Investing in Soils:

Field Bunds and Microcatchments in Burkina Faso

March 13, 2001

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Summary
This research uses field-level data from Burkina Faso to ask what determines farmers' investment in two well-known soil and water conservation techniques: field bunds (barriers to soil and water runoff), and microcatchments (small holes in which seeds and fertilizers are placed). Survey data for 1993 and 1994 are used to estimate Tobit functions, compute elasticities of adoption and intensity of use, perform robustness tests and estimate alternative models. Controlling for land and labor abundance and other factors we find that those who have more ownership rights over farmland, and who do more controlled feeding of livestock, tend to invest more in both technologies. The result suggests that responding to land scarcity with clearer property rights over cropland and pasture could help promote investment in soil conservation, and raise the productivity of factors applied to land.

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Selected Paper: American Agricultural Economists Association Annual Meeting, August 5-8, 2001

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Acknowledgement: The data used in this study were collected by a project funded by the Canadian Agency for International Development and conducted by the University of Ouagadougou (Burkina Faso) and Laval University (Quebec, Canada). The authors thank Taladidia Thiombiano and Frederic Martin for making the data available, and Gerald Shively, Jess Lowenberg-DeBoer, and three referees for very helpful comments.

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1. Introduction and background

Africa has the world's highest rates of rural population growth, and fastest decline in the land area available per farm worker (FAO 2000). Prominent observers have argued that increasing land scarcity could lead to soil degradation, and perhaps irreversible declines in the productivity of labor and other resources applied to land (e.g. WRI 1999, UNEP 2000). Alternatively, land scarcity could lead farmers to invest in soil improvement, perhaps eventually triggering sustained growth in productivity and income as suggested by Boserup (1965).

Earlier work has found some evidence for a Boserup effect at the aggregate level in Africa, using cross-country data (Lusigi and Thirtle 1997). In this paper we look at the field level, using two years of survey data from Burkina Faso to quantify farmers' adoption of specific soil improvement techniques, and ask how economic or policy conditions affect the intensity of their adoption. Respondents are very low-income farmers, facing a variety of land-scarcity and land tenure regimes (Sourabi 1999). Their choices could provide important insight into how cropland is managed under conditions of extreme scarcity and widespread degradation.

Whether land scarcity leads to a downward spiral of soil degradation and yield decline, or to a virtuous cycle of soil conservation and productivity growth, might depend in part on the evolution of property rights over land. Traditional land tenure systems in Burkina Faso and most of Africa involve revocable use-rights managed by community leaders (Bassett and Crummey 1993). Such systems may have been useful in the past, but could be increasingly costly as population growth raises the need for long-term investments whose returns may be heavily "taxed" by the absence of ownership rights (Goldstein and Udry 1999). Property rights are likely to be important not only for cropland but also for pastures, to the extent that enclosing animals facilitates the recovery of manure which is usually lost when herders have access to commons grazing (Dalton and Masters 1998).

What is at stake in soil quality is not only the productivity of natural resources, but also the productivity of labor and other inputs applied to land. Thus an increase in land scarcity that leads to a new property-rights regime and hence accelerated investment in soil quality could be the mechanism for a Boserup effect, translating higher population density into faster total productivity growth and faster growth of real incomes (Rosenzweig, Binswanger and McIntire 1988).

In our survey regions as elsewhere, farmers have long experience using labor to improve their fields. Two of the oldest and most important such soil and water conservation (SWC) techniques in Burkina Faso are bunds (low stone or dirt walls to stop surface runoff) and microcatchments (small holes into which compost or manure is placed and plants are seeded, to concentrate available moisture and nutrients). Both techniques help hold soil and water for delivery to plants, producing a well-documented increase in the productivity of land and inputs (Ouedraogo and Illy 1996; Ouedraogo and Bertelsen

1997). By holding soil and water in place they represent fundamental long-term investments that complement variable inputs, including organic as well as inorganic fertilizers. Such investments could become more attractive as land becomes increasingly scarce relative to labor. They may also become more attractive as farmers gain more secure ownership rights over land. A third kind of incentive could come from reduced access to commons grazing, as more intensive livestock management makes manure more available for use on cropland. This paper tests these propositions, which provide possible mechanisms for Boserup-type effects by which increased population, interacting with property rights, could lead to productivity growth over time.

2. Determinants of SWC investment

The average level of soil and water conservation investment in Burkina Faso can be described as moderate. Measuring investment level in terms of the share of land on which SWC techniques have been applied, in our survey areas we found bunds on 19 percent of cropped land, microcatchments on 27 percent of cropped land, and both techniques together on 7 percent (Table 2).

Previous studies of the determinants of SWC investment have focused on farmers' subjective beliefs and sources of information (e.g. Shively 1997, Anim 1999, Baidu-Forson 1999), as well as farmers' material conditions such as farm assets, factor markets, and population pressure (e.g. Laper and Pandey 1999, Pender and Kerr 1998, Barbier 1998 and the review by Templeton and Scherr 1997). Here we aim to isolate the influence of the relative abundance of land and labor (entering separately in the model), from the property-rights regime that governs cropland ("ownership" as opposed to use-rights) and grazing (intensive livestock management as opposed to open-access grazing). These factors are investigated in the context of several control variables, such as socioeconomic conditions and physical geography, as listed in Table 1 and detailed below.

2.1 Availability of cropland and farm labor

Our core measures of land and labor abundance are cropped acreage per farm, and the number of men and women aged 15 and over. We count males and females separately because gender influences the kinds of tasks most often undertaken, and families differ in composition. We enter separate variables for land and labor, rather than the land/labor ratio, to capture scale effects that might arise from having more of both in a single household.

In Burkina Faso, average farm size varies across villages by far more than could be explained by underlying differences in land quality, due to disease pressure and political boundaries influencing migration. Since the mid-1970s, there have been large population movements southward to escape drought, and into valleys to take advantage of onchocerciasis control (Sourabie 1999). The result is large variance in cropland scarcity across surveyed regions, with farm size varying by a factor of 100, from 0.2 to over 20 hectares per household (Table 2). Across villages, controlling for family size and composition, we see village-average land-labor ratios ranging from 0.2 to 0.87 hectares per worker (Annex Table 1). (These data convert the population into adult-equivalent workers to facilitate comparison across households, using conversion factors from Tabatai 1993.)

The effect cropland scarcity on SWC investment is ambiguous. On the one hand, higher land scarcity could bring a substitution effect towards land-saving, labor-using techniques (e.g. Anim 1999 found that South African farmers with less land make greater investments in soil conservation, and Adesina and Zinnah 1993 found that smaller farmers invest more in new rice varieties). On the other hand, indivisibilities and scale effects could make some new technologies more profitable on larger farms (e.g. Nichola and Sanders 1996 found that larger farms were more likely to adopt a hybrid sorghum in Sudan). For bunds and microcatchments, farmers with less land but more labor may have a greater incentive to use labor to raise yields, but farmers with more land may make greater investments of all kinds, so the net effect of land scarcity remains ambiguous. In any event, since the degree of land scarcity is largely exogenous to policy decisions, we are concerned less with its direct effects than with policy responses to it, including particularly the evolution of property rights.

2.2 Property rights

We use two distinct indicators to capture the property-rights regime governing cropland and grazing areas. For cropland, we measure the security of tenure by the proportion of area that the farmer reported to be “borrowed” or “rented” as opposed to “owned”. For pasture, we measure ease of access to commons grazing by the labor-intensity with which livestock are managed. Each measure is discussed in turn below.

Cropland markets in Burkina offer no formal land tenure categories. Colonial authorities and post-independence governments have sustained traditional use-rights, through which village leaders allocate land across extended families, whose leaders in turn allocate it among individual households. Since 1984 a series of land-tenure decrees have been enacted, but in practice tenure continues to be governed by traditional arrangements (Sourabie 1999). In our data, farmers reported as "owned" the land that was securely within the control of their own extended family. "Borrowed" or "rented" land had been obtained on a temporary basis from another family. Across our survey villages, the proportion of cropland not owned by the operator's family ranged from zero in one village, to 54 percent in another (Appendix Table 1). We expect that land not owned is less likely to be improved with bunds and microcatchments, due to the long-term nature of these investments.

Livestock grazing in Burkina are still predominantly done on common lands. The dominance of commons grazing over other feeding arrangements is often an appropriate response to the low density and "patchy" distribution of pasture resources (Scoones et al. 1996). Nonetheless, a rising density of people and livestock is leading farmers to take livestock into more intensive feeding systems, in response to less abundant pasture and less access to what pasture there is (Fisher et al. 2000). One effect of more intensive feeding is that manure becomes more easily available, raising the productivity of soils and the potential value of SWC investments to prevent erosion and retain moisture (Sanchez et al. 1997, Palm et al. 1997).

In our data we measure the combined effect of pasture scarcity and pasture rights in terms of the intensity with which farmers manage their livestock, as the number of adults involved in feeding and monitoring animals on the farm. Typical practice in commons grazing is for children to walk with the herds to monitor strays, deter theft, and return the animals at night. As pasture becomes scarce and conflict over grazing areas worsens, herd owners adopt more intensive feeding systems that require increasing numbers of adult workers. Thus child and adult labor represent distinct animal-feeding technologies, and are not close substitutes: in an auxiliary regression, the number of children monitoring animals is found to have no effect on the number of adults involved. The number of adults is zero for many households, and the village-wide averages vary from 0.03 to 4.67 (Appendix Table 1).[1]

The link between open-access grazing, manure use, and crop productivity was detailed by Dalton and Masters (1998), using a biophysical model of crop production linked to an economic model of crop and livestock choices, calibrated to farming conditions in Southern Mali. In their model, it is optimal for farmers who have access to public grazing to use that resource, but when pasture taxes or forage scarcity induce farmers to intensify livestock management, doing so increases manure use and raises crop productivity. We hypothesize that, in the Burkina Faso context, more intensive livestock

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[1] For this calculation we define as adult any person aged 15 or more, not in school at the time of the survey. During the survey, each individual aged of 15 or more was asked to list his principal and secondary activities during the rainy season and the off-season. The number of adults involved in livestock monitoring in each household is the sum of those who reported that activity as their principal one in either season.

management could also lead to more investment in bunds and microcatchments, since manure availability helps increase the value of soil and the cost of erosion. We expect that livestock management decisions are driven by pasture scarcity independently of SWC investment, but there is also some possibility of reverse causality as intensification of livestock care may be an endogenous response to SWC investment. We investigate that possibility with exogeneity tests.

2.3 Control variables

To test for independent effects of our land, labor and property-rights variables, we must control for a wide range of other factors that may influence SWC investments.

Our first set of controls are regional dummy variables, to account for omitted variables reflecting soil quality or other agroeconomic factors. There may be some residual variance in these factors across villages and households, but to use village dummies would exhaust our degrees of freedom.

A second kind of control is the share of the household's land that is exploited by women as opposed to men. This could matter for SWC investment if gender influences preferences, or affects access to particular resources. In the Burkina context, women are likely to face more severe constraints in credit markets which would inhibit all kinds of investment, are may also have less secure land-use rights whether or not the land is owned by their family. They may also have relatively less of the upper-body strength needed to construct bunds and microcatchments, although in the Burkina context women do undertake these and many other onerous tasks.

A third kind of control concerns household wealth and income. Wealthier households may be have greater access to capital, facilitating investment, but they may also have higher opportunity costs of labor, inhibiting labor-intensive activities such as SWC. One way we measure wealth is through households' reported real expenditure on non-food consumption goods, per adult equivalent, converted into foodgrain units at local relative prices for ease of comparison. The underlying assumption is Engel's law, by which nonfood expenditure rises rapidly with wealth, making it a particularly sensitive measure for our purposes. Another observed measure of wealth is the value of agricultural equipment on the farm, representing the accumulation of capital assets over time. And a third measure concerns the household's access to off-farm income, which may provide farm finance but also draw labor off the farm.

3. Analytical approach

To distinguish the marginal effects of each variable, we assume that farmers respond to their circumstances in a consistent utility-maximizing way, as in Rahm and Huffman (1984) and Adesina and Zinnah (1993). A particular technology is adopted when the anticipated utility from using it exceeds that of non-adoption. Though it is not observed directly, the utility (U) for a particular farmer (i) to use a particular technique (j) can be defined as a farm-specific function of some vector of technology characteristics, plus a disturbance term with zero mean:

$$U_{ij} = a_{ij}G_i(X_j) + e_{ij},\ j = 1, 0\ ;\ i = 1,\ldots,n \qquad (1)$$

where 1 represents adoption of the new technology and 0 represents continued use of the old technology. The i^{th} farmer adopts j=1 if $U_{i1} > U_{i0}$.

For empirical purposes, the utility of adoption U_{ij} can be inferred from farmers' binary choice (adopt or not adopt) or some continuous choice over a predefined interval (intensity of adoption). The former implies a probit or a logit model, as in Lapar and Pander (1999) and Anim (1999). To consider the intensity of adoption, a Tobit model is needed, as in Lynne et al (1988), Adesina and Zinnah (1993) and Baidu-Forson (1999). Assuming that G is linear, from McDonald and Moffit (1980) we have the underlying stochastic model in Tobit form:

$$\begin{aligned} Y &= X\beta + \mu \quad if \quad X\beta + \mu > 0 \\ &= 0 \qquad\quad\ \ if \quad X\beta + \mu \leq 0 \end{aligned} \qquad (2)$$

Where X is as defined above, Y is the dependent variable vector, β is a vector of unknown parameters and μ is a normally distributed disturbance term with mean 0 and constant variance σ^2. The expected value of Y can be written as:

$$EY = F(z)EY^* \qquad (3)$$

Where F is the cumulative normal distribution, z is defined as $X\beta/\sigma$, Y^* is the observations above the threshold, and E stands for the expectation operator (see Greene 1997 for full discussion.). Using (3), McDonald and Moffit first showed that the marginal effect of an independent variable has two components and can be decomposed as follows:

$$\frac{\partial E[y_i \mid x_i]}{\partial x_i} = P(y_i > 0)\frac{\partial E[y_i \mid x_i, y_i > 0]}{\partial x_i} + E[y_i \mid x_i, y_i > 0]\frac{\partial P(y_i > 0)}{\partial x_i} \qquad (4)$$

The first term on the RHS is the expected response of current users to the change in x_i and the second term is the response of non-users. By multiplying both sides by $x_i/E(y_i)$, one can interpret the results as the usual elasticities. These elasticities have been termed as the elasticity of expected use intensity and the elasticity of adoption probability respectively.

4. Data sources and survey methods

The data were collected in eight villages in four different regions of Burkina Faso during the 1993 and 1994 cropping years. The covered regions are the Namentenga province in the Central Plateau, the Soum province in the North, the Kossi province in the West and the Nahouri province in the Southeast.

In each region, two representative villages were chosen, one representing the wealthier villages and the other reflecting the poorer ones in that region, and then 35 households were randomly selected in each village except in the North where 40 households were chosen in anticipation of a higher dropout rate due to out-migration. Agriculture is the main activity in all regions, but livestock is more important in the North, which has also experienced the greatest population pressure and soil degradation.

The survey covered farm characteristics, production technologies, inputs and outcomes, consumption levels and marketing activities. To facilitate repeat visits, an enumerator was installed in each village with a coordinator for each survey region. The farmer responsible each individual plot was interviewed, and the head of the household was interviewed regarding the common plots. For some variables, such as field area, each plot operator was visited once, while multiple visits were required for management variables such labor allocation, animals feeding and monitoring. Table 2 presents statistics for the variables used in our model, and selected others.

5. Estimation methods and model specification

To recover correlations between SWC investments and their determinants (the β parameters of equation 2), we begin with standard MLE methods (Maddala 1983, Greene 1997), and then use semi-parametric methods (following Powell 1984 and Deaton 1997) to remedy some non-standard characteristics of our data. We also report results for the Cragg (1971) generalization of the Tobit, as a more flexible specification.[2] The MLE results and implied elasticities are presented in Tables 3 and 6, while the semi-parametric results are in Tables 4 and 7, and the Cragg model results are in Tables 5 and 8. In all cases, separate regressions are reported for bunds, for microcatchments, and for the two techniques together.

One of the key variables whose influence we wish to estimate, livestock intensification, could itself have been influenced by farmers' SWC choices. To test whether endogeneity

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[2] All estimates and test statistics were computed in Gauss. Program and data files are available from the authors on request.

matters in this context we use the approach developed by Smith and Blundell (1986), as applied by Shively (1998), in which exogeneity holds if $\alpha=0$ in the regression:

$$y_1 = \beta_1 y_2 + \beta_2 X_1 + \alpha \tilde{v}_2 + \varepsilon , \qquad (5)$$

where y_1 is the adoption variable, y_2 is the potentially endogenous variable, and $\tilde{v}_2$ is the residuals from an OLS regression of y_2 on a set of instrumental variables.[3] We can reject endogeneity at the 1 percent level for the three regressions, and hence no remedy is needed.

Maximum likelihood Tobit estimates can be highly sensitive to non-normality and heteroskedasticity of the disturbance terms (Deaton 1997), and indeed our diagnostic tests reject normality and homoskedasticity for these regressions. We present MLE results because the technique remains widely used, but also apply semi-parametric Censored Least Absolute Deviations (CLAD) estimators that are less sensitive to non-normality and are robust to heteroskedasticity (Powell 1984). Comparison between the CLAD and the MLE estimates provide an indication of the effects of non-normality and heteroskedasticity on the regression coefficients (Deaton 1987). In this case, estimates are of somewhat lower magnitude and different significance levels using CLAD than using MLEs, but the principal results are the same.

[3] The instruments used for this test were dummy variables for each village, the number of children in each household, and the number of animals owned by each household. These are relevant to our instrumented variable (livestock intensification) because the villages differ in grazing resources, the children facilitate open-access grazing, and larger herds are more difficult to enclose, but likely to be uncorrelated with the error term in the Tobit.

In addition to normality and homoskedasticity of the errors, we are also concerned with specification of the model. A first kind of specification test is whether Tobit itself is appropriate. Despite its wide use to study adoption of SWC (Pender and Kerr 1999) and other techniques (Adesina and Zinnah 1993; Baidu-Forson 1999), it imposes restrictions that could bias our estimates. In particular, the Tobit assumes that the explanatory variables have the same direction of effect on the probability of adoption and on its intensity (Greene 1997). We find some evidence that this assumption does not hold, using the tests due to Lee and Maddala (1985) and Lin and Schmidt (1984), and so compare our Tobit results with estimates from the more general specification suggested by Cragg (1971).

A further kind of specification test asks whether the same model parameters hold across all regions. The basic model includes dummy variables to capture regional differences in the average level of investment, but we would also like to know if there are regional differences in the response of investment to land scarcity or property rights. Our data set is not large enough to estimate separate regressions for each region, but we can construct a test for regional differences in the coefficients on key variables of interest, by adding the interaction of that variable with a dummy for each region (excluding the omitted one). To avoid adding a large number of regressors, we conduct separate tests for each variable, so the model becomes:

$$Y_i = \beta X + \alpha_1 R_1 X_k + \alpha_2 R_2 X_k + \alpha_3 R_3 X_k \tag{6}$$

Where Y and X are as defined previously, the R_i are dummy variables for the Namentenga, Kossi and Nahouri regions (with Soum the omitted region), and k is cropland scarcity, cropland ownership, or livestock intensification. Our test asks whether the three R_iX_k variables in (6) can be omitted from the equation; using conditional moments following Chesher and Irish (1987). In this case we are unable to reject that hypothesis, and therefore maintain the simpler aggregate model without regional interaction effects.

All diagnostic and specification test results are presented at the bottom of Table 3. In the Tobit context, these tests use the formula for generalized residuals due to Pagan and Vella (1989, p. S37). All test statistics are Lagrange multipliers distributed χ^2 with degrees of freedom equal to the number of restrictions under the null hypothesis. The relevant degrees of freedom are shown with each test, and significance levels are indicated using asterisks.

6. Regression results

Considering the results of our diagnostic and specification tests, we use three kinds of coefficient estimates: the Tobit model with maximum-likelihood estimates (Table 3) and semi-parametric CLAD estimates (Table 4), and then the Cragg model with MLEs (Table 5). A total of twelve coefficients are estimated for each variable, testing its correlation with adoption of both techniques together, of bunds only, and of microcatchments only, plus separate estimates for adoption and intensity in the Cragg model.

Looking across the twelve specifications, cropland area and male labor availability per household have generally insignificant effects on both kinds of SWC investment, while female labor availability generally reduces it, when controlling for other factors. This result is consistent with the discussion in section 2.1 above, which noted that the anticipated effect of land and labor availability on SWC investment is ambiguous.

The effects of cropland ownership and livestock intensification are expected to be positive, however, and the regression results generally support that hypothesis. When controlling for factor abundance and other influences, the coefficient on cropland ownership is consistent in sign (negative in all cases except one, so that a greater share of land not owned is associated with less SWC investment) and significant at the 1 percent level in five of the twelve cases and at the 10 percent level in another five cases. The coefficient on livestock intensification is also consistent in sign (positive in all cases except one, so that having more adults caring for livestock is associated with more SWC investment), although the magnitude is small and only significant in 4 of the 12 cases.

Across the specifications, we see a clear pattern of support for the hypothesis that households are more likely to have made more SWC investment if they own the land they farm, and some further support for the hypothesis of more SWC investment if they have devoted more effort to taking animals off of commons grazing. The effects of land scarcity and labor supply, which were thought to be ambiguous, turn out to be varied in sign and generally not significant.

Among the control variables, none of the region dummy variables have coefficients that are consistent in sign, but the coefficient on gender is consistently negative (a larger proportion of land under female control is associated with lower SWC investment), and the three measures related to wealth or income (namely nonfood expenditure, agricultural equipment and off-farm income) are consistently negative, although only the agricultural equipment measure is consistently significant.

The significance of property-rights variables, but not of land scarcity itself, supports the idea that institutional responses to population density rather than population density itself are what drive technical change. In other words, increased density *can* lead to soil improvement, but only to the extent that it spurs changes in property rights that give the farmer an incentive to do so, by clarifying ownership of cropland and by forcing animals off commons grazing. Differences in property rights could matter not only across households, but within them as well, to the extent that women's less secure land rights helps explain the negative correlations we find between female labor or management and SWC investment.

To illustrate the magnitude of the effects we estimate, Tables 6, 7 and 8 present the implied elasticities and bootstrapped standard errors for each regression. Elasticities with respect to the share of cropland not owned and the number of adults feeding livestock are both under 50 percent using MLE methods, but over 90 percent in three of the six CLAD estimates. These magnitudes are clearly nontrivial, but to obtain more reliable estimates we would need larger sample sizes.

7. Conclusion

This research uses farm-survey data to investigate the determinants of investment in soil and water conservation technologies at the field level. We consider two different techniques, bunds and microcatchments, plus simultaneous adoption of both. A maximum-likelihood Tobit model was used to link farmers' investment in these techniques to a wide variety of observable variables, using data collected in four different regions of Burkina Faso. Various diagnostic and robustness tests led to estimation of the Tobit using the semi-parametric method suggested by Powell (1984), and to relaxing Tobit assumptions using the more general model of Cragg (1971). Across these various specifications, the empirical results of interest vary in magnitude but are consistent in sign and significance.

Our central result is that, when controlling for land and labor availability plus a range of other factors, farmers' SWC investments respond particularly to two policy-influenced variables: the degree to which their land is securely owned (as opposed to being borrowed or rented), and the degree to which their livestock are intensively managed (as opposed to being fed from open-access grazing). These results imply that, as land becomes increasingly scarce, policies to take reflect land scarcity in more clearly defined property rights over cropped areas and commons grazing are likely to encourage investment in soils. These findings provide some grounds for optimism that even the most resource-poor farmers can and do invest in conservation activities, when institutional responses to resource scarcity include clearer definition of property rights.

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Table 1. Measures and hypothesized determinants of SWC investment

Variable	Definition and units
SWC investment	
Bunds	Percent of cropland covered (%)
Microcatchments	Percent of cropland covered (%)
Both bunds and microcatchments	Percent of cropland covered (%)
Land scarcity & property rights	
Cropland scarcity	Cropland used per worker (adult equivalents) (ha)
Cropland ownership	Cropland used but not “owned” (%)
Livestock intensification	Adults involved in monitoring animals (no.)
Control variables	
Gender of farmer	Cropland exploited by women (%)
Wealth of household	Non-food consumption per cap., in kg of cereals
Equipment availability	Value of agricultural material (FCFA)
Off-farm income	Annual off-farm income per adult equivalent (FCFA)
Namentenga	Dummy (1=Namentenga, 0=others)
Kossi	Dummy (1=Kossi, 0=others)
Nahouri	Dummy (1=Nahouri, 0=others)
Soum	(omitted region)

Table 2: Descriptive statistics by area and for whole sample

	Namentenga (n=61)				Soum (n=69)				Kossi (n=66)				Nahouri (n=62)				Overall (n=258)			
	Mean	St dev	Min	Max	Mean	St dev	Min	Max	Mean	St dev	Min	Max	Mean	St dev	Min	Max	Mean	St dev	Min	Max
Dependent variables																				
Bunds (%)	7.73	23.04	0.00	100.00	0.44	2.35	0.00	16.48	36.13	45.90	0.00	100.00	11.28	28.01	0.00	100.00	13.90	32.10	0.00	100.00
Microcatchments (%)	21.60	33.49	0.00	100.00	50.01	41.49	0.00	100.00	14.88	21.86	0.00	77.12	28.07	33.47	0.00	100.00	29.03	35.88	0.00	100.00
Bunds+microc. (%)	6.53	22.28	0.00	100.00	0.15	1.23	0.00	10.18	12.49	20.45	0.00	77.12	6.97	20.40	0.00	100.00	6.45	18.46	0.00	100.00
Land scarcity & property rights																				
Cropland/worker (ha)	0.94	0.75	0.12	3.88	0.85	0.83	0.07	3.51	1.00	0.93	0.18	7.18	0.55	0.54	0.08	2.74	0.84	0.79	0.07	7.18
Memo: cropland/hh (ha)	5.76	5.18	0.38	26.52	3.66	3.08	0.35	16.54	5.83	8.21	0.19	64.20	2.76	2.47	0.56	17.14	4.49	5.39	0.19	64.20
Cropland not owned (%)	15.15	31.77	0.00	100.00	17.30	34.57	0.00	100.00	42.24	47.39	0.00	100.00	0.93	0.25	0.00	100.00	21.26	37.74	0.00	100.00
Labor supply, female (no)	2.30	1.96	0.00	13.00	2.38	1.43	0.00	8.00	1.91	1.29	0.00	7.00	2.35	1.89	0.00	10.00	2.23	1.66	0.00	13.00
Labor supply, male (no)	1.90	1.49	0.00	7.00	2.13	1.38	0.00	8.00	1.91	1.20	0.00	5.00	1.97	1.13	0.00	5.00	1.98	1.30	0.00	8.00
Lvtsk. Intens. (# adults)	1.41	1.92	0.00	9.00	0.46	1.02	0.00	5.00	0.98	1.57	0.00	6.00	3.52	2.41	0.00	13.00	1.55	2.11	0.00	13.00
Control variables																				
Gender (% by women)	29.09	30.16	0.00	100.00	14.05	24.47	0.00	100.00	0.88	23.89	0.00	100.00	12.47	30.23	0.00	100.00	15.89	28.10	0.00	100.00
Off-farm inc.('000 fcfa/yr)	26623	68150	0.00	522000	64489	104819	0.00	624000	30624	44035	0.00	222000	21156	19433	0.00	92250	36995	70011	0.00	624000
Wealth* (Nonfood cons.)	67.49	99.78	2.86	759.95	144.98	132.05	14.02	740.04	151.41	187.55	11.28	1374.54	101.73	117.63	9.22	751.57	117.91	142.37	2.86	1374.54
Ag. Equip. (1000 cfa)	11952	34632	0.00	142000	11422	34899	0.00	210000	30000	58472	0.00	278000	15454	32896	0.00	150000	17270	42215	0.00	278000

Note: * Our wealth measure is real nonfood expenditure per adult-equivalent, expressed in terms of cereal crops to facilitate comparison across households.

Table 3. Tobit regression results using MLE

	Dependent variables:		
Independent variables:	Adoption of both techniques	Adoption of bunds	Adoption of microcatchments
Land and Labor Availability			
Cropland scarcity (ha)	-0.0030	0.0090	-0.0020
	0.0031	*0.0030* ***	*0.0068*
Labor supply, female (no.)	-0.0332	-0.0523	-0.0649
	0.0102 ***	*0.0144* ***	*0.0183* ***
Labor supply, male (no.)	0.0013	-0.0348	0.0381
	0.0070	*0.0114****	*0.0144* ***
Property Rights			
Cropland ownership (% not owned)	-0.1700	-0.2820	-0.1434
	0.0251 ***	*0.0361* ***	*0.0512* ***
Livestock intens. (no. of adults)	0.0001	0.0001	-0.0001
	0.000024 ***	*0.000034* ***	*0.0001*
Control Variables			
Namentenga region (dummy)	0.0225	0.0310	-0.0384
	0.0278	*0.0445*	*0.0554*
Kossi region (dummy)	-0.1146	-0.1644	0.3934
	0.0324 ***	*0.0495* ***	*0.0490* ***
Nahouri region (dummy)	0.1577	0.4128	-0.0892
	0.0281 ***	*0.0403* ***	*0.0633* *
Gender (% farmed by women)	-0.0759	-0.0933	-0.2560
	0.0371 **	*0.0535* **	*0.0605* ***
Wealth (nonfood expenditure)	0.0371	0.0873	0.0585
	0.0133 ***	*0.0197* ***	*0.0230* ***
Agric. equipment (FCFA)	0.0012	0.0025	0.0012
	0.0003	*0.00035* ***	*0.0006* **
Off-farm income (FCFA/yr)	0.0005	0.0006	0.0001
	0.000075 ***	*0.00015* ***	*0.0002*
Constant	-0.0410	-0.0658	0.2647
	0.0301 *	*0.0466* *	*0.0575*

Table 3. (continued)

	Dependent variables:		
Independent variables:	Adoption of both techniques	Adoption of bunds	Adoption of microcatchments
Log-likelihood	-176.680	-181.871	-204.680
Diagnostic and specification tests			
Normality(2)	75.5 ***	277.9 ***	203.3 ***
Homoskedasticity (1)	9.86 ***	6.70 ***	7.038 ***
Tobit--Lee&Maddala(13)	171.9 ***	105.7 ***	37.60 ***
Tobit--Lin&Schmidt(14)	379.5 ***	182.9 ***	27.12 **
Regional differences tests			
Land (3)	4.238	3.726	2.386
Adults (3)	3.114	4.410	1.846
Ownerships (3)	0.772	2.594	1.116

Notes: Figures in small italics are standard errors. Asterisks indicate rejection of each null hypothesis, at 10% (*), 5% (**) and 1% (***) confidence levels. The null hypotheses are that coefficients are zero, the error term is normal and homoskedastic, the Tobit assumption of same explanatory for adoption and use-intensity holds, and the regional effects are zero, as described in the text. All diagnostic and specification tests are distributed as $\chi(2)$ and the corresponding degree of freedom are in parenthesis.

Table 4. Tobit regressions results using semi-parametric CLAD

	Dependent variables:		
Independent variables:	Adoption of both techniques	Adoption of bunds	Adoption of microcatchments
Land and Labor Availability			
Cropland scarcity (ha)	-0.0016	0.0056	-0.0012
	0.0044	*0.0063*	*0.0079*
Labor supply, female (no.)	-0.0183	-0.0271	-0.0360
	*0.0157 **	*0.0324*	*0.0435*
Labor supply, male (no.)	0.0001	-0.0227	0.0233
	0.0153	*0.0181 **	*0.0274*
Property Rights			
Cropland ownership (% not owned)	-0.0778	-0.1745	-0.0616
	*0.0488 **	*0.1392 **	*0.2695*
Livestock intens. (no. of adults)	0.0000	0.0001	0.0000
	0.000035 *	0.0001	0.0002
Control Variables			
Namentenga region (dummy)	0.0841	0.0722	-0.2590
	0.1128	*0.0963*	*0.1482 ***
Kossi region (dummy)	0.1298	0.3287	-0.3362
	*0.0765 ***	*0.1082 ****	*0.3090*
Nahouri region (dummy)	0.0515	0.0561	-0.2649
	0.1074	0.4308	0.2413
Gender (% farmed by women)	-0.0481	-0.0381	-0.1753
	0.0730	0.2002	0.3879
Wealth (nonfood expenditure)	0.0224	0.0549	0.0303
	0.0294	*0.0435 **	*0.0649*
Agric. equipment (FCFA)	0.0006	0.0016	0.0004
	0.0010	*0.00114 **	*0.0020*
Off-farm income (FCFA/yr)	0.0004	0.0004	0.0000
	0.0005	*0.0004*	*0.0012*
Constant	0.0124	0.0392	0.5550
	0.1135	*0.1079*	*0.198055****

Notes: Figures in small italics are standard errors. Asterisks indicate rejection of the null hypothesis that coefficients are zero, at 10% (*), 5% (**) and 1% (***) confidence levels.

Table 5. Cragg model regression results using MLE

	Dependent variables:					
	Adoption of both tech.		Adoption of bunds		Adoption of microcatch.	
Independent variables:	Adoption	Use-intensity	Adoption	Use-intensity	Adoption	Use-intensity
Land and Labor Availability						
Cropland scarcity (ha)	0.0323	0.0051	0.0405	0.0012	0.0215	-0.0120
	*0.0232 **	*0.0094*	*0.0283 **	*0.0052*	*0.0197*	*0.0087 **
Labor supply, female (no.)	-0.2931	-0.1841	-0.2347	-0.1203	-0.0407	-0.0715
	*0.1252 ***	*0.1054 ***	*0.1089 ***	*0.0560 ***	*0.0790*	*0.0311 ***
Labor supply, male (no.)	-0.0173	0.0387	-0.0379	0.0741	-0.0061	0.0572
	0.0788	*0.0247 **	*0.0746*	*0.0375 ***	*0.0629*	*0.0232 ****
Property Rights						
Cropland ownership (% not owned)	-0.9887	-0.5475	-0.8817	-0.2810	0.0252	-0.2543
	*0.3817 **	*0.3911 **	*0.3242 ****	*0.1657 **	*0.2380*	*0.1000 ****
Livestock intens. (no. of adults)	0.0003	0.0001	0.0003	0.0000	0.0000	0.0000
	0.0003	*0.0002*	*0.00028 **	*0.0002*	*0.0003*	*0.0002*
Control Variables						
Namentenga region (dummy)	1.1274	1.2326	0.7156	0.1384	-0.5099	-0.1977
	*0.5032 ****	*0.5041 ****	*0.3768 ***	*0.1876*	*0.2459 ***	*0.1187 **
Kossi region (dummy)	1.8054	1.3972	1.5814	-1.2342	-1.2616	0.1134
	*0.4964 ***	*0.7433 ***	*0.3708 ****	*0.6278 ***	*0.2693 ****	*0.0968*
Nahouri region (dummy)	0.9648	1.0910	0.9627	0.4748	-0.9281	-0.1424
	*0.4991 ****	*0.4586 ****	*0.3725 ****	*0.1912 ****	*0.2669 ****	*0.1536*
Gender (% farmed by women)	-0.5389	-0.3622	-0.2824	-0.2882	-0.4784	-0.2297
	*0.4767 **	*0.2648 **	*0.3954*	*0.1911 **	*0.3098 **	*0.1566 **
Wealth (nonfood expenditure)	0.2882	0.0913	0.2149	0.0254	0.1300	0.0165
	0.1670	*0.0970*	*0.150244**	*0.0684*	*0.1226*	*0.0469*
Agric. equipment (FCFA)	0.0063	0.0024	0.0065	0.0007	0.0069	-0.0011
	*0.00277 **	*0.0018 **	*0.0026 ****	*0.0009*	*0.00246 ****	*0.0009 **
Off-farm income (FCFA/yr)	0.0018	0.0014	0.0012	0.0007	-0.0007	0.0007
	*0.00164 ***	*0.0008***	*0.0015*	*0.0007*	*0.0012*	*0.0004 ***
Constant	-2.0702	-1.3660	-1.6414	0.7765	0.6758	0.6499
	0.5127	*1.2109*	*0.3930 ****	*0.1826 ****	*0.2969 ****	*0.1149 ****
Log-likelihood	-33.2368	-76.1115	-100.8230	-4.6114	-158.1950	-28.4422
Specification test						
Log-likelihood ratio test (14)	134.66 ***		152.87 ***		36.09 ***	

Notes: Figures in small italics are standard errors. Asterisks indicate rejection of the null hypotheses that coefficients are zero, at 10% (*), 5% (**) and 1% (***) confidence levels. The null hypothesis for the specification test is a Tobit model, and rejection of the null sustains the Cragg specification.

Table 6. Elasticities at sample mean using Tobit MLE

	Adoption of both tech.		Adoption of bunds		Adopt. of microcatch.	
	Adoption	Use-intensity	Adoption	Use-intensity	Adoption	Use-intensity
Independent variables						
Cropland scarcity (ha)	-0.0466	-0.1108	0.1712	0.3362	-0.0606	-0.0598
Labor supply, female (no.)	-0.2242	-0.5328	-0.4392	-0.8623	-0.8826	-0.8712
Labor supply, male (no.)	0.0099	0.0236	-0.3294	-0.6468	0.5847	0.5771
Cropland ownership (% not owned)	-0.1230	-0.2924	-0.2543	-0.4993	-0.2093	-0.2066
Livestock intens. (no. of adults)	0.0791	0.1880	0.2530	0.4968	-0.1409	-0.1391
Namentenga region (dummy)	0.0181	0.0430	0.0311	0.0611	-0.0623	-0.0615
Kossi region (dummy)	-0.1044	-0.2481	-0.1865	-0.3662	0.7223	0.7129
Nahouri region (dummy)	0.1373	0.3264	0.4479	0.8795	-0.1567	-0.1547
Gender (% farmed by women)	-0.0411	-0.0976	-0.0628	-0.1234	-0.2791	-0.2755
Wealth (nonfood expenditure)	0.0678	0.1610	0.1988	0.3904	0.2156	0.2128
Agric. equipment (FCFA)	0.0718	0.1707	0.1845	0.3624	0.1408	0.1390
Off-farm income (FCFA/yr)	0.0570	0.1354	0.0895	0.1758	0.0131	0.0129

Notes: For regional dummy variables, the values reported are changes in the dependent variable in response to the change in the binary variable from zero to one.

Table 7. Elasticities at sample mean using Tobit CLAD

	Both techniques		Bunds		Microcatchments	
	Adoption	Use-intens.	Adoption	Use-intens.	Adoption	Use-intens.
Independent variables						
Cropland scarcity (ha)	-0.3316	-0.4020	0.6147	0.6391	-0.0915	-0.0631
Labor supply, female (no.)	-1.6330	-1.9796	*-1.3184*	*-1.3706*	-1.1755	-0.8107
Labor supply, male (no.)	0.0141	0.0171	-1.2429	-1.2922	0.8557	0.5902
Cropland ownership (% not owned)	-0.7462	-0.9046	*-0.9113*	*-0.9474*	-0.2157	-0.1488
Livestock intens. (no. of adults)	0.8328	1.0096	0.9161	0.9524	-0.2084	-0.1438
Namentenga region (dummy)	0.8965	1.0868	*0.4191*	*0.4357*	-1.0092	-0.6961
Kossi region (dummy)	1.4976	1.8155	2.0657	2.1476	-1.4177	-0.9778
Nahouri region (dummy)	0.5586	0.6772	*0.3311*	*0.3442*	-1.0493	-0.7238
Gender (% farmed by women)	-0.3442	-0.4173	-0.1487	-0.1545	-0.4589	-0.3165
Wealth (nonfood expenditure)	0.5425	0.6577	*0.7233*	0.7520	0.2676	0.1846
Agric. equipment (FCFA)	0.4607	0.5585	0.6677	0.6942	0.1174	0.0810
Off-farm income (FCFA/yr)	0.6083	0.7374	*0.3372*	0.3506	0.0220	0.0152

Notes: For regional dummy variables, the values reported are changes in the dependent variable in response to the change in the binary variable from zero to one.

Table 8. Elasticities at sample mean using the Cragg model estimates

	Both techniques		Bunds		Microcatchments	
	Adoption	Use-intens.	Adoption	Use-intens.	Adoption	Use-intens.
Independent variables						
Cropland scarcity (ha)	0.0046	0.0770	0.0096	0.1196	0.0085	-0.0051
Labor supply, female (no.)	-0.0417	-0.7401	-0.0554	-0.5239	-0.0161	-0.2218
Labor supply, male (no.)	-0.0025	0.1927	-0.0089	0.1523	-0.0024	0.1494
Cropland ownership (% not owned)	-0.1407	-0.1238	-0.2081	-0.1217	0.0100	-0.0568
Livestock intens. (no. of adults)	0.0000	0.1889	0.0001	0.1341	0.0000	-0.0196
Namentenga region (dummy)	0.1604	0.5176	0.1689	0.2186	-0.2023	-0.1543
Kossi region (dummy)	0.2569	1.7602	0.3733	1.2200	-0.5006	-0.1512
Nahouri region (dummy)	0.1373	0.5236	0.2272	0.3671	-0.3683	-0.1183
Gender (% farmed by women)	-0.0767	-0.0858	-0.0667	-0.0769	-0.1898	-0.0721
Wealth (nonfood expenditure)	0.0410	0.1536	0.0507	0.1146	0.0516	0.0526
Agric. equipment (FCFA)	0.0009	0.2499	0.0015	0.1538	0.0027	0.0253
Off-farm income (FCFA/yr)	0.0003	0.1243	0.0003	0.0657	-0.0003	0.0356

Notes: For regional dummy variables, the values reported are changes in the dependent variable in response to the change in the binary variable from zero to one.

Appendix: Variable means by survey village

	Namentenga		Soum		Kossi		Nahouri	
	vill. 1 (n=33)	vill. 2 (n=29)	vill. 1 (n=37)	vill. 2 (n=32)	vill. 1 (n=34)	vill. 2 (n=32)	vill. 1 (n=32)	vill. 2 (n=30)
Dependent variables								
Bunds (%)	9.23	6.09	0.00	0.95	70.13	0	1.35	21.88
Microcatchments (%)	24.09	18.85	59.88	38.58	28.89	0	0.75	57.20
Bunds+Microc. (%)	9.22	3.55	0.00	0.32	24.25	0.00	0.00	14.41
Land scarcity & property rights								
Cropland (ha/adult-equivalent)	0.79	1.11	0.46	1.28	0.95	1.05	0.48	0.63
Cropland/household (ha)	6.56	4.87	3.86	3.43	6.38	5.24	3.56	1.90
Labor supply, female (no)	2.63	1.93	2.81	1.88	1.82	2.00	2.75	1.70
Labor supply, male (no)	1.90	1.90	2.35	1.88	1.85	1.97	2.22	1.93
Cropland not owned (%)	4.46	26.96	26.99	6.10	19.22	44.56	0.00	19.31
Livestock intens. (# adults)	.94	1.93	.027	.97	1.61	.31	2.44	4.67
Control variables								
Gender (%farmed by women)	21.53	37.42	16.86	10.80	9.52	8.07	9.41	15.73
Off-farm income (cfa/yr)	20810	33037	82133	48400	28093	33312	22772	19432
Nonfood expenditure	50.92	85.77	72.94	228.26	239.99	57.31	144.66	55.93
Agricultural equip. (cfa)	16300	7155	14743	7582	56986	1328	28067	2000

Note: Area per adult equivalent is total land divided by the number of household members older than 15 years who report agricultural production as principal activity, converted to adult equivalents.