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On the Use of Productivity-Increasing Technologies in Sub-Saharan Africa: The Case of Inland Valley Swamp Rice Farming in Southern Mali[1]

by

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Abstract. There is no improved seed-fertilizer technology available that can generate the needed growth in agricultural production in Sub-Saharan Africa to meet food demand by the rapidly increasing population. This paper identifies factors associated with inland valley swamp rice farmers' decisions to adopt "improved" varieties and/or fertilizer. To achieve this objective, input-specific logistic models were estimated using survey-generated data collected from a random sample of 221 rice plots (one per farmer) selected from a purposive sample of 12 Mali-Sud *bas-fond* villages during the 1995-96 cropping season. The model estimation results show that the farther the village is from the closest market, the lower the probability to adopt the "improved" variety, increasing the size of the rice plot will decrease this probability, and men are more likely to adopt "improved" varieties than women because men have access to credit through CMDT, and more alternative sources of income to finance input purchases than women. For fertilizer, the use of "improved" varieties, the presence of water control infrastructure, and the village experience in cotton production increase the likelihood that a farmer will apply this input. The significance of the village experience in cotton production and women limited access to credit suggests that one of the constrains to a wider use of modern inputs is the absence of a reliable source of these inputs and/or seasonal credits. The significance of village distance to the closest market and the presence of water control the likelihood of using these inputs suggests that there exits some technological payoff associated with well-functioning markets and road improvements because such investments reduce the effective distance between the farm and the market.

Keywords: Small-scale irrigation, Rice production, gender, determinants of adoption, variety adoption, fertilizer adoption, logistic regression, *bas-fond*, Mali.

1. Introduction

In the last two decades, food production has failed to keep pace with increases in the demand for food by growing populations in most Sub-Saharan African (SSA) countries. Recent projections suggest that this food gap could more than double during the next 25 years (Pinstrup-Andersen *et al.*, 1997). Although SSA is experiencing economic recovery after years of low (rarely exceeding 2%) or negative growth, most of these low-income countries will not be able to generate the necessary foreign exchange to purchase needed food on the world market. As a result, while child malnutrition is expected to decline in other major developing regions of the World including South Asia, in SSA the number of malnourished children could increase by 45% between 1993 and 2020 to reach 40 million (FAO, 1996). In addition, SSA's share of the world's insecure is projected to almost quadruple between 1961-71 and 2010 from 11 to 39% (FAO, 1996). By 2010 every third person in SSA is likely to be food insecure compared to every 8th person in South Asia and every 20th person in East Asia (Pinstrup-Andersen *et al.*, 1997).

The World Bank (1989) estimates that an agricultural annual production growth rate of 4% is required to stimulate a satisfactory level of general economic development in SSA. To achieve this, labor productivity must increase by 1.5% and land productivity by 3% (World Bank, 1993). Thus, policy makers, researchers, donors and other developers must take proactive steps to minimize uncertainty in the future food situation in SSA through greater use of on appropriate productivity-increasing technologies and better policies that are conducive to expanded productivity in staple food crops. Evidence from Asia show that where such technologies have been effectively developed and utilized, food production has expanded faster than population.

While there are encouraging signs that productivity-enhancing technologies are beginning to accelerate yield growth of SSA food crops such as maize in West and Central Africa[2], a much greater effort is needed to promote greater intensification in small-scale farms. Because SSA has often been

[2] The introduction of improved maize varieties resulted in productivity increases in West and Central Africa at rates as high as 4% per year during the period 1983-92 (CGIAR, 1997). Byerlee and Heisey (1992), and Byerlee and Eicher (1997) provide evidence that seed-fertilizer technologies have led to steady yield increases in rain-fed agriculture.

referred to as land abundant, this abundance has been identified by many researchers as a constraint to yield-increasing technological change characteristics of the green revolution in Asia and Latin America (Bingswanger 1986, Bingswanger and McIntire 1987, Bingswanger and Pingali 1988). Under such circumstances, labor and working capital are more likely to be the binding production constraints. Thus, intensification will not be a cost-effective option for farmers. For example, in arid and semi arid regions where there exists substantial weather risk, farmers would favor the adoption of stress-resistant varieties or shift to higher quality or higher value crops, particularly if these do not increase labor requirements. Incentive to adopt land-saving technology will exist only until land becomes a scarce resource.

While the land-abundance argument may have been true up to the 80s, the era of land abundance is coming to an end in much of SSA as many countries now face land scarcity with shifting cultivation gradually disappearing (shorter or no fallows). Extensification in the absence of substantial yield increases can no longer support economically and environmentally sustainable development paths. There is evidence that Africa's soils are being mined for nutrients (Bishop and Allen 1989, Stocking 1987, Lele *et al*. 1989, CIMMYT 1990, IITA 1991, Kanampui *et al*. 1991, Speirs and Olsen 1992, Cleaver and Schreiber 1992, and Smaling 1993). Average fertilizer use rates need to be increased from the current 10kg/ha to 50 kg/ha within 10 years to prevent continued soil mining (Larson and Frisvold, 1996). Indeed, there are no improved seed-fertilizer free technologies available that can generate the needed increase if the goal of 4% growth rate is to be achieved. It is also true that these technologies will not be fully utilized if policy makers, and other developers do not deal with the growing water scarcity, along with the need to improve the current management of the natural resource base and markets opportunities and performance. The mix of needed initiatives will differ between countries, depending on their specific circumstances.

This paper examines the question: what policies and collective actions and investments are needed to assure a broader use of productivity-increasing technologies such as fertilizer and improved varieties, including across gender? Who can or will be able to benefit from such technologies? What role can cash crops such as cotton play in helping to promote food crop production? To answer these questions, the paper focuses on rice production in Mali to identify the distinctive characteristics between *bas-fond* rice farmers who have adopted the use of "improved" varieties and/or fertilizer application and those who have not? The Mali government efforts to modernize rice farming have largely centered on promoting the adoption of modern varieties and increased fertilizer application (*i.e.*, land-saving technologies), as well as mechanization and the use of labor-saving herbicides among farmers under the government-managed *Office du Niger*, which supplies about 50% of Mali's domestic rice production. Because the cost of expanding and/or rehabilitating those irrigation schemes is high, researchers and policy-makers are increasingly interested in the production potential of the farmers-managed *bas-fond* rice production, about which very little is known. To fill this gap, a study was initiated in 1995 to generate information that will help policy-makers assess the potential for meeting future rice requirements through improving the complementary but long-neglected *bas-fond* rice production systems. *Bas-fond* rice yields are low (1,216 kg/ha[3]) relative to those observed in the *Office du Niger* (averaging about 4,600 kg/ha over the 1990-95 cropping seasons and 4,900 kg/ha a year earlier). Thus, if *bas-fond* rice production is to be a significant complementary alternative for meeting future Mali rice requirements, it is critical that research programs be designed to identify ways to improve productivity.

The paper is structured in four parts. First, it provides a brief synthesis on farmers' use of these modern inputs in Mali-Sud *bas-fond* rice farming. Then, after reviewing the theoretical basis for using a logistic model to analyze factors associated with farmers' decisions to adopt modern inputs, the paper describes the variables used to specify the estimated models, and discusses the estimation results in terms of insights that would help researchers and extension agents prioritize their strategies for achieving wider adoption of "improved" rice seed and fertilizer use. The paper uses survey-generated data collected from

[3] Yield calculated using data collected from 223 rice plots in 11 *bas-fond* villages during the 1995-96 cropping season (Appendix 1). The associated standard deviation is 792 kg/ha.

a random sample of 221 rice plots (one per farmer) selected from a purposive sample of 12 *bas-fond* villages in Mali-Sud during the cropping season 1995-96. Enumerators stationed in the villages monitored each plot throughout the cropping season and administered questionnaires to each farmer.

2. Bas-Fond Farmers Use Modern Inputs

Diversity of Rice Varieties Used by Farmers in Southern Mali

The 221 *bas-fond* rice farmers monitored in this survey reported planting 60 different rice varieties, based on the names farmers gave for their varieties. However, because a variety is often named after the person who introduced it in the village, some varieties with different names may actually be the same variety. Of the 60 varieties named in the 12 villages surveyed, only nine had "improved" varieties' names (*i.e.*, Gambiaka, BR 4, BG 90-92, IRAT, SNA, IER 148, Niger/Zaïre, C 74, and Bouaké). On the average, about seven different varieties were planted in each village, with a standard deviation of three varieties. While 63% of these farmers reported planting "traditional" varieties, only 32% planted "improved" varieties, and 6% grew both varieties. There is a great deal of variability in the number of days from germination to maturity among the varieties farmers used. The majority of farmers (53%) used late-maturing varieties (130 days or more), while 32% sowed intermediate-maturing varieties (95-130 days), and 15% planted early-maturing varieties (less than 95 days).

The Scope of Fertilizer Application

While farmers complained that fertilizers are expensive, 42% of the 221 farmers monitored applied chemical fertilizers. The most frequently used fertilizer is urea, which is sometimes applied in combination with diammonium phosphate (DAP) and a compound 15-15-15 cereal fertilizer. On the average, when used alone, farmers applied about 63 kg of urea (with a standard deviation of 41 kg). Those who applied urea in combination with a source of phosphorous used higher rates: 102 kg of urea (with a standard deviation of 98 kg) in combination with 95 kg of DAP (with a standard deviation of 98 kg), or 83 kg of urea (with a standard deviation of 44 kg) in combination with 65 kg of the NPK cereal complex 15-15-15 (with a standard deviation of 35 kg). These average application rates are below the recommended rate of 150 kg of urea and 150 kg of DAP per ha, and they vary from farm to farm depending in part on the level of intensification as defined by the combination of inputs (variety, fertilizer, herbicide, water control) farmers used (Dimithè, 1997).

3. Analytical Model

A logistic model is used to identify factors associated with *bas-fond* farmers' adoption of "improved" varieties or fertilizer during the 1995-96 cropping season, and to predict the likelihood of a farmer using "improved" rice seeds and fertilizer, given selected observable attributes.

Justifications for the Use of the Logistic Model

The adoption of an "improved" technology is assumed to be an economic decision based on farmers' expected profitability (or expected utility) of using this new technology, given a set of individual factors (*i.e*,. age, gender, and education), agronomic factors (*i.e.*, management practices and hydrologic features of the field--maximum sustained water depth, rate of increase in the water depth, and length of the flooding period), household characteristics (*i.e.*, household and farm sizes), institutional factors (technology availability and accessibility), and climatic factors (length of the rainy season and intensity of rains). Identifying the distinctive characteristics of farmers using different technologies and predicting the likelihood of a particular farmer to use a technology is a classification or discrimination problem. Given farmers' observable characteristics, the goal is to classify each of them into one of two categories -- an "adopter" or a "non-adopter" of the "improved" technology-- by identifying factors associated with adoption behavior.

Economists use qualitative response models to model the relationship between a discrete dependent variable such as the probability of an event occurring, and a set of continuous and/or discrete independent variables. The general form of the qualitative response models is formulated mathematically by relating the probability of an event "Y" (*i.e.*, "using improved technology") occurring conditional on a vector "X" of explanatory variables, to the vector "X", through a cumulative density function F as follows:

$$\begin{aligned} &E[Y_i] \equiv P_j \equiv P(Y_i = j) = F(X_i, \beta) \\ &\text{with} \quad i = 1,2,\ldots,n \quad j = 1,2,\ldots J \end{aligned} \qquad \textbf{(1)}$$

where ß is a vector of unknown parameters, i is a sampled individual, and j is the event's outcome (here, adoption or non-adoption of improved technology). For response data, F can be a linear discriminant, a probit, or a logit function. The discriminant function is appropriate and justifiable only under multivariate normality of the independent variables, and complete equality of all the underlying covariance matrices (Press and Wilson, 1978). Unfortunately, in practice, the assumption of joint normality of the regressors is difficult to satisfy, and transformations often used to achieve multivariate normality will not typically guarantee equality of covariance matrices (Press and Wilson, 1978).

The probit and logit functions are the most familiar, and in many ways[4] the most useful analogue to a linear function for normally distributed data (Ameminya, 1981; Aldrich and Nelson, 1984). These two models differ in what they assume about the distribution of the disturbances over the set of outcomes. The qualitative response models for which F is a logistic distribution function are called logistic regression models, while those for which F is a cumulative normal distribution function are called probit models. Although the probit model was the first of the two models to be developed, the choice between these two models is usually made on the basis of practical concerns such as personal preference, experience, and availability and flexibility of computer software (Aldrich and Nelson, 1984; Judge *et al.*, 1988). For this particular study, the logit model was retained based on these considerations.

Mathematical Formulation of the Logistic Model

In this paper, the regressor is binomial, taking the value "1" if the farmer used the "improved" technology and "0" if he/she did not. While there are many specifications of the binomial logistic model, choosing one particular specification is arbitrary (Aldrich and Nelson, 1984). For this study, this choice is imposed by the computer software available (*i.e.*, LIMDEP and SPSS). The LIMDEP and SPSS specifications, which are a model proposed by Chamberlain in 1982, are as follows:

$$P_1 = P(Y_i{=}1) = \frac{\exp(\beta' X)}{1 + \exp(\beta' X)} \qquad \textbf{(2)}$$

where for each individual i, the probability of an event's outcome j depends on a single regressor vector of individual or grouped data[5], "X", which describes the individual, and a set of J parameters $ß_i$. The

[4] For example, it can be proven that these functions are continuous, bounded between 0 and 1, monotonically increasing with ß'X, and they approximate the normal distribution (Ameminya, 1980; Judge et al., 1988).

[5] Individual data are defined as data for which measurements on dependent variable consist of individual responses, while with the grouped data, the regressor consists of proportions.

parameters β_is are estimated using the maximum likelihood method (MLE), which chooses those values that make the observed results most "likely". In other words, the MLE method maximizes the probability of obtaining the sample actually observed. For specific values of the independent variables, the corresponding estimated value of P_1 is the probability for the event "adopting the technology" to occur. Therefore, alternative values of the regressors can be used in the estimated model to predict the likelihood of the event under those conditions.

Each estimated coefficient reflects the effect of a one-unit change in the corresponding regressor on the logarithm of the odds[6] of the event to occur, *ceteris paribus*. These coefficients are difficult to interpret because the magnitude of the increase in probability depends on the original probability, which is determined by the individual values of all independent variables and their coefficients. However, the effect of individual characteristics can be assessed by estimating the marginal effects δ_1 of the regressors in the logistic model as follows:

$$\delta_1 = \frac{\partial P_1}{\partial X} = F(\bar{X},\beta)\beta \qquad \textbf{(2)}$$

where $P_1 = \text{Prob}[y_i=1]$, X is a vector of the regressors in the logistic function, and β is a vector of the estimated parameters of the function. These marginal effects δ_1 correspond to changes in the probability of adopting the "improved" technology, given a unit change in the characteristics vector **X**. The computer software used for this analysis (LIMDEP) includes a routine to perform the algebraic computations necessary to estimate δ_1. It is important to note that neither the sign nor the magnitude of δ_1 necessarily have to be similar to those of ß (Greene, 1992). Furthermore, ß and δ_1 do not necessarily have the same statistical significance since the standard error of δ_1 depends on the standard error of ß and F.

4. Characteristics of Adopters of "Improved" Varieties

Model Specification

As mentioned earlier, farmers' adoption of "improved" varieties is influenced by several socio-demographic, economic, agronomic and institutional factors. Table 1 presents the variables used in this study, and the hypothesized direction of the relationship between the identified variables and the probability of farmers' adoption behavior.

[6] The odds of an event to occur is the ratio of the probability that the event will occur over the probability that it will not occur. This can be expressed mathematically as follows:

$$\log \textit{of the odds of an event} = \log\left(\frac{\textit{Prob(event)}}{\textit{prob(no event)}}\right) = \beta_0 + \beta_1 X_1 + .. + \beta_J X_J$$

Table 1: Factors Hypothesized to Affect Farmers' Adoption of "Improved" Rice Varieties for the *Bas-Fond* Production Systems.

Factors	Measurement in the Study	Variable Name	Hypothesized Sign
Socio-Demographic Factors:			
- farmer's age	- years	AGEXPL	-
- farmer's gender	- gender (male/female or 0/1)	GENDER	-
- farmer's education	- schooling rate in the PU[7] (%)	PCTSCOL	+
	- literary rate in the PU (%)	PCTALP	+
	- female schooling rate in the PU (%)	FPCTSCO	+
	- female literary rate in the PU (%)	FPCTALP	+
PU Factors:			
- farm size	- hectares of rice area planted	SURFACE	+
- size of the PU	- number of people in the PU	UPASIZE	+
Agronomic Factors:			
- max. sustained water depth - rate of increase of water depth - length of flooding period	- } plant stress } during the season } (no/yes or 0/1)	STRESS1	-
- water control	- water control infrastructure (no/yes or 0/1)	WTCONT	+
Institutional Factors:			
- awareness, availability and access to seeds	- } presence of extension service (no/yes or 0/1)	STECHELP	+
	} village experience in cotton production (years)	HISTCOT	+
	} cotton production in the farmer's PU (no/yes)	COTFIELD	+
- access to markets	- } distance closest weekly market (km)	WMKTD	-
	} distance closest urban market (km)	URBMKTD	-

Because the meaning of the identified variables and their hypothesized signs are fairly straightforward, they are not discussed in detail. However, variables STRESS1 and GENDER warrant further explanation. The variable STRESS1 is used to capture the effect of plots' hydrologic characteristics on farmers' decision to adopt "improved" rice varieties. Theoretically, these characteristics include factors such as the maximum sustained water depth, the rate of increase in water depth, and the length of the flooding period. Because such data do not exit and were practically impossible to gather, as a proxy, this analysis uses farmers' perception of the water stress suffered by the rice plant during the critical periods of the crop cycle (*i.e.*, germination, tillering, flowering, and grain filling). For each farmer, the variable STRESS1 is coded "1" if, she/he observed evidence of significant water stress on the rice plants during any of these periods, and "0" if she/he did not. During the analysis, alternative stress variables (*i.e.*, combinations of the water stress proxies) were evaluated, but are not

[7] Stands for "production unit" and is defined as

reported because none was statistically significant.

The education variable is included as a proxy for farmers' capacity to apply the technology in a technically efficient manner. The negative sign for the variable GENDER indicates our hypothesis that men are more likely to adopt "improved" varieties than women, mainly because although *bas-fond* rice farmers are predominantly women (88%), existing institutional arrangements do not provide women direct access to new rice technologies and other resources such as credit[8], and these women have fewer alternative sources of cash flow to finance "improved" seed purchases. This condition is worsened by the patriarchal nature of the rural social structure which tends not to expect women to generate household income. As a result, women have limited access to household resources for investing in rice inputs.

While this study focuses on the variables identified in Table 1, the authors recognize that other variables can be used in modeling farmers' technology adoption decisions. For example, the extent to which the technology can be tested on a small scale (*i.e.*, trialability and divisibility) and the extent to which it is possible to visualize the change in the resulting outcome (*i.e.*, observability) are potentially important determinants of adoption. Similarly, taste and grain color, as well as the difference in net returns between the "traditional" and "improved" varieties, and the availability of and access to seasonal credit are often important determinants. However, the trialability, divisibility, and observability of the technology being studied (*i.e.*, variety) are not included in the analysis because this technology satisfies these conditions. Varieties taste and color, as well as the access to credit are not considered because the data was not available. Finally, net return differential are not included in this analysis because these farmers are predominantly subsistence farmers.

Table 2 presents a summary of the descriptive statistics computed from this sub-sample for the variables used in the estimation process. The sub-sample is composed by 221 farmers, 84% of whom are female, 61% from a *bas-fond* with a water control infrastructure, and 48% of whom planted "improved" rice varieties.

[8] Currently, the main source of "improved" technology is the CMDT, a government agency which only provides credit to cotton farmers. Because all cotton farmers are men, many of whom are not willing to borrow for their wives, very few women farmers have access to modern inputs.

Table 2: Descriptive Statistics of the Variables Hypothesized to Affect Farmers' Adoption of "Improved" Rice Varieties for the *Bas-Fond* Production Systems (N=221).

Variables	Unit	Mean Value	Standard deviation	Minimum	Maximum
Socio-Demographic:					
GENDER (1=female)	dummy	0.84	0.37	0	1
AGEXPL	years	43.92	12.86	20	81
PCTSCOL	%	10.71	17.01	0	100
PCTALP	%	7.40	10.62	0	73
FPCTSCO	%	3.90	14.88	0	100
FPCTALP	%	2.91	11.58	0	100
Economic:					
SURFACE	ha	0.42	0.93	0.02	12
UPASIZE	persons	16.13	12.42	2	94
Agronomic:					
STRESS1 (1=yes)	dummy	0.48	0.50	0	1
WTCONT (1=yes)	dummy	0.61	0.49	0	1
VARIETY (1=improved)	dummy	0.48	0.50	0	1
Institutional:					
STECHELP (1=yes)	dummy	0.27	0.45	0	1
HISTCOT		0.52	0.50	0	1
COTFIELD (1=yes)	dummy	0.52	0.50	0	1
WMKTD	km	3.27	2.61	0	7
URBMKTD	km	34.78	26.05	0	80

Source: Survey Data.

Results, Interpretation, and Implications for Research and Extension

Various specifications of the binomial logit model were estimated using a stepwise regression procedure for selecting variables to be included in the model. Variables were excluded or included in the model based on the probability associated with their F-statistics whose cutoff point was set to 0.05 for the inclusion and 0.10 for the exclusion rules. This procedure ensured that when two variables were (statistically) significantly correlated, only one of them was used in a specification.

The estimated model specifications were evaluated based on (i) theoretical considerations, (ii) the statistical significance of the regressors' coefficients and the direction of their effect on the probability of adopting "improved" varieties, (iii) how well the models classify the sampled farmers into their observed adoption category, and (iv) how likely the sample results are, given the parameter estimates. The LIMDEP classification table was used to assess how well each model classifies the observed data. This table compares the model's prediction to the observed outcomes by giving the number of observations that are correctly and incorrectly classified as adopters versus non-adopters. For each farmer, this comparison is based on whether or not the estimated probability that the farmer used "improved" rice varieties is greater or less than one-half. If for a particular farmer this estimated probability is more than one-half, that farmer is classified as an "adopter" of the "improved" rice variety. Alternatively, if this probability is less than one-half, the farmer is classified as a "non-adopter" of the "improved" rice variety. To assess how likely the sample results are, the null hypothesis that the explanatory variables other than the intercept have no impact on the choice probability (*i.e.*, the β_is are jointly equal to zero) was tested using the model's chi-square (P^2) statistics.

The results generated by the estimation process showed that three of the specifications have coefficients that are fairly similar in magnitude, statistical significance, and the direction of the effects of each regressor on the probability P_1 to adopt "improved" varieties. These three models differ in terms of the education variable used (*i.e.*, literacy rate or schooling rate) and the inclusion or exclusion of the variable "STRESS1" used to capture the effect of the hydrological characteristics of each plot on adoption. Ultimately, the model with the literacy rate was retained because of CMDT and ONGs involvement in literacy campaign, and the estimation results are reported in Table 3.

Table 3: Adoption of "Improved" Rice Varieties-- Estimated Coefficients (ß), Marginal Effects ($*_1$), and Percent Successful Classification, Mali, Cropping Season 1995-96.

Variables	Estimated Coefficient (ß)	Standard Error	Significance	Partial Correlation Coefficient	Marginal Effect ($*_1$)[a]
------------------------------------- Variables in the Equation ----------------------------------					
WTCONT	2.0277	0.4468	0.0000	0.2465	0.5069
GENDER	-2.1526	0.9133	0.0184	-0.1078	-0.5385**
WMKTD	-0.2167	0.0871	0.0128	-0.1170	-0.0542*
SURFACE	-0.3803	0.2655	0.1521	-0.0130	-0.0951*
HISTCOT	0.7544	0.3903	0.0533	0.0753	0.1886
Constant	1.0840	0.9148	0.2360		0.2713
------------------------------- Variables not in the Equation ------------------------					
<u>Residual P^2</u>	7.188		0.3038		
UPASIZE	1.4784		0.2240	0.0000	
AGEXPL	1.0000		0.3173	0.0000	
URBMKTD	4.5336		0.0332	0.0910	
STECHELP	0.0048		0.9445	0.0000	
FPCTALP	0.1380		0.7103	0.0000	
STRESS1	0.1073		0.7432	0.0000	
<u>Model's P^2</u>	92.8730**				
<u>% Correct Prediction</u>:					
non-adopters (n=115)	84.35%				
adopters (n=106)	74.53%				
both (N=221)	79.64%				

[a] "*" is used when P # 0.02 while "**" indicates that P # 0.01 (2-tailed significance). The coefficients with no asterisk are not significantly different from zero for " # 0.05.

For the dependent variable, there is a fairly good balance between the size of the sub-sample of adopters (106 farmers) and non-adopters (115 farmers). As noted earlier, a significant estimated coefficient does not necessarily imply a significant marginal effect of the variable on the regressand because the standard error of marginal effects depends on the standard error of the estimated coefficients and F (see Equation 4) as shown in Table 3. The village years experience in cotton production (HISTCOT) and the presence of water control infrastructure (WTCONT) have statistically significant estimated coefficients, but non-significant marginal effects. In contrast, farmers' rice plot size (SURFACE) has a non-significant estimated coefficient but a significant marginal effect.

The coefficients of the two village-level variables --the presence of water control infrastructure and years of experience in cotton production-- have positive signs, which indicates that each variable increases the logarithm of the odds of adopting "improved" varieties. While the positive effect of water control may be attributed to farmers' perception that "improved" varieties are better suited to the resulting water conditions than "traditional" varieties[9], the effect of the village cotton production experience is due to the fact that CMDT, a parastatal promoting cotton, makes inputs (including seeds) available on credit to cotton producers. In contrast, the negative coefficient for market distance variable (WMKTD) indicates that the farther the village is from the closest market, the lower the logarithm of the odds of adopting the "improved" variety. The negative coefficient for the gender variable (GENDER) indicates that men are more likely than women to adopt "improved" varieties. This gender difference with respect to variety adoption can be explained by the fact that men have access to credit through CMDT, and more alternative sources of income to finance input purchases and exposure to extension agents and researchers than women.

However, more importantly, the estimation result shows that only farmer's gender, rice plot size, and the village distance to the weakly closest market have statistically significant negative marginal effect among the five variables included in the final equation. Unlike the estimated coefficients (β_i), each estimated marginal effect indicates the change in the probability of adopting the "improved" variety, given a unit change in the corresponding attribute. Farmer's gender has the highest statistically significant negative marginal effect (-54%) among the five variables included in the final equation, followed by farmers' rice plot size (-10%), and the village distance to the weakly closest market (-5%). These results indicate that moving from male to female farmers tends to decrease the probability for farmers to adopt "improved" varieties by about 54%. Similarly, moving a village one km closer to a market increases the probability of adoption by 5%, while increasing the size of the rice plot by one ha (which is unlikely given the small average plot size) will decrease this probability by about 10%.

While the 5% increase in probability for farmers to adopt the "improved" variety due to the village distance to the closest market may appear to be negligible, it could indeed be important given that it is estimated on a per kilometer basis. More importantly, this result suggests that there exits some technological payoff associated with well-functioning markets and road improvement because such investments reduce the effective distance between the farm and the market.

These models also reveal that expanding female farmers' access to seasonal credit and seeds could significantly increase the adoption of "improved" varieties. Indeed, key informants reported that one of the constraints to a wider adoption of "improved" rice varieties is the absence of a reliable supply of seeds. Currently, CMDT is the only formal source of "improved" seeds, mostly through loans that are later repaid for from cotton sales. However, the role of CMDT as a seed credit source is constrained by the fact that farmers have a credit limit, which is determined by their respective cotton production levels and is limited to no more than 30% of their cotton revenues. Even if CMDT revised its credit policy on seeds to enable more farmers (including non-cotton farmers) to buy seeds from the firm (CMDT), it is

[9] While a larger proportion of the "improved" varieties (75%) are found in the *bas-fonds* with water control infrastructure, a larger proportion of the "traditional" varieties (62%) are found in the *bas-fonds* with no water control infrastructure. This may be due to "improved" varieties being shorter and thus more vulnerable in *bas-fonds* with no water control infrastructure.

likely that CMDT would not be able to meet the potential demand for rice seeds, given that cotton is its main thrust.

Of course, speculation about the need to expand seed availability is contingent on the"improved" varieties performing better than the "traditional" ones, and favorable output/input price ratios. Farmers' yields are low (1,216 kg/ha) and highly variable within each village, from one village to another, and across the entire sample. Grouping yields by type of rice variety farmers planted indicates that "improved" seeds significantly (P#0.04) increased yields by 22% (from 1,133 to 1,379 kg/ha). This result needs to be interpreted with caution since the analysis does not control for other possible sources of variability as discussed in detailed by Dimithè (1997). However, it remains certain that *bas-fond* rice yields are low, mainly because the varieties farmers currently plant were developed for a much drier area. For a greater intensification of *bas-fond* rice farming, scientists must develop appropriate high-yielding varieties. Transferring the high experimental yields achieved on-station to the heterogenous *bas-fond* environment represents an enormous challenge for Malian researchers.

The inability of these models to show the significance of the marginal effect of water control on variety adoption can be explained by the fact that, as measured, this variable may not properly capture essential plots' hydrologic characteristics such as the maximum sustained water depth, the rate of increase in water depth, and the length of the flooding period. However, discussions with farmers revealed that the irregular pattern of precipitation has historically contributed to discourage rice farming in the *bas-fonds* because the amount of moisture available to the rice plant is often insufficient to ensure acceptable yields.

Finally, the inability of these models to show statistical significance of the coefficients associated with variables such as PU size and farmer's age can be explained by their low variability among the sample of farmers, which is sometimes typical of survey data. Almost all rice plots in each of the 12 *bas-fonds* have fairly equal in size and most rice farmers are older members of the households. Although the models failed to indicate an expected statistical significance for these other regressors, its goodness of fit is acceptable, based on the (statistically) highly significant chi-square values and the high percent of correct prediction. The model correctly classified 75% of the farmers who actually used "improved" varieties, and as much as 84% of those who used "traditional" varieties. Overall, 80% of the farmers were correctly classified into their actual variety adoption category.

5. Characteristics of Adopters of Fertilizer Application

Model Specification

As with "improved" varieties, farmers' decision to apply fertilizer is affected by several socio-economic, agronomic and institutional factors. Table 4 presents the specific variables used in this study to model fertilizer adoption. These variables are similar to those included in the variety adoption model, except that the rice variety planted is assumed to be a determinant of fertilizer use, based on farmers' belief that "improved" varieties require using this input.

The hypothesized positive sign on the variables LABOR indicates that the larger the household, the more likely are farmers to apply fertilizer because they need to increase their yields to feed their larger household. For example, Byerlee and Heisey (1992) report evidence from Malawi and Zambia showing a positive relationship between farm size and the likelihood of applying fertilizers. Farmers age and the crop vulnerability to water stress are expected to have a negative effect on the probability to adopt fertilizer. In contrast, farmer's education is expected to have a positive effect on the probability to use fertilizer. For VARIETY, the hypothesized sign indicates that farmers who plant "improved" varieties are more likely to adopt fertilizer than those who plant "traditional" varieties. By including VARIETY as a regressor, we are recursively including all the variables we found to be significant in affecting varietal adoption. As result, the inclusion of those variables in this model allows us to test whether they have an impact on fertilizer use in addition to the impact they have via their effect on varietal choice.

Table 4: Factors Hypothesized to Affect Farmers' Adoption of Fertilizer in the *Bas-Fond* Rice Production Systems.

Factors	Measurement in the Study	Variable Name	Hypothesized Sign
Socio-Demographic Factors:			
- farmer's age	- years	AGEXPL	-
- farmer's gender	- gender (male/female, 0/1)	GENDER	-
- farmer's education	- schooling rate in the PU (%)	PCTSCOL	+
	- literary rate in the PU (%)	PCTALP	+
	- female schooling rate in the PU (%)	FPCTSCO	+
	- female literary rate in the PU (%)	FPCTALP	+
Household Factors:			
- farm size	- hectares of rice area planted	SURFACE	+
- size of the PU	- number of people in the PU	UPASIZE	+
- relative size of the PU	- UPASIZE/SURFACE	LABOR	+
Agronomic Factors:			
- maximum sustained water depth - rate of increase of water depth - length of flooding period	- } plant stress } during the season } (no/yes or 0/1)	STRESS1	-
- water control	- water control infrastructure (no/yes or 0/1)	WTCONT	+
- rice variety type	- traditional vs improved (0/1)	VARIETY	+
Institutional Factors:			
- access to the input	- presence of extension service (no/yes or 0/1)	STECHELP	+
	- village experience in cotton production (years)	HISTCOT	+
	- cotton production in the farmer's PU (no/yes)	COTFIELD	+
	- distance closest urban market (km)	URBMKTD	-
	- distance closest weekly market (km)	WMKTD	-

Results, Interpretation, and Implications for Research and Extension

This model utilizes data from a sub-sample similar to the one used for the variety adoption analysis. Using the variables identified in Table 4 and data for the entire sub-sample of monitored farmers, various specifications of the binomial logit model for farmers' decision to adopt fertilizer application were estimated, using the stepwise procedure. The estimated model specifications were evaluated using the same tools and standards discussed earlier for the varieties' adoption models. From the estimation process, one specification was retained. These results are reported in Table 5.

Table 5: Fertilizer Adoption-- Estimated Coefficients (ß), Marginal Effects (*1), and Percent Successful Classification, Mali, Cropping Season 1995-96.

Variables	Estimated Coef. (ß)	Standard Error	Significance	Partial Cor. Coefficient	Marginal Effect (*1)[a]
---------- Variables in the Equation ----------					
VARIETY	1.0922	0.5394	0.0429	0.1159	0.2564*
WTCONT	2.0908	0.5264	0.0001	0.2969	0.4913**
HISTCOT	1.5474	0.5157	0.0027	0.2117	0.3636**
Constant	-2.7586	0.4951	0.0000		-0.6482**
---------- Variables not in the Equation ----------					
Residual P^2	2.664		0.91342		
LABOR	0.4148		0.5195	0.0000	
AGEXPL	0.3574		0.5500	0.0000	
GENDER	1.2590		0.2618	0.0000	
URBMKTD	0.2956		0.5867	0.0000	
STECHELP	0.0925		0.7610	0.0000	
FPCTALP	0.8989		0.3431	0.0000	
STRESS1	0.0046		0.9460	0.0000	
Model's P^2	56.8574**				
% Correct Prediction:					
non-adopters (n=67)	91.04%				
adopters (n=48)	75.00%				
both (N=115)	84.35%				

[a] "*" is used when P # 0.05 while "**" indicates that P # 0.01 (2-tailed significance). The coefficients with no asterisk are not significantly different from zero for " # 0.05.

Table 5 reveals that factors that affect the probability for farmers' to apply chemical fertilizers are the presence of a water control infrastructure, the village experience in cotton production, and the type of variety planted (and thus the factors associated with the use of these varieties). For these three variables, both the estimated coefficients and the marginal effects are statistically significant. In contrast with the varietal adoption analysis results (Table 3), Table 5 shows that, while water control and the village experience in cotton production have no marginal effects on the probability to adopt "improved" varieties, they do impact the use of fertilizer marginally. Furthermore, the village distance to the closest market, farmers' gender and plot size influence the use of fertilizer only through their effect on the adoption of "improved" varieties. The positive sign on the estimated coefficient of the type of variety planted indicates that farmers planting "improved" varieties are more likely to adopt fertilizer than those who do not[10]. As a result, (1) men are more likely than women to use fertilizer, (2) increasing the size of the rice plot will decrease the probability of using fertilizer, and (3) the farther the village is from the closest market the lower the probability to farmers will use fertilizer. Thus, improved marketing systems, particularly through better infrastructures is essential for increasing fertilizer use as it reduces farm-gate prices of fertilizers. For example, Lele *et al.* report that domestic transportation cost make up 22% of fertilizer marketing costs in Malawi, 33% in Kenya and 50% in Tanzania.

The positive sign on the estimated coefficient for water control variable suggests that farmers are more likely to use inorganic fertilizer in *bas-fonds* with water control infrastructure than in unimproved *bas-fonds*. The relative size of the estimated marginal effects clearly shows that water control most strongly influences fertilizer adoption. Installing water control infrastructure in the *bas-fond* increases the probability that farmers will adopt chemical fertilizer by 49%, while village experience in cotton production increases this probability by 36%, and using "improved" varieties increases this probability by 26%. The positive effect of water control is explained by the fact that fertilizer tends to be washed away in fields without water control. This result suggests that increased investment in water control through low-cost and effective small-scale irrigation can make a significant contribution to food production in the *bas-fond* villages in Mali, and indeed throughout SSA. Unless properly managed, water availability may well emerge as one of the key constraints to the intensification of *bas-fond* rice farming. Indeed, this concern extends beyond the *bas-fond* and throughout SSA water because availability is declining and varies considerably across SSA[11]. With the increasing population, the need for low-cost small-scale water control investments for agriculture will continue to grow and acreage under irrigation will remain very low. While the amount of *bas-fond* land potentially exploitable may not be large enough to generate revolutionary increases in rice production in Mali, its contribution to improving household food security is important (Dimithè 1997, Dimithè *et al.*, 1998).

The positive correlation between village years of experience in cotton production (HISTCOT) and farmers' adoption of fertilizer indicates that, as expected, the longer the village has been growing cotton, the more likely farmers will apply fertilizer. This is because such farmers have easier access to fertilizer from CMDT through a household's cotton farmer. This parastatal makes fertilizer available to all cotton farmers every cropping season in the form of a loan farmers repay at harvest. Anecdotal evidence suggests that, in cases where the credit limit of the farmer allows him to get fertilizer only for the cotton field, farmers divert part of their fertilizer to non-cotton fields, including rice. Indeed, from discussions with farmers, as with variety adoption, one of the constraints to wider chemical fertilizers use is the absence of a reliable source of these inputs. CMDT is the only formal source of "improved" inputs, mostly through limited loans that are repaid for from cotton sales. As with seeds, it is apparent that CMDT alone cannot possibly satisfy the potential demand for fertilizers. Thus, the significant effect of the village experience in cotton production suggests a credit and/or input supply constraint in the non-cotton villages. To overcome this constraint CMDT successfully interlocked output and input markets by using farmers' expected future harvest as a collateral for guaranteeing seasonal input loans.

As with variety adoption, the fertilizer model shows an acceptable goodness of fit, based on the highly significant chi-square and the high percent of correct classification. This model correctly classified 75% of the farmers who actually used chemical fertilizers, and 91% of those who did not. Overall, 84% of the farmers were correctly classified into their actual fertilizer adoption category.

[10] The proportion of farmers who applied fertilizer is larger among those who planted "improved" varieties (76%) than among those with "traditional" varieties (22%).

[11] While the humid lowlands of west and central Africa and the mountainous highlands of eastern Africa have favorable rainfall conditions, in more arid region such as the sudano-sahelian zone, water remains a key constraint outside of irrigated areas (Seckler *et al.*, 1991).

6. Summary and Policy Implications

This paper focused on determining the factors associated with farmers' adoption of "improved" varieties and fertilizer application. Logistic regression models used to model farmers' adoption behavior reveal that only farmer's gender, the village distance to the closest market, and plot size have significant (though negative) effect on farmers' likelihood to use "improved" varieties. The model's ability to correctly predict farmers' fertilizer adoption behavior was satisfactory (84% for non-adopters, 75% for adopters, and 80% overall). Logistic analysis also reveals that, in addition to variety (and thus gender, plot size, and village distance to the closest market), the presence of a water control infrastructure and the village years of experience in cotton production increase the likelihood of farmers applying fertilizer. The model's ability to correctly predict farmers' fertilizer adoption behavior was satisfactory (93% for non-adopters, 69% for adopters, and 83% overall).

The positive effect of the presence of farmers' likelihood to use fertilizer suggests that it is critical to provide some form of water control in the *bas-fond* to increase the probability of greater intensification of rice farming in this environment. Discussions with farmers revealed that the irregular pattern of precipitation has historically contributed to discourage rice farming in the *bas-fonds* because the amount of moisture available to the rice plant is often insufficient to ensure acceptable yield levels. Thus, in many *bas-fonds*, water control is a necessary condition for rice production. Currently, only part of the *bas-fonds* is utilized because poor water control condition limits the command area. In order to utilize the total potential area of Mali-Sud *bas-fonds* fully, it would be necessary to improve the water control system. Investing in water control is important to improving *bas-fond* rice production, not only because it increases the likelihood of farmers using fertilizers and leads to an expansion of the command area as the ground water table goes up, thereby allowing farmers to plant a significantly larger proportion of the *bas-fond* area that otherwise could not be cropped, but also because it contributes to PU food security by:

(i) increasing the presence of critical growth and productivity factors (*i.e.*, water and nutrients), particularly in drought prone areas, by allowing farmers to maintain the desired level of water in the *bas-fond* for a longer period of time than would otherwise be possible, thereby reducing drought-induced risks, and as a result, increasing the rate of adoption of new technologies, and thus the returns to research and extension;

(ii) releasing labor for other productive activities through the reduction of non-aquatic weed pressure, especially when land preparation is done properly;

(iii) offering farmers the opportunity to increase their land use intensity by allowing them to first plant crops such as maize, followed by transplanted rice;

(iv) reducing the conflicts on farm labor demand between upland and *bas-fond* farm through a better control of water flow in the *bas-fond*;

(v) contributing to a sustainable rice production environment by reducing soil erosion when infrastructure such as contour ridges are used; and

(vi) encouraging farming families (mostly men) who had previously abandoned rice production because of declining rainfall to return to the *bas-fond* and to intensify rice production.

However, in practice, the extent to which these benefits are captured depends on the effectiveness of the water control. The existing quality and effectiveness of water control infrastructure (*i.e.*, dams across streams with no internal control of the water level) can be improved with complementary investments in plot-level water control (*e.g.*, internal bonding) and a system of canals.

The study shows that men are more likely than women to adopt "improved" varieties. This stems from the paradoxical situation that, although *bas-fond* rice farmers are predominantly women (88%), men have more access to credit and alternative cash flow sources than women. Existing institutional arrangements do not provide women direct access to new rice technologies and other resources such as credit. Currently, the main source of "improved" technology is the CMDT, a government agency which only provides credit to cotton farmers. Because all cotton farmers are men, many of whom are not willing to borrow for their wives, very few women farmers have access to modern inputs. This condition is worsened by the patriarchal nature of the rural social structure which tends not to expect women to generate household income. In cases where cotton farmers may be willing to borrow for their rice spouse, these farmers' input loan amount is constrained by their credit limit (no more than 36% of cotton revenues). As a result, women have limited access to household resources for investing in rice inputs. It is therefore essential that credit opportunities specifically targeting women be design to promote a greater intensification of agriculture in general and *bas-fond* rice farming in particular.

Indeed, the low level of agricultural input marketing and use observed in SSA, even where input use is theoretically profitable, is largely attributable to the failure of seasonal rural credit markets. Typically, only few farmers manage to auto-finance input purchase out of earnings retained from previous season harvest or from other income-generating activities (importance of income-generating non-farm activities). Similarly, few small-scale farmers have the type of assets that are suitable from the point of view of existing formal lending agencies as collateral for guaranteeing seasonal input loans. Attempts to address this constraint through micro-finance/banking have not been successful because they rarely provided seasonal credit for inputs and focused on short-term loans for marketing and processing. In cases where loans were provided for seasonal input, repayment rates were extremely low because of the rampant strategic default behavior of the borrowers because default was rarely punished and loan repayment rarely rewarded (automatic guarantee to receive loan next season).

While the important question regarding the extent to which the policy reforms lunched in 1990s stimulate the development of reliable sources of seeds in Mali is not addressed in this study, various studies show that the liberalization of agricultural markets and privatization of such service delivery in the agricultural sector have had a number of positive effects and created new incentives for the private sector in many SSA countries. However, in many of these countries, active and competitive private input supply markets meeting the needs of most rural people for seed and fertilizer have not yet fully developed. Successful agricultural programs have, with few exceptions, worked around the problem of poorly developed agricultural input markets, by developing *ad hoc* solutions that serve the program needs but do not leave a broad sustainable private sector-led agricultural input supply systems in place.

Empirical studies of agricultural input supply systems show that the development of a sustainable agricultural input supply system requires market signaling and the most efficient private-based systems are those with a high degree of competition. As market systems become competitive and more efficient (through specialization), transaction costs will decline, resulting in net gain to input suppliers and farmers. However, as evidence by CMDT experience, commercial input providers operating in this competitive market need to be able to exercise some control over farmers' marketing activities in order to guarantee loan repayment while ensuring that farmers get competitive prices for their harvest. Indeed, in the pre-liberalization era, the successful marketing boards overcame the rural credit problem by supplying seasonal input credits (usually in-kind) to farmers which was paid for directly from deduction in the resulting farmers crop sale which they controlled. However, it is important to recognize that this use of borrower's expected crop harvest as collateral substitute to guarantee loan repayment operated mainly on cash crops, and only rarely on food crops. This points out to the importance of the value of the crop harvested, and thus the existence and performance of the output markets.

Therefore, the study recommends that if the Mali government or any other donor wish to promote private sector participation in the development of sustainable agricultural input supply, their strategy should support a high degree of competition in a way which provides market signaling in reducing information asymmetry and credible commitments necessary for the development of input markets systems with low transaction costs. One can use expected future harvest as a collateral for guaranteeing seasonal input loans, especially in high potential areas where the likelihood of climatic-induced crop failures is minimal. Still, there is uncertainty surrounding other people's real intention when contracting because of imperfect information (bounded rationality) and opportunistic human behavior (tendency to renege on an agreement when one perceives it to be on his interest to do so). This gives rise to the cost of screening potential contracting parties, monitoring their activities during the contract, and enforcing the terms of the contract if they try to renege on them in any way. This cost rises as specialization increases and transactions become more complex and specific. These costs usually undermine the development of such contracting between potential parties, and thus the development of rural credit markets. To promote greater interaction between these parties, one needs to create an environment that will minimize the risks faced by the parties and which is associated with not knowing other people's real intentions, while at the same time providing incentives to both parties to maximize efforts in the fulfilment of the contract.

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