Stabilization of upland rice production under shortened fallow in West Africa: Research priority setting in a dynamic environmental and economic climate

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Introduction

Cropping intensification of the uplands, without the adaptation of management practices to intensified production activities, may occur at the expense of the land resource base. The objective of this paper is to demonstrate the potential impact of technological alternatives in upland rice growing ecosystems of West Africa. These inferences are derived by estimating a transcendental logarithmic production function for three sites representative of the Guinean Savanna, the Humid Forest and the Derived Transition agroecologies and estimating factor substitution possibilities. Based upon the parameters estimated in the model, prospects for land and labor saving technologies are evaluated.

Context

West African rice ecosystems, now covering about 4.1 million hectares, are extremely diverse and may be categorized by hydrology and agro-ecological zone. Traditional rainfed upland rice systems are the most widespread production systems and cover approximately 2.3 million hectares, approximately two-thirds of which is found in the humid forest environments of Côte d'Ivoire, Sierra Leone, Liberia and Guinea. The remaining areas are located in the moist Guinean savanna stretching from east to west across the region and the derived savanna transitional belt dividing the savanna and the forest zones (figure 1). These systems are subsistence oriented with productivity dependent largely upon plant genetic potential, land and labor inputs.

Land productivity no less than 15 years ago was managed through shifting cultivation practices, but, as table 1 indicates, these systems have given way to more cultivation intensive savanna and bush fallow management systems which deviate from the low-level but steady-state production equilibrium. Numerous sources have documented the decline in fallow precipitated primarily by national economies which are (1) largely agrarian in nature and structurally dependent upon agricultural production, and (2) experiencing population growth rates in excess of three percent per year. These two factors, when combined with a non-agricultural sector that is increasing at slow pace (from a small absolute share of economy's overall size) provide a scenario under which quality adjusted land resources will become increasingly scarce. Current evidence of this scarcity is indicated by Ruthenberg's "R" value, a land use indicator measuring cropping intensity. As Table 1 indicates, the "R" values for all upland systems are increasing towards permanent cultivation but less rapidly in the forest ecology.

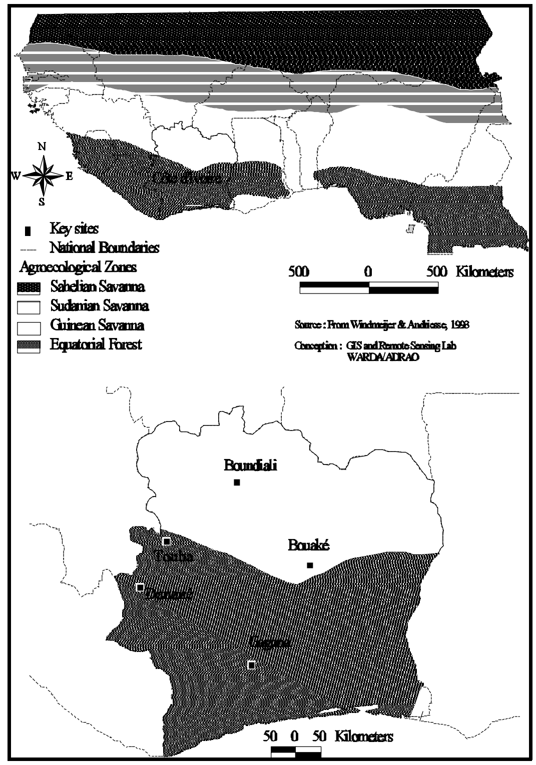

Figure 1: Distribution of Agroecological Zones and the Location of the Ivorian Research Sites

Table 1. Land-use Values for Upland Rice Systems in West Africa

	Guinean Savanna		Humid Forest	
	1984	1994	1984	1994
Fallow Length (years)	12-20	3-15	9-20	2-6
Cropping Period (years)	3-4	5-9	1-3	1-3
Ruthenberg's R-value	20-16	62.5-37.5	10-15	33

Source: Adapted from Becker, M. *et al.*, 1996.

Under the low-level equilibrium, rice productivity was largely dependent upon labor input, as it was the most limiting factor and quality land was relatively abundant. Decreasing fallow periods cause a decline in the soil's nitrogen supplying capacity and also allow for the build-up of insect pests and weeds. Labor is scarce in these systems for dramatically different reasons: in the Guinean savanna, alternative labor opportunities exist, primarily related to cotton and other cash crops while in the humid forest region rice productivity is limited by weeding and clearing labor efficiency. As land use intensity increases, farmers begin applying greater labor input to substitute for declining land productivity but the most limiting input may shift from labor to land owing to declining marginal productivity of labor, in particular weeding labor. In the savanna region, the opportunity cost of labor in competing crops exceeds the marginal value product in rice, while in the forest zone, the marginal productivity of labor decreases owing to weed and pest build-up, highly negatively correlated with the switch from shifting cultivation to fallow management and declining fallow length. Summary labor statistics for upland rice production are presented in table 2.

Table 2. Aggregate Labor Usage and Grain Yields in Upland Rice Fields in West Africa

		Labor (hours/ha)					Productivity	
	N (Fields)	Land Prep.	Seeding	Weeding	Harvest	Total	Yield (kg/ha)	Yield per hour
Guinea Savanna	98	200	94	204	250	748	1057	1.41
Derived Savanna	94	226	76	366	333	1001	840	0.84
Humid Forest	135	211	165	355	528	1259	1526	1.21

Source: WARDA Farm Management and Household Survey, 1993-1995 cited in Dalton, Kamara and Gaye, 1997.

Motivation

Ex-ante economic analyses of farm level technical interventions have often been limited by a lack of basic data on technical parameters and in particular parameters estimating the substitutability between production factors (Dalton *et al*., 1997). For example, figure 1 presents an illustrated example of production practices under two types of scarcity conditions: the West African case, where land is relatively abundant in rural areas and labor is scarce because of sparse population settlement patterns (point A in panel A) or under a typical Asian context, where land is scarce and highly limited because population densities are high, and labor is relatively abundant and inexpensive (point B). These isoquants represent the combinations of labor and land that can be used to produce a unit of output, say one ton of paddy rice. Their geometric shape, however, heretofore has not been estimated and is a key element to ensure appropriate technology targeting by matching the factor requirements of new technologies in environments of factor abundance.

Technological change shifts the frontier closer to the origin, as T_1 does in panel A. T_1 still represents 1 ton of output but by moving it closer to the origin, it indicates that we can produce this level of output with less resources, for example if average yields per hectare increase from 1 mt/ha to 1.5 mt/ha, we could produce the one ton of output using one-third less land and labor and improve input efficiency.

Panel B represents the introduction of an Asian type of new technology, one which does not improve input efficiency uniformly, like the idyllic parallel shift in Panel A, because it makes land relatively more productive than average labor productivity, thereby pivoting the frontier towards the northwest as it shifts inward. This type of shift represents the additional labor input required, for example as more weeding labor is required to clear vegetative growth promoted by fertilizer application. These two frontiers cross, indicating that under conditions representative of West Africa, the new technology demands proportionately more of the costly input, labor, and less of the cheap input, land, thus increasing cost per unit of output. An Asian technology, under these conditions is regressive, and hence inappropriate given factor availability of West African farmers.

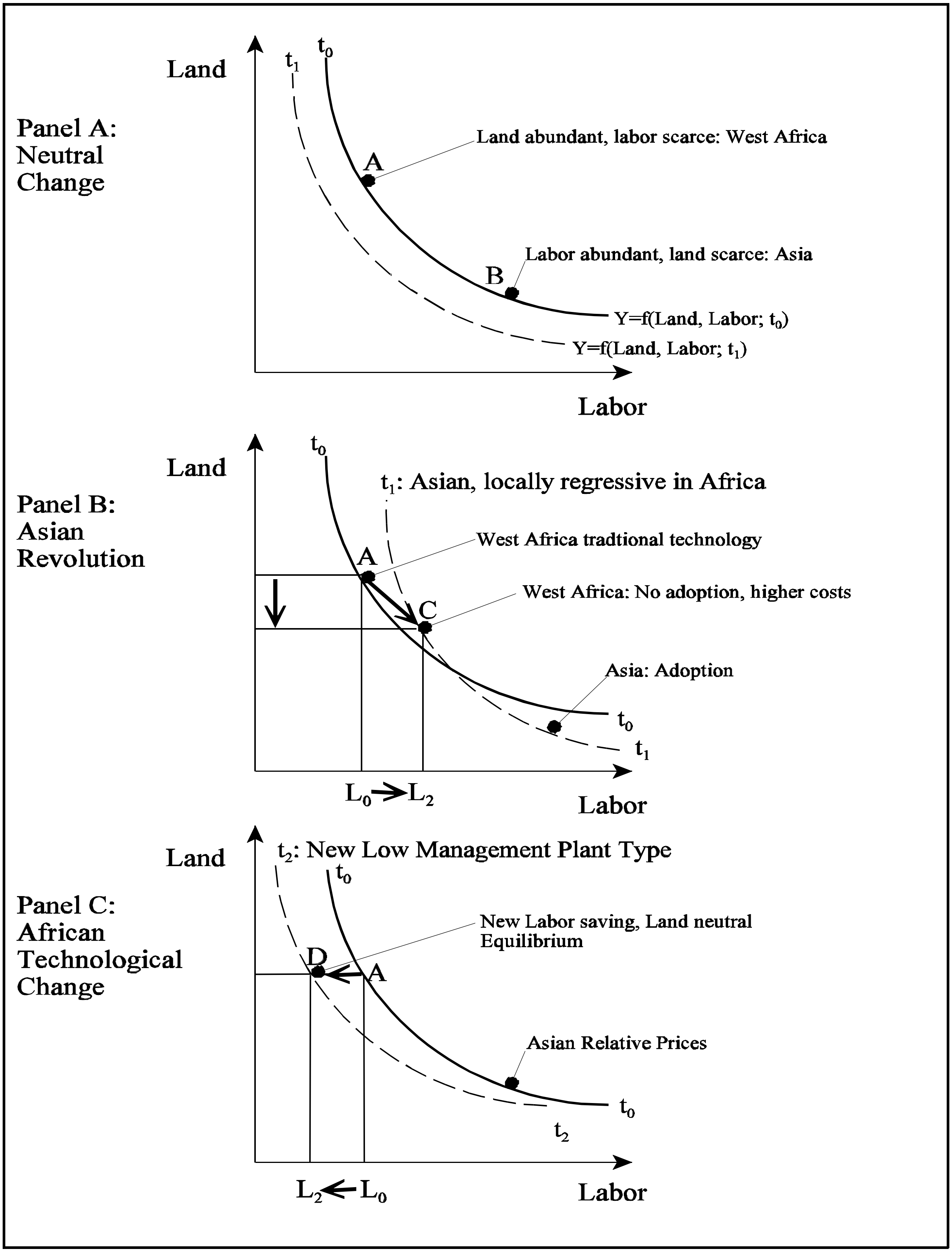

Figure 1. Land and labor use per unit of rice output and the impact of technological change under West African and Asian factor scarcity conditions

Technological Options

Panel C represents the development of a new low management plant type, a technology that improves the efficiency of transforming labor input into output, by virtue of its ability to compete more vigorously with pests, while remaining land neutral or slightly land-saving. Under the scarcity conditions facing West African farmers, where labor is scarce and often the most limiting production input, the low management plant type is designed to free labor for additional activities, whether it be expansion of cultivated rice area or for other high valued crops and improve labor productivity. This technology would see farmer adoption, and the shift from point A to point D because it represents a labor cost savings but neutral in land.

A second technological option to reduce per-hectare labor requirements is to introduce fallow management technologies. Improved fallow management techniques can improve rice productivity through several mechanisms: (1) improved soil physical and chemical properties which increase per-hectare output, (2) reduced labor requirements for clearing and weeding. In the first mechanism, yields may be increased through biological nitrogen fixation by the legumes (Becker and Johnson, 1996). The second mechanism alters the vegetative ecology and results in less labor for weeding and clearing. Legumes reduce weed pressure by suppressing weed growth through shading and competition which in turn interrupts the reproductive cycle of weeds and hence accumulation in the seed bank, much in the same manner as traditional long fallow. Short fallow periods, on the other hand, do not succeed in interrupting the reproductive cycle of weed nor do they allow for the accumulation of soil nutrients.

This particular option would require generalizing the graphs presented in figure 1 by disaggregating total labor input into clearing and weeding labor. What is empirically unknown is how the isoquants would shift with clearing and weeding labor on the axes. While considerable research has been conducted on improved fallow with legumes, these technologies heretofore have not had significant impact. Most analyses have focused on specific cost and benefits or the yield increasing aspect of legumes. We extend the *ex ante* analysis to capture the specific "cost saving" advantages of reduced labor input and the difficult task of their estimation and then incorporate this information with land scarcity values.

Model and Estimation

The starting point for this analysis is based upon the Dvořàk (1992) in which she determines decision rules for the amount of land to be cleared and the optimal weeding labor based upon the subsistence food requirements of the autarkic household. In her model the household minimizes clearing and weeding labor, which is a function of the fallow period, given the household subsistence food requirement. In her work, the average productivity of weeding plus clearing labor per hectare is set equal to the marginal productivity of weeding labor per hectare which is dependent upon fallow length. In her case, the decision to crop on fallow land is characterized by an unconstrained timing variable typifying land abundance, a factor which is less relevant than in the past and certainly less plausible given the physics of population expansion in the region.

Another approach is to model the cropping decision following an empirical household modeling approach where household production and consumption decisions are taken simultaneously or recursively dependent upon the characteristics of the study population. This approach may produce results analogous to Dvořàk's but requires the addition of price information and transformation of the optimization problem into its dual counterpart. The second method is more data intensive but insures that the recovered production function is the unique function generating the economic behavior and not only a monotonic transformation of the level production set. While inherently superior on theoretical grounds, this approach is difficult to implement with the current data set because of the absence of labor and output markets.

The data used in this analysis is a unique set of plot and household data collected by the West Africa Rice Development Association between 1993 and 1995. As the focus of the data collection exercise concentrated on rice-based cropping systems, both upland and lowland, our interest lies in those rural households not participating in market purchases for their primary food staple: upland rice. The data were collected by resident field assistants in three regions of Côte d'Ivoire representing the three major sub-humid West African rice producing agroecologies: the Guinean Savanna in the north(Boundiali), the Humid Forest in the south (Gagnoa) and the derived savanna transition zone (Touba). Labor data was collected by recall, production using a three-unit average crop cutting technique and areas using a tape and compass method (WARDA Farm Management and Household Survey cited in Dalton, Kamara and Gaye, 1997).

The first step in this analysis is to estimate a unrestricted transcendental logarithmic production function using variables suggested by Dvořàk plus regional and plot specific fixed effects. The model is written and estimated using standard OLS procedures:

$$\ln Y = a_0 + \sum_{i=1}^{3} a_i \ln(x_i) + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} b_{ij} \ln(x_i)\ln(x_j) + \sum_{k}^{2} d_k F_k + \sum_{l}^{2} f_l A_l + \sum_{m}^{2} g_m R_m + e$$

All variables are defined as follows:

Y Plot level upland rice production
X_1 Plot area (hectares)

X_2 Total clearing labor (hours)
X_3 Total weeding labor (hours)
F_1 Binary variable for farmer's subjective assessment that the soil is very fertile
F_2 Binary variable for farmer's subjective assessment that the soil is moderately fertile
A_1 Binary variable for 1993
A_2 Binary variable for 1994
R_1 Binary variable for the Derived Savanna region
R_1 Binary variable for the Humid Forest region

The parameter estimates and their asymptotic t-ratios appear in Table 3. Many of the parameter estimate (10 out of 16) were significantly different from zero including the instrumental dummy variables designed to control for heterogenous fixed factors. Regional and annual differences emerged as significant (consistent with summary statistics presented in table 2), as were plot level factors, summarized in the farmer's subjective assessment of the soil fertility.

Table 3. Parameter Estimates for the Translog Unrestricted Production Function for Three West African Upland Rice Ecologies, 1993-1995

	Unstandardized Coefficients			
	B	Std. Error	t ratio	Significance level
Intercept	5.92	1.44	4.112	0
Area	1.078	0.506	2.131	0.034
Clearing Labor	0.918	0.317	2.895	0.004
Weeding Labor	-0.463	0.38	-1.219	0.224
Area squared	0.04347	0.123	0.355	0.723
Area*Clearing Labor	0.171	0.13	1.32	0.188
Area*Weeding Labor	-0.173	0.142	-1.22	0.223
Clearing Labor squared	-0.006351	0.066	-0.096	0.923
Clearing*Weeding Labor	-0.298	0.103	-2.888	0.004
Weeding Labor squared	0.219	0.063	3.462	0.001
High Fertility	0.173	0.07	2.452	0.015
Moderate Fertility	0.159	0.062	2.579	0.01
1993	0.08926	0.047	1.88	0.061
1994	-0.06712	0.043	-1.546	0.123
Derived Savanna Zone	-0.245	0.068	-3.62	0
Humid Forest Zone	0.328	0.061	5.36	0

Adjusted R square 0.840; n=310

One important objective of this paper is to estimate the elasticity of output with respect to the three primary inputs and the elasticity of substitution between factors from the production function in order to derive implications for technology generation. Differentiating the Translog production function with respect to the log of the inputs derives the three respective point elasticities of output. From this starting point, the Morishima elasticities of substitution may be estimated. Morishima elasticities are an asymmetric measure of input substitutability that more closely capture the idea of Hicksian substitutability. The Morishima elasticity measures how the marginal rate of technical substitution changes as relative factor intensity changes.[1] These results are presented in table 4.

Table 4. Elasticities of Output and Substitution

	Area	Clearing Labor	Weeding Labor
Point Elasticities $s_{yx} = \left(\frac{dy}{dx}\frac{x}{y}\right)$	0.952*	-0.792**	-0.697**
Morishima Elasticities of Substitution $s_{ij} = \left(\frac{f_j}{x_i}\frac{F_{ij}}{F} - \frac{f_j}{x_j}\frac{F_{ij}}{F}\right)$			
Area	0	0.006**	0.015**
Clearing Labor	1.632**	0	0.002
Weeding Labor	4.608**	-0.009**	0

Notes: f_i is the marginal physical product of factor i, F_{ij} is the cofactor corresponding to factors i, j and F the determinant of the bordered Hessian of the production function.
* Significant at 5% (standard error estimates generated by Taylor series expansion)
**Significant at 1% (standard error estimates generated by Taylor series expansion)

Discussion

Production function estimation has highlighted the relative importance of land and labor inputs in producing upland rice. It was determined that plot level output can increase by increasing the size of the plot, but the rate of increase in production is less than proportional to size. Secondly, it was noted that the elasticity of output with respect to labor inputs was negative indicating a negative marginal factor productivity or super-optimal usage of labor input. Overuse of labor may be a function of several factors. Households rely upon upland rice as their primary

[1]Allen partial elasticities of substitution, as derived by Uzawa, are more commonly presented. However, the Allen measure does not indicate curvature or ease of substitution. See Blackorby and Russell for a complete discussion on the shortcomings and merits of the Allen and Morishima elasticity measures.

food staple and extreme consumption uncertainty, in the light of a production failure from weed or other pest infestation, may lead to an estimated overuse when this source of risk is not accounted. This source of bias may be mitigated by either modeling this attitude towards biological risk, by incorporating weed populations as a separate regressor or by using a two-stage procedure and incorporating the predicted level of weeding into the production function.

This estimation highlights the high degree of subsititability between (1) weeding labor and land and (2) clearing and land (column 1 of table 4). Labor saving technologies, and in particular technologies that require less weeding labor, will result in an area expansion under that technology. Potential technologies that require less weeding input include weed competitive rice cultivars developed through the interspecific hybridization of African rice *Oryza glaberrima* which are more competitive with weeds and other pests than Asian germplasm(*O. sativa*) and fallow legumes. Certain legume species such as *Cajanus cajan* and *Crotalaria anygeroides*, have been documented to reduce weeding labor requirements by up to 20% while weed competitive rice varieties have bene shown to decrease weed biomass by 10% to 36% (Johnson, *et al*., 1997). Labor demanding technologies, such as improved tillage affecting clearing requirements, or those technologies requiring complementary weeding labor, such as fertilizer, will not generate area expansion effects thereby limiting their overall output effects.

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