Indexing Soil Conservation: Farmer Perceptions of Agroforestry Benefits

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ABSTRACT. Soil erosion poses economic and environmental concerns in many tropical uplands. Agroforestry has been proposed as a sustainable land use that can mitigate soil erosion and promote the economic welfare of small farmers. To evaluate such claims, we must (a) develop a composite measure of effectiveness, such as a soil conservation index, and (b) define it in terms understood by the farmers who ultimately choose to adopt and implement agroforestry. We construct an empirical soil conservation index as a weighted average of farmer perceptions of four soil attributes and develop a statistical model of soil conservation benefits of agroforestry by using survey data from the Philippines. Accounting for self-selection bias, we evaluate the soil conservation benefits by testing the correlation between the index and the level of agroforestry adoption. Our estimated model shows that agroforestry can generate 1 S-20 percent soil conservation for the typical small farmer. We offer several methodological, practical, and policy insights. Because many farmers in developing countries face informational and capital constraints, our study suggests that public policies should support smallholder agoforestry, a type of "natural investment" in soil capital, to generate private and public benefits.

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Journal of Sustainable Forestry, Vol. 15(2) 2002

KEYWORDS. Philippines, contour farming, soil indexes, local knowledge, survey data, probit, two-stage least square estimates, agroforestry policies

Soil erosion poses economic and environmental concern in many parts of the world where farming is an important and expanding activity, such as the tropical uplands (Gill, 1995; Dixon, 1997). Proponents of agroforestry claim that it is a sustainable land use that can prevent or mitigate soil erosion without seriously compromising the economic welfare of small farmers in these areas. To evaluate these claims, it is critical to develop a composite measure of effectiveness, such as a soil conservation index, that must be defined in terms understood by the farmers who ultimately choose to adopt and implement agroforestry based on its perceived benefits. In this paper, we use household survey data to construct an empirical index of soil conservation that is based on farmer perceptions of soil health. We develop a statistical model of soil conservation benefits of agroforestry that accounts for any selection bias in the self-reported soil conservation data. Using this model, we evaluate the soil conservation benefits by testing the correlation between the soil conservation index and the level of agroforestry adoption.

Our study focuses on agroforestry projects on the island of Leyte, Philippines that were established between 1983 and 1988 by the United States Agency for International Development and the Government of Philippines. Agroforestry encompasses a spectrum of land uses in which trees are deliberately combined with agricultural crops and/or animals in various spatial or temporal arrangements (Lundgren and Raintree, 1982). The primary agroforestry practice in Leyte was contour hedgerows, in which food crops are planted between hedges of woody perennials established along the contours of sloping upland farm plots. Prunings from the hedgerow trees or shrubs are placed at the up-slope base of the hedges to trap eroding soil so that over time natural terraces are formed. The presence of trees and shrubs in agroforestry systems may influence several biophysical and biochemical processes that determine the health of the soil substrate (Sanchez, 1995). In addition to erosion control, the less disputed biophysical effects of contour hedgerows on soil include: maintenance or increase of organic matter and diversity: nitrogen fixation: enhancement of physical properties such as soil structure, porosity, and moisture retention; and enhanced efficiency of nutrient use (Nair, 1993).

Previous studies of contour hedgerow farming in Leyte conclude that the viability of such farming technology is uncertain (Cruz et al., 1987; Londhe et al., 1989; Armenia et al., 1990). Only one of these studies, however, addresses soil factors, and even that analysis is limited because soil thickness, soil fertility, topography, and site quality are all incorporated in a single binary variable. In contrast, our approach is to study four on-farm soil attributes and statistically link them to ongoing agroforestry practices.

Our evaluation metric is an index number that combines different soil attributes because individual soil properties, in isolation, do not capture all aspects of change in soil quality and quantity. As discussed in the soils assessment literature, composite index numbers are basically constructed to summarize detailed information and to provide a metric for monitoring soil conditions and evaluating conservation activities. As described by Parr et al. (1992), such indices can be used to classify land capability that can help (a) allocate conservation funds, and (b) set land prices, loan values and tax assessments. We use a soil conservation index to measure the effectiveness of agroforestry practices for conserving soil.

The data for our index number comes from farmer perceptions of soil health. Local soil knowledge is an important source of information when designing sustainable land uses (e.g., agroforestry) because farmers are attuned to local conditions and can offer guidance for realistic land management (Winkler Prins, 1999). Romig et at. (I 995) suggest that farmers interest in soil health may have been encouraged by their desire to examine and validate their farm management practices. Farmer perceptions of soil health can be reasonably accurate; for example, Leibig and Doran (1999) find that farmer perceptions were accurate in over 75% of the cases in comparison with other soil evaluation approaches. While complex biogeochemical processes of crop rotations are probably beyond the everyday concerns of farmers, many farmers often possess a series of management "scripts" related to soil quality, which reveal a tacit understanding of the soil resource and the requirements for sustained production (Alcorn, 1989). Importantly, descriptive approaches used by farmers to characterize soil health have practical implications for field assessment and monitoring by scientists and farmers (Romig et al., 1995).

The remaining paper is organized as follows. In Section 2, we describe statistical models of soil conservation and agroforestry adoption. First, we describe how soil characteristics (including depth, texture, color and fertility) are combined to construct an index that can empirically measure the impacts of agroforestry on soil conservation. Second, we present a statistical model that explains soil conservation as a function of the nature and size of household agroforestry activities. Environmental factors and socio-demographics constitute the other explanatory variables included in the mode!. Because adoption of agroforestry is a non-random choice, we describe a process for estimating a selection parameter and accounting for self-selection by first estimating a simple model of adoption. In Section 3, we characterize the study area with data on socioeconomic characteristics, soil indices and agroforestry practices. We use survey data collected by Francisco and Mercer (1995) in Leyte, Philippines to develop and test our model and indexes. Next, in Section 4 we present the results of regression analyses of agroforestry adoption and soil conservation models. We discuss several soil models that correspond to different soil indexes to illustrate the robustness of the results. In Section 5, we conclude with a discussion of methodological and policy implications.

EMPIRICAL MODEL OF SOIL CONSERVATION BENEFITS OF AGROFORESTRY

Estimation of a model of soil conservation requires linking a soil conservation index, W_{Si}, to the extent of agroforestry practices, T_{ai}. This relationship will be conditional on several environmental attributes, Z_{wi} and socioeconomic characteristics, H_{hi} as shown in Equation [I]. The subscript, i, refers to the household.

$$W_{Si} = W(T_{Ai} | Z_{wi}, H_{hi}) \qquad [1]$$

Soil conservation (W_{Si}) can be defined as a flow variable that is the difference between the two levels of soil stock or as a change in the soil stock variable (S_i) since the time of adoption of agroforestry practices (τ). Thus, positive or negative changes reflect the amount of soil conservation or soil degradation, respectively.'

Changes in the soil attributes are measured using farmers perceptions partly because farmers in traditional farming systems have been credited with their understanding of local agro-systems and a level of concern for soil quality, which matches or exceeds the interest of scientists and resource managers. The accumulated practical experiences of farmers can ensure that farmers are attuned to the ecological and social realities of the local environment. Perhaps most importantly for this study, descriptive approaches used by farmers to characterize soil health can be reasonably accurate (Leibig and Dot-an, 1999). See Romig et al. (1995) for a detailed discussion of how farmers assess soil health and the issues discussed here.

We follow the soils assessment literature in combining different soil attributes to generate a soil conservation index. Larson et al. (1983) is an example of previous studies that have used a product of various soil attributes (water holding capacity, aeration, bulk density, pH, and electrical conductivity) in a "productivity index" to aggregate soil stock. An index number can reduce excessive information and simplify analysis and assessment in cases in which the components of the index are highly correlated. Based on a soil conservation index we can compare conservation efforts across space (e.g., farms with and without agroforestry) and over time (e.g., before and after agroforestry adoption). Here we use a soil conservation index to measure the effectiveness of agroforestry practices for conserving soil. Thus, W_{si} is a weighted combination of the changes in soil thickness, fertility, color, and texture. These four attributes are assumed to proxy the outcome of the crucial biophysical and biochemical processes that are important for plant growth. Details on these are provided in the data section and in Table 1.

T_{Ai} is an index of agroforestry activities that are described in the data section. The impact of agroforestry on soil conservation is measured by the regression coefficient on the agroforestry index. To control for other influences, we include a set of environmental variables, Z_{wi}, comprised of water quality, extent of land fragmentation, two dummy variables for land type and site, and two household variables, H_{hi}, comprised of tenure status and f-arming history. Given the scant literature on models of this kind, the specification in Equation [1] relies on a combination of biophysical and socioeconomic variables that are intuitively likely to affect soil conservation.

Agroforestry Adoption and Calculation of the Selection Parameter (A)

In relating adoption of agroforestry and soil conservation in a statistical model, self-selection bias may result because the adoption of agroforestry is not random, but a conscious choice of farming households. This bias may be compounded by the fact that the data on soil conservation is measured using farmers' perceptions of changes in soil condition. Because adopters are more likely to perceive improvements in soil

TABLE 1. Improvements in Soil Attributes Due to Agroforestry (Descriptive Statistics)

	Description	Mean (std. dev.)	Correlations			
			s_1	s_2	s_3	s_4
s_1	Improvement in fertility: Yes = 1, No = 0 ′	0.27 (0.44)	1.00			
s_2	Improvement in texture (fine to coarse): Yes= 1, No = 0	0.23 (0.42)	0.74	1.00		
s_3	Improvement in color (grey-yellow to brown-black): Yes = 1, No = 0	0.26 (0.44)	0.90	0.80	1.00	
s_4	Increase in thickness of top soil (inches)	0.87 (2.1)	0.60	0.57	0.65	1.00
W_s	Linear combination using weights equal to: 0.3, 0.3, 0.3, and 0.1 ″	0.30				0.53

′ Households were asked to rate changes in soil fertility on a Likert Scale ranging from 1 (= significantly deteriorate), via 3 (= no change), to 5 (= significantly improve). The soil fertility data are consolidated as binary variables coded as 1 if respondents provided values 4 or 5. A similar approach was adopted for the water quality data.
″ These weights are based on the analyst's judgement of the differential quality of the data. Four alternative sets of weights (including the first principal components) and two non-linear indices were also used to test the robustness of the empirical model (Table 6).

condition, simple models may overestimate the impacts of agroforestry on soil conservation. A two-step formulation is used to address the self-selection bias with an inverse-Mills ratio, A, which measures the probability of the household adopting agroforestry (Maddala, 1983). In the first step, a household's decision to adopt, A_i, is estimated with the following probit model:

$$\mathrm{Prob}(A_i = 1)\ \gamma_k' K_i + \gamma_h' H_{hi} + \varepsilon_{li} \qquad [2]$$

The independent variables explaining the adoption decision follow the literature on agricultural technology adoption (Lynne et al., 1988; Gould et al., 1989; Lohr and Park, 1994) and agroforestry adoption in this region (Londhe et al., 1989; Armenia et al., 1990; van Wagner, 199 1; Francisco and Mercer, 1995). The set K_i is comprised of dummy variables for farmer participation in or knowledge of three project related activities: (1) information on contour hedgerow technology, (2) experience with planting trees on farms, and (3) assistance from project officials. Household specific characteristics such as steepness of farm, dependence on farming income, and the number of years the household has resided in the village constitute set H_{hi}. The probit model explaining the agroforestry adoption choice of the households (Equation [2]) utilizes a standard linear specification of independent regressors K_i and H_{hi}.

Estimation of the first step of the Heckman model allows the calculation of the household specific self-selection variable, Λ_i, with the following equation:

$$\forall \text{ adopters (i): } \Lambda i = \frac{\phi_1 (\gamma_k{}' K_i + \gamma_h{}' H_{hi})}{\Phi_1 (\gamma_k{}' K_i + \gamma_h{}' H_{hi})}$$

$$\forall \text{ non-adopters (j): } \Lambda i = \frac{-\phi_1 (\gamma_k{}' K_j + \gamma_h{}' H_{hj})}{1 - \Phi_1 (\gamma_k{}' K_j + \gamma_h{}' H_{hj})} \qquad [3]$$

In Equation [3], ϕ_1 and Φ_1 are the probability density and cumulative distribution of the normal error term, respectively. In the second step of the Heckman model, Λ_i is used as an explanatory regressor in the soils eyuation [4] to correct for any biases in the estimated coefficients due to the self-selection.

$$W_{Si} = w(T_{Ai}, Z_{wi}, H_{hi}, \Lambda_i) + \varepsilon_{2i} \qquad [4]$$

DATA AND STUDY AREA

The data for this study were collected through a socioeconomic survey, in 1993 and 1994, of 277 agricultural households, sampled from lists of both adopters and non-adopters of agroforestry technology in the two villages of Visares and Cagnocot on the island of Leyte, Philippines (see Appendix 1: Map of Study Area). Two pre-tested questionnaires, focusing on socioeconomic and agronomic characteristics, were administered to households through direct interviews. The survey collected data on: (I) household socioeconomic characteristics: age, farming experience, sex, education, family size, membership in community organizations, and years of residency, and (2) farm agro-ecological profile: slope; type of land (upland or lowland); soil attributes of thickness, color, fertility and texture; and water quality.

Both sites are hilly and subject to significant erosion. Visares has a pronounced rainy season in December but no dry season, while Cagnocot receives even rainfall throughout the year except for the dry months of February to April. The soils are acidic and varying from sandy loam to clay in Visares, and they are extremely clayey in Cagnocot. Both sites have schools, health centers, flea markets and village halls. Visares is on the main highway and receives some irrigation water. Additional information on field logistics, data gathering and site characteristics are presented in Francisco and Mercer (1995).

The socioeconomic characteristics of the study area, based on average measures, are as follows. Households on Leyte have little education and low levels of income. Farming is the main source of income with corn, rice and banana as the dominant crops, and labor and seed as the most important inputs. Pigs and chickens are the primary livestock. Households in both communities engage in fishing, carpentry and other non-farm activities. On average, the households farm 2.62 hectares that have a 30 degree slope. Agroforestry adopters, who comprise a third of the sample, dedicate approximately 0.31 hectares to contour hedgerows, and have practiced agroforestry for 4 years. Ipil-ipil (*Luecaena leucocephala*) and kakawate (*Gliricidia sepium*) are the two tree species most frequently used as hedgerows. About 40% of the surveyed farmers believe that water quality has improved since agroforestry was initiated in Leyte.

Soil Conservation Data

Variables that are common to both the soils and adoption equations are only discussed on their first appearance. Following the suggestion in the previous section for constructing indexes, W_{Si} is a weighted combination of changes in four attributes of the soil stock: color (s_1), texture (s_2), thickness (s_3), and fertility (s_4).[2] Descriptive statistics for the attributes, based on household responses to various questions on changes in soil stock, are presented in Table I. Since W is defined as an increment, we use an additive index. A product index, such as the one used by Larson et al. (1983), will be highly restrictive for our case because even if only one soil attribute fails to improve, the index records no soil conservation. This would imply that improvement in each attribute is essential for improvements in overall soil stock, i.e., for soil conservation. On the other hand, a weighted sum indicates that incremental improvements in thickness, texture, color and fertility are substitutes. Note, the emphasis is on improvements in attributes; we are not suggesting that the attributes themselves are substitutable in defining soil stock. While the less restrictive weighted sum (reported in Table 2) is the preferred index for this analysis, multiplicative and exponential indices are also used to test for robustness. Equation [5] describes the method for constructing the preferred soil conservation index, W_{Si}:

$$W_{Si} = \sum_{j}^{4} \omega_j \cdot s_j \quad \text{where } \omega_j = (0.3, 0.3, 0.3, 0.1) \qquad [5]$$

The authors' judgement of the differential quality of the data is perhaps the only *a priori* reason to use the particular combination of weights specified in Equation [5]. Three alternative sets of weights were also used to test the robustness of the empirical model. These, along with the non-linear indices, are presented in Table 2.

An additional issue to consider is the fact that non-adopters were not asked to describe their perceptions of change in soil quality. There are two ways to address the data on soil quality for non-adopters. First, we estimate the soil model for the *full sample* with a zero change in soil quality (or no soil conservation) recorded for this sub-sample. This is a conservative approach because quality, particularly the thickness of soil, is likely to decline. Our second approach is to estimate the soil model only for the *partial sample* of adopters for whom we have non-zero soil quality changes. The selection parameter from the first of the two-stage approach corrects for any bias that may result from this

TABLE 2. Alternative Soil Conservation Indices

	Method of Combining Attributes	Mean	Std. Dev.
W1	Linear: $0.25_{s1} + 0.25_{s2} + 0.25_{s3} + 0.25_{s4}$	1.26	0.90
w2	Linear: $0.2_{s1} + 0.2_{s2} + 0.2_{s3} + 0.4_{s4}$	1.56	1.34
w3	Linear: $0.3_{s1} + 0.3_{s2} + 0.3_{s3} + 0.1_{s4}$	0.96	0.51
w4 '	Linear: principal components	3.01	3.10
W5	Multiplicative: s1 • s2*s3*s4	1.89	3.16
W6 "	Exponential: (s4)*(exp (s1 + s2 + s3))	44.29	61.02

' Principal components are weighted averages of the collinear variables in which the weights are chosen to maximize the variation present in the weighted averages. The weights for the first principal component are comprised of the elements of the first characteristic (eigen) vector of a matrix comprised of the standardized deviations of all collinear variables.

" This combination assumes that since fertility, texture, and color are binary measures, they serve as qualifiers on thickness of top soil which is the most important attribute of soil conservation.

strategy of looking at only adopters. We present and discuss the results of both approaches in the next section.

Table 3 presents the descriptive statistics for the regressors used in the soils equation [4]. Approximately 46% of our sample is from Visares and 83% of all farm parcels were in upland areas. The average Simpson Index (SI) representing the amount of land fragmentation, such that 1 = completely fragmented and 0 = completely consolidated, is equal to 0.35.[3] About 38% of the farmers are tenants. Households' farming experience is measured by number of years farmed; respondents had farmed for an average of 14 years. A dummy variable indicates that 32% of respondents believed that the water quality had improved in the region since the adoption of agroforestry.

T_{Ai}, an index of agroforestry indicators, is comprised of the following: (1) the portion of farm area with contour hedgerows at the time of installment, (2) the number of years of agroforestry practice, (3) the rank assigned by respondents to soil conservation as the reason for adopting agroforestry, and (4) the number of years that households have engaged in other agroforestry based soil conservation practices. A correlation assessment of these agroforestry activities suggests that they are collinear, implying that their individual contribution would be unidentifiable due to multi-collinearity in regression analysis. Therefore,

TABLE 3. Variables Used in Soils Equation (Descriptive Statistics)

Description	Mean	Std. Dev.
Tenant? (Yes = 1, No = 0)	0.38	0.421
Site (Visares = 1, Cagnocot = 0)	0.396	0.490
Simpson's index for land fragmentation [1]	0.351	0.271
Upland (= 1) or lowland (= 0)	0.822	0.310
Water quality improvement (Yes = 1, No = 0)	0.32	0.47
Length of farming experience (years)	15.55	11.64
Ever planted trees on farm? (Yes = 1, No = 0)	0.657	0.476
Frequency of mulching activities (times/year)	3.913	31.53
Index of Agroforestry (T)	1.253	2.659

[1] The Simpson Index (SI) for land fragmentation is such that 1 = completely fragmented, 0 = completely consolidated. It is calculated by the following: $SI = 1 - \Sigma SZ_i^2/(\Sigma SZ_i)^2$ where SZ_i is the size of each land parcel.

the first principal component of the first four variables in this vector is used as a weighted index of agroforestry indicators (T_{Ai} in Eyuation [1]).[4] Kennedy (1993) discusses the use of principal components to group collinear variables, suggesting its use only if the grouping has some interpretation as a combination. In this case, the first principal component can be interpreted as a behavioral index of household agroforestry practice.

Agroforestry Adoption Data

Summary statistics for data used to estimate the adoption equation [2] are presented in Table 4. The dependent variable is a binary variable coded as A I" for contour hedgerow agroforestry adopters (3 1 % of sample) and A0″ for non-adopters. The first independent regressor is a dummy variable, which has the value A 1″ if households had previously planted trees on their farms (66%). The second is another dummy variable, which has the value A 1″ if households were aware of contour hedgerow farming (77%). The slope of the farm parcel, 29% on the average, provides a measure of' the household's need for contour hedge-

TABLE 4. Variables Used in Agroforestry Adoption Equation (Descriptive Statistics)

Description	Mean	Std. Dev.
Made contour hedgerows on your farm? (Yes = 1, No = 0)	0.31	0.47
Ever planted trees on farm? (Yes = 1, No = 0)	0.66	0.48
Heard of contour hedgerow farming? (Yes = 1, No = 0)	0.77	0.42
Extent of assistance from project official '	0.10	0.20
Steepness of farmland (degree)	28.56	15.75
Percent of income from farm agriculture	57.76	34.0
Length of residency in the village (years)	33.04	15.50
Tenant? (Yes = 1, No = 0)	0.38	0.43
Average education of household head	1.93	1.18
Member of farmer or community development group (Yes = 1, No = 0)	0.50	0.66

' The extent of assistance is measured as the normalized sum of dummy variables where each dummy measures the receipt of one of four types of assistance (cash, technical information, labor, and seeds) from project staff.

rows to counter soil erosion. Households' dependence on agricultural production is measured in terms of percent of household income from agriculture (58% on the average). External technical assistance levels, measured as the normalized sum of four dummy variables which measure the receipt of project assistance (cash, technical information, labor, and seeds), has an average value of 0. I. Finally, respondent characteristics are represented by the length of residency, farm ownership, membership in community organizations, and education. On average, respondents have resided in their village for 33 years. About 50% of the respondents are members of a farming or community development co-operative. The average farming household head has approximately 2 years of schooling.

Equation [3] describes the formula used to calculate household specific selection parameters that are derived from an adoption model based on the data listed here. For the full sample described in the soil data section, we follow the literature on "treatment effects" or "program evaluation" (Barnow et al., 198 1) and use selection parameters for adopters and non-adopters. For the partial sample, on the other hand, we follow the more standard two-stage Heckman selection model (Maddala, 1983) and use the selection parameters for the adopters only.

ESTIMATION RESULTS

Adoption Equation

Even though the soil equation is the main focus of this paper, we present the adoption model first because it provides the estimates to calculate the selection parameter that is a regressor in the soils model. The results of the probit analysis for contour hedgerow adoption are presented in Table 5. The dependent variable is the probability of being a contour hedgerows adopter: 0 = not adopter, and 1 = adopter. The overall model fit the data well, as indicated by the high χ^2, McFadden and Veall/Zimmerman statistics and the percentage of correct predictions (94%).

The signs of statistically significant regressors have theoretical and intuitive appeal. Those households which have historically planted trees on their own farms and which were familiar with agroforestry (significant only at the 25% level) were more likely to adopt. As in many rural development projects, greater project assistance appears to have a

TABLE 5. Maximum Likelihood Estimates of Agroforestry Adoption (Probit Model)

Variable	y-coeff	P-value
Constant	−3.27	0.000
Ever planted trees on farm? (Yes = 1, No = 0)	1.17	0.02
Heard of contour hedgerow farming? (Yes = 1, No = 0)	0.55	0.24
Extent of assistance from project officials	17.06	0.000
Steepness of farmland (degree)	0.02	0.07
Percent of income from farm agriculture	0.83	0.09
Length of residency in the village (years)	-0.02	0.05
Tenant? (Yes = 1, No = 0)	-0.24	0.53
Average education of household head	0.04	0.78
Member of Farmer or Community Development Group (Yes = 1, No = 0)	0.03	0.90
χ^2 statistic	254	0.000
McFadden pseudo R^2 statistic	0.74	
Veall Zimmerman pseudo R^2 statistic	0.86	
% Correctly Predicted	94	
N	277	

substantial impact on the adoption of agroforestry technology; its coefficient is positive, significant and large. This finding is consistent with two previous studies of agroforestry adoption in Leyte (Londhe et al., 1989; van Wagner, 199 1). As in the Lynne et al. (1988) study of Florida farmers, economic and agro-ecological needs influenced the adoption choice; households which earn a greater percentage of their income from agriculture and which farm steeper lands were more likely to adopt. The length of residency indicates that households that have lived in the area for a long time are less likely to adopt. Analyses of the Conservation Reserve Program in the US Midwest found similar results and hypothesized that this may reflect increasing cynicism toward government sponsored technologies (Gould et al., 1989; Lohr and Park, 1994). The tenure variable is negatively correlated with the assistance index. In a model without the “assistance” variable (not reported here), the coefficient on the tenancy variable is significant and negative, as expected. Tenants are less inclined to make long-term soil conservation investments, and/or project managers may have been more willing to assist landowners. We do not find a significant relationship for education presumably because there is very little statistical variation in our sample to tease out the effect of education. This is not surprising, given the low pervasive level of education in the region. Finally, the variable indicating membership in community organizations is also negatively correlated with the "assistance" variable. In a model without "assistance," it is statistically significant at the 86% level and positively related with adoption. To the extent that community organizations provide information on new technologies and infrastructural support, membership in such groups should encourage adoption.

Soils Equation

The results of estimating the soils equation [4] are presented in Table 6. The dependent variable is the linear weighted soil index, W_{Si}, described in Equation [3]. The full sample results are reported in columns 2 and 3 and the partial sample results are reported in columns 4 and 5. Starting with the full sample model, the overall "goodness of fit" of the model is indicated by the adjusted R^2 (0.58) and F-statistic (48.82). Confidence in the model is also enhanced by the expected signs of significant coefficients.

The coefficient on the site dummy variable is insignificant, suggesting that there is no discernible difference in soil quality change across the two study sites. Soil conservation appears to benefit more those households with a greater percentage of upland parcels, presumably because they are more susceptible to erosion. Farm households with more fragmented farm holdings achieve higher levels of conservation. This "diseconomies of scale" may stem from the difficulty of using large farm animals or machinery on small parcels, therefore limiting the compaction of the top soil. Not surprisingly, tenants are less likely to adopt agroforestry and therefore less likely to realize soil conservation. Farming experience, which is not the same as conservation experience, has no statistical influence on the change in soil quality. The positive coefficient on the water quality variable indicates that water and soil resources are covariates. Because it takes more than one subsistence farmer to influence the water quality, this variable is an indicator of the overall health of the hydrologic system. Thus the positive coefficient on this variable indicates that, when the overall hydrological system im-

TABLE 6. Two Stage Least Square Estimates: Effects of Agroforestry on Soil Conservation

Description	Full Sample		Partial Sample	
	β (coefficient)	P-value	β (coefficient)	P-value
Constant	--0.13	0.15	-0.01	0.98
Site (Visares = 1, Cognacot = 0)	0.02	0.61	0.09	0.39
Upland (= 1) or lowland (= 0)	0.18	0.01	0.43	0.03
Simpson's index for land fragmentation	0.37	0.000	0.66	0.01
Tenant? (Yes = 1, No = 0)	-0.12	0.03	-0.30	0.10
Length of farming experience (years)	0.002	0.19	0.004	0.34
Water quality improvement (Yes = 1, No = 0)	0.10	0.03	0.12	0.23
Index of Agroforestry	0.08	0.000	0.03	0.02
Selection Parameter (A)	0.38	0.000	0.15	0.10
N	277		87	
Adjusted R^2	0.58		0.15	
F (10, 266)	48.82	**0.000**	2.85	0.01
ρ (adoption and soils equations)	1.00		0.33	

proves, each individual farmer realizes soil conservation benefits that result not from her own actions, but from those of a larger community of farmers. For example, more contour hedges upstream will lower the erosivity potential of farms downstream. Finally, and most critically, the coefficient on the agroforestry index is significant and positive, validating the hypothesis that conservation oriented land uses can induce improvements in soil assets.

The statistical significance of the inverse-Mill's ratio, A, and the perfect cross-equation (adoption and soil) correlation, suggest that adoption of agroforestry and perception of its soil conservation benefits are positively correlated. Inclusion of A in the specification corrects for this selection bias, ensuring unbiased estimates for other regression coefficients.

Turning to the partial sample results, the lower F and adjusted R^2 statistics, and the relatively higher p-values on the model coefficients, suggest that this model has considerably less statistical explanatory power.

This is probably because we are looking at a reduced sample that is approximately a third of the full sample. What is striking, however, is that the overall results are preserved. That is, while the size of the coefficients and the probability values are somewhat different, the sign and significance (at the 10% critical values) are stable. This stability of results lends credibility to our overall findings.

The estimated coefficients from these models can be used to predict the levels of soil conservation with, $\hat{W}_{S1}$, and without, $\hat{W}_{S0}$, agroforestry and therefore to calculate the soil conservation benefits in terms of the soil index. This calculation is simply the product of coefficient on the agroforestry index and the value of the index ($\beta = T_{Ai}$). That is, this product measures the contribution of agroforestry, which is equivalent to going from an agroforestry index value of 0 to the current level. Using this approach, for the full sample we see that agroforestry contributes 0.12 units of soil conservation or an improvement of approximately 13% for the typical farmer. A typical farming household is characterized by the sample mean values of all independent variables, including the agroforestry index, T_{Ai}, in the model. Using the results of the partial sample, agroforestry contributes 0.14 units of soil conservation, which is equal to an improvement of approximately 14% for the typical farmer.

In order to test the robustness of the soil conservation index, five alternative indices were used to estimate the model of soil conservation using the full and partial samples. The dummy variable for water quality was the only variable that did not maintain its statistical significance across the twelve models. By and large, the models of the non-linear soil indices had lower statistical explanatory power. Most critically, however, the agroforestry index was positive and significant in all models except in the non-linear partial sample models (i.e., in 2 of 12 models). Although the size of the estimated coefficients and the predicted levels of W varied across the models, the percentage change in soil quality was comparable. Tables of all 12 statistical models are not reported here. Instead, given the focus of this study on calculating the overall impact on soil conservation, only the final soil conservation values, corresponding to each of the five additional specifications and the soil conservation discussed in detail till now (W3), are summarized in the conclusion and Table 7. The key conclusion of the sensitivity analysis is that the results reported in the previous paragraphs are robust to the specification of the soil conservation index.

TABLE 7. Tests for Robustness-Alternative Soil indices

Soil Indices	Mean	%$\Delta\hat{W}$ Full Sample	%$\Delta\hat{W}$ Partial Sample
W1	1.26	13%	16.5%
w2	1.56	13%	18%
w3 '	0.96	13%	14%
W 4	3.01	13.5%	19.5%
W5	1 .a9	12.5%	1 a%
W 6	44.29	13%	20%

' The index discussed in detail in the paper

DISCUSSION AND CONCLUSION

Although policymakers and farmers in developing countries recognize that agroforestry can be a sustainable technology that provides valuable on-farm ecological services such as soil conservation, wide spread adoption of such technologies has not occurred. Uncertainty regarding the nature and size of soil conservation benefits is one of the reasons for limited adoption of agroforestry. This study attempts to fill the gap in both research methods and quantitative information by developing and implementing a socio-agronomic model to trace out the link between agroforestry activities and farmer perceptions of soil resources. By exploiting cross-sectional variation in agronomic and socioeconomic factors in a household survey data set, we (a) construct a soil conservation index, (b) estimate a soil conservation function, and (c) establish the size of soil conservation provided by agroforestry to agricultural households. Thus, we respond to Sanchez's (1995) challenge to use empirical evidence and objective analysis to evaluate the unsubstantiated, and sometimes sentimental, enthusiasm for contour hedgerow farming. In order to assess whether agroforestry adoption is an economically viable strategy, our estimated indices of soil conservation need to be linked to an economic model of farmer welfare. The results of our study could provide critical model inputs to any economic assessment of the net benefits of soil conservation?

Methodological Insights

In order to purge the mode1 of biases, various methods are employed. We follow the soils assessment literature in combining different soil attributes to generate a soil conservation index because individual soil properties, in isolation, do not capture all aspects of change in soil quality and quantity. In addition to providing a composite metric for soil quality change, the index number can reduce excessive information and therefore simplify the problems of multi-collinearity among the various soil attributes, such as the four used in this study.

There are mixed analytical consequences of the facts that (a) our measure of soil quality is based on farmer perceptions, (b) farmers can choose both their level of agroforestry, and (c) farmers can choose their level of soil conservation. On the one hand, estimation of the model requires correction for a potential self-selection bias. On the other hand, it provides additional information for calculating "pre" (without agroforestry) and "post" (with agroforestry) levels of soil conservation. A two-step Heckman formulation is used to eliminate the self-selection bias in the estimation of a model that relates the level of soil conservation to the extent of agroforestry. This same selection model accounts for selection bias due to the self-reported nature of our data: that is, the fact that our measure of soil conservation, W_{Si}, is based on farmers' perceptions rather than objective measurements. We do not have technical data, unfortunately, to construct an alternative measure of W_{Si}. In this regard, "ground truthing" by the local soil conservation service to obtain precise scientific measurements for a sub-sample of the households may have improved the reliability of the results.

We evaluate the robustness of the estimated values by using five alternative formulae to combine the four soil attributes into a single index (see Table 2), because there is scant literature on constructing agronomic indices, and because the soil variable is the focus of this study. The estimated soil conservation, measured in terms of percentage change, is remarkably robust to various formulae for constructing W_{si}. The results of this sensitivity analysis are summarized in Table 7.

Our approach illustrates the use of farmer perceptions of soil health to construct a soil conservation index and to evaluate the effectiveness of land uses such as agroforestry practices for conserving soil. The practical implications of the approach presented here, and promoted in the soils assessment literature, are several. The idea of using indexes generalizes Romig et al.'s (I 995) suggestion that descriptive approaches used by farmers can characterize soil health and facilitate field assessment and monitoring. These perception based indexes are useful because farmers are attuned to local conditions (Winkler Prins, 1999). Such composite indexes can enable (a) evaluation of soil conservation activities, (b) classification of land capability to facilitate allocation of government funds, setting of land prices, loan values and tax assessments, and (c) prediction of change of the environmental landscape (Parr et al., 1992).

Policy Conclusions

Several general qualitative and quantitative results may be useful to policymakers. The estimated soil model reveals that agroforestry can improve soil conservation by as much as 15-20%, measured in terms of a unit-less index, W_{si}, for the typical adopter, who is characterized by the mean values of all variables. This suggests that natural investments in the form of trees in soil capital can generate substantive payoffs in the form of ecological services. Even though these are private benefits, private provision of soil conservation may be inadequate because agricultural households either are not aware of the magnitude of these benefits (informational constraints) or lack the resources and capital (capital constraints) to invest in agroforestry. This justifies public support for the private provision of soil conservation. As argued below, these private benefits are a lower bound for total benefits because there are significant "downstream" public benefits from soil conservation. In addition, the positive influence of the government support variables (e.g., assistance, extension services, and membership in cooperatives) in encouraging agroforestry adoption (see Table 5) validates the appeal for greater public involvement in private agroforestry activities.

The two regression equations (adoption and soils) also provide quantitative information on behavioral, environmental, and agricultural production relationships in the Leyte region of Philippines. For example, the signs and sizes of estimated parameters suggests that previous experience with planting trees can increase the likelihood of adoption of agroforestry by 42 percent for the typical farmer, and agroforestry adoption is likely to improve soil quality by 19 percent on upland farm parcels. A comprehensive list of such implications is beyond the objective of this study, but is easily discernible from the regression coefficients and variable means.

Consider an additional factor in evaluating soil conservation from agroforestry. Even though the agroforestry index, and therefore the soils index, are modeled as increasing functions of "time since adoption" of contour hedgerows, all "long run" improvements in the agro-ecological profile may not have been realized in the decade since the initiation of the agroforestry project. The soils and agroforestry indices are linear by construction, implying that if over time there are non-linear improvements in the soil profile, the present model may underestimate soi l conservation benefits.

From the social planner's perspective, there is yet another important consideration. The soil conservation benefits described here are edaphic, i.e., they relate to potential improvements or sustenance of on-site agricultural productivity. They do not account for several, possibly significant, off-site benefits-typically categorized as in-stream and off-stream-that are external to the individual households (Brooks et al., 1992). In-stream soil conservation benefits include habitat protection for aquatic life, recreational values, water storage in lakes, and navigation. Off-stream soil conservation benefits include flood mitigation, improved water conveyance, decreased water treatment requirements, and increased quality and quantity of water. The private on-farm benefits are a lower bound of the overall benefits of soil conservation. Given the central role of small farmers in tropical uplands in mitigating soil erosion through sustainable land uses, there may, therefore, be good reasons for the government to support farmers in the early years of agroforestry adoption.

In conclusion, this study implements a socio-agronomic model to index soil conservation provided by agroforestry and generates several methodological and policy insights. We illustrate the use of farmer perceptions of soil health to (a) construct a soil conservation index, and (b) use the index in a statistical model to evaluate the effectiveness of agroforestry practices for conserving soil. The estimated size of soil conservation benefits suggest that trees in agroforestry systems are a type of "natural" investment in soil capital that can generate substantive ecological services for small farmers in tropical uplands. We recognize that there are several off-site non-edaphic benefits not included in our measure. Because many farmers face informational and capital constraints, public policies should support these natural investments to generate private and public payoffs.

NOTES

1. $W_{St} = \dot{S} = S_t - S_t - \tau$

In the absence of soil conserving farming practices such as agroforestry, the natural rate of soil conservation is likely to be negative, i.e., such practices wilt lead to soil degradation.

2. See Table t , which presents the correlation matrix for the four soil attributes, to gauge the potential for multi-collinearity. High pair-wise correlations are sufficient, though not necessary conditions, for the existence of multi-collinearity (Kennedy, 1993: 180).

3. SI is calculated as follows: $SI = 1 - \Sigma SZ_i^2/(\Sigma SZ_i)^2$ where SZ_i is the size of each land parcel.

4. Principal components are weighted averages of the collinear variables in which the weights are chosen to maximize the variation present in the weighted averages. The weights for the first principal component are comprised of the elements of the first characteristic (eigen) vector of a matrix comprised of the standardized deviations of all collinear variables (Kennedy, 1993).

5. The motivation for estimating the economic value of soil conservation analysis is the concept that incorrect price signals may lead to bad policies, a fundamental principle of neoclassical economics. Typically, the net benefits (the "shadow price") of soil conservation are underestimated due to inadequate information on the benefits (Gill, 1995; Dixon. 1997). For agrarian communities in developing countries this can be a costly oversight because of the strong linkages between agricultural livelihoods and environmental assets such as soil resources.

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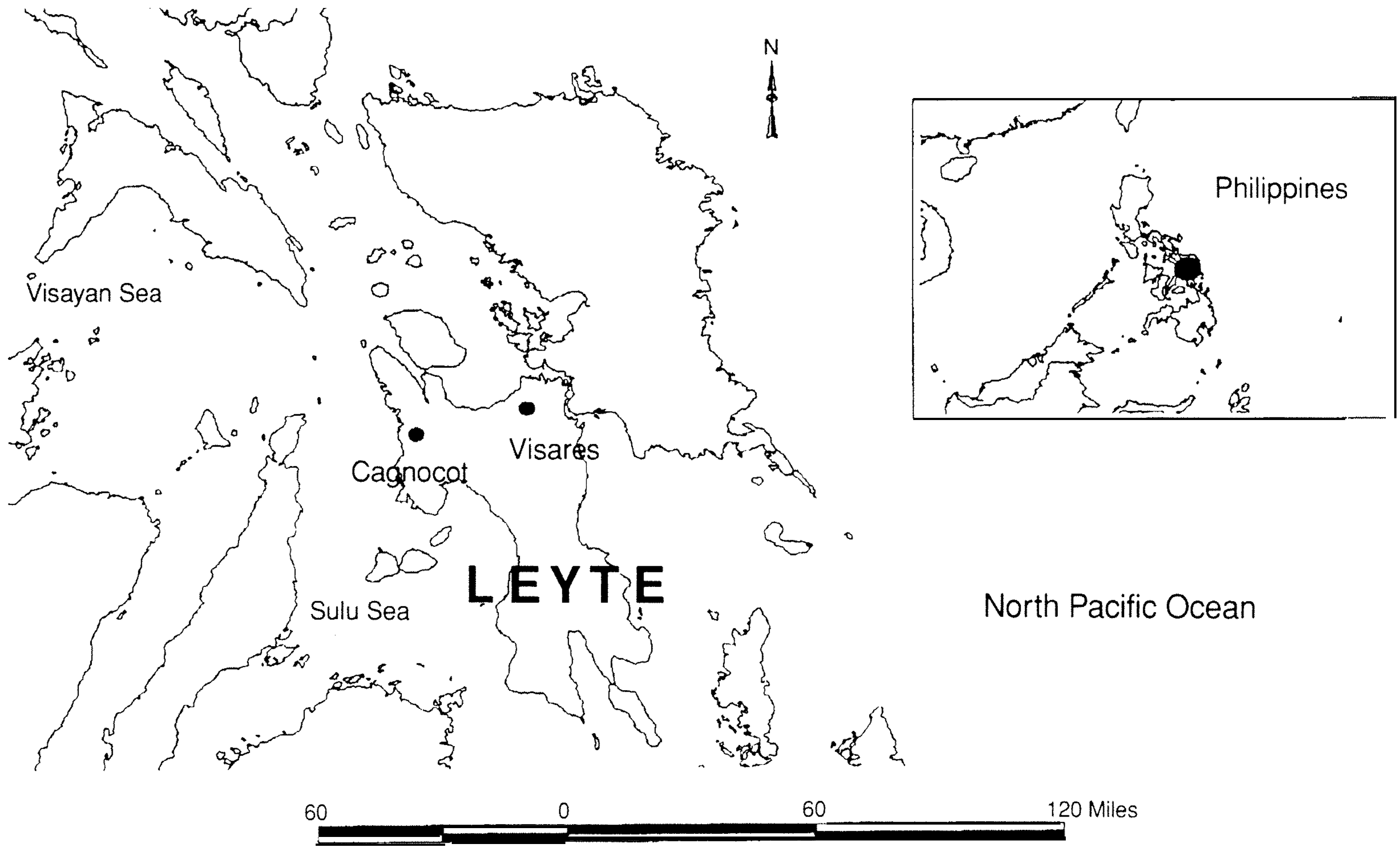
APPENDIX 1. Map of Study Area



Map of Study Area: Leyte, Philippines