Is Poverty to Blame for Soil, Pasture and Forest Degradation in Peru’s Altiplano?

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Summary. — Multiple regression analysis of 1999 farm survey data from the Peruvian Altiplano finds that natural resource sustainability is not correlated with poverty; rather it varies by management activity. Soil erosion and fertility loss are reduced by fallowing, a practice of poorer farmers. Overgrazing and range species loss are increased by herd size (a measure of wealth) but reduced by rotational grazing, which is size-neutral. Deforestation—the only case of a clear poverty–environment link—results from fuel wood harvesting by the poorest households. Social and human capital variables favor the choice of more sustainable practices. When government investment is unavailable, change agents in poor areas can limit natural resource degradation by diffusing knowledge about natural resource stewardship using affordable practices.

Key words — poverty, overgrazing, erosion, deforestation, Peru, Latin America

1. EVOLVING THOUGHT ON LINKS BETWEEN POVERTY AND ENVIRONMENT

Perceptions of how poverty alleviation, agricultural intensification, and environmental outcomes interact have evolved importantly over the past four decades. The current evolution began with Boserup’s (1965) attack on Malthusian thought. She argued that population does not result from limited carrying capacity of the land. Rather, population density is a key cause driving agricultural intensification which can lead to economic growth and sustained productivity increases. An important corollary of her thesis is that although environmental degradation may result from population growth, it is not a necessary result (Boserup, 1965, p. 22). This claim has been supported by a number of subsequent studies (Templeton & Scherr, 1999).

How can population growth cause both declines and gains in agricultural productivity and natural resource conservation? The economic rationale is that agricultural productivity (per land unit) follows a U-shaped curve in response to the abundance of land per worker. Land productivity falls and then rises again as growing population reduces the price ratio of labor to land (Templeton & Scherr, 1999). This theory is consistent with Hayami and Ruttan’s (1985) theory of induced innovation, whereby technological change saves the scarce factor. As land becomes relatively more scarce, farming technologies evolve away from those that saved...
labor and capital toward those that save land. This intensification process leads to greater land productivity, often including investments in sustaining productivity over the long term.

If the good news is that environmental degradation need not occur, the bad news is that degradation still does occur in certain circumstances. Some authors have pinned the blame on poor farmers who intensify production with labor-led strategies, unable to afford such complementary capital inputs as fertilizers and conservation investments that might support sustainable intensification (Clay, Reardon, & Kangasniemi, 1998; Mink, 1993). This line of argument shifts the blame for environmental degradation from population to poverty. But poverty is not a simple substitute for population, for agriculturally related environmental degradation often occurs in economically depressed rural areas that are experiencing out-migration (García-Barrios & García-Barrios, 1990; Zimmerer, 1993). This suggests a dynamic interplay between population and poverty whereby intensification may fail to occur if too many people “vote with their feet” and depopulate a region. The environmental effects may be especially severe if the emigrants are working-age adults (García-Barrios & García-Barrios, 1990).

As evidenced in the Northern Hemisphere, agricultural environmental problems are hardly confined to impoverished areas. Exceptions to the poverty–degradation causal chain in the developing world include rangeland productivity losses due to overgrazing by large cattle herds. Such cases have engendered a literature that pins the blame for degradation on the wealthy or on institutional or market failures (Duraiappah, 1998).

Lacking in most of the economic literature is careful examination of the natural resource base (Reardon & Vosti, 1997). Natural resources provide the setting that makes attractive their exploitation by humans. In agriculture, this is largely determined by the availability and quality of soils, moisture, warmth, and sunshine. Agriculturally related natural resource problems can be divided into two categories. Resource depletion encompasses problems of aquifer exhaustion, soil fertility mining, soil erosion, deforestation, and overgrazing (the latter two both being forms of biodiversity loss). Resource contamination encompasses water pollution (e.g., by agrochemicals, fertilizers or excess manure runoff), land salination, pesticide and antibiotic residues in food, and—at the large scale—global warming. Either of these two classes of problem can result either from “mistakes” due to gaps in farmers’ information and knowledge or else from rational behavior by farmers with multiple objectives, including risk aversion. But if farmers are reasonably well informed and if maximizing consumption or net income is their primary objective, then it is reasonable to associate wealth with the contamination problems and poverty with the depletion problems.

If this conjecture is true, then neither population growth nor poverty leads simply to natural resource degradation. Instead, degradation will depend on the kind of farming practices and their natural resource setting. The severity of the environmental problem is likely to depend not only on its causes, but also on the vulnerability of the specific natural resource setting (Lutz, Pagiola, & Reiche, 1994). Moreover, in some settings, the agricultural determinants of natural resource problems may turn out to have little link to conventional definitions of poverty.

This research examines a unique ecoregional setting: the Altiplano around Lake Titicaca in South America. As in other parts of the Andes, the area has suffered outmigration in recent years (Zimmerer, 1993). The environmental degradation problems identified there include: (a) soil erosion, (b) soil fertility decline, (c) overgrazing, and (d) deforestation. These problems all fall into the resource depletion category, with its implicit link to poverty as a determinant. But they encompass not only the apparently poverty-related problem of soil mining, but also the seemingly wealth-related problem of overgrazing. For each of these problems, our objectives are to answer:

(i) How are natural resource outcomes related to agricultural practices?
(ii) How does poverty affect the choice of those agricultural or forestry practices that degrade the natural resource base?

In the remainder of this paper, we present a conceptual model of linkages between poverty (as measured by farm assets), choice of farming practices, and natural resource outcomes. That model is examined empirically in search of links between low-asset levels and natural resource degradation. We close by discussing how results for this eco-region and the relevant asset categories contribute to the state of knowledge on poverty–environment linkages.
2. A CONCEPTUAL FRAMEWORK FOR POVERTY–ENVIRONMENT LINKAGES

The framework used here for understanding poverty–environment linkages proceeds through two stages, as illustrated in Figure 1. First, farmers choose their agricultural practices. Their choices are influenced by household asset levels, the external economic environment, and natural resource endowments. Second, their farming practices, in turn, combine with natural environment characteristics plus random environmental changes to create natural resource outcomes. Those outcomes, positive or negative, shape farmers’ subsequent choices in future periods.

In order to diagnose the specific agricultural practices and household assets that determine outcomes of the two stages, the problem is best examined backwards, beginning with outcomes and searching for their determinants. The first step is to identify the agricultural practices that affect natural resource outcomes. The following equation converts the processes from Figure 1 into algebraic form for natural resource characteristic $i$ (NR$_i$):

$$ NR_{it+1} = NR_{it} + f(x_t, z_{Nt}) + e_{it+1}. $$  \hspace{1cm} (1)

Eqn. (1) states that the status of natural resource $i$ at time $t+1$ depends on its status in the previous period as well as changes wrought by a vector of agricultural practices ($x_t$) as conditioned by other natural characteristics ($z_{Nt}$) and random effects ($e_{it+1}$). Eqn. (1) can be restated in terms of change in natural resource status by subtracting NR$_{it}$ from both sides of the equation to yield the difference equation:

$$ \Delta NR_i = f(\Delta x, \Delta z_{N}) + e. $$  \hspace{1cm} (2)

Natural conditions ($z_{N}$) include land characteristics such as elevation, slope, aspect and soil type, as well as other location and climate characteristics governed by geography. These characteristics cannot be changed, so for public policy purposes, it does no particular good to know that erosion is more severe on steep slopes. What does matter for the design of natural resource policy are the farming practice variables ($x$) that are chosen by human decision makers.

Once a particular farming practice has been determined to affect natural resource status, the second stage question is which factors govern the choice to adopt that practice. As modeled here, this microeconomic decision emerges from the household’s attempt to optimize its perceived welfare subject to limitations imposed by the available economic and natural resources, as well as the parameters imposed by the larger economy. In simplified form, the household’s problem can be modeled as follows:

![Figure 1. Flowchart of links between household assets, farming practices, and natural resource outcomes.](image-url)
The model in Eqn. (3) states that the farm household chooses the agricultural practices \( x \) that will maximize the expected utility from consuming marketed consumption good \( c \) and home produced good \( y \) in quantity \( y' \). The maximization is constrained by the technology for producing good \( y \) on the farm, specifically its requirements in agricultural labor \( (L_a) \) and agricultural practices \( (x) \), as conditioned by farm level capital \( (k, \text{ in various forms}) \) and other natural and external economic characteristics \( (z) \). It is assumed that the production function for \( y \) is differentiable, increasing, and concave. We do not assume that production function \( y(\cdot) \) is separable in inputs \( x \). A budget constraint states that no more of \( c \) can be purchased at price \( p_c \) than the household can afford with net income from sales of \( y \) (after subtracting home consumption \( (y') \)), the cost of production practices \( (p_x) \), and the cost of hired farm labor \( (p_{ah}L_{ah}) \) plus income from nonfarm employment \( (p_nL_n) \). Finally, the labor available for on-farm production work \( (L_a) \) must either come from the family \( (L_{af}) \) or from hired labor \( (L_{ah}) \). Family labor may be devoted either to on-farm agricultural work \( (L_{af}) \) or to nonfarm work \( (L_n) \). The solution to this constrained optimization problem yields a reduced-form input demand equation for farming practice \( x_{ji} \), the specific practice \( x_j \) associated with the state of natural resource \( i \) in Eqns. (1) and (2). 

\[
x^{*}_{ji} = x^{*}_{ji}(p, x_{(j)}, k, z)
\]  

The optimal input demand function for \( x_{ji} \) in Eqn. (4) depends on the prices \( (p) \) of output \( y \), inputs \( x \), and labor \( L_a \) and \( L_n \), the levels of other agricultural practices \( x_{(j)} \), other than \( x_j \), farm capital \( (k) \), and conditioning factors \( (z) \) related to economic infrastructure, natural characteristics, and the household’s management knowledge and information.

Of particular interest in this study will be the levels of assets, \( k \), which measure poverty. Reardon and Vosti (1995) make a useful distinction among categories of assets that allows them to distinguish between “welfare poverty” and “investment poverty.” The former definition is based on human survival, usually measured in nutritional intake requirements. But for natural resource management, the more relevant definition is “investment poverty,” the level below which it becomes impossible “to make minimum investments in resource improvements to maintain or enhance the quality and quantity of the resource based—to forestall or reverse resource degradation” (p. 1498).

A very wide range of asset categories can be relevant to natural resource management. In citing natural resources, human resources, and physical and financial resources, Reardon and Vosti (1995) go far beyond conventional accounting definitions of “assets.” Such definitions would measure capital assets \( (k) \) as physical and financial assets, including land, equipment, buildings, livestock, financial assets and other inventories with marketable value. People are, of course, a key productive resource whose value as a productive asset depends on their number as well as their “quality” as superficially measured by age, health and education. In the simple household model in Eqn. (3), the \( z \) variable accounts for such broader asset categories as natural resource characteristics and institutional setting. An additional asset category meriting consideration is social capital. The degree to which people in a community care about one another may ameliorate other conventional resource constraints such as market access or credit limitations (Bebbington, 1997). Social capital may also allow a community to impose social norms to discourage individual behavior that undermines the long-term interests of the community as a whole. Such an internalization of economic externalities may include natural resource conservation.

In the absence of excessively limiting assumptions, the variety of agriculturally related natural resource issues makes it impossible to derive \( a \ priori \) analytical results from a conceptual model like this one. Hence, insights must come from empirical evaluation of the natural resource and farming conditions in specific agro-ecological settings.

3. DATA AND EMPIRICAL MODELS

(a) Research setting

The empirical analyses presented here focus on soil erosion, soil fertility decline, overgrazing, and deforestation in the Peruvian Alti-
The Altiplano is a high Andean plain centered geographically and socioeconomically on Lake Titicaca. The plain rises from the lake level at 3,800 meters (m) to over 4,500 m altitude and is bisected by the international border between Peru and Bolivia.

The data reported here come from a survey of 265 farms conducted during April–June, 1999, at the end of the 1998–99 agricultural season. The study took place in the watershed formed by the Ilave and Huenque rivers on the south side of Lake Titicaca in southeastern Puno Department, shown in Figure 2. This watershed was chosen for having documented problems of soil erosion (PELT, 1993). Peruvian census data show that district-level poverty in the zone ranged from 63% to 95% of households with at least one Unmet Basic Need (INEI, 1994).

The survey employed a clustered, stratified sampling design. Strata were defined based on four agro-ecological zones that vary with distance from Lake Titicaca (Swinton, Quiroz, Paredes, Reinoso, & Valdivia, 2001; Tapia, 1996). The flat, Lakeside zone has a frost-free cropping season of 5–6 months and 700–750 mm. of rainfall annually. Farming in the Lakeside zone is characterized by intensive potato-based crop rotations that include rising shares of forage crops to supplement the lake reeds traditionally used for livestock feed. Official measures of poverty are lowest in the Lakeside zone. Moving up and away from the lake, the Suni zone is next, with a frost-free season ranging from three to five months and slightly less rainfall than the Lakeside zone. Frost risk depends upon landscape position, leading to a distinction between the Suni A and Suni B zones, where the former has more “lake effect” and is less prone to night-time frosts. Potatoes can be grown in the Suni A zone, whereas they are a very risky crop in the Suni B zone. Consequently, households in the Suni B zone rely more heavily on range-fed livestock production and less on crops than their counterparts in the Suni A zone. Moving higher and farther yet from Lake Titicaca, the Dry Puna zone has a frost-free season under three months and precipitation under 600 mm annually. Agricultural production systems in the land-abundant Dry Puna are overwhelmingly oriented toward grazing, predominantly sheep and alpacas. The Dry Puna has the highest levels of poverty, as officially defined.

Within each of the four agro-ecological zone strata, two to three villages were selected as sample clusters to reduce the cost of transportation. Based on testimony of government

![Figure 2. Location of Ilave–Huenque watershed in southern Puno Department, Peru.](image-url)
officials in the area, villages were chosen such that one was relatively less and one relatively more poor than the norm for the zone. Within villages, an attempt was made to stratify households by apparent wealth level, in consultation with village leaders; however, records were not retained on the original asset classification of households. The sampling stratification scheme was designed to insure a broad range of asset levels across all four agro-ecological zones in order to test the research hypotheses about poverty–environment links.

(b) Econometric models

The empirical approach was to examine each of the three major natural resource areas in two steps. First, regression analysis was applied to Eqn. (2) in order to answer the question, “Which farming or forestry practices are key determinants of this natural resource outcome?” Next, Eqn. (4) was analyzed for those farming or forestry practices that were important determinants of soil nutrient loss, erosion and overgrazing. Specifically, the second stage regressions sought to answer the questions, “Do asset levels matter in determining the choice of farming/forestry practices? If so, which assets matter most—(a) land, equipment, livestock, buildings, (b) household labor, (c) human capital (education), (d) social capital?”

The survey’s clustered sample design embedded village clusters within the agro-ecological zone strata. Due to similarities that typically occur in a community, it was inappropriate to assume independent observations within village clusters (Deaton, 1997). Village-based cluster effects were factored into the natural resource regressions using village binary variables. In the agricultural practices regressions, where other village-level variables were present, the cluster effect was captured by using random-effects regression models (StataCorp, 1999). Random-effects econometric models assume that the error term has two parts, one at the cluster level and one that is independently distributed at the individual level. A correlation coefficient, rho, estimates the proportion of total variance accounted for at the cluster level. Although spatial autocorrelation was detected across households, random-effects regression based on agro-ecological zones was found to correct fully for spatial structure in the data (Swinton, 2002).

In the paragraphs below, we first describe the natural resource models used to identify agricultural practices that were key determinants of natural resource degradation. Afterward, we describe the generalized asset model that was applied to each of the key agricultural and forestry practices to identify those assets that were major determinants of the choice of practices.

(i) Soil nutrient loss

Soil nutrient loss is a major concern among farmers in the Ilave–Huenque watershed. Fifty-eight percent of farmer respondents blamed productivity losses on “lack of nutrients” or “tired land,” more than any other response. This binary dependent variable was the basis of a probit regression to identify causal factors. Because it applied chiefly to crop production, the analysis was confined to the three agro-ecological zones where crops are grown (omitting the livestock zone of the Dry Puna).

Explanatory variables in the model included binary variables for agro-ecological zone and village, the change in proportion of fallow farmland over the past 20 years, the proportions of fields with vertical and contour furrows, and expenditures per hectare on fertilizers and pesticides (including fungicides). Quadratic forms of most explanatory variables were tested for inclusion in the model. Final model variables were selected on the basis of theoretical consistency, parsimony, and statistical Wald tests (not reported) (Lau, 1986). The base model situation (with values of binary variables at zero) was a flat field in the Lakeside zone, where tillage was unrelated to slope gradient.

(ii) Soil erosion

As a process that occurs gradually over time, soil erosion is difficult to measure in a single visit survey. The soil erosion model used two measures of soil erosion. The first is a Likert scale that increases with perceived loss in soil depth over the past 20 years (values ranged from 1 = major gain to 5 = major loss of soil). The second measure was the perceived proportion of yield lost under typical growing conditions over the past 20 years. Because this value was reported only for those survey respondents who reported that yields had declined (89.3% of those living in the three crop production zones), the data are censored at zero. Consequently, the yield loss model was
estimated using tobit regression; the soil depth model was estimated using ordered probit.

Like fertility loss, erosion also applies to the soil, so the same explanatory variables used in the soil nutrient loss probit model were repeated here. In addition, several environmental variables were added relating specifically to likelihood of erosion. These added variables included the proportion of farm fields in foot slope and hillside positions (as proxies for slope characteristics), the proportion of fields planted to small grains (a crop cover with fibrous roots that tends to reduce erosion), and the estimated value of farm labor (a proxy for tillage and mechanical movement of soil). The Dry Puna zone was again omitted from these regressions on water-based soil erosion due to its lack of cropping activities.

(iii) Overgrazing

Overgrazing can result in both sparse pasture cover and loss of the range species that are preferred by livestock. The survey measured these two outcomes in distinct ways. All farmers were asked if they had observed a decline in agricultural productivity over the past 20 years. Those that replied “yes” (91.3%) were asked to name up to six causes, three for crops and three for livestock. A binary variable was created from those answers naming overgrazing or poor pasture quality as the reasons for productivity decline (35.4% of respondents). This variable was used as the dependent variable in probit regressions.

Loss of range species was measured by a separate question asking whether natural pasture species had disappeared. If so, the respondent was asked to name up to four and to identify up to three reasons for their loss. A new count variable was created for the number of species lost. This second measure of overgrazing was used as the dependent variable in a Poisson regression.

The overgrazing and the species loss regressions shared the same set of explanatory variables that are preferred by livestock. The survey measured these two outcomes in distinct ways. All farmers were asked if they had observed a decline in agricultural productivity over the past 20 years. Those that replied “yes” (91.3%) were asked to name up to six causes, three for crops and three for livestock. A binary variable was created from those answers naming overgrazing or poor pasture quality as the reasons for productivity decline (35.4% of respondents). This variable was used as the dependent variable in probit regressions.

(iv) Deforestation

Most households surveyed cut trees or bushes for cooking fuel. Timber harvest affects the population, age and height distribution of remaining trees. In small areas of the Lakeside zone, pines, eucalyptus, and other new tree varieties had been planted. In most areas, the trees were harvested without replacement, although harvesters typically leave rooted branches of bushy species such as tola (Polypsis incana).

Households that answered affirmatively to the question, “Do you participate in the extraction of bushes and trees?” (58.8%) were asked to identify the forest species that is most important to the household. Next, the respondent was asked to compare the present with 20 years ago for the following: round-trip time required to collect a load of wood; height to which the tree or bush is allowed to grow before being cut; number of years required to reach that height, and what kinds of fuel were used for cooking.

The degree of forest resource degradation was measured by reported changes over 20 years in wood cutting time, tree height, and tree age at cutting. Explanatory variables included whether the household cut trees, whether it had reported using trees for fuel, whether it cooked with wood (all binary), the normalized value of wood collected, and the distance to a gravel road. In addition, the agro-ecological zone binary variables were included.

(v) Choice of agricultural or forestry practices

The agricultural practice regressions used generalized least squares and probit random-effects regression to compensate for the clustered sampling design. Where feasible, all models used the same set of explanatory variables, based on the input demand function in Eqn. (4). These variables include prices, complementary agricultural inputs, capital (fixed, human, and social), nonfarm income, management information, economic infrastructure, and natural resource capital. Given the distinct orientation toward range-fed livestock in the Dry Puna zone, many of the farming practices regressions were either irrelevant or specific to
the Dry Puna. Models specific to the Dry Puna used a more restricted set of variables.

4. RESULTS

(a) Agricultural practices are key determinants of natural resource status in the Altiplano

Results of the soil nutrient loss and erosion models highlight the importance of fallows and tillage practices (Table 1). The probability of a farmer experiencing soil nutrient loss over the past 20 years depended upon village, soil depth loss, soil texture, and farming practices. Soil depth loss contributed significantly to the probability of experiencing soil nutrient loss. The probability of soil nutrient loss was aggravated on sandy soils. The practices of tilling furrows (either contour or vertical) and using pesticides both detracted from the likelihood of perceived soil nutrient loss. These results are somewhat unexpected, as neither directly affects soil fertility.

Soil depth loss over the previous 20 years became the dependent variable in an ordered probit model of erosion determinants (Table 1). Perceived soil loss was much more likely in the hilly Suni A and Suni B zones than in the Lakeside area. The proportion of fields in fallow and fertilizer expenditures per hectare were both associated with reduced reported soil loss.

The yield loss tobit model highlighted the nutrient management benefit of fallowing. The proportion of fallow fields had a highly significant effect reducing reported yield loss over a 20-year period. Curiously, the proportion of fields with vertical furrows was associated with reduced yield loss. Consistent with expectations, yield loss was worse on sandy soils but lessened on fields located at foot slope position (up to a maximum of 32% of fields, beyond which yield loss would increase). Foot slope fields benefit from sediment deposition from upslope locations. Yield loss was also mitigated by pesticide use and labor value (the latter typically linked to weeding and harvest tasks).

The overgrazing and range species loss regression models pointed to herd size reduction over time and rotational grazing as the chief agricultural practices with important benefits for pasture sustainability (Table 2). Of secondary note were stocking rate and improved pastures. Village binary variables were nowhere significant and so were dropped from all models.

The poor pasture probit models examined determinants of the probability that farmers mentioned poor pastures as a major cause of reduced productivity over the past 20 years. In the overall sample, poor pastures were strongly associated with decreases in herd size and reports of drought damage. The correlation between poor pastures and herd size change is misleading, since decreases in herd size are more likely to be the result of poor pastures, rather than the cause. Due to the distinct characteristics of the Dry Puna zone, where livestock are raised extensively, a separate probit analysis was run for that zone. There an additional variable was available to indicate the presence or absence of rotational grazing, whereby pastoralists move livestock to new pastures according to the season of the year. Results for the Dry Puna again found drought to contribute to poor pastures. Rotational grazing significantly reduced the probability of poor pastures (as did reports of frost damage, which may have reduced herd sizes).

The results of the Poisson regression of range species loss had many parallels to those from the poor pasture probit. Reported loss of range species was worst in the Dry Puna zone. Drought, pasture pests and sunburn damage exacerbated the likelihood of range species loss. Unexpectedly, so did the availability of improved pastures and lake area where totora reeds could be harvested for forage. But since improved pastures replace cropping areas and the pasture grown in fallow land, the land available for native pasture species decreases proportional to the area with improved pasture. Near the lake, fallows are absent, crop plots are small, and animal feeding is based on aquatic plants. Certain native species (notably *llachu*) are being depleted by excessive use.

The range species loss analysis was run separately for the Dry Puna zone. There, the stocking rate and drought damage both contributed to range species loss. The practice of rotational grazing again significantly reduced range species loss.

Of the deforestation determinants regressions, only the ones on change in cutting time and tree height were significant (Table 3). Tree cutting was the sole practice that contributed significantly to the increase in observed time required to go and cut wood over the past 20 years. Neither of the two practices analyzed (tree cutting and cooking with wood) proved significant in influencing the observed reduction in reported tree height. Instead, the reduction
in tree height was explained chiefly by location in the Dry Puna agro-ecological zone. All three models were tested for random effects, but finding no evidence, the results are reported based on ordinary least squares models. The regression on change in tree age at harvest remained insignificant even after outlier observations were dropped.  

To summarize the empirical responses to the first research question regarding agricultural and forestry practices as determinants of natural resource outcomes:

— Fallow in crop rotations is strongly associated with reduced soil erosion and reduced long-term crop yield loss. (Soil erosion, in turn, is strongly linked to soil nutrient loss.)
— Tilled furrows and pesticide use are associated with reduced soil nutrient loss; vertical furrows are also linked to reduced yield loss over time (contrary to expectations).
— Herd size decrease over 20 years is associated with probability of poor pastures.
— In the Dry Puna zone, rotational grazing is strongly associated with reduced probability of poor pastures and reduced number of range species lost.
— Tree cutting was associated with reduction in reported tree height over 20 years.

Table 1. Soil nutrient loss, soil loss and 20-year yield loss regression results, cropped zones of Ilave–Huenque basin, Puno, Peru, 1999

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<td>Village 9 (Lake)</td>
<td>Binary</td>
<td>0.945</td>
<td>2.04**</td>
<td>1.753</td>
<td>4.64***</td>
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<td>Binary</td>
<td>-0.645</td>
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<td>Village 1 (Suni A)</td>
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<td>1.015</td>
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<td>Village 4 (Suni A)</td>
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<td>Zone: Suni B</td>
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<td>Village 10 (Suni B)</td>
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<td>Footslope</td>
<td>Proportion of fields</td>
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<td>0.59</td>
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<td>-1.90*</td>
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<td>Sq. footslope</td>
<td>Proportion of fields</td>
<td>0.614</td>
<td>1.97*</td>
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<td>Slope</td>
<td>Proportion of fields</td>
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<td>0.81</td>
<td>0.162</td>
<td>1.67</td>
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<td>Sandy soil</td>
<td>Proportion of fields</td>
<td>0.912</td>
<td>2.02**</td>
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<td>-0.35</td>
<td>0.138</td>
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<td>Soil depth loss</td>
<td>Likert (5 levels)</td>
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<td>Fallow fields</td>
<td>Proportion of fields</td>
<td>-1.193</td>
<td>-1.37</td>
<td>-1.365</td>
<td>-1.81*</td>
<td>-0.340</td>
<td>-3.27***</td>
</tr>
<tr>
<td>Small grains</td>
<td>Proportion of planted area</td>
<td>-0.445</td>
<td>-0.88</td>
<td>0.080</td>
<td>1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical furrows</td>
<td>Proportion of fields</td>
<td>-0.999</td>
<td>-2.26**</td>
<td>-0.398</td>
<td>-1.18*</td>
<td>-0.089</td>
<td>-1.88*</td>
</tr>
<tr>
<td>Contour furrows</td>
<td>Proportion of fields</td>
<td>-1.501</td>
<td>-1.63*</td>
<td>-0.368</td>
<td>-0.44</td>
<td>0.078</td>
<td>0.63</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>kg/ha</td>
<td>0.001</td>
<td>0.57</td>
<td>-0.002</td>
<td>-1.80*</td>
<td>0.000</td>
<td>-0.21</td>
</tr>
<tr>
<td>Pesticides</td>
<td>kg/ha</td>
<td>-0.026</td>
<td>-2.02**</td>
<td>-0.008</td>
<td>-0.57</td>
<td>-0.009</td>
<td>-2.03**</td>
</tr>
<tr>
<td>Sq. pesticides</td>
<td>kg/ha</td>
<td>0.001</td>
<td>1.33</td>
<td>0.000</td>
<td>1.94*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor value</td>
<td>New soles</td>
<td>0.000</td>
<td>-0.62</td>
<td>0.000</td>
<td>-2.31**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sq. labor value</td>
<td>New soles</td>
<td>0.000</td>
<td>1.95*</td>
<td>0.000</td>
<td>7.70***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td>-0.793</td>
<td>-1.02</td>
<td>0.474</td>
<td>7.70***</td>
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<td></td>
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Regression diagnostics

<table>
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<tr>
<th>Observations (n)</th>
<th>Chi-square</th>
<th>P-value</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>181</td>
<td>36.69</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>173</td>
<td>41.98</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* Significant at the 0.10 level.
** Significant at the 0.05 level.
*** Significant at the 0.01 level.
Table 2. *Overgrazing and range species loss regression results, Ilave–Huenque watershed, Puno, Peru, 1999*.  

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit of measure</th>
<th>Poor pasture models</th>
<th>Range species loss models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All zones (probit)</td>
<td>Dry Puna (probit)</td>
</tr>
<tr>
<td>Location and natural factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone: Suni A</td>
<td>Binary</td>
<td>0.070</td>
<td>0.2</td>
</tr>
<tr>
<td>Zone: Suni B</td>
<td>Binary</td>
<td>0.284</td>
<td>0.78</td>
</tr>
<tr>
<td>Zone: Dry Puna</td>
<td>Binary</td>
<td>0.519</td>
<td>1.32</td>
</tr>
<tr>
<td>Pasture pest damage</td>
<td>Binary</td>
<td>-0.153</td>
<td>-0.37</td>
</tr>
<tr>
<td>Drought damage</td>
<td>Binary</td>
<td>0.435</td>
<td>2.33**</td>
</tr>
<tr>
<td>Frost damage</td>
<td>Binary</td>
<td>-0.174</td>
<td>-0.78</td>
</tr>
<tr>
<td>Sun damage</td>
<td>Binary</td>
<td>0.079</td>
<td>0.32</td>
</tr>
<tr>
<td>Wind damage</td>
<td>Binary</td>
<td>-0.042</td>
<td>-0.11</td>
</tr>
<tr>
<td>Management factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocking rate</td>
<td>SEVU/ha</td>
<td>0.000</td>
<td>1.23</td>
</tr>
<tr>
<td>Forage availability</td>
<td>Cereal has./SEV^a</td>
<td>0.029</td>
<td>0.04</td>
</tr>
<tr>
<td>Herd decrease</td>
<td>Likert (5-levels)</td>
<td>0.175</td>
<td>2.38**</td>
</tr>
<tr>
<td>Rotational grazing</td>
<td>Binary</td>
<td>-0.837</td>
<td>-2.12**</td>
</tr>
<tr>
<td>Pasture area</td>
<td>Hectares</td>
<td>-0.723</td>
<td>-1.33</td>
</tr>
<tr>
<td>Improved pastures</td>
<td>Proportion of pasture area</td>
<td>-0.119</td>
<td>-0.26</td>
</tr>
<tr>
<td>Lake reed pasture</td>
<td>Proportion of pasture area</td>
<td>-1.296</td>
<td>-3.02***</td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td>-1.296</td>
<td>-3.02***</td>
</tr>
<tr>
<td>Regression diagnostics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations (n)</td>
<td></td>
<td>248</td>
<td>61</td>
</tr>
<tr>
<td>Chi-square</td>
<td></td>
<td>26.5</td>
<td>21.1</td>
</tr>
</tbody>
</table>

^a SEVU = sheep-equivalent value unit.

* Significant at the 0.10 level.

** Significant at the 0.05 level.

*** Significant at the 0.01 level.
Determinants of farming practices

The second stage analyses sought to determine what factors influence the choice of those farming practices linked to natural resource degradation (or sustainability). Of particular interest is the effect of poverty—and type of poverty—on choice of agricultural practices. The practices of interest (listed above) were fallowing cropland, vertical furrows, change in herd size, and (for the Dry Puna) the use of rotational grazing. These analyses were modeled using a single set of explanatory variables derived from the categories in input demand Eqn. (4).

The categories of explanatory variables included prices and economic infrastructure, poverty level, capital (fixed, human, and social), labor, nonfarm income, natural resource capital, and other agricultural inputs. The price/infrastructure category included potato price and distance from village center to nearest paved road. Poverty level was measured as the sum of Unmet Basic Needs as defined by Peru’s national statistical service (INEI, 1994). Fixed capital included cropped area, pasture area, vehicles owned, stores or farm buildings owned, well equipment, other agricultural equipment, home appliances, and total livestock (measured as sheep-equivalent value units [SEVU]). Farm labor was measured as the total adult family labor supply minus the person-years worked in nonfarm employment during 1998–99. Credit and nonfarm income were measured in cash amounts declared during the year from April 1, 1998 to March 31, 1999. Human capital measures were years of schooling by household head and number of household adults having completed secondary school. Social capital variables included whether the household head had held an official position in the community during the past five years, the number of association memberships by household members, village area devoted to aynoca land (where individual owners must follow community-dictated crop rotations), and village families using communal pastures. In addition, several of the same natural resource and agricultural practice variables were included that appeared in the natural resources regression models. Finally, in order to capture knowledge transfer in a setting where agricultural extension has disappeared, a village-level binary variable was included for existence of a natural resource-oriented development project during the past 10 years.

The results are as surprising for the relationships that are absent as they are for the relationships that are present. As shown in Tables 4 and 5, prices and economic infrastructure have no significant effect on the choice of these agricultural practices. Several fixed capital variables are significant, but in inconsistent ways that offer no clear support or contradiction of the opposing sides in the poverty–environment debate. The proportion

Table 3. Deforestation regression results, Ilave–Huenque watershed, Puno, Peru, 1999

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit of measure</th>
<th>Change in cutting time (OLS)</th>
<th>Change in tree height (OLS)</th>
<th>Change in tree age (OLS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location and natural factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone: Suni A Binary</td>
<td>-0.088</td>
<td>-0.45</td>
<td>-0.164</td>
<td>-1.47</td>
</tr>
<tr>
<td>Zone: Suni B Binary</td>
<td>0.202</td>
<td>1.07</td>
<td>0.113</td>
<td>1.06</td>
</tr>
<tr>
<td>Zone: Dry Puna Binary</td>
<td>-0.287</td>
<td>-1.30</td>
<td>0.331</td>
<td>2.64***</td>
</tr>
<tr>
<td><strong>Management factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuts trees Binary</td>
<td>1.162</td>
<td>3.81***</td>
<td>0.254</td>
<td>1.46</td>
</tr>
<tr>
<td>Cooks with wood Binary</td>
<td>-0.253</td>
<td>-0.82</td>
<td>-0.097</td>
<td>-0.55</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.027</td>
<td>-0.21</td>
<td>0.001</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Regression diagnostics**

| Observations (n) | 246 | 246 | 246 |
| Adj. R-square | 0.184 | 0.172 | 0.031 |

*** Significant at the 0.01 level.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Prices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price of potato</td>
<td>Peru soles/kg</td>
<td>$-0.029$</td>
<td>$-0.29$</td>
<td>$-0.037$</td>
<td>$-0.16$</td>
</tr>
<tr>
<td>Physical assets and income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unmet basic needs</td>
<td>Sum</td>
<td>$0.027$</td>
<td>$1.42$</td>
<td>$-0.076$</td>
<td>$-1.70^*$</td>
</tr>
<tr>
<td>Cropped area</td>
<td>Hectares</td>
<td>$0.012$</td>
<td>$0.89$</td>
<td>$0.017$</td>
<td>$0.56$</td>
</tr>
<tr>
<td>Pasture area</td>
<td>Hectares</td>
<td>$0.000$</td>
<td>$1.18$</td>
<td>$0.001$</td>
<td>$0.88$</td>
</tr>
<tr>
<td>Vehicles owned</td>
<td>Units</td>
<td>$0.008$</td>
<td>$0.48$</td>
<td>$0.007$</td>
<td>$0.17$</td>
</tr>
<tr>
<td>Store/warehouse</td>
<td>Units</td>
<td>$0.030$</td>
<td>$1.37$</td>
<td>$-0.017$</td>
<td>$-0.34$</td>
</tr>
<tr>
<td>Well equipment</td>
<td>Units</td>
<td>$0.079$</td>
<td>$2.81^{**}$</td>
<td>$0.011$</td>
<td>$0.18$</td>
</tr>
<tr>
<td>Other agric. equipment</td>
<td>Units</td>
<td>$0.001$</td>
<td>$0.09$</td>
<td>$-0.001$</td>
<td>$-0.07$</td>
</tr>
<tr>
<td>Home equipment</td>
<td>Units</td>
<td>$0.007$</td>
<td>$1.04$</td>
<td>$-0.024$</td>
<td>$-1.48$</td>
</tr>
<tr>
<td>Total SEVU’s</td>
<td>Sheep value units</td>
<td>$0.000$</td>
<td>$-0.42$</td>
<td>$0.000$</td>
<td>$0.49$</td>
</tr>
<tr>
<td>Nonfarm income</td>
<td>Peru soles</td>
<td>$0.000007$</td>
<td>$-2.28^{**}$</td>
<td>$-0.000$</td>
<td>$-1.25$</td>
</tr>
<tr>
<td>Family labor and local infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family agric. labor available</td>
<td>Person-years</td>
<td>$-0.015$</td>
<td>$-1.60$</td>
<td>$0.011$</td>
<td>$0.53$</td>
</tr>
<tr>
<td>Credit</td>
<td>Peru soles</td>
<td>$0.000$</td>
<td>$-0.59$</td>
<td>$0.000$</td>
<td>$0.84$</td>
</tr>
<tr>
<td>Distance to paved road</td>
<td>Minutes on foot</td>
<td>$0.119$</td>
<td>$1.04$</td>
<td>$-0.115$</td>
<td>$-0.43$</td>
</tr>
<tr>
<td>Human capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education of HH head</td>
<td>Years</td>
<td>$-0.007$</td>
<td>$-0.83$</td>
<td>$0.009$</td>
<td>$0.47$</td>
</tr>
<tr>
<td>Adults with high school</td>
<td>Units</td>
<td>$0.030$</td>
<td>$2.20^{**}$</td>
<td>$-0.045$</td>
<td>$-1.42$</td>
</tr>
<tr>
<td>Social capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position of HH head</td>
<td>Binary</td>
<td>$-0.004$</td>
<td>$-0.15$</td>
<td>$-0.019$</td>
<td>$-0.34$</td>
</tr>
<tr>
<td>Association memberships</td>
<td>Units</td>
<td>$0.027$</td>
<td>$2.07^{**}$</td>
<td>$0.037$</td>
<td>$1.23$</td>
</tr>
<tr>
<td>Aymoca area</td>
<td>Hectares</td>
<td>$0.001$</td>
<td>$2.65^{**}$</td>
<td>$0.000$</td>
<td>$0.58$</td>
</tr>
<tr>
<td>Families using communal pastures</td>
<td></td>
<td>$-0.001$</td>
<td>$-1.18$</td>
<td>$-0.002$</td>
<td>$-0.87$</td>
</tr>
<tr>
<td>Natural and conditioning factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suni A zone</td>
<td>Binary</td>
<td>$0.188$</td>
<td>$3.85^{***}$</td>
<td>$0.025$</td>
<td>$0.22$</td>
</tr>
<tr>
<td>Suni B zone</td>
<td>Binary</td>
<td>$0.364$</td>
<td>$5.42^{***}$</td>
<td>$-0.223$</td>
<td>$1.44$</td>
</tr>
<tr>
<td>Footslope</td>
<td>Proportion of fields</td>
<td>$-0.004$</td>
<td>$-0.06$</td>
<td>$0.265$</td>
<td>$1.82^{*}$</td>
</tr>
<tr>
<td>Slope</td>
<td>Proportion of fields</td>
<td>$-0.082$</td>
<td>$-1.13$</td>
<td>$0.102$</td>
<td>$0.61$</td>
</tr>
<tr>
<td>Sandy soil</td>
<td>Proportion of fields</td>
<td>$0.025$</td>
<td>$0.63$</td>
<td>$0.031$</td>
<td>$0.98$</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>kg/ha</td>
<td>$0.000$</td>
<td>$-0.97$</td>
<td>$-0.000$</td>
<td>$-0.04$</td>
</tr>
<tr>
<td>Pesticides</td>
<td>kg/ha</td>
<td>$-0.001$</td>
<td>$-0.75$</td>
<td>$0.001$</td>
<td>$0.23$</td>
</tr>
<tr>
<td>Natural Resource project</td>
<td>Binary</td>
<td>$0.161$</td>
<td>$2.34^{**}$</td>
<td>$0.152$</td>
<td>$0.96$</td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td>$-0.227$</td>
<td>$-1.76$</td>
<td>$0.701$</td>
<td>$2.35^{**}$</td>
</tr>
<tr>
<td>Regression diagnostics</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Nbr. of observations</td>
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<td>179</td>
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<td>Nbr. of groupings</td>
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<td>8</td>
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<tr>
<td>Chi-square</td>
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<td>40.01</td>
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<td>$F$-value</td>
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<tr>
<td>rho</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a* During 1998–99, the exchange rate of Peru’s nuevo sol was approximately US$1 = S/.3.20.

*b* SEVU = sheep-equivalent value unit.

* Significant at the 0.10 level.

** Significant at the 0.05 level.

*** Significant at the 0.01 level.
### Table 5. Determinants of livestock management practices: random-effects regression results, Ilave–Huenque basin, Puno, Peru, 1999

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit of measure</th>
<th>Herd decrease(^a) (ordered probit)</th>
<th>Rotation grazing (probit)—Dry Puna</th>
<th>Coef.</th>
<th>z-Stat.</th>
<th>Coef.</th>
<th>z-Stat.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical assets and income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unmet basic needs</td>
<td>Sum</td>
<td>0.170</td>
<td>1.24</td>
<td>0.419</td>
<td>0.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cropped area</td>
<td>Hectares</td>
<td>0.146</td>
<td>1.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pasture area</td>
<td>Hectares</td>
<td>0.000</td>
<td>-0.06</td>
<td>-0.001</td>
<td>-0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles owned</td>
<td>Units</td>
<td>0.021</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Store/warehouse</td>
<td>Units</td>
<td>0.233</td>
<td>1.65*</td>
<td>-1.093</td>
<td>-2.40**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well equipment</td>
<td>Units</td>
<td>-0.710</td>
<td>-3.31***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other agric. equipment</td>
<td>Units</td>
<td>-0.106</td>
<td>-2.36**</td>
<td>-0.181</td>
<td>-0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home equipment</td>
<td>Units</td>
<td>-0.029</td>
<td>-0.62</td>
<td>0.526</td>
<td>2.44**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total SEVU's(^b)</td>
<td>Sheep value units</td>
<td>-0.002</td>
<td>-2.61**</td>
<td>0.004</td>
<td>2.27**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonfarm income</td>
<td>Peru soles</td>
<td>0.000</td>
<td>-0.74</td>
<td>0.000</td>
<td>0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Family labor and local infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family agric. labor available</td>
<td>Person-years</td>
<td>-0.086</td>
<td>-1.34</td>
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<td>-0.227</td>
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<td>61</td>
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<td>78.37</td>
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<tr>
<td>Rho</td>
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<td>n.a.(^a)</td>
<td>0.00</td>
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</table>

\(^a\)The herd decrease model was run as an ordinary ordered probit, as software for random-effects ordered probit was unavailable (StataCorp, 1999). But the other random-effects models showed no appreciable village-level error component, suggesting that the likely effect of not applying random-effects regression in this instance is negligible.

\(^b\)SEVU = sheep-equivalent value unit.

* Significant at the 0.10 level.
** Significant at the 0.05 level.
*** Significant at the 0.01 level.
of fields in fallow increases with well equipment units and decreases with nonfarm income. The proportion of fields with vertical furrows decreases with Unmet Basic Needs. Livestock herd size decreases are boosted by store and building ownership but decreased by ownership of wells and other agricultural equipment and (tautologically) by livestock capital. Rotational grazing is more likely among owners of more livestock capital and less likely among store and building owners.

Among the garbled effects of fixed capital on adoption of sustainable agricultural practices, livestock capital offers the chief discernable pattern. Livestock-related management changes are closely linked to capital in the form of

<table>
<thead>
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<th>Variable</th>
<th>Unit of measure</th>
<th>Coef.</th>
<th>z-Stat.</th>
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<tr>
<td>Unmet basic needs</td>
<td>Sum</td>
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<td>-1.53*</td>
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<td>Cropped area</td>
<td>Hectares</td>
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<td>-3.18***</td>
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<td>Pasture area</td>
<td>Hectares</td>
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<td>Vehicles owned</td>
<td>Units</td>
<td>-0.078</td>
<td>-0.34</td>
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<td>Store/warehouse</td>
<td>Units</td>
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<td>Well equipment</td>
<td>Units</td>
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<td>0.41</td>
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<td>Other agric. equipment</td>
<td>Units</td>
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<td>Home equipment</td>
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<td>Total SEVU’s*</td>
<td>Sheep value units</td>
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<td>Nonfarm income</td>
<td>Peru soles</td>
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<td>Person-years</td>
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<td>Credit</td>
<td>Peru soles</td>
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<td>-1.96**</td>
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<td>Distance to paved road</td>
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<td>-3.08***</td>
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<td>Distance to improved road</td>
<td>Minutes on foot</td>
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<td>Education of HH head</td>
<td>Years</td>
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<td>-1.97**</td>
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<td>Adults with high school</td>
<td>Units</td>
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<td>Association memberships</td>
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<td>Ayacucho area</td>
<td>Hectares</td>
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<td>Families using communal</td>
<td>Pastures</td>
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<td>Suni A zone</td>
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<td>Constantb</td>
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<td>1.526</td>
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</table>

Regression diagnostics

| Nbr. of observations | 197 |
| Nbr. of groupings | 10 |
| Chi-square | 58.88 |
| P-value | 0.0001 |
| Rho | 0.000 |

*SEVU = sheep-equivalent value unit.

bConstant includes both Lakeside and Dry Puna zones with most cases in Dry Puna.

*Significant at the 0.10 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.
livestock numbers and the availability of water for them (via well equipment). But, the causal link between herd size and poor pastures remains unclear, and larger herds are associated with more sustainable rotational grazing. If these results are hard to interpret for management of livestock, they are even more so for crops. Overall, the results show no clear link between fixed asset ownership and choice of agricultural practices that degrade natural resources.

Social and human capital variables display a clearer link to the choice of sustainable agricultural practices. The social capital variables play positive roles in almost all cases. Land area under aynoca management is strongly associated with more cropland in fallow and less tree cutting. The aynoca is a traditional land management system under which villagers with fields in a designated aynoca area are obliged to follow an established crop rotation. The rotation typically includes a fallow period. Apart from the statistical analyses reported here, one explanation farmers mentioned for loss of soil fertility was that they had given up their aynoca fields; 14% of all respondents (including 35% of those in one village) blamed crop productivity loss on the abandonment of aynocas.

The other social capital variables also largely favored adoption of good land stewardship practices. Association memberships are associated with more cropland in fallow (good), but also reduced rotational grazing (not good). A public position held by the household head is associated with increased rotational grazing. Household heads who held a public position were also linked to more tree harvesting.

Human capital too appears to promote the use of more sustainable agricultural practices. Use of fallow was more common among households with more adults who completed secondary school and in villages that had enjoyed a natural resources development project. Livestock herd size was less likely to decrease where the household head was better educated (and herd decreases were associated with poorer pastures). Likewise, tree cutting was less common where household heads held higher levels of education.

Forestry practices, by contrast, are clearly linked to asset poverty. As shown in Table 6, the probability of engaging in tree extraction was reduced by land holdings (for both crops and grazing) and access to credit. It was further reduced by access to public infrastructure in the form of paved or improved dirt roads. Among human capital variables, educational level of the household head reduced the likelihood of cutting trees. Social capital variables had mixed effects, but in communities with a larger area under joint aynoca crop management, the probability of tree cutting was reduced. The only forms of capital associated with more tree harvest were herd size and leadership experience, both of which have alternative explanations linked to information rather than capital. Herding brings household members into contact with woodlands, while community leadership may acquaint the leader with resources beyond the bounds of his or her own lands.

5. DISCUSSION AND CONCLUSIONS

The link between certain agricultural practices and natural resource sustainability is clear. In the impoverished setting of the Peruvian Altiplano, soil nutrient loss and erosion were diminished by the use of fallow and, in some cases, by the use of vertical furrows. Overgrazing was reduced by rotational grazing. With the direction of causality unclear, overgrazing was also positively associated with decreases in herd size.

The three agricultural practices with clear natural resource impacts require either land (for fields in fallow rotation) or labor (for tillage or rotational grazing). None requires much investment capital. So it should not be surprising that fixed capital variables had little ability to explain adoption of these methods.

By contrast, deforestation in this area is chiefly caused by the search for fuel wood. Not cutting wood carries the financial opportunity cost of buying some other fuel for cooking and heating. As a result, the households poorest in land ownership, access to credit and community lands, schooling, and access to roads were those most likely to cut the native alpine shrubs.

Does the minor role of fixed capital assets in affecting soil and grassland resources mean that the debate over poverty and natural resource degradation is irrelevant in the Altiplano? Can policymakers conclude that deforestation is the only area where poverty is related to natural resource degradation in this setting? Almost certainly not, but a firm conclusion can only be reached by studying a wider range of asset levels. Poverty was pervasive among the farm households surveyed. Seventy-two percent lacked a latrine, among other unmet basic
needs. Two-thirds earned less than Peru's monthly minimum wage of US$100 per month. Since nearly everyone interviewed suffered "welfare poverty," not to mention "investment poverty," this study cannot draw conclusions about agricultural practices that are affordable only to the relatively wealthy.

This study does offer insights about the adoption of natural resource-conserving agricultural practices in a setting where poverty is widespread. It demonstrates that relative improvements can be made in natural resource stewardship—even among the very poor. Awareness of sustainability problems and low-cost steps to address them, combined with closely knit community structures are the key factors that support good stewardship in such a setting. Traditional social institutions like the aynoca continue to play a valuable role in a setting where fallow rotations are the primary means of restoring soil fertility and preventing erosion.

The long slow emigration from the Andean highlands gives ample evidence that residents view life chances elsewhere as more favorable. Continuing emigration may leave Altiplano agriculture stagnating in a low-productivity equilibrium where the relative price of labor to land never triggers the kind of investments that raise land productivity beyond the bottom of Templeton and Scherr's (1999) U-curve. Unspoken in the literature about intensification is that as economies develop, some regions see agricultural intensification while others see agricultural abandonment. The latter can also offer environmental benefits, as witnessed by the reforestation of the eastern United States in the past 70 years. The fact that Altiplano farmers are not making significant investments in agricultural conservation may be due to their poverty, but it may also be due to a belief that their scarce funds are better invested elsewhere—perhaps not in agriculture and perhaps not in the Altiplano. Only dramatic changes in market access and local employment opportunities are likely to change this in a fundamental way. The results here show that even incremental changes in market and credit access can reduce deforestation. But the effects for agricultural natural resources may be hidden by a low-level poverty equilibrium.

In the absence of dramatic changes in market access and employment opportunities, the policy lesson from this research is that incremental natural resource benefits can be had at very low cost. In areas where the social fabric is strong and capital is scarce, natural resource policies should focus on diffusing knowledge about natural resource stewardship using affordable practices. Traditional social norms and institutions such as the aynoca already provide incentives for sustainable farming. These institutions should be understood and built upon if the objective is to encourage marginal changes to effect better stewardship using traditional practices.

NOTES

1. Based on farmer recollection, the cross-sectional distribution of the number of years in rotational fallow shifted markedly downward over the previous 20 years (from a mode of seven years to one of five years) (Swinton & Quiroz, forthcoming).

2. Various authors classify tola as Baccharis spp., Diplostephium spp., Parastrephia lediphylla (ONERN); and Lepidophyllum cuadrangulare (Gomez).

3. One household in the Lakeside zone with newly planted pine trees was dropped from the change in tree cutting time regression as a (negative) outlier. Two others in the Suni A zone were dropped from the change in tree age model due to extreme values.

REFERENCES


StataCorp. (1999). *Stata statistical software: release 6.0*. College Station, TX: Stata Corporation.


