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Effects of Technological Change in Agriculture on Food Consumption and Nutrition: Rice in a West African Setting

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Summary. — This paper traces the effects of technological change in agriculture to production and income effects, and to consumption and nutritional effects. The study environment is West Africa (The Gambia). The technological change considered is various new modes of rice production versus traditional rice production. Main findings of this empirical analysis are the following. (1) It cannot be assumed that by focusing investment on a "woman's crop," one helps women farmers. The more a new technology increased labor productivity in rice, the more there was a takeover of the rice production technology by male producers, and the more the crop became a "communal" crop for household food security. Household income increased substantially. (2) Much of the increased income is spent on increased calorie consumption. It makes no difference for the degree of change in calorie consumption levels if change in real income is in the form of cash or subsistence food. (3) Technological change effects mediated through income are traced to increased food consumption (calories) at the household level where it is found to significantly improve children's nutritional status, especially in the "rainy" season.

1. INTRODUCTION

This paper deals with the effects of new rice technology on household-level food security in a West African setting. The complexity of linkages between technological change, food security, and nutrition increases with the complexity of household organization. The setting of this study is a complex production-consumption system in West Africa (The Gambia), characterized by communal and individual farming, and by separate, though interacting, farm production by men and women farmers into which modern irrigation for rice is introduced. The system and the change are briefly described in the following section.

The specific research questions addressed in this paper are: (a) Through what mechanisms and to what extent does rapid and substantial technological change in food crop production improve household-level food security? (b) How does this translate into measurable nutritional improvement?

Food security is understood in this context as the ability of all members of a household to acquire sufficient amounts of food continuously over time for a healthy and productive life.

This paper concentrates on those direct relationships between production and food security which may, at the household level, be altered by technological change. The potentially powerful growth linkage effects of technological change in agriculture, and their stimulation of growth and development in the rural economy are disregarded in this assessment [1]

2. THE PRODUCTION SYSTEM IN THE STUDY AREA AND NATURE OF THE TECHNOLOGICAL CHANGE

Households, commonly referred to as "compounds" in The Gambia, are large (17 persons on average) and income-earning and consumption activities are institutionalized through complex consumption and production sub-units of the compound. Instead of the term "household," the term "compound" is used here which is not only the locally used word for the unit but

*Careful reviews by P. Svedberg (WIDER) and M. Lipton (IFPRI) were helpful for revisions of an earlier draft.

also expresses neatly the "compounded" nature of the production-consumption unit at the location which consists of various sub-systems.

The empirical research results presented are based on a detailed farm-household survey of 200 compounds undertaken during 1985/86 in The Gambia by the International Food Policy Research Institute (IFPRI) in collaboration with the Programming, Planning, and Monitoring Unit for the Agricultural Sector (PPMU).[2]

The study area is located in central Gambia, 300 kilometers west of Banjul. It is an almost ideal West African laboratory case because four different ethnic groups are affected by the same programs of technological change. (The groups are Fula, Wollof, Mandinka, and Serahule.) Farming at the location is organized into two distinct forms: a communal farm under the control of the compound head, and a set of private farms which comprise groups of fields allocated to individuals who will use them for growing (cash) crops under their personal control (mainly groundnuts, cotton, and rice). The communal crops (mainly millet, sorghum, maize, and rice) are produced by the combined labor of all compound members — all men and women have a customary obligation to provide labor to the communal fields.[3] Very few of the communally grown food crops are sold. They are grown to meet domestic food consumption needs for the whole compound.

The technological change being considered in this setting is the upgrading of rice production technologies brought about by the introduction of a large-scale rice irrigation project. Implemented in 1983, this project covers over 1,500 hectares, and is designed to raise rice yields and output through the centralized control of water pumping and draining around 0.5 hectare plots. The project is owned and managed by the state, with plowing services and a package of fertilizer and improved seed being provided on a credit basis. However, all other farming activities are carried out by smallholders who are registered as tenants of the plots. An attempt was made in this project to maintain the traditional use rights of female farmers to rice land by giving priority to women during the official registration of plots.

The rice production technology in the new scheme is not uniform, nor are the technological conditions outside the scheme. Four distinct *technologies* can be distinguished, some of which are further subdivided at the location but remained aggregated for the purpose of this paper:

(1) Production in the traditional swamps irrigated in the rainy season by the river's flooding (partly deep-water rice); yields are on average 1.3 tons per hectare per crop.[4]
(2) Production in small pump irrigation schemes established in the 1970s; some of the plots are producing two crops per annum, but most produce only one; yields range between 2.5 to 4.5 tons per crop.
(3) Production under partly water-controlled conditions; irrigation is achieved either through tidal fluctuations of the river or simply through precipitation; one crop per year is produced from these plots in the rainy season; yields are 2.5 to 3.5 tons per crop.
(4) Production under fully water-controlled conditions in perimeters which are centrally irrigated and drained; two crops per year are produced; yields are 5.5 to 6.5 tons per crop.

The study area is well known for its high prevalence of child undernutrition, especially in the "rainy" season.[5] During that period of the year, workload (energy expenditure) as well as food energy prices are at their highest, leading to a "hungry season" syndrome. It is hypothesized that improved crop technology — i.e., a second rice crop — reduces this imbalance.

Table 1 shows that calorie consumption levels differ substantially by income, and differences are particularly wide between the bottom and the top income groups in the "hungry" (wet) season. Prevalence of stunting is 17.1% among children in the 6–59 months group and 6.9% in the 60–120 months group. In the wet season, 38.5% of children in the 6–59 months category were seriously underweight, while in the dry season, it was 28.8%. Differences in prevalence of malnutrition between income groups in terms of weight-for-age were more pronounced among older children (60–120 months) than among the youngest ones (6–59 months). During the wet season, 32.8% of these older children (60–120 months) in the bottom income quartile were found to be malnourished (below 80% weight-for-age), while only 15.2% belonging to the top income quartile were found to be so. Apparently, seasonality affects food consumption and nutritional status of all households, but more seriously the bottom income households are affected.

3. CONCEPT

Figure 1 gives an overview on the conceptual framework guiding the analysis. The analysis concentrates on the following four key linkages which are crucial for the relationships be-

Table 1. *Food energy consumption and nutritional status of children in The Gambia by household per capita income and by season*, 1985/86

Household per capita income*	Calories per capita per day Wet season	Calories per capita per day Dry season	Prevalence of malnutrition: Height-for-age < 90% of standard† Age in months 6–59	Height-for-age < 90% of standard† Age in months 60–120	Weight-for-age < 80% of standard† Age in months (6–59) Wet season	Weight-for-age < 80% of standard† Age in months (6–59) Dry season	Weight-for-age < 80% of standard† Age in months (60–120) Wet season	Weight-for-age < 80% of standard† Age in months (60–120) Dry season
	(calories)		(percent of children below stated percentage of standard)					
Lowest quartile	1,893	2,176	30.1	11.0	40.5	28.3	32.8	16.7
Second quartile	2,222	2,226	13.8	3.6	37.9	30.1	29.2	19.0
Third quartile	2,622	2,811	13.1	7.7	36.9	36.3	24.3	20.6
Fourth quartile	2,917	2,972	14.3	3.0	39.3	20.8	15.2	10.5
Total average	2,380	2,522	17.1	6.9	38.5	28.8	25.8	16.7

Source: IFPRI/PPMU Survey, 1985/86.
*Total expenditures (including value of own-produced food) used as income proxy.
†NCHS/WHO standards are used for the identification of the nutritional status.

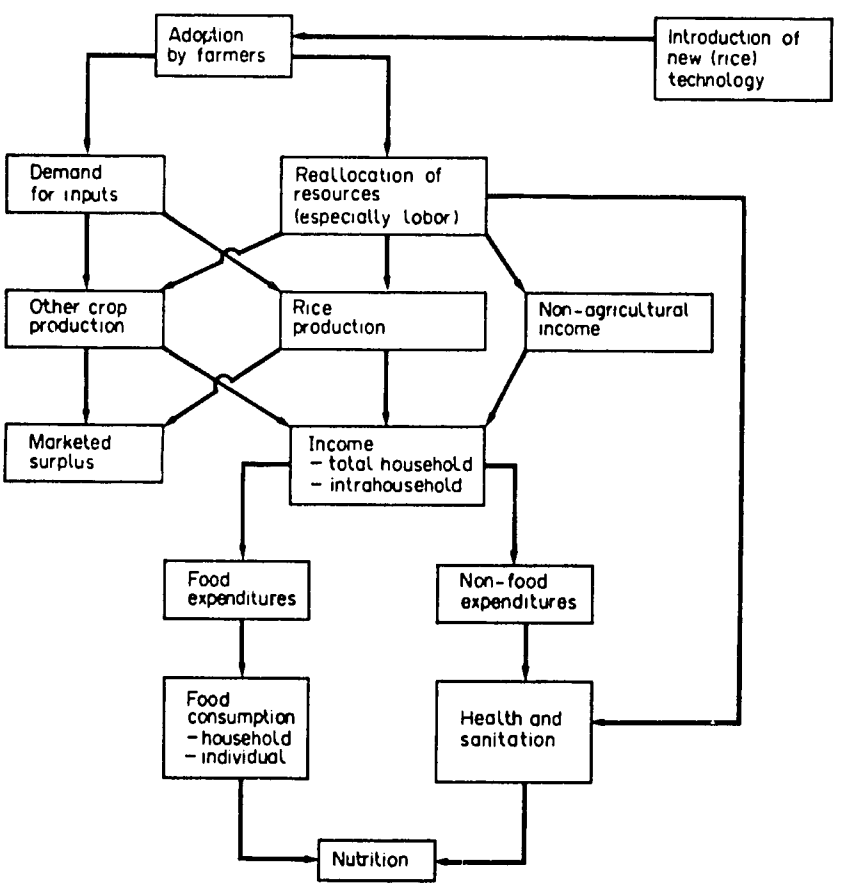

Figure 1. *Conceptual framework for analysis of household-level effects of new technology and commercialization.*

tween technological change and household-level food security and which are particularly poorly understood, especially in the West African setting:

(1) The *adoption of new technology* in a farm production system comprising separate individual and communal farming, where the technological change applies to one individually grown crop — rice (traditional rice being a "woman's crop" in the area);
(2) The *reallocation of resources (labor)* between crops as a consequence of adoption of new technology and changes in crop control (with its related effects on labor productivity differentials by gender within the household);
(3) The *food consumption effects* of increased income deriving from technical change and related changes in sources of income (in-kind, cash, etc.); and
(4) The *effects on nutritional status*, especially of children and women as a result of changes in food consumption.

These four issues are now taken up in sequence.

4. ADOPTION OF NEW TECHNOLOGY: COMPLICATIONS WHEN COMMUNAL AND INDIVIDUAL FARMING COEXIST

The pattern of adoption of the new technology very much determines compounds' resource allocation and the effect on income and, as indicated in Figure 1 further downstream, the effects on consumption and nutrition. The adoption of new rice technology by farmers in this West African environment takes the form of a rationed distribution of access to the improved irrigated land. Demand for the improved irrigated land much exceeded supply. The adoption process is mediated through managerial decisions at the program level, and through village- and compound-level decisions on "who gets what."

With regard to traditional cereal production, there is a fairly clear distinction between men's and women's crop. Men traditionally organize upland cereals production where more than 90% of the fields are under male responsibility. Nearly all of this is communal farming. Women, on the other hand, organize traditional rice production. More than 90% of traditional rice fields are under female responsibility, but hardly any upland cereals. Most of this rice is considered individual farming. Both men and women are in charge of organizing non-cereal cash crop production in their individual upland farm enterprise. Women, for instance, are responsible for 28% of the groundnut and 27% of the cotton area.

Distribution of the new rice land to farmers in the irrigation scheme poses problems of equity. Yet, the distributional issue here does not relate well to the criteria of "large or small" farmers frequently used in describing adoption of technology issues in Asian agriculture or in Latin America. Here it is an issue of differentiation between villages, between compounds of the same village, and — most important — between male and female farmers of various socioeconomic characteristics within the same compound.

The project's land distribution policy was specifically aimed at assuring women's access to the project rice land in order to increase women's income directly. Women were given land titles (long-term leases) in a formal registration process. To what extent this process translated into women's *de facto* control over land and its independent cultivation was assessed in the survey.

At the study location it turns out that women's control over rice fields is almost perfectly correlated with technology (yield levels). The higher the yield level, which coincides with the increase in production inputs and cash needs to finance production, the lower is women's participation versus men's (Table 2). The distribution of land titles to women who formally hold more than 80% of the irrigated land in the scheme has apparently not altered this general relationship between technology and control at this study location.

A PROBIT model addresses the "adoption" issue and assesses the factors that enhanced or reduced the probability of women's access to a new project rice field. The dependent variable in the model equals 1 if a woman farmer obtained her own rice field in the project, or else it is 0. It is hypothesized that women's status within the compound and compound sociodemographic characteristics are important factors that shape the outcome of the adoption process. The estimation results of the PROBIT model reported in Table 3 show that a disaggregated view is necessary even within the group of women farmers — not just men versus women — to comprehensively assess the access to technology issue:

- Women of higher status had a significantly higher probability of obtaining a field (variables 1 and 2).
- Women who were traditional individual rice growers also had a significantly increased

Table 2. *Women's control over rice fields and technology (yield) levels in The Gambia, 1984/85*

Types of rice technology	Average yield	Percent of fields under women's responsibility	Percent of fields under communal production	Women's labor in percent of family labor used
	(tons/hectare)			
Fully water-controlled fields in new rice scheme	6.6	14	99	29
Pump irrigated in old scheme	2.9	54	67	68
Partly water-controlled fields in new rice scheme	2.2	70	87	60
Traditional swamp rice	1.3	95	17	77

Source: IFPRI/PPMU survey, 1985/86.

Table 3. *Determinants of access of individual women to fields in the new rice scheme (probit estimate)*

Dependent variable: if woman had her own field in the scheme or shared one with other women (=1, else = 0)

Explanatory variables	Estimated parameter	*T*-value	Significance level	Change in probability to have access to field*
(1) Age of women†	0.5122	3.47	0.001	+0.21
(2) Woman is head of a cooking unit	0.6697	3.59	0.000	+0.26
(3) Woman is married to compound head	−0.0240	0.18	0.989	—
(4) Woman was traditional rice grower‡	0.5522	3.14	0.002	+0.23
(5) Number of women in cooking unit§	−0.1157	−3.26	0.001	−0.04
(6) Compound has more than one cooking unit	0.3341	2.05	0.041	+0.13
(7) Size of land in rice scheme for whole cooking unit¶	1.3588	4.70	0.000	+0.54
Constant	−4.3331	−5.44	0.000	—

Chi-squared: 86.55
N: 463

*The probability is approximated from the estimated parameter by multiplying with the factor of 0.4 following an approximation approach described by Amemiya (1981).

†In age groups, 4 = 15–19; 5 = 20–39; 6 = 40–59; else = 0.

‡Dummy variable = 1, if woman had own rice field in area before scheme *and* a personal rice store.

§Number of women of working age in the compound.

¶Size of rice land in hectare in the scheme expressed in irrigated land equivalent (for the whole cooking unit).

probability of obtaining a field (by 23%, variable 4).

- In large compound sub-units, the individual woman has less of a probability to obtain her own field because the new rice fields became "communal" (variable 5).

While the model gives us some insights on what determines differential access to new technology, it does not yet address the finding of the strong negative correlation between technological change and women's access to new technology, as reported in Table 2. This relates to women's versus men's ability to organize the operation of production and to finance the new technology in the household production system. These issues are now addressed.

5. REALLOCATION OF LABOR AND EFFECTS ON LABOR PRODUCTIVITY AND CROP PRODUCTION

The pattern of female labor inputs into rice production by type of technology follows the pattern of control over fields. Women provide the highest share of labor input into those rice fields which they control, as do men. But considerable mutual assistance between the sexes also exists, as indicated by the more even distribution of labor time allocation than distribution of control (Table 2, column 4).

While upland fields are not a scarce resource in the area, except at certain locations, labor in the wet season certainly is. Any increase in labor demand in one production activity in that season induces substitution effects. Increased labor productivity in rice due to new technology is, therefore, expected to pull labor away from other crop production, at least in the medium run, as long as the local labor supply situation does not adjust with in-migration. The related effects of an increased access to new rice land in the scheme on labor reallocation were evaluated with a simple labor input model. The details cannot be presented in this article.[6]

It is hypothesized in the model that labor inputs to the various crops and to non-agricultural work — given the various demographic characteristics of farm household units — are determined by relative net returns to labor in the various alternative activities and to total income levels. At rising income, total labor supply is expected to decrease at the margin. The main focus of the labor input analysis is to quantify the effect of new rice land made available to compounds on labor inputs to the other crops. The labor substitution effects induced by the new rice fields on the various crops were found highly significant. From the quantitative findings, the following are reported here:

- Evaluated at the respective sample means, access to an average piece of project land reduces household labor inputs to traditional rice by 16%; to upland cereals by 18%; and to groundnuts by 20% because less such crop land is farmed and less labor is allocated per unit of land under these crops.
- Tracing the substitution effects in labor allocation to production, by means of production functions estimated for the same crop groups, shows that for any additional ton of rice produced in the new scheme, 390 kilograms of cereals (millet, sorghum, traditional rice) and 400 kilograms of groundnuts are foregone.[7] In monetary terms, these substitution effects mean that for one dollar incrementally earned in the new rice, 71 cents of net income in other wet season crop production is given up.

Average labor productivity over the growing season in upland crops exceeded labor productivity in partly water-controlled rice production but it does not exceed production under fully water-controlled conditions (which benefits from a substantial subsidy on the irrigation infrastructure). Yet it turns out that marginal returns to labor in upland crops (both millets and groundnuts) were higher than in the new rice fields in wet season 1985 (Table 4). The low marginal labor productivity, despite high average labor productivity in the fully water-controlled rice, does not come as a surprise. Farmers participating in the scheme are under considerable pressure to perform work tasks defined by the project's management at a given schedule. This is geared toward maximizing yields rather than to equating marginal returns with marginal (opportunity) costs of labor. Farmers not following the schedule and achieving inappropriate yield levels run the risk of being excluded from the scheme.

In sum, labor productivity is highest in the fields of the technology type which was largely taken into communal food production under the supervision of the male heads of households. Thus, women have benefited less than men from the new technology, at least in a direct way, on the production and income-earning side. For the compounds as a whole, however, favorable income and food supply effects were identified, along with the major substitution effects in labor allocation.

How did these changes in agricultural resource allocation and income transmit into food consumption and nutrition? This question is addressed in the remaining part of the paper.

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Table 4. *Average and marginal labor productivity in major crops in the wet season*, 1985

Crops	Average labor productivity: Gross margin (net returns) per labor day	Marginal labor productivity: Derived from production functions*
	(in Dalasi per person day)†	
Upland cereals (millet, sorghum, and maize)	9.00	7.50
Groundnuts	8.70	4.61
Traditional rice	5.70	3.20‡
Partly water-controlled rice in scheme	7.40	
Fully water-controlled rice in scheme	14.70	3.00§

*The marginal labor productivity evaluated at respective mean values of labor input and average sales prices of output. Estimation results are presented in von Braun, Puetz, and Webb (1987).
†In 1985, 1 Dalasi equalled about US $0.20 on the parallel market.
‡Traditional rice and partly water-controlled rice in the scheme are dealt with in one model.
§The parameter on which this value is based is statistically significant at 15% level only.

6. EFFECTS ON FOOD CONSUMPTION

Income differences are substantial and persistent at the location. Compound units in the bottom expenditure quartile spend 68.5% of their total expenditures on food. Seasonality in food energy consumption is pronounced among the poorest 50% but not among the other half. Thus, supporting Hill's indictment, the notion of the homogeneous "peasant" would be very misleading for this West African setting.[8]

In the wet ("hungry") season per capita daily calorie consumption in the bottom quartile was, on average, 13% below the level of the dry season; 49% of the compounds in that group were below 80% of recommended requirement levels of per capita calorie consumption. This was only the case for 2% in the top quartile. The main rural consumption policy issue is an effective increase in food energy consumption of low-income people in the wet season. This consumption analysis therefore focuses on calories and on the wet season.

While a high correlation is found between per capita income (or total expenditure) and calorie consumption, availability of cereals from own-production and calorie consumption are only to a little extent correlated. This becomes also evident when compound cooking units — the unit of observation of this consumption analysis — are arranged by quartiles of per capita expenditure (including value of own-produced food) versus quartiles of per capita cereals production in Table 5. The data stress that it is income that matters for consumption and food security, rather than cereal production in a physical sense. The following analysis of the determinants of calorie consumption sheds further light on this.

A calorie-consumption model is specified and estimated for the critical wet season. The dependent variable is the total calorie consumption per adult equivalent person in each household unit (variable CALAE in model below). Consumption consists of food prepared for joint meals in the common cooking units (*sinkiro*) and of individual's acquired snack food. Technological change in rice may impinge on food consumption via its effect on income, local prices, and determinants mediated via the control over and pattern of the income stream in the compound.

We hypothesize, following conventional demand theory, that calorie consumption is determined by income level (INCOME) — with a decreasing effect as income rises (INCOME SQUARED) — and price. Total expenditure

Table 5. *Calorie consumption by quartiles of cereal production and by total expenditure quartiles in the wet season*

	By quartiles of cereal production*	By expenditure quartiles
	(calories per adult equivalent person/day)	
Lowest quartile	2,734	2,293
Second quartile	2,780	2,672
Third quartile	3,018	3,162
Fourth quartile	3,133	3,428

Source: IFPRI/PPMU survey, 1985/86.
*Cereal production per capita minus seed, waste after harvest, and about 10% donation to the mosque.

including the value of own-produced food is used as an income proxy and the price of rice — the major traded staple — is used as price indicator for calories (RICEPR) .

We hypothesize that a higher share of cereals produced under women's control (WOMCER) has a positive consumption effect over and above the income effect of cereal production because women are assumed to have a higher propensity to provide for household calories.

Wet season storage levels are largely determined by the access to fully water-controlled rice in the scheme, thus, a result of technological change. We hypothesize that higher actual storage levels (STORAGE) in the context of expected and current income increase offtake and, thus, calorie consumption especially in the wet season when markets are occasionally disrupted.

Finally, we hypothesize that an increased share of income in the form of cash (CASHIN) reduces the consumption of calories when income level is controlled. Readily fungible cash may end up in non-food expenditure or more luxury purchased foods to a larger extent than does subsistence food income as speculated in numerous studies.[9]

The stated hypotheses lead us to the following model specification with each compound sub-unit (*sinkiro, i*):

$$\begin{aligned} CALAE_i = f(&INCOME_i, (INCOME_i)^2, \\ &RICEPR_i, STORAGE_i, \\ &WOMCER_i, CASHIN_i, \\ &LOCATION_i, DEMOGR_i) \end{aligned}$$

The model results are presented in Table 6. The following findings shall be highlighted:

- Calorie consumption per adult equivalent is significantly income elastic, but with increased income the increase in calorie consumption is reduced, as is indicated by the negative parameter estimated for the squared term. A 10% increase in income — at sample means — leads to a 4.8% increase in wet season ("hungry" season) calorie consumption.
- An increased rice price reduces calorie consumption as expected but the effect is not found to be statistically significant.
- A reduced share of cereals from women's production significantly reduces calorie consumption. Thus, it can be expected that as a consequence of the new rice technology, a shift in the traditional women's crop to the control of the compound head leads to reduced calorie consumption if income is held constant. The income growth from technological change in rice must, therefore, be higher to compensate for this adverse intrahousehold effect if beneficial effects for calorie consumption are to be achieved. This compensation, by higher income, would require an increase of 4.6% of income at sample mean, which is only a fraction of the income increase deriving from the technological change in rice. The relative diversion of income from calories after women partly lost control is, thus, less than the favorable effect for calorie consumption from increased total compound income. Nevertheless, in some compounds of the scheme, the trade-off may work out adversely for calorie consumption. The gainer-loser patterns at the micro and intrahousehold level are extremely complex.
- An increased share of cash income does not — as hypothesized — reduce calorie consumption once household income is controlled for. Increased monetization of the economy in this West African setting appears not to be adverse for food consumption.

Table 6. *Calorie consumption model for the wet season*
(Dependent variable: calorie consumption in the cooking unit (*sinkiro*) per adult equivalent person per day in respective season)

Variable	Parameters	*T*-values	Sig *T*-values
INCOME	1.59329	7.218	0.000
INCOMESQ	−2.067 E-04	−5.316	0.000
RICEPR	−572.59043	−1.590	0.113
STORAGE	4.26204	1.702	0.090
WOMCER	321.83780	2.088	0.038
CASHIN	67.74398	0.444	0.658
LOCATION	−360.16405	−3.321	0.001
SIZE	−16.89481	−1.949	0.053
WOMSH	817.08670	1.823	0.070
CHLD5SH	624.70833	1.038	0.301
CHLD10SH	834.17860	1.812	0.072
CHLD14SH	981.11329	1.867	0.063
CONSTANT	1616.86638	2.937	0.004
R^2	= 0.37		
F	= 9.65		
Degrees of freedom	= 197		

List of variables:

INCOME	= As income proxy serves total expenditure including value of food consumption from own production per adult equivalent person for year 1985/86 (Dalasi).
INCOMESQ	= Squared INCOME.
RICEPR	= Rice price in Dalasi/kilogram actually paid for purchases by household (if no purchase, village mean price of season).
STORAGE	= Storage of all grains (in rice equivalents) per adult equivalent person in respective season.
WOMCER	= Share of cereals produced in compound unit under women's control.
CASHIN	= Share of cash income over total income earned by compound unit in respective season.
LOCATION	= Dummy variable = 1, if lowland village (else = 0).
SIZE	= Size of cooking unit (*sinkiro*) in adult equivalent person.
WOMSH	= Share of women in adult equivalent person.
CHLD5SH	= Share of children under 5 in adult equivalent person.
CHLD10SH	= Share of children under 5–10 in adult equivalent person.
CHLD14SH	= Share of children under 10–14 in adult equivalent person.

7. EFFECTS ON NUTRITIONAL STATUS

When technological change raises income and income raises food consumption, especially in the worst season, the "hungry season," as found above, these positive effects of technological change should be identifiable in an improved nutritional status. The relationships are, however, not straightforward. Multifaceted relationships of interacting determinants establish the nutritional status situation and its change. The chain which apparently leads to high prevalence rates of malnutrition and high mortality rates among children partly relates to low birth weights, especially of children born late in the wet season. This partly results from mother's stress due to high energy expenditures and low energy intakes during the wet season. Similarly

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this energy stress situation reduces breastmilk production which, in turn, reduces weight gains of children who approach weaning age.[10] Older children are affected by the availability and quality of food and by the frequency of servings in the cooking units (*sinkiros*). For them, household-level calorie availability may be of more direct relevance.

Separating the actual effects of unsatisfactory food consumption from health problems (infectious diseases, diarrhea, etc.) remains difficult. It is their interaction, rather than a clearly separable cause and effect chain, which leads to the alarming nutritional deterioration of many children by the age of 12 to 24 months, as indicated by nutritional status figures from anthropometric measurements (weight, height). In the wet season, 35% of children under five are found to be below 80% of weight-for-age standard (NCHS-median), and in the dry season it was 26%.

(a) *Technological change and nutritional improvement of women*

Women's body weight fluctuates on average by 2.2 kilogram between the wet and the dry season. As shown in the detailed research work at Keneba station (Gambia), this fluctuation in weight is a result of seasonal low energy intake because of shortage in that season and high energy expenditures because of labor peaks in field preparation and weeding.[11] It has profound implications for children's health and growth performance. A reduction of this seasonal stress on mothers, by means of increased food consumption and/or reduced work load in the wet season, could be expected to have a favorable effect on both mothers and children. How does the new rice production technology impinge on this?

We find that women's weight fluctuations are reduced in households with greater access to land in the new rice scheme. While weight-for-height of women from compounds with least access to the new rice technology fluctuates by 5.4% (bottom quartile), this is only 1.8% for women from compounds in the top quartile (Table 7). Women's reduced weight stress over the seasons may be seen as a substantial benefit of the new rice technology in that it levels out seasonal imbalances.

(b) *Technological change and nutritional improvement of children*

The following analysis attempts to explain differences in nutritional status of children in the context of food consumption and the health and sanitation environment of the compounds in which they live. The link to technological change in agriculture is established with the above analysis in which the income and food consumption effects of technological change were assessed. The endogenous nutritional status variable explained in the following model (NUTSTAT) is formed of Z-score values[12] of weight-for-age.

A set of hypotheses forms the basis for this model: Increased per capita calorie consumption of the household (CAL) also increases food consumption of children, which capture a part of greater food availability. This increased

Table 7. *Women's (mother's) nutritional status in the wet and dry season by level of access to new rice land*

Access to new rice land*	Change in mean weight from wet to dry season	Change in weight-for-height from wet to dry season
	(kilogram)	(percent)
Lowest quartile	+2.9	+5.4
Second quartile	+2.6	+4.8
Third quartile	+1.7	+3.0
Fourth quartile	+1.1	+1.8
Average	+2.2	+4.0

Source: IFPRI/PPMU survey, 1985/86.
*Expressed in amount of fully water-controlled equivalent land per adult equivalent person.

consumption reduces the nutrition problem, but decreasingly so at the margin (CAL squared).

If a child had diarrhea (DIAR) for an extended time preceding the survey, his/her nutritional status is expected to be impaired. Mother's nutritional status as indicated by her weight-for-height (MOTH) is hypothesized to have a positive relationship to the child's nutritional status because of various linkages (child care ability, mother's health). While short-term nutritional status is affected by diarrhea and related diseases, bad village water quality (WATER) is an adverse factor in the nutrition and health environment in which the child lives and is expected to adversely affect growth.

In large compounds (SIZE) with many small children (NCHILD), we expect a negligence effect in child care. We also expect that children of the compound head (CHCHD) are better taken care of than others.

We hypothesize that children born in the "bad" season (late in wet or early in dry season) starting with low birth weight may have a persistent nutritional status problem due to that (SBORN).

From increased access to the rice project, we expect favorable income and consumption and, thus, nutritional effects. While these effects of new technology should be captured in the calorie consumption via its income effects, we diagnosed before adverse effects from the scheme for women's control over income. Spending income on nutritional improvement may suffer from that, if women had a different marginal propensity to spend on child welfare than had men. This effect (over and above the income-consumption effect) is expected to be captured by the "RICPROJ" variable.

With these hypotheses, the model is thus as follows:

$$(1)\ \mathrm{NUTSTAT}_{i,s,r} = f[\mathrm{CAL}_{s,r}, (\mathrm{CAL}_{s,r})^2, \mathrm{DIAR}_{i,s,r}, \mathrm{MOTH}_{i,s,r}, \mathrm{WATER}_s, \mathrm{SIZE}_s, \mathrm{NCHILD}_s, \mathrm{SEX}_{i,s}, \mathrm{AGE}_{i,s,r}, (\mathrm{AGE}_{i,s,r})^2, \mathrm{SBORN}_{i,s}, \mathrm{CHCHD}_{i,s}, \mathrm{VERDAT}_{i,s}, \mathrm{RICPROJ}_s, \mathrm{DRYS}_r]$$

with: i = child
s = compound cooking unit (*sinkiro*)
r = survey round (wet, dry season)

For the interpretation of model results, it must be stressed at the outset that this type of model which attempts to explain differences in anthropometric measures of children in a nutritional context faces a lot of random variance in the dependent variable which we are not really interested to explain. Children in high-income countries develop in very different patterns as well. A low R^2 is thus to be expected and does not pose a problem as long as the high variance in the dependent variable is actually random "noise." Significance and stability of parameter estimates is the more relevant issue. From the estimation results in Table 8, the following shall be highlighted:

- Increased food energy consumption at household (compound) level (CAL) reduces children's nutrition problem significantly (but no decreasing effect is found at the margin).[13] A 10% increase in calorie consumption per capita significantly increases the weight-for-age Z-score at the sample mean by 0.28 (2.4%). Increased calorie availability had clearly a very favorable effect for children's nutritional improvement.
- Weight-for-age is significantly reduced by infectious diseases (DIAR) as expected.
- The parameter of mother's weight-for-height (MOTH), which is seen as a health indicator, suggests a close relationship between mothers and their children's nutritional status performance. The identified improvement of mother's nutritional status in the wet season in the context of the rice scheme may thus have positive effects for children's nutritional performance.[14]
- While there is no sex bias — at least not against girls — there is a different bias: children from the compound head are found significantly better off than others in the same household unit (CHCHD). Distribution of investment in child's health and nutrition is obviously not equal within the compounds. Shift of control over resources to the compound heads, as identified for the case with the new rice technology, may further strengthen such intra-household inequality effects.
- There are no indications that the degree of access to the new irrigated rice scheme has an effect (negative or positive) on nutrition *over and above* any of the factors already included in the model. This means that the income-consumption relationships, including the income control changes, seem to transmit their impact on nutrition via those factors actually captured in the above nutrition model.

Three other results of this model — not directly related to the technological change question — are interesting to note for household-level food security:

- Children from villages with unclean drinking water (WATER) — that is, where a high index of bacteria count was found in the water

Table 8. *Determinants of children's nutritional status*
(Dependent variable: weight-for-age Z-scores of children 6–120 months)*

Variables	Parameters	*T*-values	Sig *T*-values	Mean values of sample
CAL	0.01023	3.033	0.002	2832.00
DIAR	−2.66216	−2.869	0.004	0.99
MOTH	217.96029	3.506	0.000	0.34
WATER	−8.28915 E-03	−1.849	0.064	1459.85
SIZE	−0.74188	−1.902	0.057	12.75
NCHILD	−12.03094	−0.726	0.468	0.44
SEX	−8.93610	−1.644	0.100	0.34
AGE	1.59395	4.107	0.000	56.63
AGESQ	−7.08969 E-03	−2.242	0.025	4126.00
SBORN	−13.26935	−2.422	0.015	0.54
HEIGHTM	1.68896	4.085	0.000	160.25
CHCHD	14.72510	2.519	0.011	0.52
VERDAT	−19.74208	−3.106	0.001	0.52
RICPROJ	−69.43641	−0.471	0.637	0.03
DRYS	16.61858	3.006	0.002	0.48
CONSTANT	−514.19576	−7.323	0.000	—
R^2	= 0.172			
F-value	= 17.09			
Degree of freedom	= 1,232			

*Mean value of weight-for-age Z-score is −118.28 (Z-scores multiplied by 100).

List of variables:

CAL = Calories per adult equivalent person per day from all sources including snacks.
DIAR = Number of days diarrhea in preceding 4 weeks.
MOTH = Mother's weight-for-height.
WATER = Bacteria count of water sample from most used well in village used for drinking water.
SIZE = Number of adult equivalent persons in cooking unit (*sinkiro*).
NCHILD = Number of children under 10 over number of persons in *sinkiro* (ratio).
SEX = Sex of child (= 1, boys; = 0, girls).
AGE = Age of child in months.
AGESQ = Age of child in months squared.
SBORN = If child born in "bad" season = 1 (else = 0), born during September–February.
HEIGHTM = Height of mother in centimeters.
CHCHD = If child is son or daughter of compound head = 1, else = 0.
VERDAT = If date of birth is verified by record = 1, else = 0.
RICPROJ = Size of lands in new rice scheme in hectare irrigated land equivalent per adult equivalent person.
DRYS = If observation in dry season = 1, else = 0.

sample — were significantly more stunted, and underweight for age. Frequent episodes of water-borne diseases can be assumed to be the cause of this.

- A larger size of compound cooking unit (SIZE) with food consumption held constant shows up with a significantly negative effect for children's short-term nutritional performance; while there may be positive scale effects in food consumption (as found in the calorie model above), there actually appear negative scale effects in producing child health and nutrition as indicated by this nutrition model.
- Contrary to the Asian experience, boys here are found to be less well off than girls (SEX) but the result is not of high statistical significance. Svedberg reports similar findings from other studies in Africa in an extensive review.[15]

(c) *General improvement versus improvement of the worst cases of child malnutrition*

The above nutrition model attempts to explain differences in nutritional status across the range of the whole sample population. "Nutritional status" was treated as a continuous variable in that model. While this is a justifiable approach for a population with a high share of malnutrition, we are, however, particularly concerned with nutritional improvement that occurs at the tail-end of the distribution, which thus improves the worst cases and moves malnourished children across the critical threshold to acceptable nutritional status or reduces the degree of malnutrition below a critical cut-off point. The precise definitions of such cut-off points remain highly controversial in the nutrition research community.[16] The ones used here are not free from arbitrariness. Yet, keeping these limitations in mind to address the issue, we estimated a second version of the above model redefined as a discrete regression model (LOGIT model) in which the dependent variable is no longer the actual measured Z-score of the respective child, but a 0–1 variable, which equals 1 if child is malnourished and 0 otherwise. We defined "malnourished" by the conventional below −2 Z-score level (weight/age) as a cut-off point and, in addition, a −3 Z-score level below which only the most severely malnourished children are found. The concept of the LOGIT model, which we chose here because of the fairly high concentration of observations at the tail-end of the distribution functions, is described for instance in detail by Maddala.[17] The results of the maximum likelihood estimation are presented in Table 9.

In general, the estimation results support the earlier findings from the ordinary least-square estimates but also point at some interesting additional insights. The probability that a child moves from "malnourished" to "not malnourished" increases significantly with increased per capita calorie availability in the household. Noteworthy is the role that calorie consumption plays in preventing most severe malnutrition: the estimated parameter in logit model A (below −2 Z-scores) versus B (below −3 Z-scores) shows a three times as high increased probability per unit of calories that a child would move across the −3 cut-off point as we see from the estimate for the children below −2 Z-scores. This clearly points at the crucial role of increased income raising food energy consumption among the poorest where this has a highly positive effect for nutritional improvement of children. In other words, extra food matters more relative to extra health in preventing severe as opposed to mild undernutrition. Technological change in agriculture can provide the key point of departure for kicking off this process in rural areas, provided it is not labor displacing.

8. CONCLUSIONS

Technological change in African agriculture is a necessary condition for achieving sustained increases in food production.[18] The special nutrition problems in Africa relate not only to low levels of food availability but also to seasonality and to the high year-to-year variability of food intake.[19] Policymakers and program planners must be aware of the complex linkages between technological change in agriculture and nutritional improvement in order to arrive at nutritional benefits effectively with technological change.

The more complex the household structures and production organization in agriculture are, the less straightforward the predictions are on how technological change may impact on nutritional improvement. In the setting of this study, new rice technology ended up as contributing primarily to expanded communal farming under male household head's control. Women farmers lost out relatively in reduced chances for expanded individual farming. Holding income constant, the latter had an adverse effect on calorie consumption. The overall positive household income effect was, however, much stronger and despite the shift in control over the crop from women to men, this led to increased levels of,

Table 9. *Probability of children being malnourished: Results of* LOGIT-*model estimations*

Variables	Parameters	*T*-values	Sig *T*-values
Model A. Children below −2 Z-scores weight-for-age (= 1, else = 0)			
CAL	0.167821 E-03	1.712	0.086
DIAR	−0.435381 E-01	−1.989	0.046
MOTH	3.22097	1.685	0.091
WATER	−0.215225 E-03	−1.726	0.084
SIZE	−0.163487 E-01	−1.543	0.122
NCHILD	−0.557906	−2.753	0.005
SEX	−0.184420	−1.206	0.227
AGE	0.297850 E-01	2.753	0.005
AGESQ	−0.548617 E-04	−0.564	0.572
SBORN	−0.205323	−1.328	0.184
HEIGHTM	0.198752 E-01	1.787	0.073
CHCHD	0.270630	1.651	0.098
VERDAT	−0.110625	−0.602	0.547
RICPROJ	−7.55018	−1.821	0.068
DRYS	0.589766	3.569	0.000
CONSTANT	−4.03121	−2.053	0.040
Log likelihood	= −550.82		
Chi-squared	= 159.46		
Significance Level	= 0.32 E-16		
Number of observation	= 1249		
Model B. Children below −3 Z-scores weight-for-age (= 1, else = 0)			
CAL	0.481572 E-03	2.080	0.037
DIAR	−0.102241	−3.626	0.000
MOTH	0.975197	0.224	0.822
WATER	−0.533912 E-05	−0.020	0.984
SIZE	0.897700 E-02	0.401	0.688
NCHILD	−2.02955	−2.117	0.034
SEX	−0.502281	−1.197	0.231
AGE	0.193836 E-01	0.678	0.497
AGESQ	0.217358 E-03	0.635	0.525
SBORN	−0.265110	−0.789	0.430
HEIGHTM	−0.163238 E-01	−0.708	0.478
CHCHD	0.809851	2.165	0.030
VERDAT	−0.652872	−1.384	0.166
RICPROJ	1.11639	0.121	0.903
DRYS	0.932393	2.493	0.012
CONSTANT	3.75201	0.887	0.375
Log likelihood	= −149.83		
Chi-squared	= 94.28		
Significance Level	= 0.32 E-13		
Number of observation	= 1249		

List of variables: See Table 8.

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and more stability in, food consumption, which in turn improved the nutritional status of children and women. Incremental household calories were found especially improving for the nutritional status of children in a particularly bad nutritional situation.

NOTES

1. See Mellor and Lele (1973).

2. I am indebted to Detlev Puetz (International Food Policy Research Institute) for research assistance and contribution to survey work and to Yisehac Yohannes for processing of survey data.

3. A detailed descriptive account of the system is given by Webb (1987) and by Dey (1982).

4. The yield figures quoted refer to 1984 and 1985 averages.

5. The IFPRI/PPMU survey found that 35% of children under five years old were below 80% of weight-for-age standard in the 1985 rainy season.

6. The regression model and its results are described in von Braun, Puetz, and Webb (1987).

7. The production function estimates are presented in von Braun, Puetz, and Webb (1987).

8. Hill (1986).

9. A discussion of mechanisms and of various research results which address this issue is provided in von Braun and Kennedy (1986).

10. Prentice (1980).

11. Lawrence *et al.* (forthcoming).

12. The Z-score is computed as follows for each child's observation:

$$\frac{\text{(Actual Measurement — 50 Percentile Standard)}}{\text{Standard Deviation of 50 Percentile Standard}}$$

13. The specification was therefore changed and (CAL squared) was dropped.

14. Mother's weight-for-height is also influenced by calorie availability in the household, posing a potential multicollinearity problem. As the equally important energy expenditure side of mother's nutritional status determination could not be included explicitly, the weight-for-height indicator was chosen to capture the net effects.

15. Svedberg (1987).

16. For a comprehensive review of the problem, see Osmani (1987).

17. Maddala (1983).

18. The theme is extensively dealt with in Mellor, Delgado, and Blackie (1986).

19. Kumar (1986).

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