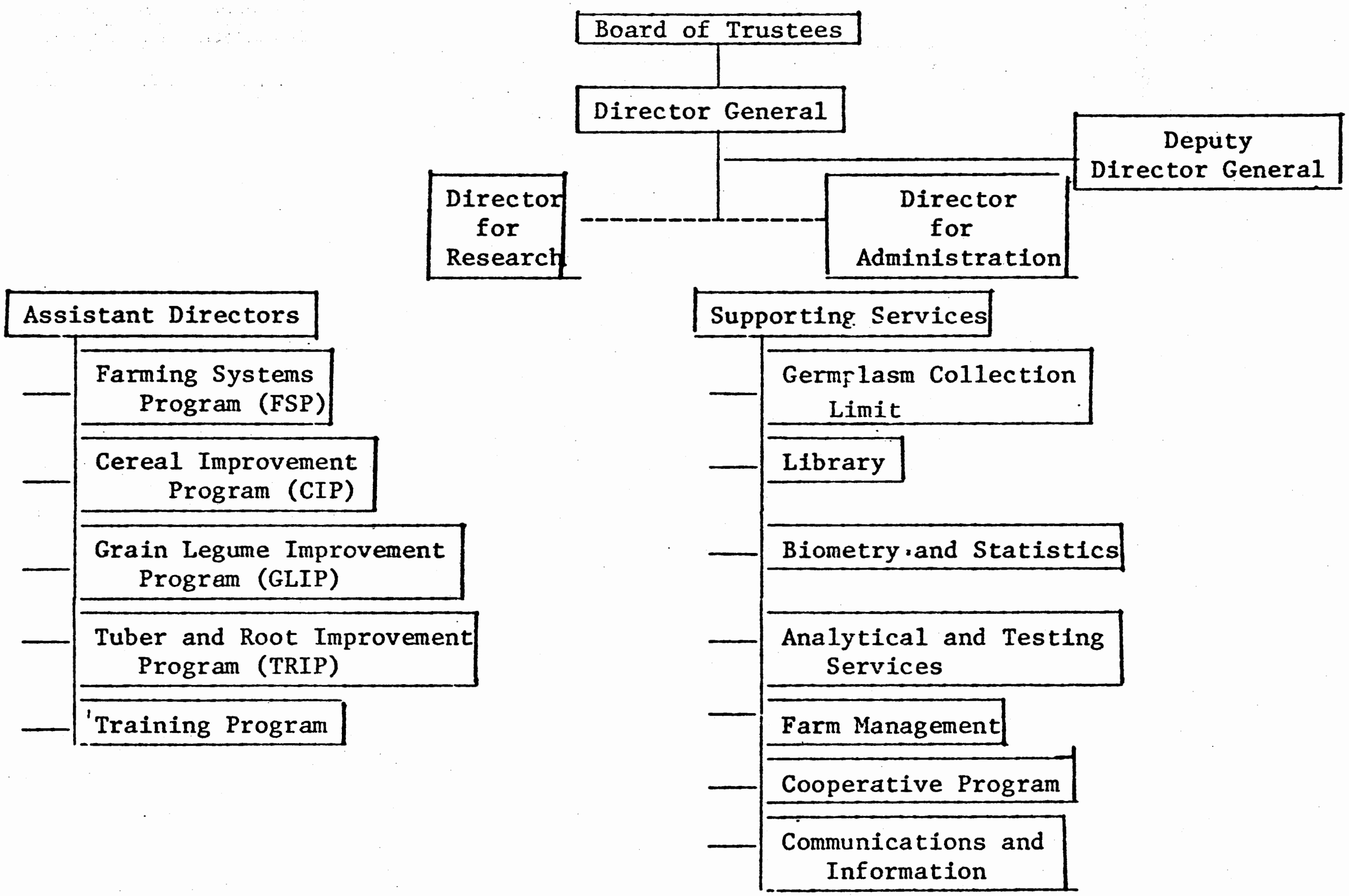


Figure 7. Research Organization at IITA

The Root and Tuber Improvement Program carries out research activities on four main crops, namely cassava, yams, sweet potatoes and aroids. The core of research tasks centers around six objectives: (1) high yield in terms of dry matter per unit of land in both monoculture and mixed cropped systems, (2) resistance to and cultural control of economically important diseases and insects, (3) improved quality in terms of consumer acceptance, (4) high storability and improved farm storage, (5) improved plant type, and (6) adaptation in a wide range of environments [IITA, 1976]. As with the Grain Legumes Improvement Program, the Root and Tuber Program has cooperative links with outside institutions, namely with National Crop Center of Umudike in Imo State, National Cassava Program at Mvuazi in Zaire and the research network at CIAT in Colombia.

To carry out these objectives, the program is organized into breeding and agronomy groups. Both of these groups are supported by basic research in plant pathology, entomology, biochemistry and physiology. The breeding group produces improved varieties and the agronomy group develops improved cultural practices. The combination of improved varieties and improved cultural practices generates a set of modern farming systems to be recommended to producers to increase output. The organization network (training omitted) of this structure is presented in Figure 8.

The Cereal Improvement Program is mainly concentrated on two major crops, maize and rice. This program seems to be highly international in its orientation. Special emphasis in the research is on increasing capacity to produce high quality protein.

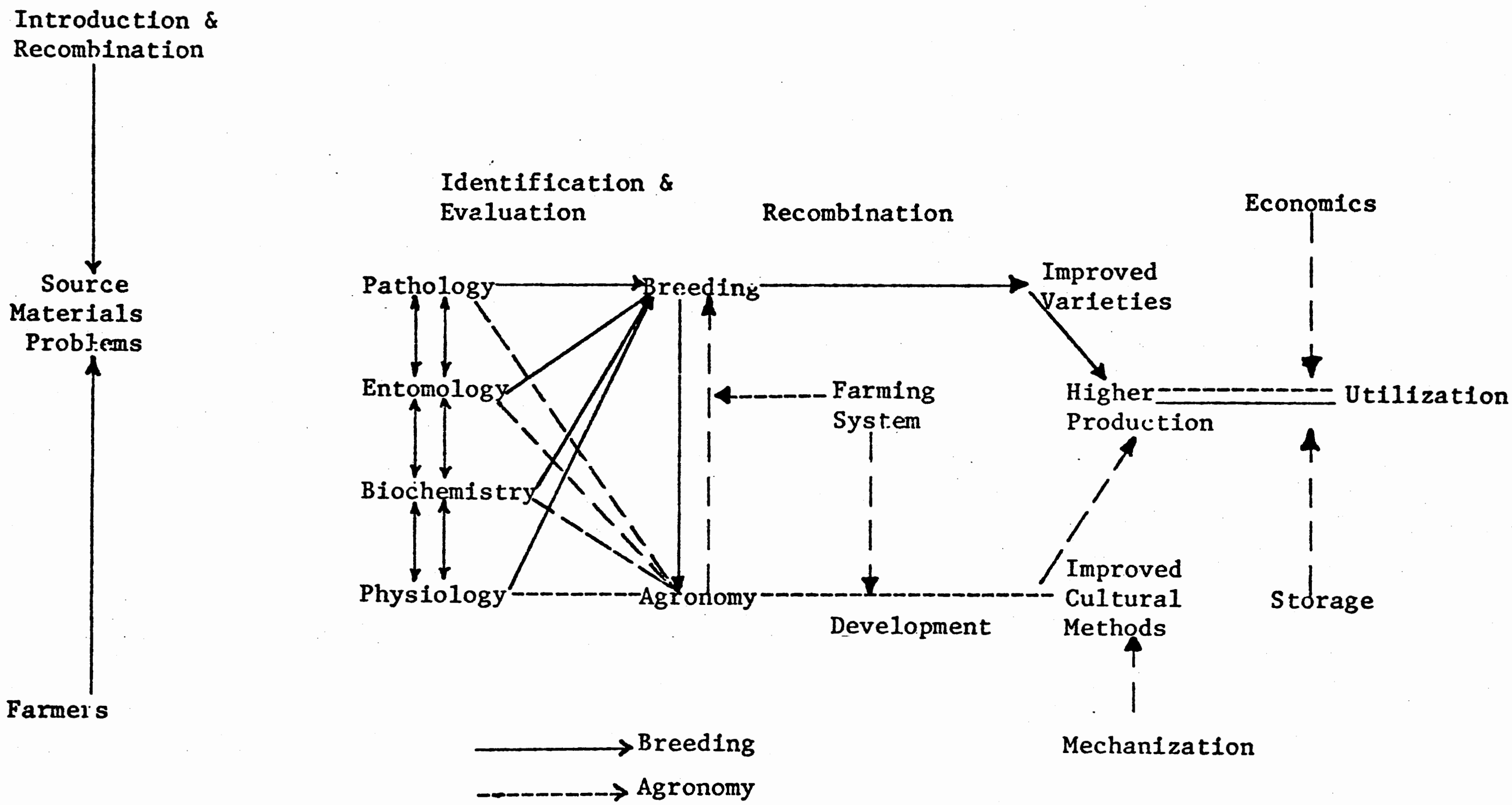


Figure 8. Outline of Root and Tuber Improvement Program (TRIP) at IITA

The germplasm or genes pool is obtained from various sources, and evaluated in specific locations to identify new factors of resistance and suitability. The results are reported to International Maize and Wheat Improvement Center (CIMMYT) research network while improved materials are field tested in Nigeria, other African countries and foreign research centers.

The Farming Systems Program is the most interdisciplinary unit of research at IITA. It follows the three first programs by searching for appropriate crop combinations, sequences and management practices that fit the tropical environment with emphasis on high yields from created varieties. The organization of the program encompasses four fields: (1) soil and environmental management, (2) cropping systems, (3) agricultural engineering, and (4) agricultural economics. In each of these fields, scientists interact with farmers. The information flow is facilitated by the Creation of the National Accelerated Food Production Plan described in the next section.

All components of the research system have outside connections. These connections are operationalized through outreach and training programs.

National Accelerated Food Production Plan (NAFPP)

To analyze the efficiency of the agricultural research system in Nigeria, it is useful to view the research system within the overall system of Nigerial agriculture. The International Institute of Tropical Agriculture, regional and national institutes as indicated in the previous section are coopted by the National Accelerated Food

Production Plan (NAFPP) in its effort to promote food production in Nigeria (see Figure 9).[2]

The NAFPP extension subsystem is structured to help the diffusion of modern agricultural practices and to feed back farmers' problems to the research component for investigation [NAFPP, 1977]. Operation of the extension network is formulated around seven important tasks, namely Mini-Kit program, Technical Assistance and Training, Farm Planning, Special Production Campaign, Training and Communication Centers, Production Demonstrations and Production Plans.

The Mini-Kit program provides for selection of capable farmers who are given kits containing recommended seeds, fertilizers and pesticides for use under supervised guidance of a local agricultural assistant who visits them on a regular basis. The mini-kit trails are different from production demonstrations in a sense that the latter are designed to educate the farmer and disseminate the technological information while the former is to set a feedback from farmers and environment to the scientists.

Technical Assistance and Training is service provided by the State Extension Service through its diversified staff, including agronomists, soil scientists, plant pathologists, economists, as well as agricultural engineers. The staff makes field recommendations during the production campaigns. This task differs from that of Training and Communication Centers by the type of clientele served. In the former, the clientele is limited only to farmers while in the latter it is extended to the non-farm public. The farm planning task is intended to help the farmer

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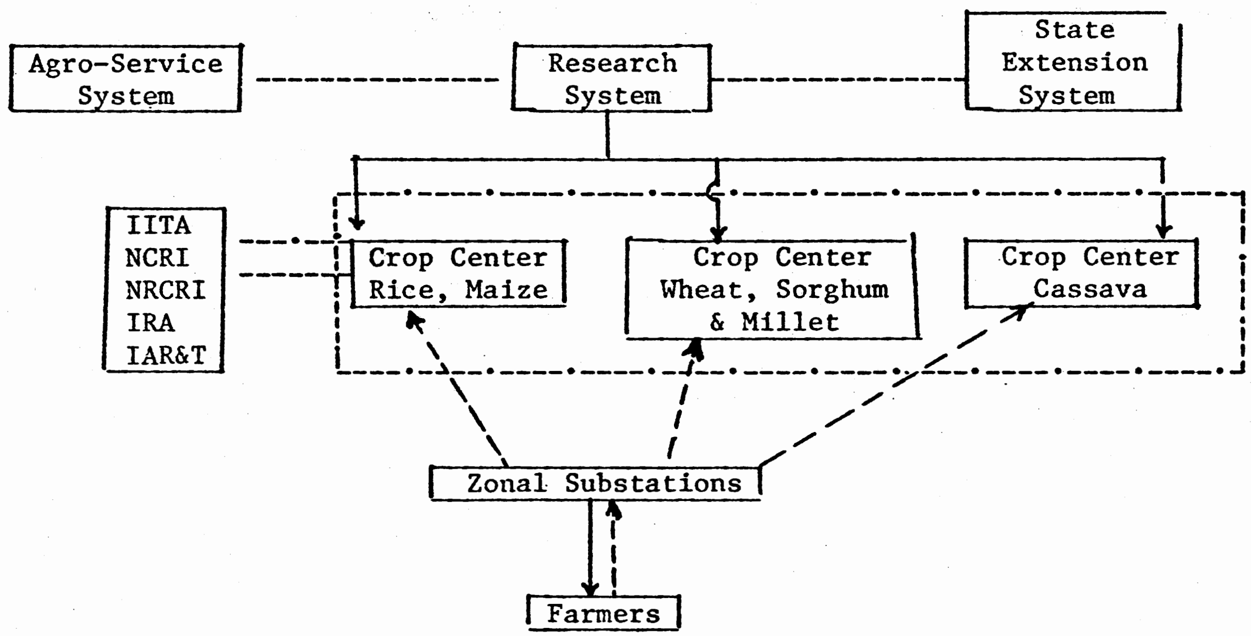
[2] Coopted is used here to mean "chosen" as partner in technology diffusion effort.



----- information flow

--.-- cooptation

Figure 9. Components and Relationships of NAFPP System

plan his production and keep farming records related to costs, loan repayment and personal income objectives. Again, this task is to be separated from that of Production Plans which are prepared not for a specific farmer but for the entire village. Finally, Special Production Campaigns are initiated from time to time for a group of villages. During such Special Production Campaigns, a new set of mini-kits can be introduced.

The organization of these tasks within the extension subsystem of NAFPP is highly bureaucractic as noted from the chart in Figure 10. The structure is intended to ensure mass adoption of improved production practices, but appears to be cumbersome. The farmer's status is very minimized because of so many levels that separate him from the researcher located in national research institutes or at IITA. Such an organizational gap has a tendency to undermine the relevancy of the type of research undertaken. This happens because the feedback process is lengthened as it goes through the established hierarchy. This contrasts with the U.S. research-extension administrative hierarchy which is "flat" and the farmer feedback cycle is short.

The above discussion ends the overview of the extension subsystem and leads to the very important subsystem of the Agro-Service.[3] The Agro-Service component is an important channel of Nigerian agribusiness development. The Agro-Service supplies farms with selected inputs including seeds, fertilizers and credit. The structure and organization of this subsystem is given in Figure 11. The National Supply Company

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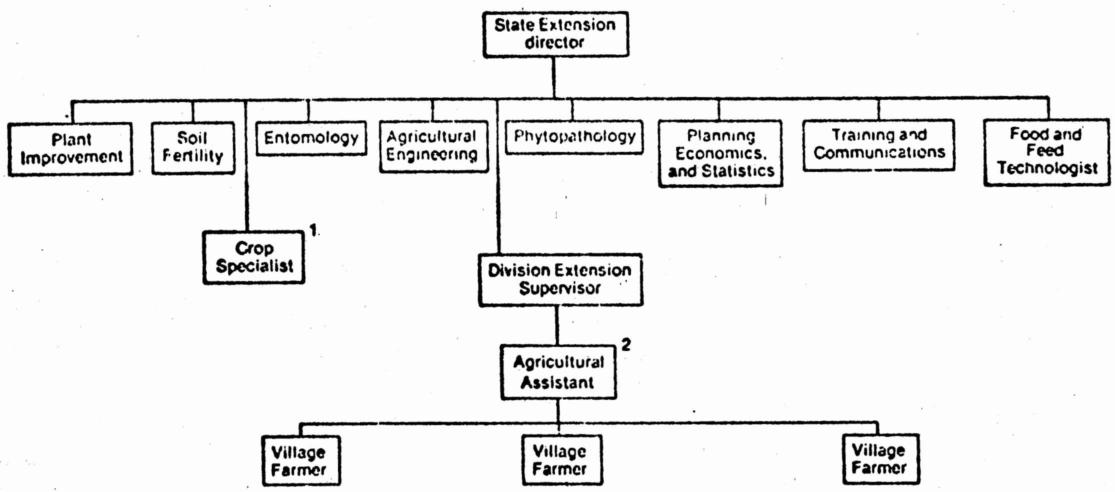
[3]The Extension and Agro-Service subsystems are equivalent, but not the same. The extension deals with providing a practical knowledge of the agriculture while Agro-Service, controlled by the National Supply Company is an agency in the agribusiness sector, with authority to sell farm supplies to farmers.



1. One per NAFPP crop in the state
2. One per 6 major villages Note: In some states these are referred to as Agricultural Officers or Agricultural Instructors

Figure 10. NAFPP Extension System Organization at the Level of State Government

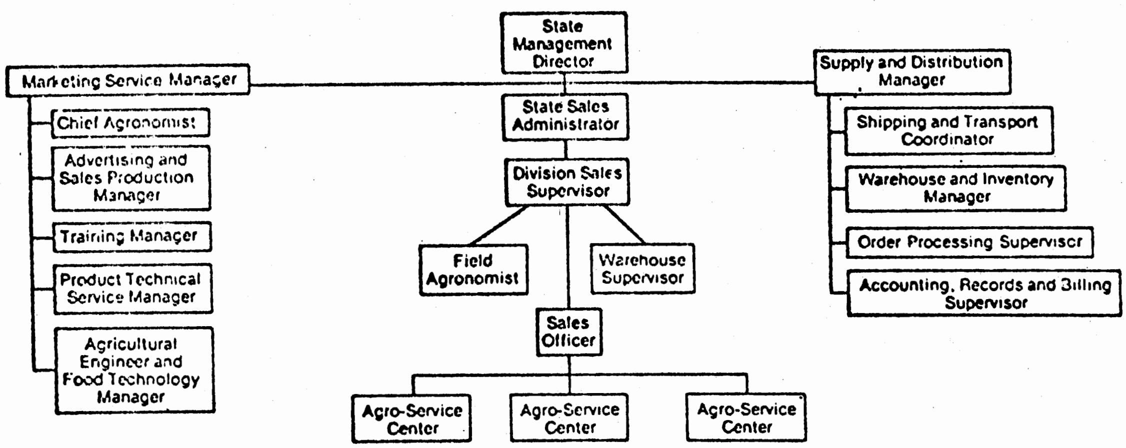


Figure 11. Organization of an Agro-Service Company in the NAFPP System

is at the top of the Agro-Service hierarchy. It purchases farm supplies from various industrial companies and transmits those products to the State Agro-Service Management Company in every state. At this level, inputs are sold to individual farmers through private organizations called Agro-Service Centers. The cycle between the producer of farm supplies to the farmer is still long, but shorter than the one encountered in the extension subsystem.

One of the reasons the hierarchy of steps between farmers and various decisionmaking bodies is so long is because the farmer needs education to improve his performance. Various agents who intervene as middlemen are essentially and purposely integrated in the system for the training task. These agents are trained according to farmer's needs. This training is provided at IITA and other regional schools of agriculture. The agents participating in the program train agricultural assistants, crop specialists and Agro-Service Center managers.

CHAPTER III

DATA BASE AND STRUCTURE OF PRODUCTION AND CONSUMPTION OF FOOD CROPS IN NIGERIA

Patterns and Determinants of Food Crops Supply

The study of food crops supply and demand in Nigeria is ably presented elsewhere [Olayide et al., 1972]. However, for a clear understanding of the background of food crops system in Nigeria, it is felt that a chapter on the economy of major food crops is needed. The description outlines the basic data structure that supports this study and some methodological problems involved in the data refinement.

The trends in aggregate supplies of maize, rice and cassava are encouraging. With rates of growth of 2.4, 10.4, and 2.5, respectively, production targets were respectively set at 982,112, 667,548, and 8,940,899 metric tons for the year 1975. Comparing targets with actual production, except for rice, the actual production has exceeded expected targets (Table III).

Was the source of the growth due to conventional production inputs or non-conventional inputs of extension and research?

Both land and labor increased substantially (Table IV). The increased use of land has, however, pushed producers into marginal lands where productivity is low. The pressure on land is evident in

TABLE III

PLANNED TARGETS AND ACTUAL PRODUCTION
FOR FIVE MAJOR FOOD CROPS
(1000 Metric Tons)

Crops	Growth Rate	Planned Targets 1975	Planned Targets 1980	Planned Targets 1985	Actual Production 1975
Maize	2.4	982,112	1,105.759	1,244.793	1,400.0
Rice	10.4	667,548	11,094.782	1,795.447	600.0
Cassava	2.5	8,940.899	10,115.806	11,445.106	13,600.0
Millet	2.4	1,977.045	2,026.967	2,078.149	2,865.0
Sorghum	-0.3	2,922.981	2,879.398	2,836.466	3,590.0

Source: From Olayide et al., 1972. "A Quantitative Analysis of Food Requirements, Supplies and Demands in Nigeria, 1968-1985."

TABLE IV

CONVENTIONAL RESOURCES USED BY FIVE MAJOR CROPS BETWEEN 1968 AND 1975

Crops	Land (000 Hectares)		Labor (000 Man Years)	
	1968	1975	1968	1975
Maize	922.0	1400.0	3260.040	3744.720
Rice	1555.0	1684.8	698.579	802.439
Cassava	1100.0	1000.0	1746.450	2006.100

Computed from USDA, ERS, No. 572. "Indices of Agricultural Production in Africa and the Near East, and Rural Survey of Nigeria." Federal Office of Statistics, Lagos, 1972.

cassava production. Cassava land area dropped from 1,100 thousand hectares in 1968 to 1,000 hectares in 1975 while cassava labor increased from 1.7 to 2.0 million man-years. Data on labor resources devoted to different crops are not available, but the Rural Economic Survey of Nigeria presents information related to allocation of labor among crops by states. By using percentage figures given and by assuming that those percentages remain constant over the years, man-years data were derived for each crop. Percentage figures used were 28, 6 and 15 percent, respectively, for maize, rice and cassava. Farm population figures were taken from the Economic Survey of Nigeria, (ESN) edited in 1976 [Olayide, 1976]. The assumption of a constant allocation ration, although shaky on practical ground, is, however, a conservative estimate of the additional labor absorbed by agriculture.

Examining Tables III and IV, the increase in production of each crop cannot be accounted for by land and labor. Managerial skill of farmers and new improved varieties at their disposal, although very limited, have some impact on the aggregate production of each crop. The flow of seeds to farmers depends, among other things, on the success of the biological research undertaken at various stations, and the sources of bioligical research in turn depend on quality and quantity of research resources. In this study, research resources are measured by research expenditures. Data on research expenditures are usually aggregate, and allocation among crops is not clear-cut. This study relied heavily on allocations estimated by experts. For the international research component, somewhat dependable information was available through annual financial reports of IITA.

In IITA, cassava research is estimated to account for 60 percent of actual expenditures allocated to the Root and Tuber Program, while maize and rice pick up 50 percent each from the Cereal Improvement Program. For the national research expenditures, the construction of data were used to derive national food crop expenditures. Observation of those data revealed that agricultural research expenditures and food crop research expenditures tended to be a constant proportion of federal expenditures. A ratio of .015 was used to derive food crop research expenditures from total federal expenditures for earlier years for which data were unavailable. To derive research expenditures for specific crops, it was assumed that rice research absorbed 8 percent of monies, while maize and cassava took, respectively, 10 and 15 percent.[1] The remaining share was allocated to millet, sorghum, wheat, beans, yams and vegetables. Those figures given by scientists in Nigeria could understate the actual amounts.

On the basis of the above information, Table V was compiled to describe the research and technological effort in Nigerian food crop sector. For the period 1966-1976, it would appear that the momentum of the modern technology continues as evidenced by changes in recurrent expenditures and scientific man-years. This effort, however, is not easily translated into appreciable and tangible results for two reasons: the time lag needed for research to materialize, and the lack of complementary inputs with created varieties.

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[1]Those percentages are arrived at by making an average estimate of percentages given to us at IITA, IAR and NRCRI during our visit there. The same ratio applies to both capital and recurrent expenditures.

TABLE V

RESEARCH EXPENDITURES (R) AND SCIENTIFIC MAN YEARS (SMY_s) IN FOOD CROP RESEARCH SYSTEM IN NIGERIA FOR 1966 AND 1976 PERIOD

Program	R ($000) 1966	R ($000) 1976	SMY_s 1966	SMY_s 1976	R/SMY_s 1966	R/SMY_s 1976	$\Delta R/\Delta SMY_s$
Maize	445	1614	9	16	49.4	100.8	167
Rice	356	1312	9	12	39.5	109.3	318
Cassava	667	2460	8	16	83.3	153.7	224
Average	489	1795	18.6	14.6	57.4	121.3	236.3

Source: Compiled from Selected Annual Reports, IITA, IAR, IAR&T, and NRCRI.

The use of fertilizer is limited. For the period 1975-1980 the projection of acreage to be fertilized was still very low. If an assumption is made that fertilized acreage is most likely to be planted with improved varieties, the ratio of acreage fertilized to total acreage can be taken as an adoption rate. Using figures from a study of fertilizer distribution [Falusi, 1975], the rates of adoption for different crops are summarized in Table VI. Those rates are very low, particularly for cassava. However, as illustrated in Table V, the cassava research program has the highest research expenditures scientific man-year.

To summarize, labor and land resources most strongly affect the pattern and trend in production of major staple foods. Expanding use of these resources could lead to negative marginal products with a resulting decline in production. The actual trend in aggregate production of major crops is positive, suggesting that technology is offsetting diminishing returns to conventional resources.

Demand and Consumption of Staple Food

The structure of demand and consumption is influenced by income and population. For income, two parameters are of great importance, namely income elasticity of demand and per capita income growth while, for population, the rate of growth is considered. Estimates of income elasticity of demand for major food items in Africa are not available. Most studies, even recent ones, still refer to the FAO study of 1967. The basic formula for estimating growth rates of demand for any food item is:

$$g_i = p + e_y Y \qquad 3.2$$

TABLE VI

ADOPTION RATES OF HYV_S OF THREE MAJOR CROPS AS DERIVED FROM PROJECTION OF FERTILIZER USE IN NIGERIA (PERCENTAGE)

Crops	1976	1977	1978	1979	1980
Maize	.27	.34	.40	.47	.57
Rice	.20	.25	.29	.35	.43
Cassava	.05	.06	.06	.08	.09

Source: Estimated from "Economics of Fertilizer Distribution in Nigeria." A. O. Falusi, 1975.

In equation 3.2, g_i is growth rate of food item i, while p and Y, respectively, represent population growth rate and per capita real income growth rate. The parameter e_y is the income elasticity of demand for food item i. Using the above equation, Table VII measures the gap between supply and demand. Potential food shortages for maize and cassava are evident. To satisfy total demand, other sources of supply are needed. Such sources could be international trade or foreign aid, but difficulties related to the importation of food were already mentioned in the introductory chapter.

Growth rates estimated in Table VII are average values that might be applicable to specific regions of Nigeria. Patterns of comsuption vary across the country; in some areas the sorghum and millet are preferred to maize, while in other areas cassava is preferred to millet. The yam has become a preferred food for most Nigerians, replacing other staple items. Under these conditions of substitutions, shortages indicated above might be overestimated and dealt with through an adeqaute internal marketing operation.

The flow of staple food from one state to others is indicated in Table VIII for maize, rice and cassava items. The northern states are net exporters of maize; the rice is equally traded by both southern and northern regions, while cassava is mainly supplied by southern states, even though some states (e.g. Kano) find themselves net exporters of it. The interstate trade of maize is only 10 percent of the total production, that of cassava is about 6 percent. The interstate trade of rice is 30 percent of total supply, suggesting that the rice economy is more commercialized than others.

TABLE VII

SUPPLY AND DEMAND GAP OF THREE MAJOR FOOD CROPS
IN NIGERIA FOR THE PERIOD 1975

Crops	Growth Rate in Demand	Growth Rate in Supply	Gap
Maize	3.9	2.4	-1.5
Rice	4.3	10.4	+6.1
Cassava	3.5	2.5	-1.0

Source: Computed from Olayide et al., 1972. Quantitative Analysis of Food Requirements Supplies and Demand in Nigeria, 1968-1985 and S. O. Olayide, 1976. Economic Survey of Nigeria, 1960-1975.

TABLE VIII

INTERSTATE TRADING OF THREE MAJOR STAPLE FOODS IN NIGERIA DURING 1970'S (ANNUAL AVERAGES THOUSAND METRIC TONS)

Crops	Supplying States	Consuming States	Volume of Trading
Maize	Benue-Plateau Kano Kwara North Central North Eastern North Western South Eastern	East Central Lagos Midwestern Rivers Western	96.0*
Rice	Benue-Plateau East Central Midwestern North Western Rivers Western	Kano Kwara Lagos North Central South Eastern	105.0*
Cassava	Benue-Plateau Kano Kwara Midwestern South Eastern	East Central Lagos North Central North Eastern North Western Rivers Western	500.0*

Source: Adapted from Olayide et al., 1972, A Quantitative Analysis of Food Requirements, Supplies and Demands in Nigeria, 1968-1975.

*Only estimate.

CHAPTER IV

EVALUATION MODELS

Environmental Adaptation Model

One approach used by agronomists to evaluate the product of research is the regression of crop yields on environmental indices. The environmental index $\hat{V}_i$ for location i is the difference between a locational mean $\overline{x}_i$ and the overall mean of varieties $\overline{X}$, or

$$\hat{V}_i = \overline{x}_i - \overline{X} \qquad (4.1.1)$$

Favorable environments have a positive $\hat{V}_i$ while unfavorable ones have a negative $\hat{V}_i$. The technique as described elsewhere [Hahn, 1979] is based on the following regression[1]

$$X_{ij} = a_0 + a_{1j}\hat{V}_i + u_j \qquad (4.1.2)$$

The sign and magnitude of the regression coefficient a_{1j} is the key to the evaluation procedure. If $a_{1j} > a_{1k}$, the varietal performance of the cultivar j is superior to that of cultivar k.

In the meantime, a word regarding the data structure for this model is in order. Two sources of data are envisioned, namely data on

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[1]The analysis is based on a technique described by Hahn. This technique has not been published and subjected to scrutiny. Therefore, its use must be regarded as an experimental one.

yield X_{ij} observed for a variety j in location i and respective means for specific varieties and locations. A two-way table can help in the understanding of data structure. In Table IX, column entries are types of varieties 1 to m cultivated in environments 1 to n listed in the rows.

The lower margin of the matrix in Table IX reports the varietal means $\overline{X}_{ij}$ while the vertical margin at the right of the matric reports locational means.

The model in (4.1.2) is modified as follows: actual observations X_{ij} are regressed on the environmental indices and other possible sources of variation. This procedure requires the use of dummy variables to account for different varieties. The modified model is written:[2]

$$X_{ij} = a_0 + a_1\hat{V}_i + \sum_{j=1}^{m-1} a_{2j}D_j + \sum_{j=1}^{m-1} a_{3j}\hat{V}_iD_j + u_{ij} \qquad (4.1.3)$$

The variable D_j is a dummy for type of variety (D_j = 1 if variety j and D_j = 0 otherwise); the coefficient a_0 is an intercept which can

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[2]What is involved in Table IX or in the equation (4.1.3) is an attempt to explain variation in Y_{ij} using three sources of variances, namely varieties, location and variety x location. The error term u_{ij} explains the residual variation. Grossly, the model in (4.1.3) can be analogous to

$$Y_{ij} = a_0 + \hat{V}_i + D_j + (VD)_{ij} \qquad (1)$$

where,

a_0 = intercept as in (4.1.3).
V_i = location.
D_j = variety.
$(\hat{V}D)_{ij}$ = location x variety.

When applying least squares method to the above two way classification, one gets the model in (4.1.3). For identifying of better varieties, parameters estimated from (4.1.3) are very useful.

TABLE IX

ENVIRONMENTAL MATRIX TABLEAU WITH LOCATION AND VARIETY AS ITS DOUBLE ENTRIES

	VAR_1	VAR_2	VAR_3		VAR_j		VAR_m	LOC. MEAN
LOC_1	X_{11}	X_{12}	X_{13}	. . .	X_{1k}	. . .	X_{1m}	$\bar{x}_1$
LOC_2	X_{21}	X_{22}	X_{23}	. . .	X_{2k}	. . .	X_{2m}	$\bar{x}_2$
LOC_3	X_{31}	X_{32}	X_{33}	. . .	X_{3k}	. . .	X_{3m}	$\bar{x}_3$
.	.	.	.		.		.	.
.	.	.	.		.		.	.
.	.	.	.		.		.	.
LOC_k	X_{k1}	X_{k2}	X_{k3}	. . .	X_{kk}	. . .	X_{km}	$\bar{x}_k$
.	.	.	.		.		.	.
.	.	.	.		.		.	.
.	.	.	.		.		.	.
LOC_n	X_{n1}	X_{n2}	X_{n3}	. . .	X_{nk}	. . .	X_{nm}	$\bar{x}_n$
VAR. MEAN	$\bar{X}_{i1}$	$\bar{X}_{i2}$	$\bar{X}_{i3}$	. . .	$\bar{X}_{ij}$	. . .	$\bar{X}_{in}$	$\bar{X}$

take any sign. The coefficient a_1 is the environmental impact of location i on yield response of variety j and u_{ij} is the error term. The coefficient a_{2j} accounts for a shift in intercept due to variety while a_{3j} measures interaction between location i and variety j. The overall performance of a given variety in a given environment is measured by the sum $a_1 + a_{3j}$ for each type of variety.

The first criterion used here for evaluating performance of varieties is that $a_{1j} + a_{3j}$ is equal to or greater than 1.0. If so, a particular variety is judged to be adapted to the environment and possessing favorable genetic potential that can be exploited for further breeding. If the sum $a_1 + a_{3j}$ is less than 1.0, the variety is judged to adapt well to the environment but lacking in genetic potential to be exploited for a new breeding program.

Another criterion for evaluation, using the environmental model concept, is stability. Stability here refers to the tendency of observed responses to be concentrated around their mean values. For analysis of yield stability, the overall mean $\overline{X}$ is reported in the abscissa while the overall mean of $a_1 + a_{3j}$ is scaled in the ordinate of Figure 12. Observed responses whose values fall within one standard deviation of both $\overline{X}$ and the pooled mean of $a_1 + a_{3j}$ are considered to be stable.

For empirical analysis based on this model, five maize varieties are selected, namely 1) LOCAL, 2) FARZ26, 3) FARZ27, 4) FARZI and 5) FARZ23. Eleven varieties are retained for rice, including five varieties for dryland rice cultivation and five from irrigated swamp rice. The remaining clone is a standard variety taken here as a

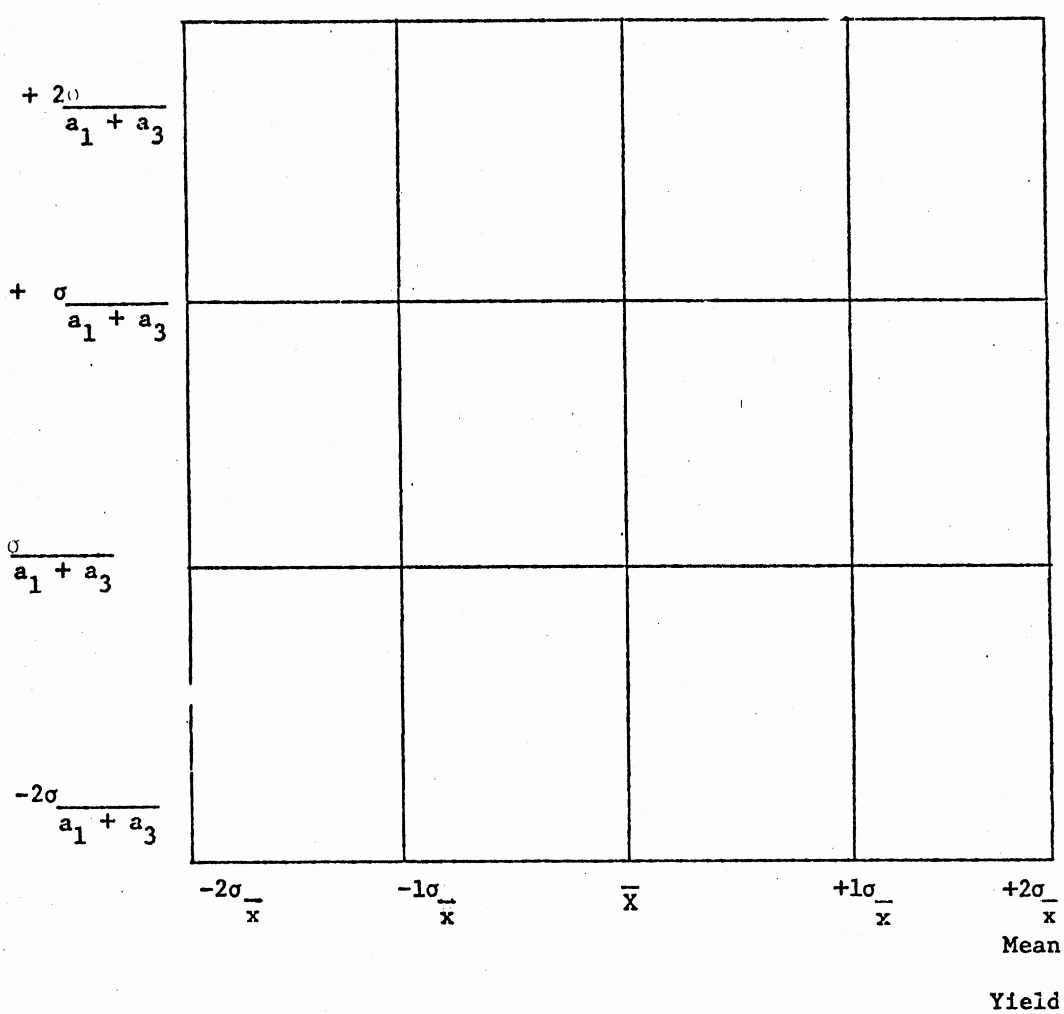

Figure 12. A Lattice for Analysis of Stability of Varieties with an Environmental Model

local reference.[3]

Stochastic Efficiency Analysis

The environmental model evaluates the physical performance of varieties solely on the basis of physical factors (environment and genetic potential) but farmers do not ordinarily adopt high yielding varieties on the basis of physical response alone. Farmers' attitudes must be considered in any recommendation made. The analysis of those attitudes requires implicit or explicit recognition of farmers' utility functions. Explicit utility functions have been estimated by classical methods (CM) of Von Neumann-Morgenstern and modifications thereof as well as by the Ramsey method. In addition to these methods used by farm-management specialists, the condensed approach by Harper and Tweeten (H-T) measures utility using psycho-sociological scales weighted to form a quality of life index in Benthamite fashion.

In both CM and H-T methods, extensive surveys and income data by groups of farmers are needed to elicit the shape of utility functions. Because such data are rarely available in developing countries, methods of making decisions under uncertainty and risk without knowledge of the utility functions of decision makers are employed herein. One such method, known in the literature as stochastic dominance or efficiency analysis, was reviewed in Chapter I. The model of analysis is formulated and its use defined below.

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[3]Names of rice varieties included are FAROX 56/30, TO_s 2583, TO_s 4020, TO_s 2513 and TO_s 2300 for dryland rice and IR8, TO_s 42, TO_s 78, TO_s 490, IR22 and SML^s140/10 (standard local).

The stochastic efficiency analysis uses three decision rules: 1) first stochastic dominance rule (FSD); 2) second stochastic dominance rule (SSD) and 3) third stochastic dominance rule (TSD). The FSD rule assumes that the decision maker prefers more to less. The SSD rule takes into consideration risk averting behavior of the decision maker. Finally the TSD rule is based under the assumption that some risk taking is allowed. For all three rules a specific probability function is assumed--uniform, triangular or other distribution. In this study, none of those specific probability functions is assumed, instead a non-parametric approach is followed by searching an empirical distribution of yields.

For a FSD, let

$$f(x_i) = p \qquad \begin{matrix} 1 > p \geq 0 \\ i = 1 \ldots n \end{matrix} \qquad (4.2.1)$$

represent a given empirical probability function of yield x_i of variety f. Given the yield distribution $f(x_i)$ for alternative varieties, the decision maker would tend to choose the distribution which has a higher probability for a given yield level. If

$$F_1(R) = \int_a^R f(x_i)dx_k < \int_a^R g(x_i)dx_j \qquad (4.2.2)$$

the decision maker would prefer variety f to variety g according to the FSD rule. Application requires the analyst to compute probability distributions of given varieties and compare them within the admissible range determined by observed minimum and maximum yields. For simplicity a discrete empirical distribution is assumed so that

$$F_1(R) = \sum_{\substack{\text{all} \\ x \leq R}} f(x_i) \leq \sum_{\substack{\text{all} \\ x \leq R}} g(x_i) \qquad (4.2.3)$$

becomes the FSD criterion. Usually there are more than two varieties to compare; in which case the rule in (4.2.2) is repeated in pairwise fashion to isolate the distribution that dominates others. In other words, if $F_1(R) \leq G_1(R) \leq \ldots \leq Q_1(R)$, then $F_1(R)$ is said to be stochastically dominant over other remaining varieties. To be precise, the comparison needs not be completely pairwise since the transitivity property of this rule can be used to infer dominance.

To introduce the SSD rule, let $F_1(R)$ in (4.2.3) be rewritten as

$$F_1(R) = \sum_{\substack{\text{all} \\ x_j \leq R}} f(x_i) \qquad i = 1 \ldots n \qquad (4.2.4)$$

The subscript i is to denote specific observations within range (a,b). The main idea behind the SSD rule is that if $F_1(x_i) = G_1(x_i)$ within the specified range then the decision maker would take that distribution which has a smaller area under its curve. For instance, in Figure 13, both distributions have the same values at a and b, but the decision maker who wants to protect himself would take the distribution which has the highest value under curve D_1 or D_2. Mathematically the rule is that

$$F_2(x_r) = \sum_{i=1}^{r} F_1(x_{i-1})\, \Delta x_i \qquad r = 2 \ldots n \qquad (4.2.5)$$

be smaller than any other competing distribution.

Intuitively the formula in (4.2.5) says that the decision maker weighs heavily his past acheivement $F_1(x_{i-1})$.[4] The TSD formula is defined in the following manner

$$F_3(x_r) = 1/2\ \Sigma[F_2(x_i) + F_2(x_{i-1})]\ \Delta x_i \qquad r = 2 \ldots n \qquad (4.2.6)$$

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[4]The subscript i-1 refers to the preceding yield observation in an ordered series increasing by Δx_i.

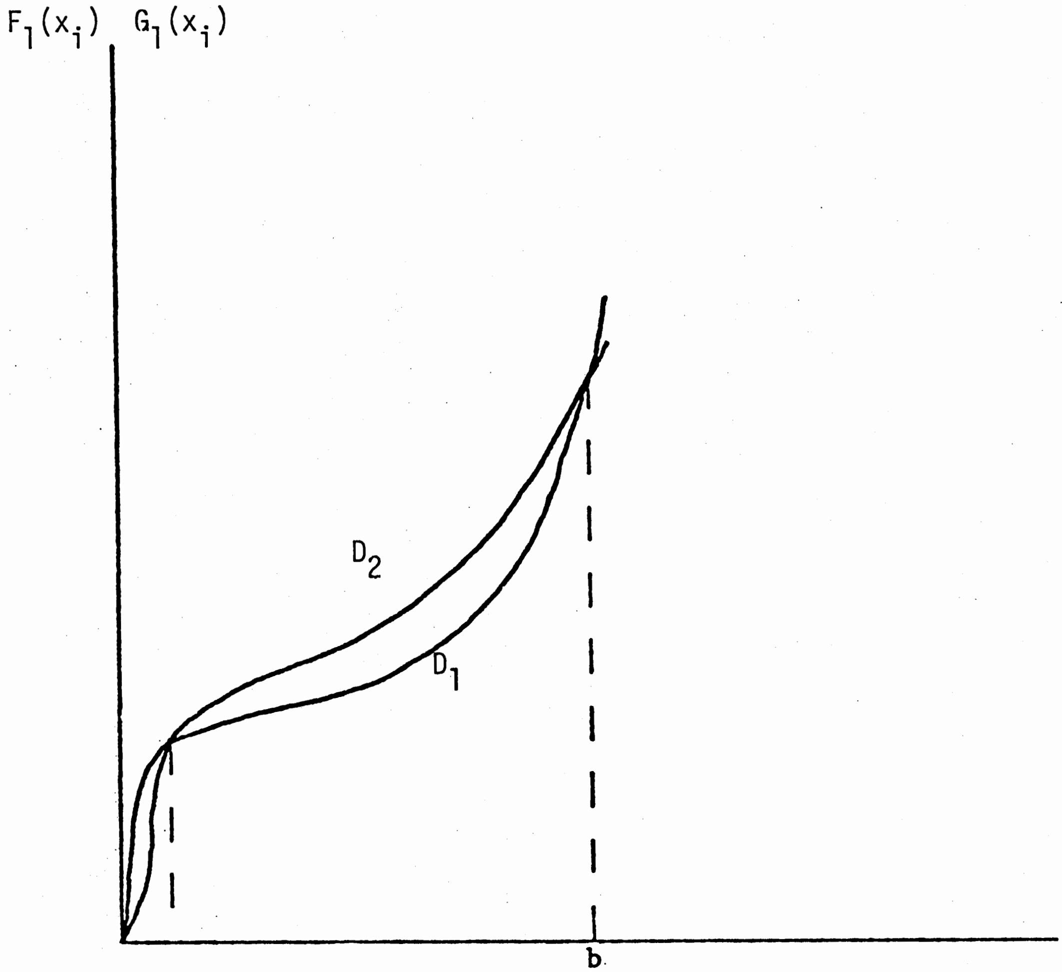

Figure 13. Alternative Distributions with Same Values at End Points

Empirical application of stochastic efficiency analysis of varieties requires two important elements, namely the probability function yields and change in yield Δx_i within the established range. Two problems complicate the analysis: Δx_i is variable and the range of one variety differs from that of another variety. The probability function is approximated in this study by an empirically derived frequency distribution. In the empirical frequency distribution, the range of yields of a given variety is divided in equal intervals such that Δx_i is constant over the entire range. A remaining problem is different ranges among varieties. To avoid this problem, the efficiency rules are independently derived for each crop before results are compared.

The decision to independently derive efficiency rules for each variety greatly simplified the stochastic dominance analysis and makes it manageable without a computer package. In comparing results, all varieties are combined; the smallest of minima is chosen as a lower bound while the greatest of maxima is taken as an upper bound in the abscissa. Values of FSD, SSD, and TSD are written in the ordinate; efficiency curves are then drawn for each rule. From these curves, one is able to determine whether a given variety dominates or is dominated by other.[5] The procedure is cumbersome though manageable manually; a computer package greatly facilitates the procedure.

Economic Evaluation of Food Crop Research

The preceding two models are purely directed at evaluating the

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[5]Due to a relatively smaller number of observations for some varieties, the smoothing of those curves might produce different results than those obtained under a discrete plotting of distributions.

physical performance of food crop research in Nigeria. They do not reveal the economic profitability of the improved versus traditional technology. Two techniques suitable for handling such information are enterprise budget analysis and estimation of an aggregate production function where research expenditure is a key input. Enterprise budget analysis is intended to determine the extent of private profitability of the adoption of the improved package produced by research whereas the aggregate production function approach is designed to estimate social rate of return to research.

The concept of private profitability is here related to gains in net income associated with the adoption of the improved package by the typical Nigerian farmer. Because the improved package is not made available to farmers in a cost free manner, the private profitability of the modern package is the difference between net income from the traditional package and net income from the improved package.

The social rate of return is defined as that discount rate which equates social costs to social benefits. Social costs include private costs paid by producers (for both research effort and technology adoption) and as well as public costs of research and technology diffusion paid by taxpayers. Because data related to research expenditures do not include private expenditures on research, the social rate of return calculated does not capture the contribution of the private sector. Although the contribution of the private sector is small, it is well to recognize that the calculated social rate of return is likely to be overestimated.

Enterprise Budget Analysis

To determine the net income from any enterprise under any package, a formula of the following form is used:

$$N_i = P_i Y_i - \sum_{j=1}^{n} c_j x_j \qquad (4.3.1)$$

where,

N_i = net income from crop i.

P_i = output unit price of crop i.

Y_i = yield per hectare of land for crop i.

X_{ij} = quantity of factor of production.

C_{ij} = unit cost of a factor of production x_j, j = 1 ... n.

Labor, land and capital are the only inputs considered to enter the production process in a traditional package. The addition of inputs such as fertilizer, chemicals and improved seeds transforms the process into a modern package.

The labor input is heterogeneous on any farm. A farming household typically includes male adult labor, female adult labor and child labor. To reduce all these to a homogeneous and comparable quality, some weights were taken from Norman [1976, p. 25] and used to express labor in male adult equivalent (MAE). Small child labor is .50 MAE, female adult labor is equal to .75 MAE while adult labor equivalent is 1.0. The Norman study mentioned above indicates the distribution of different types of labor over farming operations for an average farm.

The average size of farm is measured here by amount of land available for farming rather than by volume of product sales or equity capital. Based on the Economic Survey of Three Villages in Zaria

Province and the Rural Economic Survey of Nigeria, the average size of farm is selected to be four hectares of cultivated land per farming household.

As suggested in Chapter II the quality of land is variable across Nigeria, ranging from rainfed land of the South to Savanna land of the North. Within the latter class, two subclasses of land are recognized, namely gona or upland fields which are more or less rainfed and fadama or lowland fields with water-table near the surface and capable of supporting crops over the entire year.

Capital here refers to money for investment purposes, but due to difficulties for accurately budgeting the amount of capital imputed to food crops, net income is treated here as covering some return to the capital.

Discussion now turns to modern inputs as part of the improved package. In Chapter II it was mentioned that fertilizer was in limited use in Nigeria, a fact which may restrict the widespread adoption of improved seeds. For budget analysis, it is important to know fertilizer and chemicals required per hectare by crop and type of soil. Such information is available in annual reports of research institutions in Nigeria.

Difficulties arise in choosing types of seeds for budgets because of many varieties for each crop. Estimates of average yields of improved seeds are available for each crop and allow an estimate of total production. The combinations of crops are numerous, but for simplicity only a single-crop system is assumed.

The use of modern inputs influences production, farming practices, and use of traditional inputs. There is no clearcut apriori basis to judge the net impact of the improved package on labor required per hectare. Norman [1963, p. 29] reports that the relative importance of cultivating operations (thinning, weeding and ridging) is about 43 percent of total labor while harvesting operations account for 30 percent of total labor used per hectare.

The cost and return budgets contain three sections: 1) production and gross income, 2) inputs and costs of production, and 3) net incomes. For the production section, two items are considered, namely yield and price. Yields are related to the level of management, and for this study, average management is considered. If the test of private profitability is met with average yields assumptions, it seems likely that profitability of improved systems will be enhanced with higher management level. As to prices and costs assumptions, NAFPP estimates were used for enterprise budgets of southern rainfed lands while Norman's data were adjusted for inflation and applied to fadama and gona lands of Northern Nigeria. The rate of inflation of 30 percent is assumed in the deflation of prices.

The second section dealing with inputs gives the cost and quantity requirement per hectare that would prevail under conditions of average management. Technical coefficients are from sources mentioned above. However, for the modern package labor increasing technology was assumed with the increased labor required because of increased production. Norman's study [1976] has shown that in Northern Nigeria the harvested labor represented the 30 percent of the total man hours. After determining the labor per harvested ton (LHT) of production, the additional harvest labor was estimated by multiplying the LHT by additional tons due to adoption of the improved package.

Estimation of Social Returns to Food Crop Research with Aggregate Production Function

Specification of the aggregate production function relating output (Y_t) to inputs requires the inventory of basic inputs. In Nigeria, labor (L) and land are two principal conventional resources. Fertilizer and mechanical power are omitted because they are not significant in the Nigerian agriculture, do not show marked variation over long periods of time and are not measured with consistency by current data. Unconventional resources of education and research (R) are relevant. Data on educational attainment of farmers are not available, and research expenditures constitute the only nonconventional input directly incorporated in the model. The model takes the form:

$$Y_t = AL^{\alpha}N^{\beta}R^{\gamma} \qquad (4.4.1)$$

Because the impact of R on Y is not instantaneous, equation (4.4.1) is modified by using a lagged Cobb-Douglas Spline as follows:

$$Y_t = C_o L_t^{C_1} N_t^{C_2} R_t^{C_3} R_{t-1}^{C_{3+i}} \cdot \cdot \cdot R_{t-k}^{C_{3+k}} \qquad (4.4.2)$$

Problems related to the estimation of equation (4.4.2) are well known. The length of the lag k for obsolescence of productivity gains is not given directly by ordinary least squares estimates of the equation but most be based on knowledge of the production process and statistical properties of the equation fitted for alternative lag lengths. From African experience, it appears that the research investment initially impacts the production process approximately three years after expenditure. The impact rises, peaks and eventually falls to complete obsolescence. In the environment of developed countries, complete obsolescence is reached in approximately 13-16 years on the average

[Knutson and Tweeten, 1979]. In developing countries, complete obsolescence may occur later than it does in developed countries due to a slowness in technology relacement and adoption. Given the short series of data available for this study, the lag structure was chosen to extend from year one to year twelve so that k = 12. Inferences will be made for alternative lag structures, however.

The impact curve of food crop research can be conceptualized as being of polynomial shape allowing use of the Almon distributed lag structure to estimate equation (4.4.2). The degree of such a polynomial lag structure depends on the number of turning points on the impact curve [Almon, 1965]. For simplicity and to place minimum demands on data available in the study, the degree is set to be two--a quadratic distribution curve. The quadratic shape implies that the impact first increases at a decreasing rate, reaches its maximum, and then decreases at an increasing rate until reaching zero. Such forms have been assumed in previous studies [Cline, 1975; Knutson and Tweeten, 1979].

Estimation of the Production Function

The equation to be estimated is similar to (4.4.2), but its lagged component gives a partial regression of the form:

$$Y_t = \alpha + \beta_0 \hat{R}_t + \beta_2 \hat{R}_{t-2} + \ldots \beta_k \hat{R}_{t-k} + U_t \qquad (4.4.3)$$

or

$$Y_t = \alpha + \sum_{i=0}^{k} \beta_i \hat{R}_{t-i} + U_t, \text{ with } \hat{R}_t = \log R_t \qquad (4.4.4)$$

Since β_i is assumed to follow a quadratic distribution, the equation (4.4.4) becomes:

$$Y_t = \alpha + \sum_{i=0}^{k} (a_0 + a_1 i + a_2 i^2)\, \hat{R}_{t-i} + U_t \qquad (4.4.5)$$

or by expanding each term in equation (4.4.5):

$$Y_t = \alpha + a_0 \sum_{i=0}^{k} \hat{R}_{t-i} + a_1 \sum_{i=0}^{k} i \hat{R}_{t-i} + a_2 \sum_{i=0}^{k} i^2 \hat{R}_{t-i} + U_t \qquad (4.4.6)$$

The equation (4.4.6) becomes an instrumental equation in estimating the β's in equation (4.4.3). Since it is assumed that:

$$\beta_i = a_0 + a_1 i + a_2 i^2 \qquad (4.4.7)$$

the value of each $_i$ is easily derived from equation (4.4.7) if ai's are determined. For the distributed lag structure of 12 years that was chosen, the values of original 's are:

$$\begin{aligned}
\beta_0 &= \hat{a}_0 \\
\beta_1 &= \hat{a}_0 + \hat{a}_1 + \hat{a}_2 \\
\beta_2 &= \hat{a}_0 + 2\hat{a}_1 + 4\hat{a}_2 \\
\beta_3 &= \hat{a}_0 + 3\hat{a}_1 + 9\hat{a}_2 \\
\beta_5 &= \hat{a}_0 + 5\hat{a}_1 + 25\hat{a}_2 \\
&\vdots \\
\beta_{12} &= \hat{a}_0 + 12\hat{a}_1 + 144\hat{a}_2
\end{aligned} \qquad (4.4.8)$$

By changing the notation in such a way that

$$\begin{aligned}
\sum_{i=0}^{k} \hat{R}_{t-i} &= Z_{0t} \\
\sum_{i=0}^{i} i\hat{R}_{t-i} &= Z_{1t} \\
\Sigma i^2 \hat{R}_{t-i} &= Z_{2t}
\end{aligned} \qquad (4.4.9)$$

the equation estimated becomes:

$$Y_t = f(L_t, N_t, Z_{0t}, Z_{1t}, Z_{2t}) \qquad (4.4.10)$$

From (4.4.10), the marginal product of the research (MPR) for a given period is:

$$MPR = \beta_i \frac{Y}{Z} \qquad (4.4.11_a)$$

or in monetary terms

$$MPR_m = P\beta_i \frac{Yi}{Zi} \qquad (4.4.11_b)$$

The research benefits are accumulated over time, and the time-distributed value of MPR_m is

$$MPR_m = \sum_{i=1}^{k} \beta i \frac{Yi}{Zi} \qquad (4.4.11_c)$$

Discounting the marginal benefits and setting them equal to zero gives

$$P \sum_{i=1}^{k} \frac{\beta_i Y_i}{Z_i (1-r)^k} - 1 = 0 \qquad (4.4.12_a)$$

or

$$\frac{MPR_m}{(1+r)^k} - 1 = 0 \qquad (4.4.12_b)$$

By rearranging and taking the k^{th} root, the marginal rate of return becomes

$$r = (MPR)_m^{1/k} - 1 \qquad (4.4.13)$$

CHAPTER V

RESULTS AND ANALYSIS

Varieties and Environment

Environmental Response of Varieties

Tables X, XI and XII report estimates of environmental responses for maize, rice and cassava, respectively. Results from the environmental model indicate that most varieties selected and analyzed are capable of physically responding well to different environments in Nigeria. The environmental response values which show the nature and extent of yield response of a given variety in a given environment are within an acceptable range. In fact, as postulated in Chapter IV, the sign of the sum of coefficients a_{1j} and a_{3j} is positive indicating that all varieties are adaptable to the different environments in Nigeria.

For maize, two varieties stand out as excellent with respective values of environmental responses of 1.11 for FARZ26 and 1.04 for FARZ27. The local cultivar has a positive but small environmental response, indicating inability of a traditional local variety to respond to improved practices. Table XII shows environmental responses for rice varieties. For dryland rice varieties, three out of five varieties displayed excellent performance: FAROX 56/30, TO_s 2513, and TO_s 2300. For irrigated swamp varieties, four out of five performed well; those are IR8, TO_s 42, TO_s 78 and IR22. IR's are varieties from the International

TABLE X

MAIZE ENVIRONMENTAL PERFORMANCE IN SELECTED ENVIRONMENTS IN NIGERIA 1973-76

Variety	Mean Yield	Environmental Response (a_1+a_3)	Standard Errors Sum (a_1+a_3)
1. Local	18,474	.8190	.2300
2. FARZ26 (TZA x TZB)	27,578	1.1109	.2197
3. FARZ27 (TZPB)	29,498	1.0480	.2540
4. FARZI (NSI)	26,520	.9646	.2010
5. FARZ23 (096EPG)	26,887	.9814	.0910

Source: Computed from environmental model in equation (4.1.3) with estimated results reported in Appendix, Table

TABLE XI

RICE VARIETAL PERFORMANCE IN SELECTED ENVIRONMENTS IN NIGERIA 1973-76

	Variety	Mean Yield	Environmental Response $(a_1 + a_3)$	Standard Error Sum $(a_1 + a_3)$
1.	FAROX 56/30	2391.0	1.0976	.3434
2.	TO_s 2583	1975.0	.7981	.3021
3.	TO_s 4020	1926.0	.9154	.3520
4.	TO_s 2513	1883.0	1.0583	.3400
5.	TO_s 2300	1803.3	1.1299	.3310
6.	IR8	3947.0	1.2424	.3190
7.	TO_s 42	3797.8	1.1331	.3200
8.	TO_s 78	3781.2	1.1498	.2980
9.	TO_s 490	3496.2	.8821	.3120
10.	IR22	3273.8	1.0842	.2750
11.	SML 140/10	2782.8	.5327	.1321

Source: Computed from environmental model in equation (3.1.2) with estimated results reported in Appendix, Table

TABLE XII

CASSAVA VARIETAL PERFORMANCE IN SELECTED ENVIRONMENTS IN NIGERIA 1973-78

	Variety	Mean Yield	Environmental Response ($a_1 + a_3$)	Deviation Mean Square
1.	TMS 30572	43.14	1.3100	135
2.	TMS 30555	40.96	1.7800	48
3.	TMS 30337	35.37	.9600	127
4.	TMS 30110	35.28	1.4200	289
5.	TMS 30017	35.22	.8200	301
6.	TMS 30040	32.05	.8200	42
7.	TMS 30786	32.04	1.1000	17
8.	TMS 30835	30.16	1.1700	58
9.	TMS 30054	29.83	1.1600	137
10.	TMS 30157	28.90	.7300	67
11.	TMS 30211	28.47	.6500	124
12.	TMS 30395	27.58	.8200	90
13.	TMS 30158	26.83	.6900	67
14.	TMS 60444	16.77	.5500	213

Source: Dr. S. K. Hahn, "Genetric Improvement of Cassava 1978". IITA Annual Report 1978.

Rice Research Institute (IRRI) and introduced in Nigeria for experimental purposes. Absence of negative signs for the rice model provides no basis to reject the hypothesis of an adequate biological technology in Nigeria.

Results for maize and rice when compared with those of cassava as taken from Hahn's study show a striking similarity. The overall inference is that improved varieties are superior to traditional ones. But the question of yield stability remains.

Yield Stability Analysis

The above discussion dealt with the performance of varieties in terms of yield gains in different environments. However, in the context of new varieties adoption policy, variability as well as level of yield is crucial. This aspect is dealt with further in the next section through stochastic dominance analysis, but as of now the issue of yield stability is analyzed within the context of the environmental model.

For analyzing the stability of yields, Figures 13 through 15 were assembled for all three crops. The criterion of stability, as indicated previously, is the dispersion of environmental responses and varietal means from their respective pooled means. For this study one standard deviation from the mean is taken as a benchmark for stability determination; that is, observations falling outside one standard deviation are considered unstable.

From reported results, all improved maize varieties selected in the study had values within the stability area while the traditional variety displayed a value outside the stability zone. For all types of

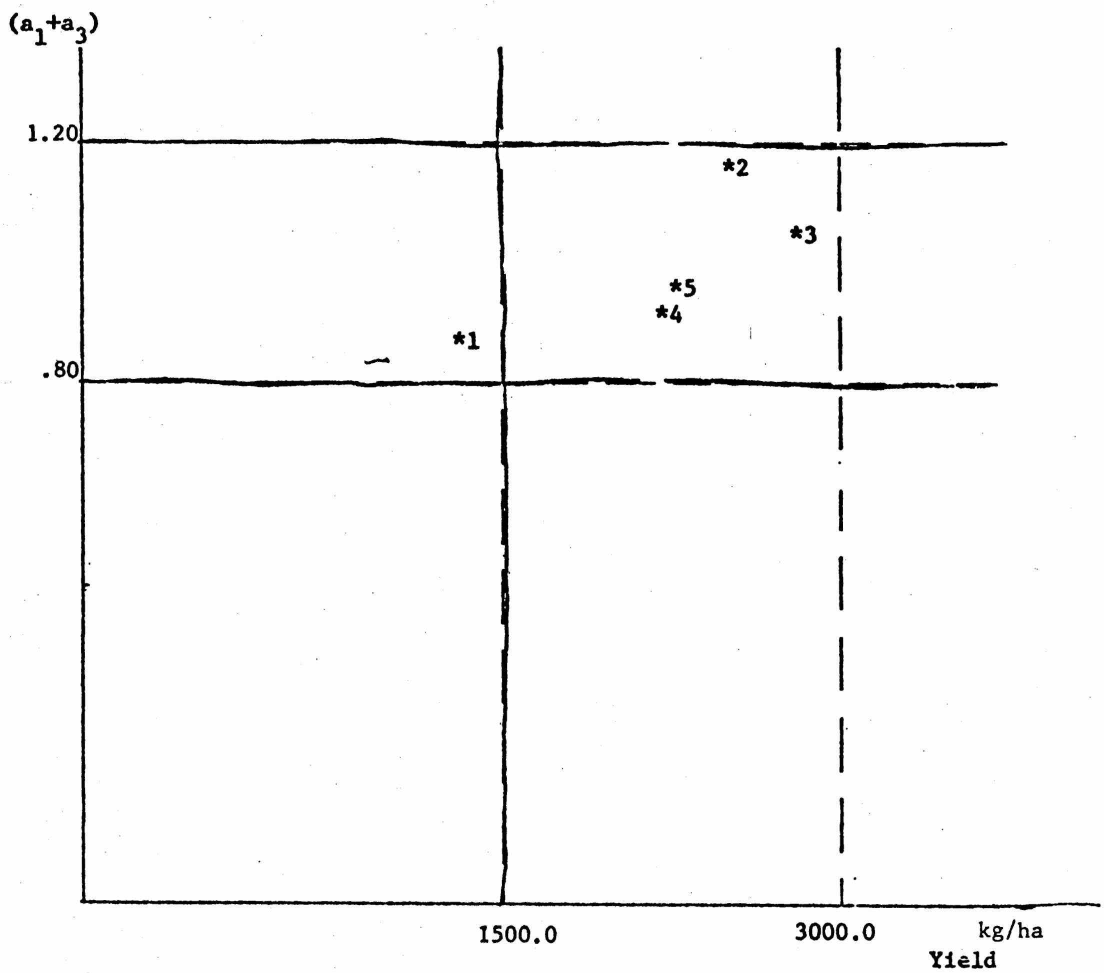

Figure 14. Stability Analysis of Selected Maize Varieties in Nigeria

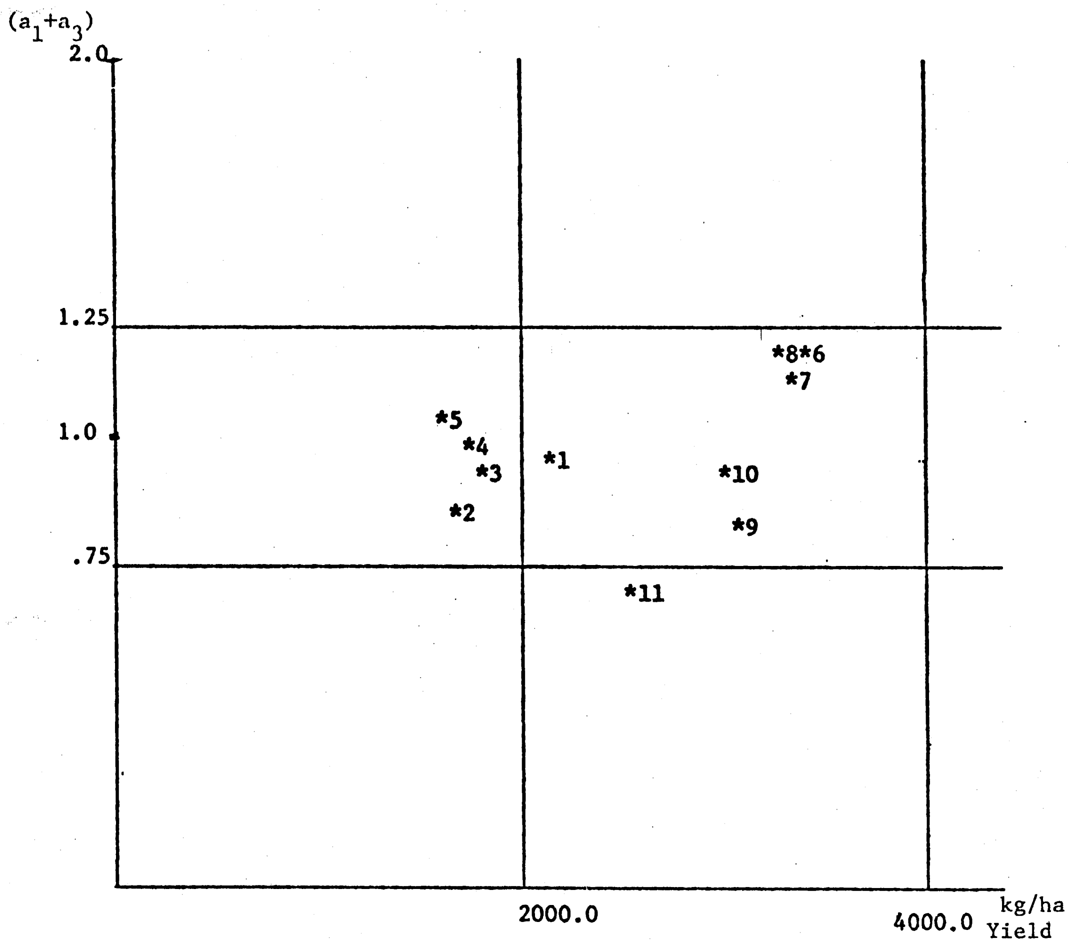

Figure 15. Stability Analysis of Selected Rice Varieties in Nigeria (For Variety Identification Match Number in This Figure with Those in Table XII)

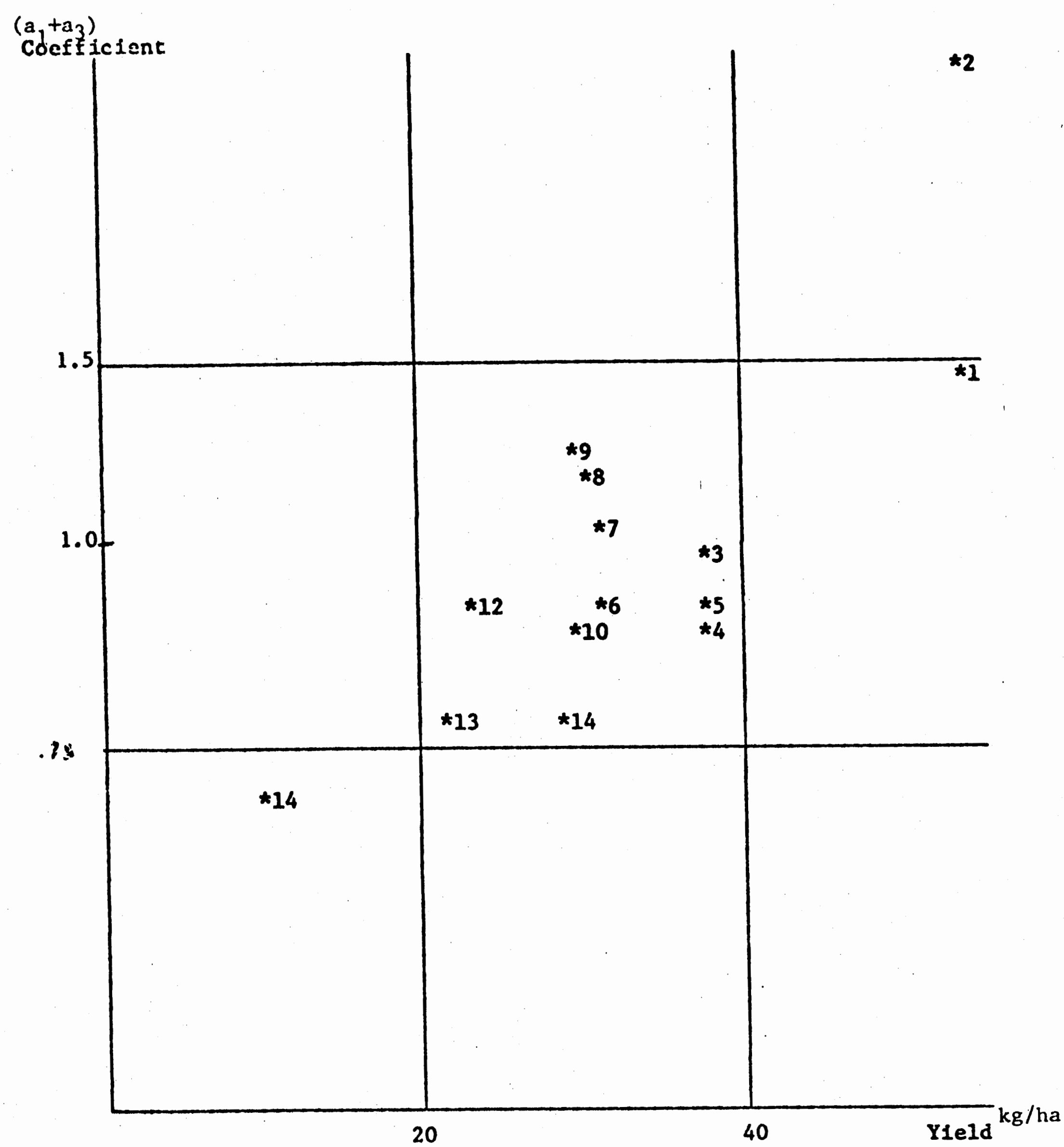

Figure 16. Stability Analysis of Selected Cassava Varieties in Nigeria (Hahn Results)

rice (dryland and irrigated) fifty percent of varieties are outside the stability boundary and most of these are dryland varieties.

The pattern of stability given by Figure 15 for cassava is superior to that of rice. Two cassava varieties, TMS 60444 and TMS 30555, are outside the stability area. For TMS 60444, the deviation from the center indicates performance below average while for TMS 30555, deviation from the mean (in the northeast corner of the figure) indicates superior performance. TMS 30555 holds promise as a parental material for further breeding.

In conclusions, this section provides evidence that food crop research in Nigeria in maize, rice and cassava has produced some viable clones as evidenced by the magnitude of environemntal responses and stability. The issue of identifying varieties that satisfy farmers with alternative risk preferences is analyzed in the following section.

Stochastic Efficiency Analysis

The Tables XIII through XV summarize the information regarding stochastic efficiency of tested varieties. Before analyzing results, some review of methodology involved in calculating the efficiency level is useful. The frequency distribution of yield was identified for each variety. This frequency was empirically treated as equivalent to the probability function in equation (4.2.1). Once the probability function was found, formulas in (4.2.1) were applied to derive dominance values related to each level within the range of yields of each variety. The values are reported in Tables XXIV through XXXIX in Appendix B.

To select those varieties that dominate others, a decision was made to have a common range of yield over which to compare varieties.

For this purpose the smallest yield of all minima was taken as a lower bound while the greatest yield of maxima constituted the upper bound. The plotting of dominance values against yields within the defined range gives efficiency curves. At any yield, the dominant variety should have its efficiency curve to the right of all others. Using this rule, Tables XIII through XV were derived.

For interpretation of results, emphasis should be put on FSD and SSD efficiencies.[1] Those two types of efficiency are the ones that can be considered relevant for the appraisal of applied agricultural research in low income countries. The TSD rule allows for the economic agent to accept some risk in his enterprises as he becomes wealthier. The mean-variance tradeoff is ambiguous, however, and TSD has limited relevance to small scale farmers in Nigeria. Other studies have indicated that the TSD criterion was not empirically useful or important in the evaluation of alternative choices [Anderson et. al., 1977, p. 289].

On the basis of results reported on Table XIII, it would appear that the local variety is inefficient at all levels. One would expect to see the local variety qualify as a potential variety for risk avert farmers, but on the contrary it is the improved variety FARZ26 that is revealed to be SSD efficient, meaning that a farmer who faces

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[1] In layman's term, the First Stochastic Dominance (FSD) would mean the ability of the variety to satisfy a farmer who wants higher yields to lower ones and this rule is satisfied by varieties with higher means. The Second Stochastic Dominance (SSD) allows the elimination of those varieties from FSD set that are inefficient in a sense that they do not satisfy a farmer who is averse to risk and the rule is satisfied by varieties with smaller variance. The Third Stochastic Dominance (TSD) would reduce the SSD set to a fewer varieties that have some positive skewness in distributions of yields, that is, varieties suited to farmers disposed to accepting some risk.

TABLE XIII

STOCHASTIC EFFICIENCY OF MAIZE VARIETIES

Clone	Yield (kg/ha) 1,847	2,652	2,688	2,757	2,949
Local	[0.0]	0.0	0.0	0.0	0.0
FARZI	2,3	[0.0]	0.0	1	1
FARZ23	1	0.0	[0.0]	0.0	0.0
FARZ26	0.0	1,2,3	2,3	[2,3]	2,3
FARZ27	0.0	0.0	1	0.0	[0.0]

*A zero entry means inefficiency according to FSD. The no-zero entries denote the efficiency levels achieved. Boxed entries are those corresponding to the mean yield of a given variety, and as such represent the level of efficiency for that variety.

TABLE XIV

STOCHASTIC EFFICIENCY OF DRYLAND VARIETIES

Clone	Yield (kg/ha) 1,803	1,883	1,926	1,975	2,391
TO_s 2300	0.0	0.0	0.0	0.0	0.0
TO_s 2513	0.0	0.0	0.0	0.0	0.0
TO_s 4020	0.0	0.0	0.0	0.0	0.0
TO_s 2583	0.0	0.0	0.0	0.0	0.0
FAROX 56/30	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3

*For interpretation of the table, refer to Table XIII.

TABLE XV

STOCHASTIC EFFICIENCY OF IRRIGATED RICE VARIETIES

Clone	Yield (kg/ha) 2,782.0	3,496.0	3,781	3,797	3,947
SML 140/10	0.0	0.0	0.0	0.0	0.0
TO_s 490	1	1	0.0	1	1
TO_s 78	0.0	3	2,3	2,3	2,3
TO_s 42	2,3	2,3	2,3	2,3	2,3
IR8	0.0	0.0	1	0.0	0.0

*For interpretation of this table, refer to Table XIII.

uncertainties about crop yield response would be better off with FARZ26. Other improved maize varieties are as inefficient as the local one. But there are some differences between the local maize and those inefficient improved clones. While the local variety is inefficient over the entire range of recorded means, other varieties are efficient at one level or another on some points of the yield range. This is the case of FARZI, which is SSD efficient at 1,847 kg/ha, and also of FARZ23 and FARZ27 that are FSD efficient at 1,847 kg/ha and 2,688 kg/ha, respectively.

The significance of such a difference is important in this way: the mean yield under which boxed efficiency levels are reported are the overall means of those varieties from observations taken in different environments. If a specific environment whose mean yield is 2,652 kg/ha is considered, FARZ26 will turn out to be efficient at all levels. The same reasoning applies to FARZI and FARZ27. Thus, even though it is known that for maize varieties, FARZ26 is the SSD efficient for all environments, it is interesting to recognize that in some specific environments, FARZI, FARZ23 and FARZ27 can be recommended to some group of farmers whose preference functions correspond to levels of efficiency reported.

The picture for dryland rice varieties in Table XIV is very different; all but one variety are inefficient over the entire range. The efficient variety, FAROX 56/30 is dominant at all levels of efficiency. An attempt to intorduce those inefficient clones will only result in poor adoption rates since those varieties do not match with any of the farmers' preference functions. For irrigated varieties, TO_s 490 is FSD efficient, while TO_s 78 and TO_s 42 are both SSD and TSD efficient.

Again, the local standard SML 140/10 is completely dominated by all improved clones. One of IRRI clones, namely IR8 is specifically efficient for environments whose mean yields are about 3781 kg/ha.

In conclusion for this section, it can be said that food crop research in Nigeria has produced maize and rice varieties that are stochastically efficient and that can be selected to meet different preference functions. Because of the existence of such a wide range of varieties, it is felt that the diffusion of those varieties in different environments in Nigerian agriculture can be easily accomplished if other economic factors are adjusted.

Profitability of the Improved Package to the Farmer in Nigeria

The economic profitability of the improved package as measured by gains in net income is great. On rainfed lands of Southern Nigeria, gains in net income are 209.7, 107.9 and 547.6 dollars for maize, rice and cassava, respectively. The results for Fadama lands show for maize, rice and cassava respective gains of 311.95, 125 and 289.5 dollars. Gains on Gona lands are 227.45, 106.7 and 356.07 dollars for the respective crops.

Net income in each package is the return to risk, management and some capital omitted from the budget because such capital is the same for the traditional and improved package. The difference between net incomes from traditional and modern package represents gains due to the adoption of the improved package. It represents private benefits which accrue to private farmers as a result of food crop research effort.

A farmer who adopts the improved package experiences greater total expenditures than before. Although the package is profitable, the farmer would not be able to adopt it right away if he does not have in advance sufficient cash. Credit is needed by many small scale farmers to facilitate the adoption of the improved package.

Budgets in Tables XVI, XVII and XVIII are based on subsidized prices for fertilizer. If the full cost of fertilizer is included in the budgets, net incomes are reduced but remain higher than those for the traditional package.

Profitibility of Improved Package to Society as Measured by Marginal Internal Rate of Return to Research (MIRR)

The analysis now turns to results from equation (4.4.10). The results related to the overall crop research system without distinguishing among sources of research funding. Using a quadratic lag structure of up to 12 years, marginal returns summarized in Tables XIX through XXI were derived for various crops. It is important to keep in mind that those results do not relate to 12 equations of different lag each but rather to one equation with 12 years lag.

Rice research yields negative marginal rates of return over the entire period whereas those same rates for maize and cassava begin as negative, then become positive in later years. The rates are lower than those reported from other parts of the world -- e.g. India, USA and Columbia. Why is this so?

The first proposition is that more widespread diffusion and adoption of research among farmers would brind a higher marginal

TABLE XVI

PRODUCTION, COSTS AND NET INCOME PER HECTARE OF CULTIVATED MAIZE, RICE AND CASSAVA ON RAINFED LAND OF SOUTHERN NIGERIA

Package / Item	Maize Price or Cost	Maize Qty	Maize Value or Cost	Rice Price or Cost	Rice Qty	Rice Value or Cost	Cassava Price or Cost	Cassava Qty	Cassava Value or Cost
1) Traditional									
Yield (Ton)	210	1.30	273.0	180.0	1.10	198.0	45.0	9.00	405.0
Inputs									
Labor (hrs.)	.55	40.0	22.0	.55	100.0	55.0	.55	162.0	89.1
Land (ha)	56.4	1.0	56.4	56.4	1.0	56.4	56.4	1.0	56.4
Net Income (U.S.$)**	---	---	194.6	---	---	86.6	---	---	259.5
2) Modern									
Production									
Yield (Ton)	210	2.80	588.0	180.0	2.45	432.0	45.0	24.0	1080.0
Inputs									
Labor (hrs.)	.55	53.0	29.2	.55	130.0	71.5	.55	234	128.7
Land (ha)	56.4	1.0	56.4	56.4	1.0	56.4	56.4	1.0	56.4
Seeds (Ton)	151	.03	4.5	102.2	.045	4.6	40.75	.04	1.63
Fertilizer (Ton)	40.0*	.14	5.6	40.0*	.104	4.0	40.0*	.14	5.6
Chemicals (Ton)	29333.0	.003	88.0	33666.	.003	101.0	16200.0	.005	81.0
Net Income (U.S.$)	---	---	404.3	---	---	194.5	---	---	806.7
Gain in Net Income	---	---	209.7	---	---	107.9	---	---	547.2

* = subsidized rate.

Qty = quantity of item per hectare.

** = net income represents returns to risk management and capital.

The capital is defined here to cover investments in buildings, tools and operating fund.

TABLE XVII

PRODUCTION, COSTS AND NET INCOME PER HECTARE OF CULTIVATED MAIZE, RICE AND CASSAVE ON FADAMA LAND OF NORTHERN NIGERIA

Package	Maize			Rice			Cassava		
	Price or Cost	Qty	Value or Cost	Price or Cost	Qty	Value or Cost	Price or Cost	Qty	Value or Cost
1) Traditional									
Production									
Yield (Ton)	210.0	1.1	231.00	180.0	1.0	180.0	45	6.0	270.0
Inputs									
Labor (hrs.)	.55	85	46.75	.55	100	55.0	.55	154.0	84.7
Land (ha)	85.0	1.0	85.00	85.0	1.0	85.0	85.0	1.0	85.0
Net Income (U.S.$)	---	---	99.25	---	---	40.0	---	---	91.3
2) Modern									
Production									
Yield (Ton)	210	3.16	663.6	180.0	2.5	450.0	45.0	15.0	675.0
Inputs									
Labor (hrs.)	.55	126.0	79.3	.55	170	93.0	.55	220	121.0
Land (ha)	85.0	1.0	85.0	85.0	1.0	85.00	85.0	1.0	85.0
Seeds (Ton)	151	.03	4.5	102.2	.02	2.0	40.75	.04	1.63
Fertilizer (Ton)	40.0*	.14	5.6	40.0*	.10	4.00	40.0*	.14	5.60
Chemicals (Ton)	29333.0	.003	88.0	33666.0	.003	101.00	16200.0	.005	81.00
Net Income (U.S.$)	---	---	411.20	---	---	165	---	---	380.8
Gain in Net Income	---	---	311.95	---	---	125	---	---	289.5

Qty = quantity of item per hectare.
* = subsidized rate.

TABLE XVIII

PRODUCTION, COSTS AND NET INCOME PER HECTARE OF CULVIATED MAIZE, RICE AND CASSAVA ON GONA LANDS OF NORTHERN NIGERIA

Package	Item	Maize Price or Cost	Maize Qty	Maize Value or Cost	Rice Price or Cost	Rice Qty	Rice Value or Cost	Cassava Price or Cost	Cassava Qty	Cassava Value or Cost
1) Traditional										
	Production									
	Yield (Ton)	210.0	.8	168.0	180.0	.70	126.0	45.0	4.0	180.0
	Inputs									
	Labor (hrs.)	.55	85.0	46.75	.55	100	55.0	.55	154.0	84.7
	Land (ha)	63.0	1.0	63.0	63.0	1.0	63.0	63.0	1.0	63.0
	Net Income (U.S.$)	---	---	58.25	---	---	8.0	---	---	32.30
2) Modern										
	Production									
	Yield (Ton)	210.0	2.5	525.0	180.0	2.0	260.0	45.0	15	675.0
	Inputs									
	Labor (hrs.)	.55	116	63.8	.55	106	58.3	.55	220	121.0
	Land (ha)	63.0	1.0	63.0	63.0	1.0	63.0	63.0	1.0	63.0
	Seeds (Ton)	151	.03	4.5	102	.03	3.0	40.75	.04	1.63
	Fertilizer (Ton)	40.0*	.50	20.0	40.0*	.50	20.0	40.0*	.50	20.00
	Chemicals (Ton)	29333	.003	88.0	33666.0	.003	101.0	16200	.005	81.00
	Net Income (U.S.$)	---	---	285.70	---	---	114.7	---	---	388.37
	Gain in Net Income	---	---	227.45	---	---	106.7	---	---	351.07

Qty = quantity of item per hectare.
* = subsidized rate.

product. This proposition is examined using the following formula.

$$MPR = PB \frac{_{it}Q_{it}}{Z} \qquad (5.4.1)$$

Equation (5.4.1) is similar to equation (4.4.11) except in the former Q_{it} is not the actual production Y but the potential production achievable under conditions of complete adoption of the results of the research, or

$$Q_{it} = \text{Yield X (Total area)}$$

By substituting the MPR obtained under this approach into equation (4.4.13), MIRR is significantly improved with 15, 11 and 19 percent rates of return respectively for maize, rice and cassava. This finding shows how the rate of adoption positively affects the marginal rate of return. But the above rates do not account for lower produce prices that would result from greater output, for imperfections in the price system and for the cost of education required to raise adoption rates to higher levels.

The second factor potentially explaining lower rates of return to Nigerian food crop research is the artificially low level of prices of analyzed crops. Public policy prevailing in Nigeria may reduce food crops prices below levels that would prevail in competitive equilibrium. An example of such policy is reported by Schultz (1978):

> The British palm research center in Nigeria developed varieties of palms that are much more productive than the native palms. But few Nigerian farmers could afford to plant and buy the better varieties to function, mainly because the state marketing board severely reduced the price that producers receive for palm fruits (p. 17).

Policies to reduce cash crops prices induce farmers to produce less cash crops and more food crops causing prices of the latter to go down. There is no available research showing equilibrium prices of crops to indicate whether prices are close to equilibrium.

The third potential factor is that technical efficiency of farmers who have moved from the traditional package to a modern package is not yet fully realized. Their combination of inputs is not yet optimal. This situation might arise either because farmers are unaware of/or tentative toward the proper input mix in the improved package or because the supply of improved inputs to farmers is limited.

On the other hand, rates of return could be inflated upward because research expenditures variable does not include private research. However, private reserach in Nigeria is insufficient to bias results.

But even though it is recognized that estimated rates of return are lower by international standards, it would appear that those rates are far better than prevailing market interest rates. The rates of interest in Nigeria have been consistently maintained between 4 and 5 percent. Certainly those interest rates do not reflect the opportunity cost of capital in the economy, but on practical ground, when investments in research are compared to financial investments in the market, food crop research in Nigeria becomes an attractive activity for further investment.

Looking at the trend of actual rates of return in Tables XIX, XX and XXI, for both maize and cassava, one notices that the production cycle of research for those two crops starts after the fourth year of investment and reaches its peak at the tenth year. This fact gives an afterthought about the best lag to use in the model.

As to the problem of allocation of research monies among analyzed crops, except for rice, there is no significant differences in rates of return to justify a funding policy in favor of maize or cassava. As for

TABLE XIX

ESTIMATED SOCIAL RATE OF RETURN TO RESEARCH FOR MAIZE IN NIGERIA (1956-1976)

Period	Sum of Monetary Marginal Products of Research	Cumulative Marginal Internal Rate of Return (MIRR)
0	.1001	Neg
1.	.2837	Neg
2.	.5341	Neg
3.	.8344	Neg
4.	1.1681	3.1
5.	1.5185	7.0
6.	1.8689	9.0
7.	2.2927	10.0
8.	2.5030	10.0
9.	2.7533	10.0
10.	2.9369	10.0
11.	3.0370	9.3

TABLE XX

ESTIMATED SOCIAL RATES OF RETURN TO RESEARCH FOR RICE IN NIGERIA (1951-1976)

Period	Sum of Monetary Marginal Products of Research	Cumulative Marginal Internal Rate of Return (MIRR)
0	.0225	Neg
1.	.0637	Neg
2.	.1200	Neg
3.	.1877	Neg
4.	.2628	Neg
5.	.3416	Neg
7.	.4956	Neg
8.	.5632	Neg
9.	.6195	Neg
10.	.6651	Neg
11.	.6832	Neg

TABLE XXI

ESTIMATED SOCIAL RATES OF RETURN TO RESEARCH
FOR CASSAVA IN NIGERIA (1956-1976)

Period	Sum of Monetary Marginal Products of Research	Cumulative Marginal Internal Rate of Return (MIRR)
0	.1141	Neg
1.	.3233	Neg
2.	.6084	Neg
3.	.9507	Neg
4.	1.3310	5.8
5.	1.7304	9.1
6.	1.2199	11.1
7.	2.5102	11.6
8.	2.8524	12.2
9.	3.1376	12.1
10.	3.3468	11.4
11.	3.4609	10.4

rice, due to its actual negative returns, it would be advisable to stress a policy which allows for adoption of existing improved varieties rather than a policy which calls for further investment in rice research. This is justified by the finding that an adoption rate of 100 percent raises rates of return from negative to 11 percent.

CHAPTER VI

SUMMARY AND CONCLUSION

This study evaluates the research investment in food crop research in Nigeria with emphasis on maize, rice and cassava.

Four complementary methods of analysis were used. The first, called in this study an environmental model, was used to determine whether crops varieties developed by the Nigerian research system responded favorably to their environment and to what extent such a response was reliable on the basis of stability criterion. Results relating to maize, rice and cassava indicated that 50 percent of tested varieties were both responsive and stable. Due to lack of detailed data on cassava varieties, Dr. Hahn's results based on the same model were presented for reference and comparison.

Since the choice of varieties depends on more than environmental response, a second technique, known as stochastic dominance analysis, was used to select varieties based on risk preferences functions of farmers. The technique does not require the estimation of farmers risk preferences, but only identifies varieties that will satisfy farmers with alternative risk preferences. The assumed risk preference patterns are associated with three stochastic rules, namely 1) first stochastic dominance, 2) second stochastic dominance, and 3) third stochastic dominance.

The risk preference function related to the first stochastic dominance was based on the assumption that the farmer wants maximum average yield. Varieties identified as satisfying such a rule were FARZI, FARZ27, and FARZ23 for maize. For Rice, TO_s 490 and FAROX 56/30 were found to be also FSD efficient. For the second risk perference function, the varieties satisfying such a rule were found to be FARZI and FARZ26 for maize; again, FAROX 56/30, along with TO_s 78 and TO_s 42 are found to be SSD efficient for rice.

The above matching of crops varieties with specific groups of farmers does not insure profit realization. The purely economic aspect was considered in crop budgets. Two packages were considered for each crop: the traditional and modern. The traditional package contained only traditional varieties, labor, land and capital, while the modern package consisted of improved varieties, labor, land, capital, fertilizer, insecticides and other chemical inputs. Results from enterprise budget analysis show that net income realized under the improved package was greater than that obtained under the traditional one. However, it was suggested that because of increased expenditure, induced by use of modern inputs and additional traditional inputs, an institutional framework for facilitating the availability of credit was needed.

The last technique used was the aggregate production function approach to estimating social marginal internal rates of return. Results from this method indicate that actual rates of return are low. Adoption rates, level of prices, and farmers technical efficiency influence rates of return.

In conclusions, results indicated that the Nigerian food crop research system as represented by maize, rice and cassava has produced some promising varieties with high degree of adaptation and capable of yielding high private returns to farmers. However, social rates of return on food crop research investment are modest.

It is possible that more complete development of the whole intra-structure of extension coupled with supply of inputs at low cost could raise rates of adoption of new varieties. Further evaluation is needed of the social rates of return to determine whether such efforts are warranted.

Results depend on techniques and quality of data. The diversity and length of data series were quite limited; more extensive data would have improved and given more weight to the conclusions. Issues of relationship between national and international food crops research need more attention in later studies. As data become available, the future analysis of returns to agricultural research can embrace an enlarged scope of farming enterprises, and resources, including public inputs such as education.

BIBLIOGRAPHY

Abelson, P. H. Food: Politics, Economics, Nutrition and Research. American Association for Advancement of Science. Washington, D. C., 1975.

Ahn, P. M. West African Soils. Oxford University Press. Oxford, 1970.

Anderson, J. R. "Sparse Data, Climatic Variability and Yield Uncertainty in Response Analysis, American Journal of Agricultural Economics, Volume 55 (1), 1973, pp. 77-82.

Anderson, J. R., J. L. Dillon and B. Hardacker. Agricultural Decision Analysis. Iowa State Press. Ames, 1977.

Ardito, Barletta N. "Costs and Social Benefits of Agricultural Research in Mexico." (Unpublished Ph.D. Dissertation, University of Chicago, 1970.)

Arndt, T. M., D. G. Dalrymple and V. W. Ruttan, Resource Allocation and Productivity in National and International Agricultural Research. University of Minnesota Press, Minneapolis, 1977.

Arnold, M. H. Agricultural Research for Development, The Namulonge Contribution. Cambridge University Press. Cambridge, 1976.

Arnon, I. The Planning and Programming of Agricultural Research. Food and Agriculture Organization. Rome, 1975.

Arnon, I. Organization and Administration of Agricultural Research. Elsevier Publishing Company, Limited, 1968.

Arrow, K. J. The Imperfections of the Private Capital Market, A Discussion. Paper prepared for RFP Seminar. March, 1965. Washington, D. C., 1965.

__________, "Discounting and Public Investment Criteria." Water Research. Edited by A. V. Kneese and S. C. Smith. Baltimore Johns Hopkins Press, 1966, pp. 13-32.

Barker, R. "Economic Aspects of High-Yielding Varieties of Rice, with Special Reference to National Price Policies." Monthly Bulletin of Agricultural Economics and Statistics, Volume 18, (6), June, 1969, pp. 1-9.

Bator, F. "The Anatomy of Market Failure." Quarterly Journal of Economics, Volume 72, 1958, pp. 351-379.

Beneke, R. R. and R. Winterboer. Linear Programming Applications to Agriculture. Iowa State Press. Ames, 1973.

Bernardt, I. and K. D. Mackenzie. "Acceptance of Change: A Theory with Models." Management Science in Planning and Control. Edited by John Blood, Special Technical Association Publication #5, 1969.

Boyce, J. K. and R. E. Evenson. Agricultural Research and Extension Programs. Agricultural Development Council, New York, 1975.

Clark, J. D. "Prehistoric Populations and Pressures Favoring Plant Domestic in Africa." Origins of African Plant Domestication. J. R. Harlan, J. M. J. DeWet and A. B. L. Stemler. Mouton Publishers. Paris, 1976.

Cline, P. L. "Sources of Productivity Change in U.S. Agriculture." (Unpublished Ph.D. Dissertation, Oklahoma State University, 1975.)

Consultative Group on International Agricultural Research, International Research in Agriculture. New York, 1974.

Cooper, S. G. C. Agricultural Research in Tropical Africa. East African Literature Bureau. Dar-es-Salaam/Nairobil Kampala, 1970.

Dalton, G. E. Study of Agricultural Systems. Applied Science Publishers, Limited. London, 1975.

Denison, E. F. "Capital Theory and the Rate of Return." American Economic Review, Volume 54 (5), September, 1964, pp. 721-25.

Des Bouvrie C. and J. R. Rydzewski. "Irrigation" in Food Crops of the Lowland Tropics. Edited by C. L. A. Leakey and J. B. Wills. Oxford University Press, 1977.

Diaz, R. O. World Cassava Production Trends. CITA, CAL. Columbia, 1971.

Ene, L. S. O., H. E. Okereke, S. O. Odurukwe, O. O. Okoli and O. B. Arene. Proceedings of the First National Seminar on Root and Tuber Crops. Freemans Press, Limited, Enugu, 1978.

Easter, K. W. and G. W. Norton. "Potential Returns From Increased Research Budget for the Land Grant Universities." Agricultural Economic Research, Volume 29 (4), October, 1974, pp. 127-33.

Evenson, R. "The Contribution of Agricultural Research and Extension to Agricultural Production." Journal of Farm Economics, Volume 49, 1967, pp. 1415-25.

__________. International Transmission of Technology in Sugarcane Production. Mimeo. New Haven, Yale University, 1969.

__________ and D. Jha. "The Contribution of Agricultural Research Systems to Agricultural Production in India." Indian Journal of Agricultural Economics. Volume 28, 1973, pp. 212-230.

Evenson, R. "Agricultural Research and U.S. Comparative Advantage." The Competitive Threat from Abroad: Fact or Fiction? Edited by M. A. Martin and L. F. Dunn. Purdue University, West Lafayette, 1978.

Falusi, A. O. Economics of Fertilizer Distribution in Nigeria. N.I.S.E.R., 1975.

Fishburn, P. C. "Convex Stochastic Dominance with Continuous Distribution Functions." Journal of Economic Theory, Volume 7 (2), February, 1974, pp. 143-158.

Food and Agriculture Organization. Provisional Food Balance Sheets, FAO, Rome, 1977.

Green, H. A. J. Aggregation in Economic Analysis, An Introductory Survey, Princeton University Press, Princeton, 1974.

__________. Agricultural Commodities Projections for 1975 and 1985. Volume 2, FAO, Rome, 1967.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." Journal of Farm Economics, Volume 66, 1958, pp. 419-431.

__________. "Research Expenditures, Education and the Aggregate Production Function." American Economic Review, Volume 54 (6), December, 1964, pp. 961-974.

Hadar, J. and W. R. Russel. "Rules for Ordering Uncertain Prospects." American Economic Review, Volume 59 (1), March, 1969, pp. 25-34.

Hahn, S. H. Cassava Improvement Program. International Institute of Tropical Agriculture. Oncoming Annual Report, 1979.

Hanoch, G. and H. Levi. "The Efficiency Analysis of Choices Involving Risk." Review of Economic Studies, Volume 36 (3), #167, July, 1969, pp. 335-346.

Harlam, J. R., J. M. J. DeWet and A. B. L. Stemler. Origins of African Plant Domestication. Mouton Publishers, Paris, 1976.

Hayami, Y. and V. W. Ruttan. Agricultural Development: An International Perspective. The Johns Hopkins Press, Baltimore, 1971.

Hertford, R. and A. S. Schmitz. "Measuring Economic Returns to Agricultural Research." Resource Allocation and Productivity in National and International Agricultural Research. Edited by T. M. Arndt, D. G. Dalrymple and V. W. Ruttan. University of Minnesota Press, Minneapolis, 1977.

Hicks, J. R. A Revision of Demand Theory. Second Edition. Oxford University Press, London, 1959.

Idachaba, F. S. Agricultural Research Policy in Nigeria. Manuscript, International Food Policy Research Institute, Washington, D. C., 1978.

Institute of Agricultural Reserach. Annual Report 1964-65. Ahmadu Bello University. Zaria, 1966.

Institute of Agricultural Research and Training. Annual Report 1975-76. University of IFE.

International Institute of Tropical Agriculture. Annual Report 1975. Ibadan, Nigeria.

__________. Annual Report 1976. Ibadan, Nigeria.

__________. Annual Report 1977. Ibadan, Nigeria.

__________. Annual Report 1978. Upcoming.

Johansen, L. Production Functions, An Integration of Micro and Macro, Short Run and Long Run Aspects, North-Holland Publishing Company, Amsterdam-London, 1972.

Jones, W. O. Manioc in Africa. Stanford University Press, 1959.

Kahlon, A. S., P. N. Saxena, H. K. Bal and D. Jha. "Returns to Investments in Agricultural Research in India." Resource Allocation and Productivity in National and International Agricultural Research. T. M. Arndt, D. G. Dalrymple and V. W. Ruttan. University of Minnesota Press, Minneapolis, 1977.

Knutson, M. and L. Tweeten. "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension." American Journal of Agricultural Economics, Volume 61 (1), February, 1979, pp. 70-75.

__________. and I. A. Akinzele. Improvement of Cassava Processing and Marketing. NAFPP, 1976.

Latimer, R. "Some Economic Aspects of Agricultural Research and Extension." (Unpublished Ph.D. Dissertation, Purdue University, Lafayette, 1964.)

Leakey, C. L. A. and J. B. Wills. Food Crops of the Lowland Tropics. Oxford University Press, Oxford, 1977.

Levi, H. "Stochastic Dominance Among Log-Normal Distribution Prospects." International Economic Review, Volume 14 (3), October, 1973, pp. 601-614.

__________. "Stochastic Dominance Efficiency Criteria and Efficient Portfolios: The Multi-Period Case." American Economic Review, Volume 63 (5), December, 1973, pp. 986-994.

Mann, J. S. "Techniques to Measure Social Benefits and Costs in Agriculture: A Survey." Agricultural Economics Research, Volume 29 (4), October, 1977, pp. 115-126.

Manshard, W. Tropical Agriculture, A Geographical Introduction and Appraisal. Longmann, New York, 1968.

Martin, M. A. and L. F. Dunn. The Competitive Threat from Abroad: Fact or Fiction? West Lafayette, 1978.

Mellor, J. W. Three Issues of Development Strategy: Food, Population, Trade. International Food Policy Research Institute, 1978.

Mosher, A. T. Getting Agriculture Moving, Essentials for Development and Modernization. Agricultural Development Council, Praeger, 1966.

Mosher, A. T. "Unresolved Issues in the Evolution of the International System." Resources Allocation and Productivity in National and International Agricultural Research, University of Minnesota, 1977.

National Academy of Sciences. African Agricultural Research Capabilities. Washington, D. C., 1974.

National Accelerated Food Production Project. A New Dimension for Nigerian Agriculture. IITA and Federal Ministry of Agriculture and Rural Development, March, 1977.

National Root Crops Research Institute. Annual Report 1978-79. Umudike, Nigeria.

Norman, D. W. An Economic Survey of Three Villages in Zaria Province - 2. Input-Output Study Volume 2. Basic Data and Survey Forms, I.A.R., Ahmadu Bello University, 1972.

Norman, D. W., J. C. Fine, A. D. Goddard, W. J. Kroeker and D. H. Pryor. A Socio-Economic Survey of Three Villages in the Sokoto Close-Settled Zone - 3. Input-Output Study Volume 1. Text. I.A.R., Ahmadu Bello University, 1976.

Olayide, S. O. Economic Survey of Nigeria, 1960-1975. Aromolaran Publishing Company, Limited, 1976.

Olayide, S. O., Olatumbosun, E. O. Idusogie and J. D. Abiagom. Quantitative Analysis of Food Requirements, Supplies and Demands in Nigeria, 1968-1985. Federal Department of Agriculture, Lagos, Nigeria, 1972.

__________. "Unrestricted Issues in the Evolution of International System." Resource Allocation and Productivity in National and International Agriculture Research. Edited by T. M. Arndt, D. G. Dalrymple and V. W. Ruttan, University of Minnesota Press, Minneapolis, 1977.

Peterson, W. L. "Returns to Poultry Research and Extension in the United States." Journal of Farm Economics, Volume 49, 1967, pp. 656-669.

Plaxico, J. S. "Optimum Allocation of Research in a Dynamic Agriculture." Journal of Farm Economics, Volume 39, 1962, pp. 1373-1382.

Poirier, D. J. The Econometrics of Structural Change, With Special Emphasis on Spline Functions. North-Holland Publishing Company, Amsterdam-London, 1975.

Poleman, T. T. "World Food: A Perspective." Food: Politics, Economics, Nutrition and Research. Edited by P. H. Abelson, AAAS, Washington, D. C., 1975.

Porter, R. B. "An Empirical Comparison of Stochastic Dominance and Mean-Variance Portfolio Choice Criteria." Journal of Financial and Quantitative Analysis, Volume 8 (4), September, 1973, pp. 609-620.

Pouliquen, L. Y. Risk Analysis in Project Appraisal. World Bank Staff Occasional Paper, No. 11, 1970.

Quirk, J. P. and R. Suposnik. "Admissibility and Measurable Utility Functions." Review of Economic Studies, Volume 29 (2), Number 79, February, 1962, pp. 140-146.

Sawada, S. "Technological Change in Japanese Agriculture: A Long-Term Analysis." Agriculture and Economic Growth, Edited by Okhawa, K., B. F. Johnston and H. Kaneda, Princeton University Press, 1968.

Schmitz, A. and D. Seckler. "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester." American Journal of Agricultural Economics, Volume 52 (4), November, 1970, pp. 569-577.

Schultz, T. W. Transforming Traditional Agriculture. Yale University Press, New Haven, 1966.

__________. Distortions of Agricultural Incentives. Indiana University Press, Bloomington, 1978.

Sprow, F. B. "Evaluation of Research Expenditures Using Triangular Distribution Functions and Monte Carlo Methods." Journal of Industrial Engineering and Chemistry, Volume 59 (7), 1967, pp. 35-38.

__________. and R. T. Posada. "The Impact of High-Yielding Rice Varieties in Latin America with Special Emphasis on Colombia." CEDEAL-CIAT Series JE-01, April, 1977.

Tang, A. "Research and Education in Japanese Agricultural Development." Economic Studies Quarterly, Volume 13, February-May, 1963, pp. 27-41.

Tweeten, L. Foundations of Farm Policy. Second Edition, Revised, University of Nebraska Press, Under Press.

United State Department of Agriculture. Indices of Agricultural Production in Africa and Near East. Statistical Bulletin Number 610, Economics Statistics and Cooperative Services, Washington, D. C., July, 1978.

West Africa Rice Development Association. Rice Statistics Yearbook. Universal Press Corporation, Monrovia, 1975.

Whitmore, G. A. "Third-Degree Stochastic Dominance." American Economic Review, Volume 60 (3), June, 1970, pp. 457-459.

Zalla, T., R. B. Diamond and M. S. Mudahar. Economic and Technical Aspects of Fertilizer Production and Use in West Africa. Working Paper #2, Michigan State University, September, 1977.

APPENDIX A

ENVIRONMENTAL MODEL ESTIMATES

TABLE XXII

MAIZE ENVIRONMENTAL MODEL ESTIMATES
(DEPENDENT VARIABLE: YIELD)

Independent Variables	Estimated Coefficients	Standard Error	R^2 = .9069
a_0	2724.0	72.4348	
a_1	.9814	.09100	
a_{21}	-876.53	102.438	
a_{22}	33.8828	102.438	
a_{23}	226.41	102.438	
a_{24}	-72.00	102.438	
a_{31}	-.1624	.2197	
a_{32}	.1295	.2197	
a_{33}	.0666	.2197	
a_{34}	-.0168	.2197	

TABLE XXIII

RICE ENVIRONMENTAL ESTIMATES

Independent Variables	Estimated Coefficients	Standard Error	R^2 = .9488
a_0	2782.69	168.746	
a_1	.5327	.1321	
a_{21}	-391.193	215.110	
a_{22}	-987.693	215.110	
a_{23}	-856.193	215.110	
a_{24}	-899.068	215.110	
a_{25}	-979.318	215.110	
a_{26}	1164.56	238.644	
a_{27}	1014.97	238.644	
a_{28}	998.276	238.644	
a_{29}	713.330	128.644	
a_{210}	490.890	238.644	
a_{31}	.5649	.2113	
a_{32}	.2654	.2113	
a_{33}	.3827	.2113	
a_{34}	.5256	.2113	
a_{35}	.5972	.2113	
a_{36}	.7097	.1869	
a_{37}	.6004	.1869	
a_{38}	.6171	.1869	
a_{39}	.3494	.1869	
a_{310}	.5515	.1869	

APPENDIX B

STOCHASTIC DOMINANCE TABLES

TABLE XXIV

STOCHASTIC DOMINANCE TABLEAU FOR FAROX 56/30

Yield (kg/ha)	1500.0	1800.0	2100.0	2400.0	2700.0	3000.0	3400.0	3700.0	4000.0	4300.0
$f(X_1)$	.25	.125	0.0	.25	.25	0.00	0.0	0.0	0.0	.125
$F_1(X_1)$	.25	.375	.375	.375	.625	.875	.875	.875	.875	1.0
DX_1	-	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0
$F_2(X_1)$	0.0	75	187.5	300.0	487.5	750.0	1017.5	1275.0	1537.5	1800.0
$F_3(X_1)$	0	11250.0	50615.0	123750.0	241875.0	427500.0	691875.0	1035000.0	1456875.0	1957500.0

TABLE XXV

STOCHASTOC DOMINANCE TABLEAU FOR TO_s 2583

Yield (kg/ha)	1360.0	1560.0	1760.0	1960.0	2160.0	2360.0	2560.0	2760.0	2960.0	3160.0
$f(X_1)$	.25	.125	0.0	.25	.25	0.0	0.0	0.0	0.0	.125
$F_1(X_1)$	.25	.375	.375	.625	.875	.875	.875	.875	.875	1.0
ΔX_1	-	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0
$F_2(X_1)$	0.0	75.0	187.5	300.0	487.5	750.0	1012.5	1275.0	1537.5	1800.0
$F_3(X_1)$	0.0	11250.0	50625.0	123750.0	241875.0	427500.0	691875.0	1035000.0	1456875.0	1957500.0

TABLE XXVI

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 4020

Yield (kg/ha)	1370.0	1620.0	1870.0	2120.0	2370.0	2620.0	2870.0	3120.0	3370.0	3620.0
$f(X_3)$	.375	.125	0.0	.125	.125	.125	0.0	0.0	0.0	0.0
$F_1(X_3)$	.375	.500	.500	.625	.750	.875	.875	.875	.875	1.0
ΔX_3	-	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
$F_2(X_3)$	0.0	93.75	218.75	343.75	499.8	687.3	906.05	1124.8	1343.5	1562.3
$F_3(X_3)$	0.0	11718.75	50781.25	121093.75	226537.5	374925.0	574093.75	827950.0	1136493.8	1499725.1

TABLE XXVII

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 2513

Yield (kg/ha)	1340.0	1614.0	1888.0	2162.0	2436.0	2710.0	2984.0	3258.0	3532.0	3806.0
$f(X_4)$	.375	.125	.125	.125	.125	0.0	0.0	0.0	0.0	.125
$F_1(X_4)$	.375	.500	.625	.750	.875	.875	.875	.875	.875	1.0
ΔX_4	-	274.0	274.0	274.0	274.0	274.0	274.0	274.0	274.0	274.0
$F_2(X_4)$	0.0	102.75	239.75	411.0	616.5	856.25	1096.0	1335.75	1575.5	1815.25
$F_3(X_4)$	0.0	14076.75	60999.25	150152.0	290919.5	492686.2	760144.5	1093294.3	1492135.0	1956668.4

TABLE XXVIII

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 2300

Yield (kg/ha)	1199.0	1482.0	1765.0	2048.0	2331.0	2614.0	2897.0	318.0	3463.0	3746.0
$f(X_5)$	.375	.125	.125	.125	0.0	0.0	.125	0.0	0.0	.125
$F_1(X_5)$	.375	.500	.625	.750	.750	.750	.750	.875	.875	.875
ΔX_5	-	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0
$F_2(X_5)$	0.0	106.12	247.6	424.5	636.75	849.0	1061.25	1308.8	1556.5	1804.1
$F_3(X_5)$	0.0	15016.1	65072.3	160178.2	310346.0	520580.7	790882.2	1126256.1	1531707.8	2007237.4

TABLE XXIX

STOCHASTIC DOMINANCE TABLEAU FOR IR8

Yield (kg/ha)	2603.0	2853.0	3103.0	3353.0	3603.0	3853.0	4103.0	4353.0	4603.0	4853.0
$f(X_6)$	.4	0.0	.2	0.0	0.0	.2	0.0	0.0	0.0	.2
$F_1(X_6)$	.4	.4	.6	.6	.6	.8	.8	.8	.8	1.0
ΔX_6	-	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
$F_2(X_6)$	0.0	100.0	200.0	350.0	500.0	650.0	850.0	1100.0	1300.0	1500.0
$F_3(X_6)$	0.0	12500.0	5000.0	118750.0	225000.0	368750.0	556250.0	800000.0	1100000.0	1450000.0

TABLE XXX

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 42

Yield (kg/ha)	2763.0	3148.0	3533.0	3918.0	4303.0	4688.0	5073.0	5458.0	5843.0	6228.0
$f_1(X_7)$	.4	.2	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0
$F_1(X_7)$	.4	.6	.6	.6	.6	.6	.8	.8	.8	1.0
ΔX_7	-	385.0	385.0	385.0	385.0	385.0	385.0	385.0	385.0	385.0
$F_2(X_7)$	0.0	154.0	385.0	616.0	847.0	1078.0	1309.0	1617.0	1925.0	2233.0
$F_3(X_7)$	0.0	29645.0	133402.5	326095.0	607722.5	978285.0	1437782.0	2001037.5	2682872.5	3483287.5

TABLE XXXI

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 78

Yield (kg/ha)	2637	3039	3441	3843	4245	4647	5049	5451	5853	6255
$f(X_8)$	.4	0.0	.2	0.0	0.0	0.0	.2	0.0	0.0	.2
$F_1(X_8)$	.4	.4	.6	.6	.6	.6	.8	.8	.8	1.0
ΔX_8	0.0	402	402	402	402	402	402	402	402	402
$F_2(X_8)$	0.0	160.8	321.6	562.8	804.0	1045.2	1286.4	1608.0	1929.6	2251.2
$F_3(X_8)$	0.0	32320.8	129283.2	307047.6	581774.4	953463.5	422115.2	2003889.6	2714947.2	3555288.0

TABLE XXXII

STOCHASTIC DOMINANCE TABLEAU FOR TO_s 490

Yield (kg/ha)	2299.0	2605.0	2911.0	3217.0	3523.0	3829.0	4135.0	4441.0	4747.0	5053.0
$f(X_9)$	.2	0.0	.2	.2	0.0	0.0	0.0	0.0	.2	.2
$F_1(X_9)$	.2	.2	.4	.6	.6	.6	.6	.6	.8	1.0
ΔX_9	-	306.0	306.0	306.0	306.0	306.0	306.0	306.0	306.0	306.0
$F_2(X_9)$	0.0	61.2	127.4	244.8	428.3	856.6	1040.2	1223.8	1407.4	1652.2
$F_3(X_9)$	0.0	9363.6	37454.4	93636.0	196620.3	393210.0	683420.4	1029812.4	1432386.0	1900504.8

TABLE XXXIII

STOCHASTIC DOMINANCE TABLEAU FOR IR 22

Yield (kg/ha)	2263.0	2610.0	2957.0	3304.0	3651.0	3998.0	4345.0	4692.0	5049.0	5386.0
$f(X_{10})$	.2	.4	0.0	0.0	0.0	0.0	0.0	0.2	0.0	.2
$F_1(X_{10})$	.2	.6	.6	.6	.6	.6	.6	.8	.8	1.0
ΔX_{10}	-	347.0	347.0	347.0	347.0	347.0	347.0	347.0	347.0	347.0
$F_2(X_{10})$	0.0	69.4	277.6	485.8	694.0	902.2	1110.4	1318.6	1596.2	1873.8
$F_3(X_{10})$	0.0	12040.9	72245.4	204695.3	409390.6	686331.3	1035517.4	1456948.0	1962666.7	2564711.7

TABLE XXXIV

STOCHASTIC DOMINANCE TABLEAU FOR SML 140/10

Yield (kg/ha)	2130.0	2424.0	2718.0	3012.0	3306.0	3600.0	5894.0	4188.0	4482.0	4776.0
$f(X_{11})$	.4	0.0	.2	.2	0.0	0.0	0.0	0.0	0.0	.2
$F_1(X_{11})$	.4	.4	.6	.8	.8	.8	.8	.8	.8	1.0
ΔX_{11}	-	294.0	294.0	294.0	294.0	294.0	294.0	294.0	294.0	294.0
$F_2(X_{11})$	0.0	117.6	235.2	411.6	646.8	882.0	1117.2	1352.4	1587.6	1822.6
$F_3(X_{11})$	0.0	17287.2	69148.8	164228.4	319813.2	544546.8	838429.2	1201460.4	1633640.4	2134969.2

TABLE XXXV

STOCHASTIC DOMINANCE TABLEAU FOR LOCAL MAIZE

Yield (kg/ha)	743.0	986.0	1229.0	1472	1715.0	1958.0	2201.0	2444.0	2687.0	2930.0
$f(X_1)$	.11	.06	.06	.06	.06	.11	.18	.06	.24	.06
$F_1(X_1)$	.11	.17	.23	.29	.35	.46	.64	.70	.94	1.0
ΔX_1	-	243.0	243.0	243.0	243.0	243.0	243.0	243.0	243.0	243.0
$F_2(X_1)$	0.0	26.73	68.04	123.93	194.40	279.45	391.23	546.75	716.85	945.27
$F_3(X_1)$	0.0	3247.7	14762.2	38086.5	76763.6	134336.3	215823.9	329788.4	483315.8	685263.4

TABLE XXXVI

STOCHASTIC DOMINANCE TABLEAU FOR FARZ 26 (TZA x TZB)

Yield (kg/ha)	1886.0	2172.0	2458.0	2744.0	3030.0	3316.0	3602.0	2888.0	4174.0	4460.0
$f(X_2)$	.18	.06	.06	.18	0.0	.18	0.0	.11	.11	.11
$F_1(X_2)$	.18	.24	.30	.48	.48	.64	.64	.74	.88	.99
ΔX_2	0.0	286.0	286.0	286.0	286.0	286.0	286.0	286.0	286.0	286.0
$F_2(X_2)$	0.0	51.48	120.12	205.9	343.18	480.46	663.5	846.54	1066.76	1318.44
$F_3(X_2)$	0.0	7361.6	31900.4	78521.2	157039.6	274820.1	438406.4	654342.12	927944.0	1269027.6

TABLE XXXVII

STOCHASTIC DOMINANCE TABLEAU FOR TZPB

Yield (kg/ha)	1683	1966	2249	2532	2815	3098	3381	3364	3947	4230
$f(X_3)$	.12	.06	.17	0.0	.06	.06	.24	.06	.06	.17
$F_1(X_3)$	.12	.18	.35	.35	.41	.47	.71	.77	.83	1.0
ΔX_3	0.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0
$F_2(X_3)$	0.0	33.96	84.9	183.95	283.0	399.03	532.04	732.97	950.88	1185.77
$F_3(X_3)$	0.0	4805.3	21624.0	59666.2	125739.6	222246.8	353993.2	532992.1	771256.8	1078592.7

TABLE XXXVIII

STOCHASTIC DOMINANCE TABLEAU FOR FARZI (WY1)

Yield (kg/ha)	1361.0	1622.0	1883.0	2144.0	2405.0	2666.0	2927.0	3188	3449	3710
$f(X_4)$	.06	.06	.06	.18	.06	0.0	.12	.17	.06	.22
$F_1(X_4)$	.06	.12	.18	.36	.42	.42	.54	.72	.78	1.0
ΔX_4	0.0	261.0	261.0	261.0	261.0	261.0	261.0	261.0	261.0	261.0
$F_2(X_4)$	0.0	15.66	46.98	93.96	187.92	297.54	407.16	548.1	736.02	939.6
$F_3(X_4)$	0.0	2043.6	10218.1	28610.77	65396.1	128748.6	220711.9	345373.3	512.950	731618.4

TABLE XXXIX

STOCHASTIC DOMINANCE TABLEAU FOR FARZ 23

Yield (kg/ha)	1393.0	1686.0	1979.0	2272.0	2565.0	2858.0	3151.0	3444.0	3737.0	4030.0
$f(X_5)$	.18	0.0	.05	.12	0.0	.12	.18	.18	.05	.12
$F_1(X_5)$	.18	.18	.23	.35	.35	.47	.65	.83	.88	1.0
ΔX_5	0.0	293.0	293.0	293.0	293.0	293.0	293.0	293.0	293.0	293.0
$F_2(X_5)$	0.0	52.74	105.48	172.87	275.42	377.97	515.68	706.13	949.32	1207.04
$F_3(X_5)$	0.0	7726.4	30905.6	71683.87	137358.3	233078.0	34905.4	528049.1	770572.5	1086479.2

APPENDIX C

CROPS AGGREGATE PRODUCTION ESTIMATES

TABLE XL

CROP PRODUCTION FUNCTIONS: DOUBLE-LOG ESTIMATION WITH INSTANTANEOUS RESEARCH IMPACT[a]

	Intercept	Land	Labor	Research	R^2	D.W.
Maize	2.22705 (1.1195)	.3334 (.1359)	.0223 (.01247)	.1642 (.02515)	.8429	1.8053
Rice	3.5127 (.5708)	-.0418 (.1355)	-.0267 (.0197)	.2213 (.0509)	.8217	1.7656
Cassava	9.7129 (1.1298)	-.4186 (.1494)	-.4479 (.1460)	.1989 (.2718)	.8339	1.2530

a) Number in parenthesis are standard errors.

TABLE XLI

AGGREGATE MAIZE PRODUCTION FUNCTION DISTRIBUTED LAG MODEL WITH 12 YEARS LAG (Double-Log Form)

Variables	Coefficient	Standard Error	$R^2 = .5870$
Intercept	4.1081	1.3135	
Land	.377268	.1740	
Labor	.020657	.01605	
R_0	.0005755	.000128	
R_1	.001055	.000235	
R_2	.001439	.000320	
R_3	.001726	.000384	
R_4	.001918	.000427	
R_5	.002014	.000448	
R_6	.002014	.000448	
R_7	.001918	.000427	
R_8	.001726	.000384	
R_9	.001439	.000320	
R_{10}	.001055	.000235	
R_{11}	.0005755	.000128	

TABLE XLII

AGGREGATE RICE PRODUCTION FUNCTION DISTRIBUTED LAG MODEL WITH 12 YEARS LAG (Double-Log Form)

Variables	Coefficient	Standard Error	$R^2 = .6607$
Intercept	4.2927	1.12387	
Land	.26841	.16712	
Labor	-.0024	.026182	
R_0	.00036	.00026	
R_1	.00066	.00049	
R_2	.00091	.00067	
R_3	.00109	.00080	
R_4	.00121	.00089	
R_5	.00127	.00093	
R_6	.00127	.00093	
R_7	.00121	.00089	
R_8	.00109	.00080	
R_9	.00091	.00067	
R_{10}	.00066	.00049	
R_{11}	.00024	.00024	

TABLE XLIII

AGGREGATE CASSAVA PRODUCTION FUNCTION DISTRIBUTED LAG MODEL WITH 12 YEARS LAG (Double-Log Form)

Variables	Coefficient	Standard Error	R^2 = 5486
Intercept	13.0814	1.8365	
Land	-.5063	.2542	
Labor	-.6031	.0236	
R_0	.000537	.000179	
R_1	.000985	.000329	
R_2	.001343	.000448	
R_3	.001612	.000538	
R_4	.001791	.000598	
R_5	.001881	.000628	
R_6	.001881	.000628	
R_7	.001791	.000598	
R_8	.001612	.000538	
R_9	.001343	.000448	
R_{10}	.00985	.000329	
R_{11}	.00537	.000179	

APPENDIX D

PRODUCTION FUNCTION DATA BASE

TABLE XLIV

PRODUCTION LEVELS OF ANALYZED CROPS IN NIGERIA (1956-76) (000 Tons)

Year	Crop		
	Rice	Maize	Cassava
1	257.000	991.000	7400.00
2	316.000	1041.00	7600.00
3	316.000	989.000	7750.00
4	363.000	1067.00	9500.00
5	360.000	914.000	9750.00
6	345.000	1000.00	10000.0
7	370.000	900.000	10200.0
8	304.000	1050.00	10400.0
9	405.000	1090.00	8840.00
10	355.000	1040.00	8840.00
11	406.000	1020.00	9565.00
12	391.000	1000.00	8840.00
13	375.000	950.000	8331.00
14	386.000	1426.00	8128.00
15	427.000	1310.00	11410.0
16	462.000	1042.00	12396.0
17	466.000	1182.00	12700.0
18	502.000	1287.00	13000.0
19	523.000	1350.00	13300.0
20	600.000	1400.00	13600.0
21	609.000	1440.00	13900.0

Sources: Committee from Rural Economic Survey of Nigeria, 1972, and USDA Indices of Agricultural Production in Africa and the Near East, 1968-1977.

TABLE XLV

TRADITIONAL RESOURCES USED IN PRODUCTION OF MAIZE, RICE, AND CASSAVA IN NIGERIA

	Resource					
	Labor			Land (000 ha)		
	Rice	Maize	Cassava	Rice[a]	Maize	Cassava
1	595.999	2408.00	1290.00	204.000	990.000	782.000
2	527.999	2464.00	1320.00	204.000	990.000	782.000
3	545.999	2548.00	1365.00	295.000	1321.00	782.000
4	563.999	2632.00	1410.00	295.000	1321.00	782.000
5	575.999	2688.00	1440.00	295.000	1321.00	782.000
6	587.639	2742.32	1469.10	332.000	1378.00	782.000
7	599.819	2799.16	1499.55	369.000	1123.00	868.000
8	612.059	2856.28	1536.15	539.000	1426.00	804.000
9	624.299	2913.40	1560.75	399.000	1475.00	1175.00
10	636.779	2971.64	1591.95	443.000	1403.00	1200.00
11	649.499	3031.00	1623.75	465.000	1384.00	1200.00
12	684.899	3196.20	1712.25	394.000	1470.00	1100.00
13	698.579	3260.04	1749.45	648.000	922.000	1100.00
14	712.559	3325.28	1781.40	581.000	1531.00	1200.00
15	726.839	3391.92	1817.10	638.000	1260.00	913.000
16	741.359	3459.68	1853.40	616.000	1270.00	920.000
17	756.179	3528.84	1890.45	752.000	1281.00	960.000
18	771.299	3599.40	1928.25	680.000	1009.00	970.000
19	786.719	3671.36	1966.80	692.000	1300.00	1000.00
20	802.439	3744.72	2006.10	704.000	1400.00	1000.00
21	809.999	3780.00	2025.00	704.000	1400.00	1100.00
	1	2	3	4	5	6

TABLE XLVII

MAIZE-RICE-CASSAVA RESEARCH EXPENDITURES IN NIGERIA DURING 1956-1976 PERIOD (In Dollars)

	Sources					
	Federal			IITIA		
	Rice	Maize	Cassava	Rice	Maize	Cassava
1	212686.	265857.	398786.	.0	.0	.0
2	241631.	302039.	453059.	.0	.0	.0
3	252184.	315230.	472845.	.0	.0	.0
4	289589.	361987.	542980.	.0	.0	.0
5	313915.	392395.	588591.	.0	.0	.0
6	363259.	454074.	681111.	.0	.0	.0
7	301756.	377195.	565793.	.0	.0	.0
8	259453.	324316.	486474.	.0	.0	.0
9	242338.	302923.	454384.	.0	.0	.0
10	315221.	394027.	591039.	.0	.0	.0
11	356244.	455345.	667957.	.0	.0	.0
12	239911.	299889.	449833.	.0	.0	.0
13	237212.	296515.	444772.	376800.	376800.	577760.
14	304147.	380183.	570275.	478750.	478750.	734083.
15	371369.	464212.	696318.	692090.	692090.	.106120E+07
16	644051.	805064.	.120760E+07	647017.	647017.	992094.
17	742787.	928484.	.139273E+07	490535.	490535.	752154.
18	796798.	995998.	.149400E+07	673700.	673700.	.103301E+07
19	.100416E+07	.125520E+07	.188280E+07	893815.	893815.	.137052E+07
20	.129158E+07	.161448E+07	.242171E+07	.108024E+07	.108024E+07	.165636E+07
21	.131232E+07	.164040E+07	.246059E+07	.246059E+07	.125296E+07	.192121E+07
	1	2	3	4	5	6

Source: Annual Reports, IITA, IAR2T, and IAR, NRCRI for selected years.

APPENDIX E

EFFICIENCY CURVES

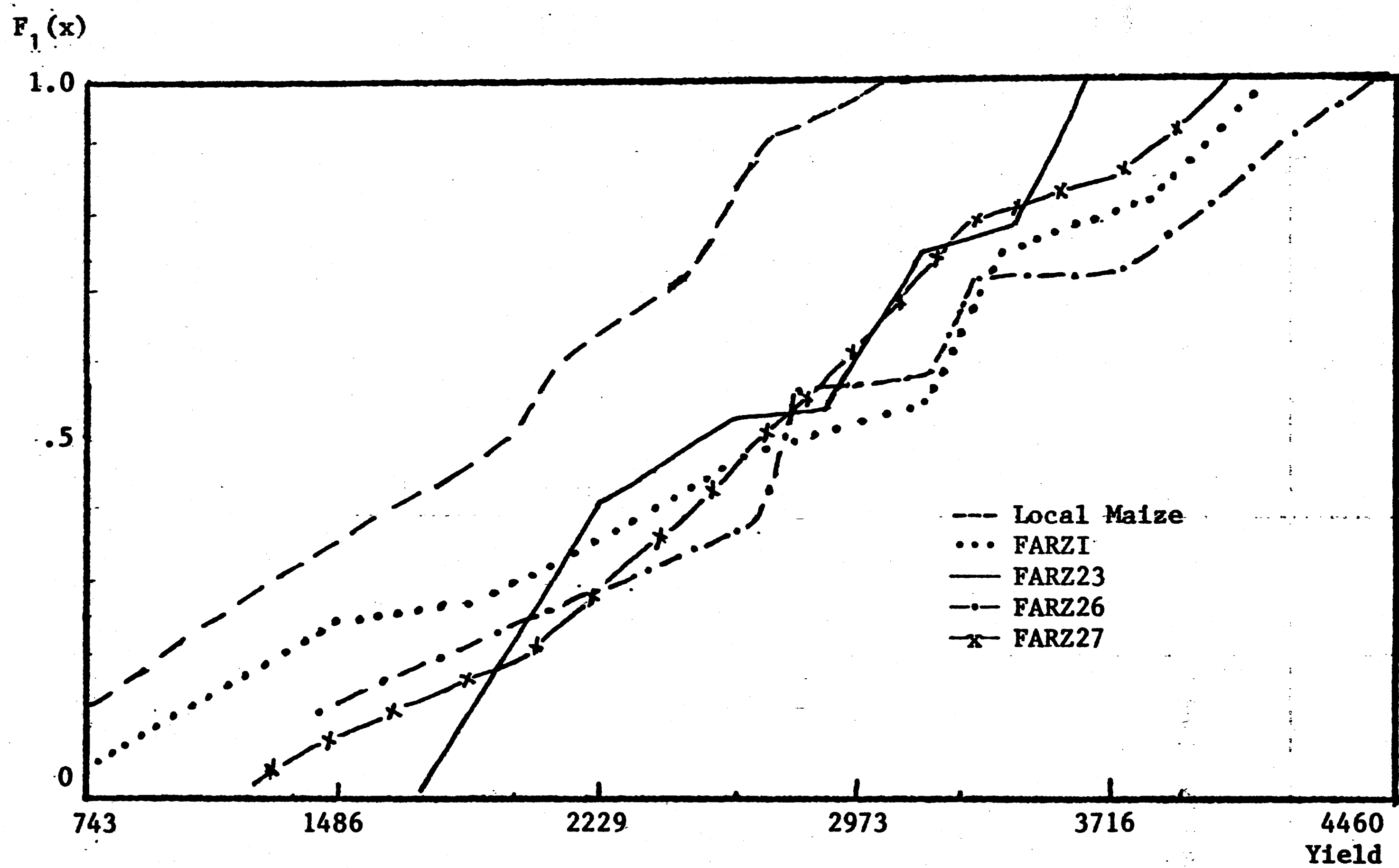

Figure 17. Maize First Stochastic Efficiency Curves

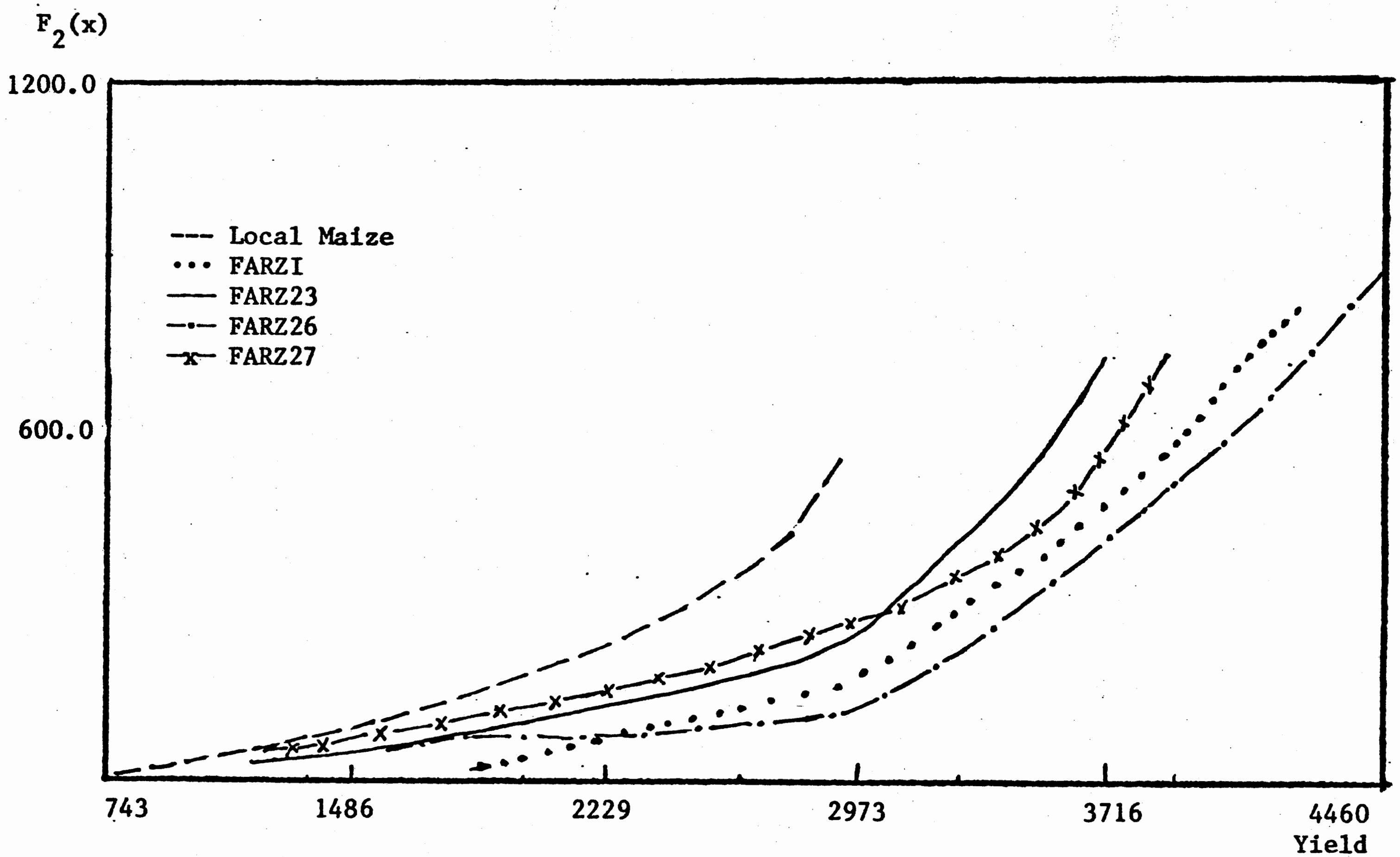

Figure 18. Maize Second Stochastic Efficiency Curves

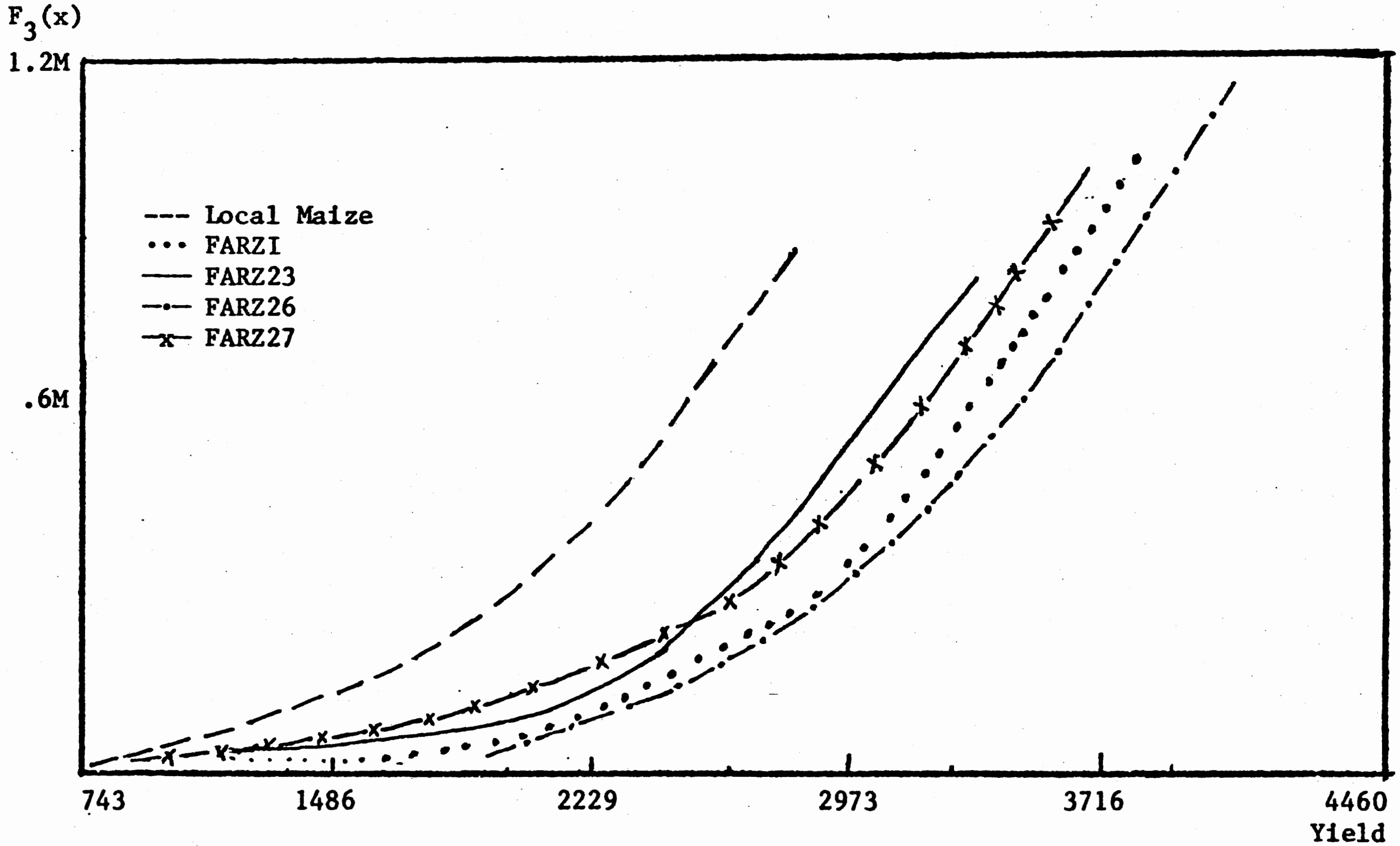

Figure 19. Maize Third Stochastic Efficiency Curves

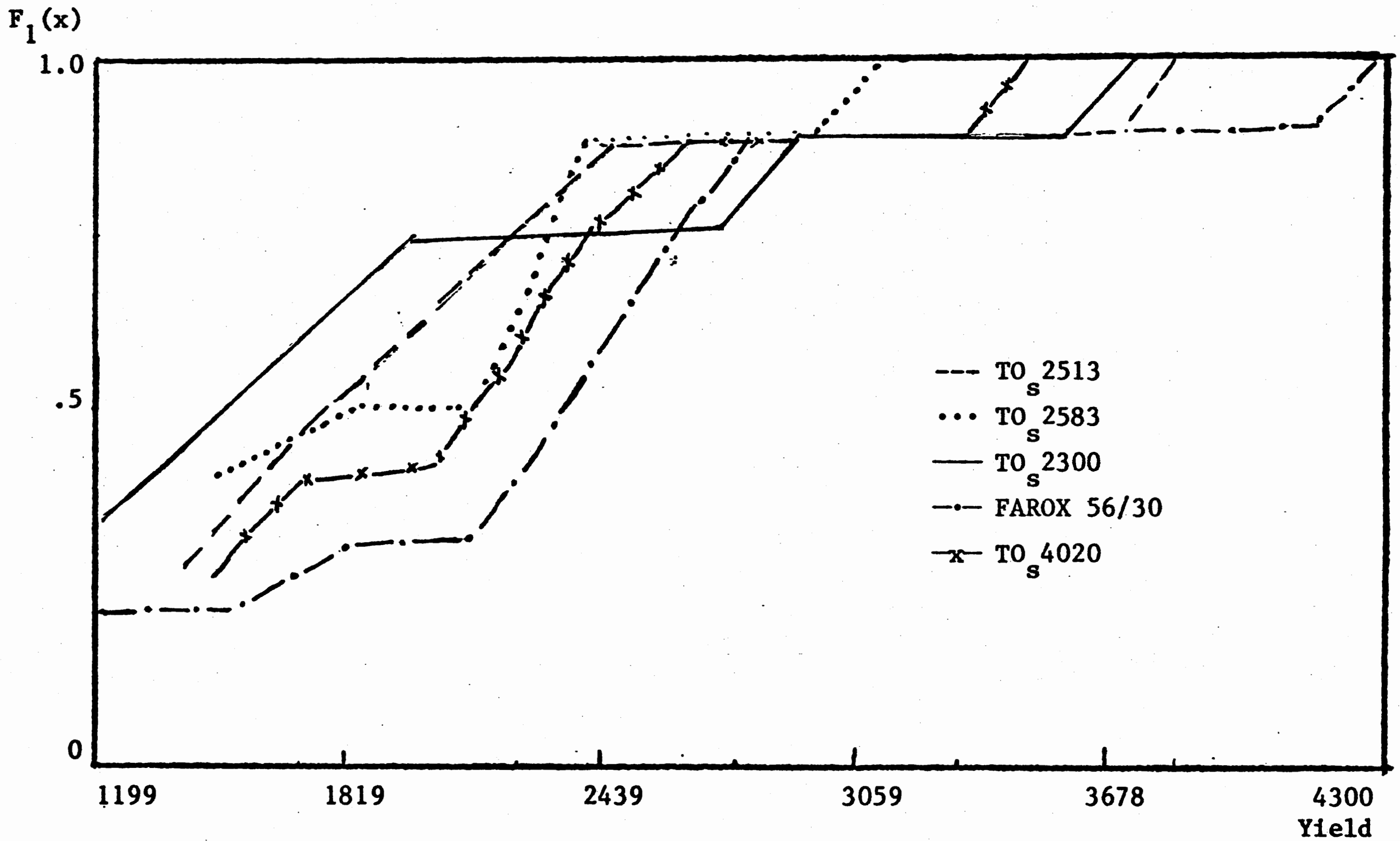

Figure 20. Dryland Rice First Stochastic Efficiency Curves

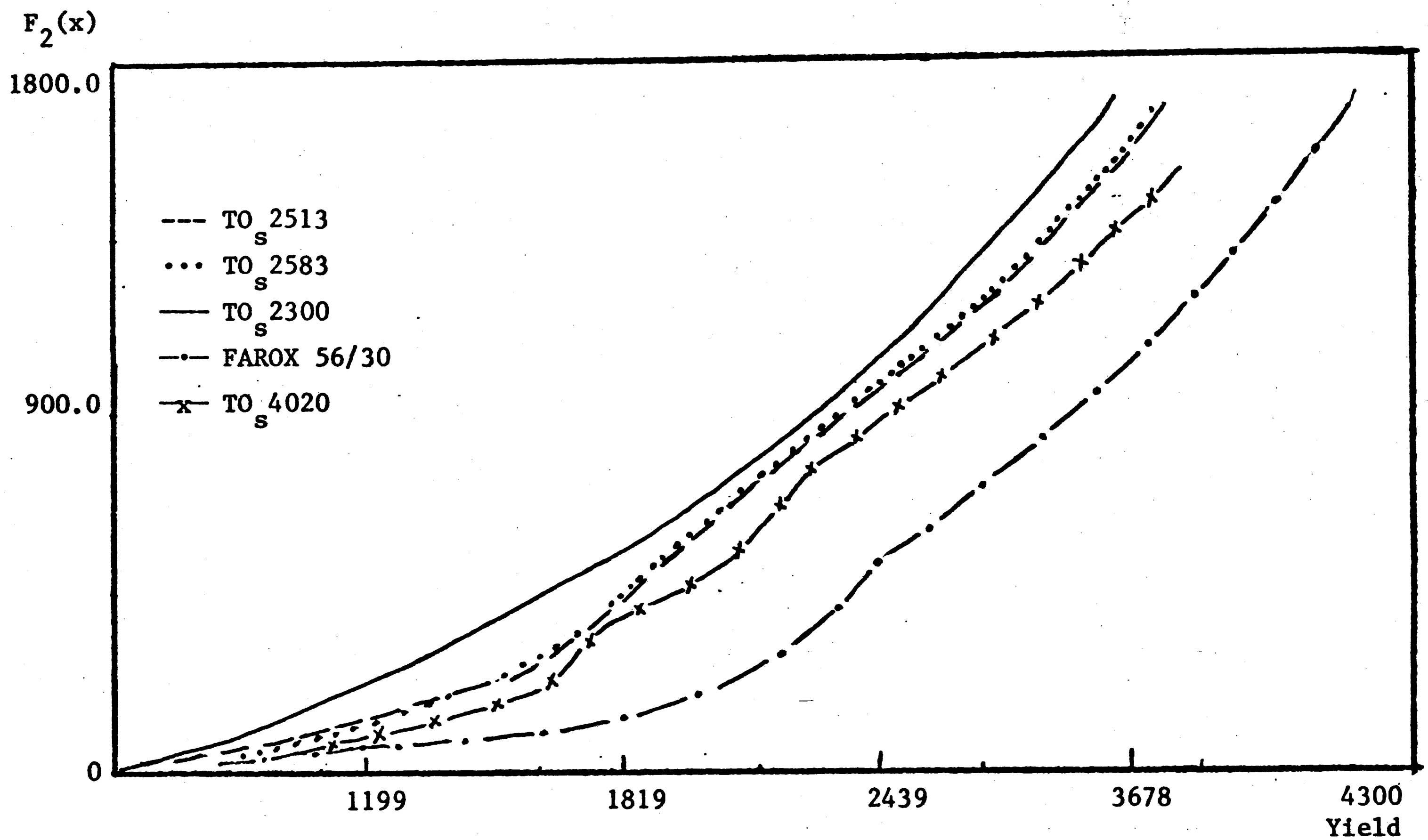

Figure 21. Dryland Rice Second Stochastic Efficiency Curves

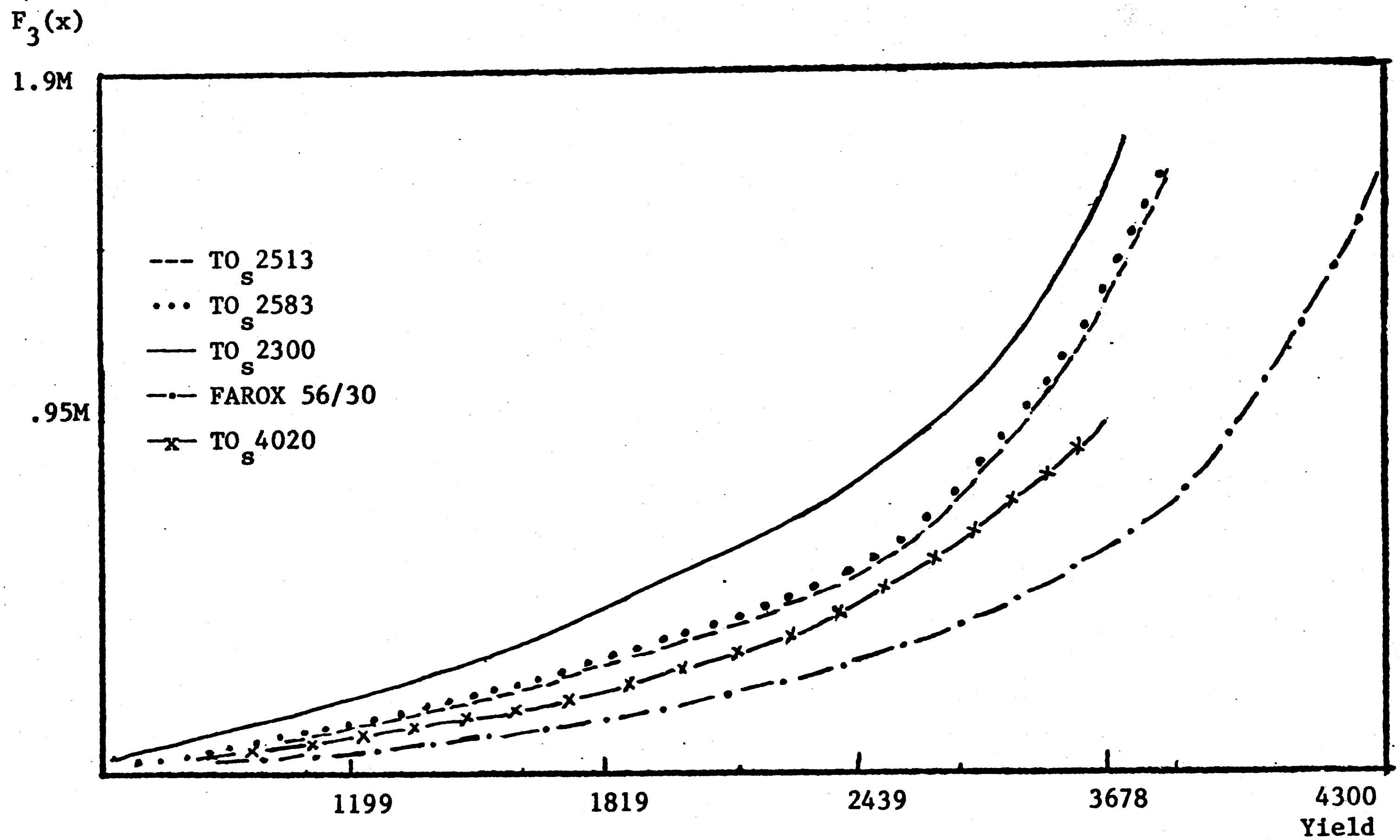

Figure 22. Dryland Rice Third Stochastic Efficiency Curves

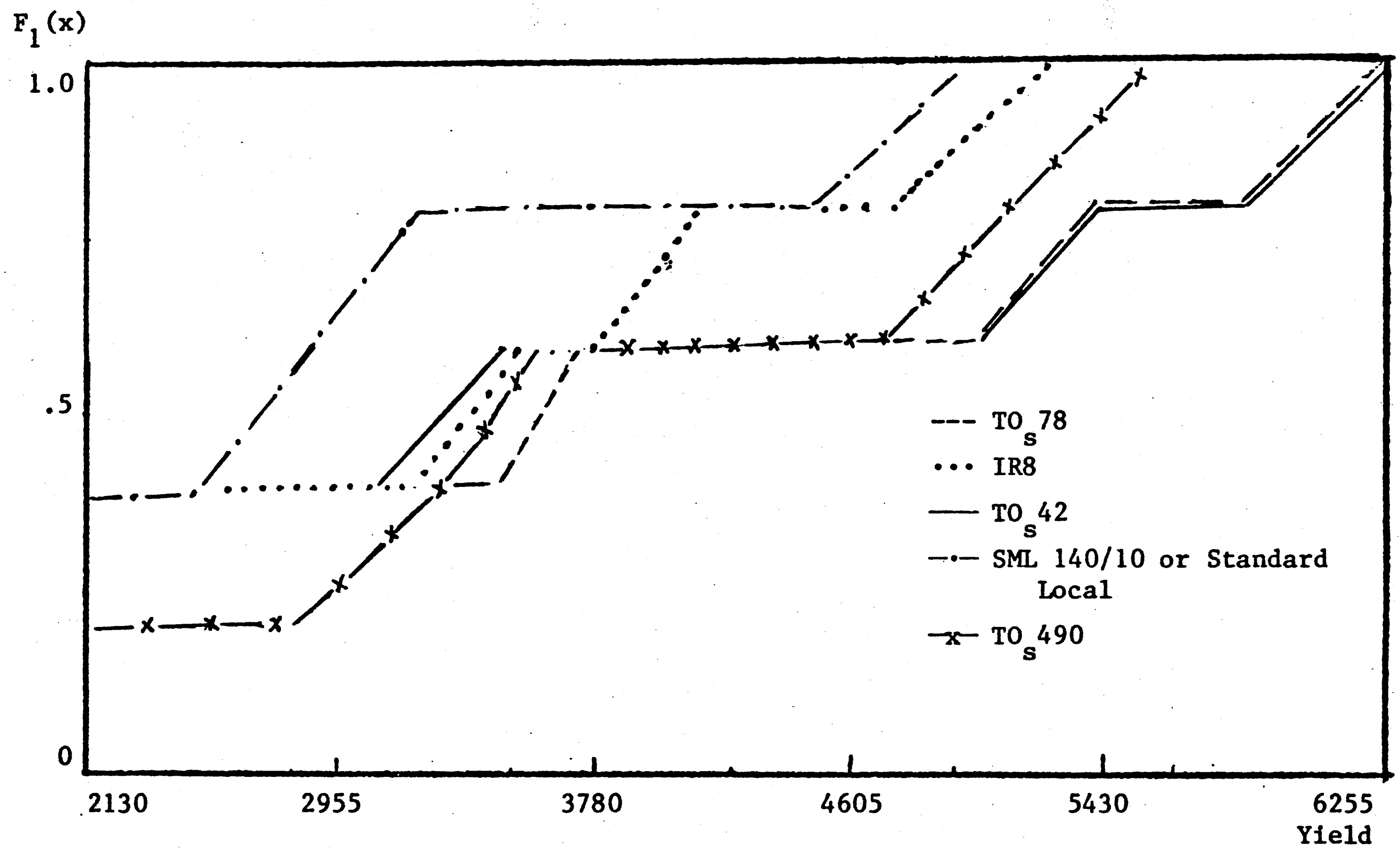

Figure 23. Irrigated Rice First Stochastic Efficiency Curves

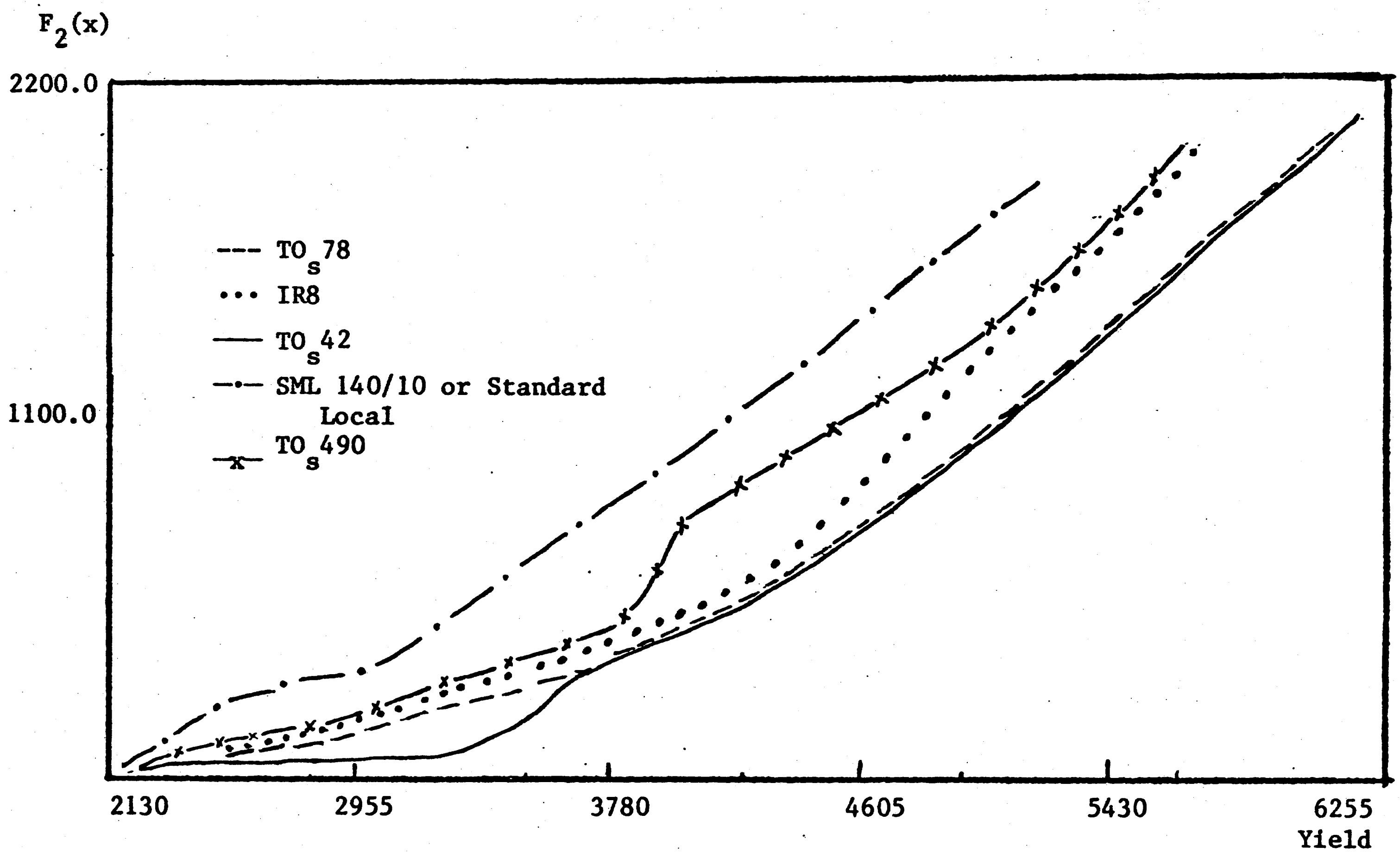

Figure 24. Irrigated Rice Second Stochastic Efficiency Curves

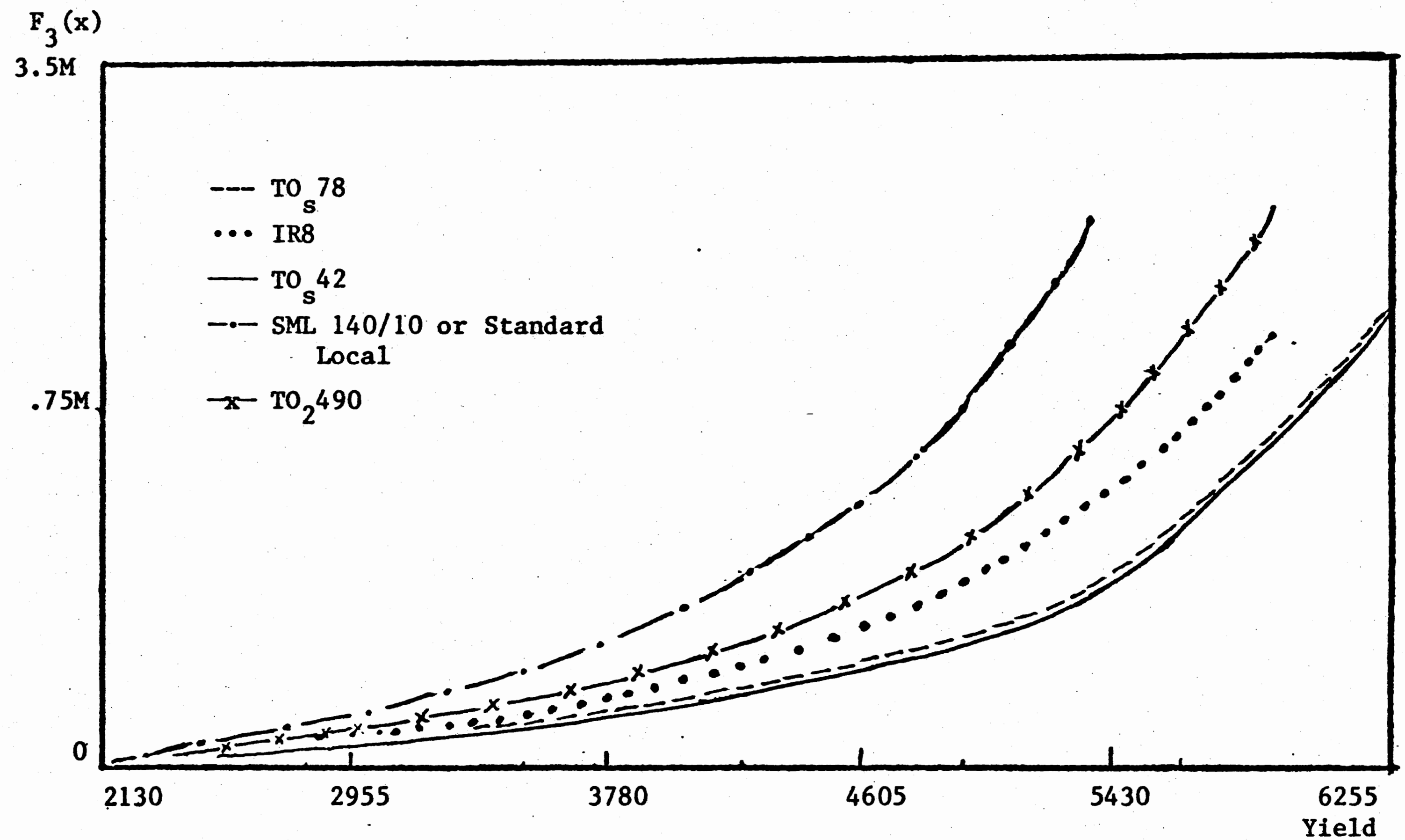

Figure 25. Irrigated Rice Third Stochastic Efficiency Curves

VITA

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