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SUSTAINABLE INTENSIFICATION IN THE HIGHLAND TROPICS: RWANDAN FARMERS' INVESTMENTS IN SOIL CONSERVATION AND FERTILITY

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Sustainable Intensification in the Highland Tropics: Rwandan Farmers' Investments in Soil Conservation and Fertility

1. Introduction

The horror of genocide and civil war have turned the world's attention to Rwanda over the past year. But before and beyond that conflict, there was hunger and the slow, grinding poverty of smallholder agriculture as it met with severe land scarcity and degradation. This paper focuses on how smallholders are trying to meet this challenge of agricultural decline, and what determines their investments in sustainable intensification of farming.

Historically, Rwandan farmers settled along the upper ridges of their hillsides where soils were more fertile and cultivation was a simpler task than it was farther down, on the steeper slopes and in the marshy valleys.[1] But rapid population growth has in recent decades brought several changes: (1) farm holdings have become smaller due to constraints on land availability; (2) holdings are more fragmented; (3) farmers cultivate fragile margins on steep slopes previously held in pasture and woodlot; (4) many households rent land, particularly those owning little land or with large families; (5) fallow periods have become shorter, and cultivation periods have grown longer.[2]

A consequence of farming more intensively and farming on steep slopes is the high incidence of soil loss due to erosion, and along with its declining fertility. Rwanda's National Agricultural Commission estimates that half the country's farmland suffers from moderate to severe erosion.[3] Clay reports that farmers observe a decline in the productivity of nearly half their holdings due to land degradation.[4] Byiringiro and Reardon show that erosion severely reduces farm yields in Rwanda.[5]

Farmers have responded to declining productivity in a variety of familiar ways. Some have changed cropping patterns toward higher value crops, or increased the amount of labor inputs in an effort to squeeze more from their holdings. Others have invested in soil conservation measures, such as grass strips, anti-erosion ditches, hedgerows, and radical terraces. Still others have increased the

amount of organic matter (mulch, manure, etc.) applied to their fields or have added chemical fertilizers and lime.[6] Though the agricultural intensification strategies embarked upon by Rwandan farmers are not new to the development literature, our understanding of the determinants and constraints that shape these farmer strategies is only patchy at best.

In her seminal work, Boserup outlines a number of technology and investment paths to agricultural intensification that farmers follow in the wake of increased land constraints[7]—conditions that result from population growth, increased demand for agricultural products, or reduced transportation costs.[8] To set the stage for our subsequent discussion, we distill and stylize from her work two broad paths. The first we refer to as *labor-led* intensification: this is where farmers merely add (unaugmented) labor to the production process on a given unit of land, allowing them to crop more densely, weed and harvest more assiduously, and so on. The second is *capital-led* intensification, which entails the use of "capital," broadly defined to include nonlabor variable inputs as well as fixed and quasi-fixed capital (e.g., where farmers augment their labor with fertilizer or organic matter), and capital that facilitates land improvement. Boserup identifies the second path as having higher land productivity than the former, citing examples of chemical fertilizer combined with "other means of fertilization" (which we take to mean organic matter), and tractors for contour plowing and similar land improvements. She also notes that "Both mechanized equipment and chemical inputs are likely to be used as land-saving devices in cases where population increase and attractive prices stimulate to more intensive use of land...".[9] Hence, she envisions both the push of demographic pressure and the pull of policy and market factors.

Empirical research on intensification in Africa has illustrated the two intensification paths initially described by Boserup, and here termed the labor-led and capital-led paths. Several studies have categorized the agricultural systems in certain regions of Africa where demographic pressure has pushed farmers to intensify along these paths. Matlon and Spencer note that the capital-led path

is more sustainable and productive in fragile, resource-poor areas.[10] Lele and Stone categorize a variety of agroclimatic and policy settings in terms of these two paths, focusing especially on the need for the capital-led path (which they term "policy-led").[11] They maintain that the labor-led path (which they term the "autonomous model") has not led to land productivity growth in Sub-Saharan Africa, and that policy-led intensification is needed so that land quality and productivity will be maintained and even enhanced as cropping is intensified.

In much of the African tropics, the labor-led path to intensification is unsustainable, and leads to land degradation and stagnation of land productivity.[12] This danger is at its maximum in the East African highland tropics, which are characterized by heavy rainfall and steep slopes. In the latter setting, the capital-led path of intensification that incorporates soil conservation investments with the use of organic matter and fertilizer is much more sustainable. By contrast, farm households that follow only the labor-led path in that setting are on course for long-run ecological degradation and poverty. Hence, the issue of what determines the particular technology and investment paths that households follow is of critical importance in the current debate on sustainable development.

In general, conceptual and empirical work in the tropics has focused on how broad groups of farmers, in particular agroclimatic zones and policy contexts, face incentives (such as relative prices) and conditions (such as access to markets or new technologies) for following one or the other intensification path. For example, Pingali, et al., examine how costs and returns to intensification by use of animal traction can be categorized according to economic and physical characteristics of agroclimatic zones.[13] Smith, et al., and Freeman examine the nature of intensification in maize production over locations with differential access to infrastructure, technology, and prices.[14]

Yet much less empirical research, especially in Africa, has addressed the issue of specifically what determines the path taken by particular groups of farm households. Unanswered are the questions of whether and why particular types of households, situated in given agroclimatic and policy

contexts, and facing similar incentives to intensify, take the labor-led or capital-led intensification path. Specifically, there have been relatively few studies that analyze the determinants of smallholder investments in soil conservation capital and the use of improved inputs such as fertilizer and organic matter in settings of rapid population growth and degradation. Recent exceptions are Place and Hazell, who focus on the effects of land tenure on land improvements in Rwanda, and Lopez-Pereira, et al., on the hillsides of Honduras.[15]

We address this gap in research using farm survey data from Rwanda. Our contribution is twofold. First, we add an empirical analysis of the capital-led path of intensification, focusing on household-level differences in the determinants of intensification within a given agroclimatic zone (the East African highland tropics) and policy context (Rwanda). Second, we highlight household-level determinants of "sustainable intensification" that have not commonly been treated in the literature on intensification. More specifically: (a) We show the importance of household-level intersectoral links—specifically, "reverse linkages," where nonfarm income affects farm investment—to enhancing the capacity of households to follow the capital-led path. (b) We address the subject of landholding structure that recent literature has brought to center stage.[16] Here we examine the links between demographic pressure, changes in the structure of landholding, and, in turn, the technology paths taken by farmers.

The paper proceeds as follows: Section 2 discusses our general model. Section 3 discusses the specific variables and our hypotheses. Section 4 describes data used and regression specification. Section 5 describes patterns in the model variables. Section 6 presents and discusses regression results. Section 7 concludes.

2. General Model

We set out a general model for farm investments, which is then broken out in the following section into four regression equations for the land and input use and soil conservation investments under study.

We follow the literature on firm and farm-level investment theory,[17] and model farm-level investments as a function of four sets of variables:

$$\text{Investment} = f((1)\ \text{financial returns},\ (2)\ \text{physical returns},\ (3)\ \text{riskiness, and}\ (4)\ \text{wealth and cash sources}) \qquad (1)$$

In general, a higher return on investment will stimulate a higher rate of investment. Conversely, greater risk leads to lower investment for risk-averse farmers. In the present context, we focus on risk from price and rainfall instability, which Feder, et al., term "confidence in short term," and from insecurity of land tenure hence risk of appropriation of capital, which they term "confidence in long term."[18]

While the incentive to invest can be great, capacity to invest may be low. Thus income and wealth (in terms of human capital and cash and labor sources) are important general determinants of such investments. In theory, household liquidity is important to include in contexts where the credit market is underdeveloped or absent. This generally the case in the tropical highlands of East Africa for these sorts of investments.

3. Explanatory Variables and Hypotheses

The general model described above explains investment in terms of the incentives and disincentives facing farm households and capacity of households to undertake the investments.

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Table 1 shows the regression specification, reproduced as follows:

Land use (C-value reflecting erosivity[19]) = f (A,B,C,D,E) (2)

Soil conservation investments (m/ha) = f (A,B,C,D,E) (3)

Use of organic inputs = f (A,B,C,D,E) (4)

Use of purchased inputs = f (A,B,C,D,E) (5)

The five groups of regressors are listed in Table 1. Note that some variables are classed for simplicity as either incentive or capacity variables, but actually are both (an example is farm size). The five variable sets are: (A) monetary incentives to invest: agricultural profitability, farm wage, nonfarm wage; (B) physical incentives to invest: fallow, slope, location on slope, distance from residence, years of operation, plot size, and rainfall; (C) risk of investment: ownership rights (rented/owned), price variation over last six years; (D) wealth and liquidity sources: farm size, nonfarm income, livestock value, crop output value; (E) other household characteristics: number of adults, dependency ratio, literacy of head, knowledge of conservation practices, age of head.

Monetary Incentives to Invest

Profitability: We expect better returns to agriculture to lead unambiguously to more soil conservation and fertility investments.

Wages, farm and nonfarm: Our hypothesis about the effect of the return to off-farm activity is ambiguous. On one hand, better returns off-farm mean competition with on-farm investment; on the other hand, greater off-farm income means more cash available to the household to invest on-farm. But labor and cash diverted to off-farm uses might also reduce the pressure on the land; it would provide cash to buy food, and might encourage the household to use land in less labor-

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demanding ways, such as perennial crops, fallow, and pasture—ways that are also less erosive and degrading of soil fertility.

Physical Incentives to Invest

Fallow: We expect that farmers with less land in fallow will be more likely to invest, as their reliance on presently-cultivated land will be greater. As with slope steepness, decline in fallow has attained more importance as an issue as population density has increased. Fallow and pasture have been declining in recent years because of the need to increase food production.[20] Only woodlots seem not to have suffered, thanks to a strong government campaign aimed at replanting and woodlot maintenance at both household and communal levels.

Declining fallow appears to be linked to changes in land use. Though some of the lost fallow and pasture may be land that has been converted into woodlot, other findings suggest that households with insufficient landholdings are being forced to plant more land in sweet potatoes and other tubers.[21] Tubers have a higher caloric value than other crops, and tend to grow relatively well in poorer soils[22] such as those commonly found on steeper slopes. But in terms of soil erosion, tubers are worse than the traditional uses of these slopes (woodlot and pasture). Elsewhere in Africa[23] and in Latin America,[24] tubers have been associated with accelerated soil loss.

Slope steepness and location: Steeper slope (particularly where rainfall is high) increases the incentive to invest in soil protection and to adopt less erosive forms of land use. Steeper plots are more susceptible to erosion. But we expect that steepness will discourage the use of fertilizer and organic matter because of runoff.

The issue of field slope has become more important with increased population density. In Rwanda, the steepest areas have traditionally been reserved for pasture, woodlot, and minor crops, and frequent fallow periods were commonly required. At the very outer rings of cultivation, toward

the base of the slope and in the swampy valleys, crops are grown along ridges that are built up for purposes of water drainage. Increasing land scarcity has obliged many farmers in recent decades to depart from this traditional system. As the preferred lands along the upper slopes became occupied, young farmers were faced with the decision to either cultivate smaller and less fertile plots farther down the hillside or to migrate elsewhere in search of sufficient land. Thus, our interest is both in steepness of slope and in hillside location (i.e., upper, mid or lower), the two of which are closely associated, with the steepest holdings being located on the mid-slope areas.

Distance from residence: Farm "fragmentation" entails the geographic dispersion of plots. We measure this by average *distance* (in terms of time) farmers must walk to their plots, rather than the number of parcels or their size.[25]

We expect that as fragmentation increases, and plots are more dispersed, farmers will have less incentive to make land improvements because of higher travel and transaction costs. Moreover, distant parcels are often at the base of the hillside and in valleys where the degenerative effects of soil erosion are less severe, and where lands have been brought into production more recently.

Plot Age: In the past, Rwandan farmers could migrate in response to growing demographic pressure; they tended to move to the drier, eastern provinces, once the exclusive domain of the pastoralists. Today, however, in the absence of unoccupied lands, farmers cultivate the same holdings year after year, and in increasingly intensive ways. It may be reasonable to hypothesize that long-term cultivation will increase the likelihood of investment in a given parcel. However, all else equal, it will be a sign of soil fatigue, and perhaps a disincentive to invest.

Rainfall: Greater rainfall is expected to lead to less erosive land use practices and more soil conservation investments. This was discussed above in the section concerning plot slope.

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Risk of Investment

Land tenure Plot use rights: This is what Feder, et al., term "confidence in the long term."[26] We expect farmers to make fewer longer-term land improvements such as bunds and terraces on holdings that are rented-in. These holdings have short-term use rights, and as such make long-term investments risky. But empirical evidence for similar contexts is mixed. For a smaller sample in Rwanda (in three prefectures: Butare, Gitarama and Ruhengeri), Place and Hazell found farmers tended to invest less in rented land.[27] And Migot-Adholla, et al., show for Ghana that plots owned or under long-term use rights are more likely to be improved (fertilized, mulched, irrigated, or have trees planted on them) than those under short-term use rights such as rental.[28] But for Kenya they found the relationship between tenure and land improvements to be weak—because farmers feel secure in their ability to cultivate rented plots continuously.

Moreover, we expect, as do Cook and Grut, that rented holdings will tend to be used for annual crop production, rather than for more protective perennial crops and woodlot whose value is returned over a longer time period.[29]

Price risk: This is classified by Feder, et al., as a variable affecting "confidence in the short term."[30] In Rwanda price variability is tied to rainfall variability, and we expect it to be a disincentive to investment.

Wealth and Liquidity Sources

Farm size: Our hypothesis concerning farm size is ambiguous, as its effects are complex and inconsistent. On the one hand, larger farmers are better able to spare land to set aside for anti-erosion measures and for fallow and pasture or woodlot. Larger farmers also tend to be wealthier, so have more cash to hire labor and buy inputs for land improvements.[31]

On the other hand, smaller farmers tend to have more household labor available per hectare, which can be used to build and maintain soil conservation infrastructure that require a substantial and continuous supply of labor.

Farmers with smaller landholdings also have greater incentive to improve their land as they are dependent (*ceteris paribus*) on less land than larger farmers.[32] Boserup maintains that as population density increases and land becomes scarce (farms grow smaller), fallow periods must be shortened, and technologies that are intensive in factors that substitute for land must be adopted.[33] Maro shows that increased population density in highland Tanzania has led to agricultural intensification using irrigation in one area, and terracing of steep slopes in another.[34] In the highland tropics, use of fertility-enhancing inputs and soil conservation capital can increase the intensity of production and sustain its use, thus substituting for long fallows. Alternatively, more intensive use of family labor has facilitated the construction of terraces, living fences, mulching and other soil conservation technologies.[35] Yet applying more labor to a given unit of land, and planting more densely, are practices that seem unlikely to improve soil fertility in the longer run. On the contrary, without additional inputs or fallowing, we expect that the labor-led path to intensification would deplete the soil further.

However, the "ceteris paribus" assumption in the above paragraph allowed us to ignore for a moment what we must now recognize—that small farmers are driven to diversify incomes off-farm to manage risk in fragile resource settings—risk that provides an incentive to diversify their asset portfolios and incomes to deal with an uncertain environment.[36]

In sum, smaller farmers are compelled on the one hand to make these investments because they depend more on their small holdings, they must seek ways to intensify as a substitute for fallow, and they have more labor per hectare to use for land improvements. On the other hand, the very smallness of their farms and the riskiness of their environments mean that the desire to divert

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resources to diversifying their incomes is stronger. Yet the cash from these off-farm activities can help them make improvements, a subject treated below.

Cash income Wealth: With perfectly functioning credit markets and perfect information, household wealth and liquidity sources, such as cash crop sales and nonfarm income, should not affect investment. But where there are imperfections in the credit market, as is probably the case in rural Rwanda, theory suggests that own liquidity sources (such as off-farm income and crop sales) will be critical to on-farm investments where there is failure of, or constraints in, the credit market.[37] Moreover, even where the credit market is functioning but underdeveloped, Reardon and Vosti contend that the least likely investments to receive credit are conservation measures.[38]

Thus we posit no clear hypothesis about the effect of nonfarm income on investment. It is conceptually a "two-edged sword," providing liquidity for on-farm investments but also potentially competing (as a destination for such income) with these investments.

Other Household Characteristics

Family size and education: The construction and maintenance of soil conservation infrastructure can be very labor-intensive. We thus expect that larger households, *ceteris paribus,* will be more able to undertake them. And the more educated the household members, and the better trained they are in land conservation practices, the more we expect them to make investments and manage resources carefully.

4. Data

One reason for the dearth of empirical research on the determinants of land improvement investments in Africa is the difficult data requirements. On one hand, such research requires data on the extent of farmers' conservation investments, implying either the physical measurement of terraces,

for example, or on cash and labor time required to build them, or both. On the other hand, a broader set of data is needed to understand the farm management and household strategy context of these investments. Household farm and nonfarm income, assets, demographic characteristics, and the ecological properties of farm holdings, are examples of the kinds of information required. Such multi-level data are rare.

The data examined here, however, meet these varied requirements. They derive principally from a nationwide stratified-random sample of 1,240 farm households (operating 6,464 parcels) interviewed in 1991 by the Agricultural Statistics Division (DSA) of Rwanda's Ministry of Agriculture. Interviews with heads of households and/or their spouses were conducted over a six-week period beginning in June 1991. The survey instrument treated both household-level variables (such as nonfarm income) and parcel-level variables (such soil conservation investments, land tenure, and steepness of slope). To complete the data set for present purposes, we integrated these data with those on farm and livestock enterprise management from the Ministry's ongoing national longitudinal survey on the same sample of households.

5. Data Patterns and Context

Ninety-three percent of Rwanda's population lives in rural areas and nearly all rural households farm. On average, households cultivate slightly less than one hectare of land; the distribution of landholdings is inequitable by the standards of African smallholder agriculture (with a seven-fold difference in land per person between highest and lowest landholder quartiles). Pulses, roots and tubers, and grains are the main food staples, and coffee and tea are important cash crops. Farming is labor intensive. Hoes and machetes are the basic farm implements; animal traction is nonexistent. Livestock husbandry is integral to the farming system, but the progressive conversion of pasture into cropland has caused a reduction in livestock production in recent decades, and a

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parallel decline in the amount of manure available for improving soil fertility. Rwanda's average population density is among the highest in Africa. Virtually all arable land is now used for agriculture; marginal lands once set aside for pasture or left in long-fallow are now coming under more intensive cultivation. Rural informal and formal credit markets are severely underdeveloped.

The model variables are grouped and listed here (Table 1) according to the model specified above. It is important to note that for purposes of the present analysis, many of the summary statistics in Table 1 are reported at the plot level, while others are reported at the household or prefectural levels (as indicated). Also, because of our current focus on conservation investments and inputs use, parcels in pasture and woodlot (13.4 percent of all parcels) have been excluded from this analysis.

Land use is on average fairly non-erosive (with a C-value of .16) though variation across parcels is high (with a coefficient of variation of .43). There is also great variation over farm households in the degree to which they invest in soil conservation measures: grass strips are most common, followed by anti-erosion ditches, then hedgerows. Only 4.9 percent of parcels receive fertilizer/lime, but most (69.5 percent) receive organic matter (mulch, manure, etc.).

Almost all land in rotation is cropped; little is kept under fallow. Larger landholders hold a greater share of land in fallow than do smaller farmers. Figure 1 shows that the quartile of households with least cultivable land per adult equivalent cultivates 86 percent of this area, whereas for the least land-scarce quartile the figure stands at only 57 percent. Fields tend to be on slopes, and annual rainfall is high. These factors provide strong incentive for farmers to take appropriate measures aimed at controlling soil loss.

Nonfarm income (wages from hired agricultural and non-agricultural work plus own-business income) constitutes about one third of total income, and about two-thirds of households earn some nonfarm income. Operational holdings are very small, and are fragmented into many smaller plots.

The vast majority of landholdings are owner-operated; only 8 percent are rented. Most households own a few small ruminants; less than a quarter own cattle. There is strong variation over households in their (self-reported) degree of knowledge of various soil conservation and productivity-enhancing practices. Agricultural profitability, as well as price variability, show considerable variation across prefectures.

6. Regression Results and Discussion

This section examines the determinants of land management strategies in Rwanda. Ordinary Least Squares (OLS) and logistic regressions on soil conservation investments, fertility-enhancing input use, and land use (C-values) are estimated using the variables described above. The regressions explaining C-values and conservation investments are run using OLS.[39] Organic inputs and purchased (chemical) inputs use are estimated using logistic regression, as the regressands are dichotomous due to data limitations. The land use regression results are discussed first, followed by those for conservation investments and input use.

Land Use Determinants

As expected, OLS results show that where agriculture is more profitable, C-values are lower, indicating protective land uses. Crops that provide the best vegetative cover against soil erosion are perennials, mostly bananas and coffee, which generally provide relatively high returns to land while requiring a high labor input. A higher agricultural wage is associated with higher C-values. As hired labor is often applied to perennial crops, this may indicate that where labor is more expensive, fewer perennials will be grown. As expected, a higher nonagricultural wage leads to lower C-values, meaning that with better opportunities off-farm, there is less pressure to crop annuals on-farm to ensure food security.

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Steeper slopes and more rainfall mean lower C-values, as expected—farmers are choosing more protective land uses for their steeper slopes and on the hillsides rather than in the valleys. In particular, woodlots, pastures, and fallow are more often located on the slopes. Moreover, more land is allocated to bananas on the hillsides than in the valleys, in part because households prefer to locate bananas close to their home compounds, which for historical and cultural reasons are more often located on the moderately steep hilltops than in the valleys. The relationship between C-value and slope would probably be even stronger except that, as Clay and Lewis argue, farmers have not grown their more protective crops (bananas and coffee) on the very steepest slopes.[40] This may also help explain why more distant fields have more erosive land uses.

Consistent with Cook and Grut's observation discussed above, land use rights also affect the use of trees and shrubs. Rwandan households are far less likely to grow low C-value crops (bananas, coffee, and other perennials) in land they rent than in land they own. And the longer farmers have operated their parcels, the lower will be the erosivity of use. This may be because they feel more confident that they and their families will reap the benefits of the investments they make in perennial crops, or simply because they have had more time to make such investments.

Having nonfarm income reduces the C-value probably for the same reasons as the nonagricultural wage does. More livestock translates into more erosive land uses, but the reason is not clear. That the value of crop output means higher C-values is probably because fallow has a very low C-value and no output value.

Farmers' knowledge of conservation and productivity-enhancing technologies is strongly and significantly associated with less erosive forms of land use (lower C-values).

Neither farm size nor the number of adults in a household nor the dependency ratio shows a statistically significant association with the erosivity of land use. No clear conclusion arises from the

regressions regarding the impact of population growth (and the resulting decline in land availability per person) on C-values.

Kangasniemi and Reardon explored in more detail the issue of the difference in C-values of smaller and larger farmers in Rwanda and shed light on the inconclusiveness of the farm and family size variables in the land use regression here.[41] They take into account (by adjusting the C-values accordingly) that small farmers: (1) crop more densely (mixed and inter-cropping), such as densely planted banana groves, and (2) grow more trees per hectare, and find that land use practices among the most land-scarce quartile of households do not appear to be any more erosive than those among higher quartiles. In other words, although the current patterns of land use threaten the long-term sustainability of Rwandan agriculture, small farmer strategies in the short to medium run have, overall, offset the inevitable impacts of population growth on the land.

However, Kangasniemi and Reardon also find that above 2,000 meters altitude, which covers one-fourth of Rwanda's agricultural area, land use practices are highly erosive and are becoming more so with population growth. The explanation lies in that few bananas are grown in these cooler areas, where banana yields are poor and their sugar content is low. Thus, while growing more bananas has been one of the main responses of rural households to increasing land scarcity in most parts of Rwanda, this option is not attractive to land-scarce farmers in the high-altitude areas. Farmers in these areas are more inclined to grow tubers, which have much higher yields (in that area) than do bananas, whether measured in terms of calories or market value, but are less effective than bananas at controlling soil loss. Also, coffee, the second most important perennial, is rare at very high altitudes.

DSA data from 1984 and 1990 also show a major expansion in the allocation of land to protective perennials. Land planted in bananas and coffee has expanded by one-fourth. Land in

tubers that provide modest protection against erosion has also increased, largely at the expense of maize and sorghum, which provide only minimal protection against erosion.

Overall, both the cross-sectional view and comparisons over time suggest that the erosive trend toward more cultivation is accompanied by a strong trend toward crops that cover the soil relatively well against erosion. However, land use practices are only one front in a larger war against erosion. How crops are managed is equally important. For instance, the effectiveness of coffee depends in large measure on mulching, and our observations in the field show that many coffee fields were without mulch in the early 1990s, in contrast to the nearly universal mulching before. Some observers of Rwandan agriculture predicted over a decade ago that as the availability of organic matter from previously uncultivated valley bottoms and other areas declines, mulching will decrease.[42] On the other hand, mulching of coffee is mandatory and was rigorously enforced until the early 1990s. The decline in mulching in recent years may have more to do with the low coffee prices which resulted in farmers neglecting their coffee trees, and the reduced government control that allowed them to do so, than with any decline in the availability of mulch.

In the case of bananas, the outlook is better, since in contrast to coffee, bananas produce their own mulch. Thus, unless fuelwood shortage forces rural households to dry and burn their banana leaves and trunks, bananas will continue to protect land well against erosion. Of the ongoing land use changes, the rapid expansion of banana groves is particularly important for soil fertility. While bananas do not fix nitrogen, they do produce much organic matter and are not dependent on fallow periods for their long-term productivity.

Conservation Investments: OLS Results

Table 2 shows that, as expected, agricultural profitability provides farmers with a strong incentive to invest in conservation technologies. Higher farm wages correlate with more conservation

investments. The opposite effect obtains for nonagricultural wages, presumably because nonfarm opportunities compete with those on-farm as discussed above.

Consistent with the capital-led intensification path discussed earlier in this chapter, conservation investments substitute for fallow. Farms with little land in fallow are more likely than others to intensify by adopting soil conservation measures.

Farmers are also more likely to make investments in soil conservation if their holdings are located higher on the slope. Historically, erosion has been the most severe on these upper slopes, where farmers tend to grow beans and other important annual crops.

The relationship between conservation investments and field slope is complex. Though the OLS regressions in Table 2 show a small but significant negative association, closer examination of the relationship between slope and conservation investments (see Figure 2) shows that farmers invest most heavily in slopes of *medium* steepness——those steep enough to need conservation investments, but not so steep as to discourage investment for the following reasons: (a) Traditionally, farmers placed their steepest slopes under pasture, woodlot, and perennial crops because of their high susceptibility to erosion. This is evidenced by the inverse relationship between slope and C-values discussed in the previous section. (b) It is very costly to maintain investments on these slopes. (c) The lightness and thinness of these soils make them especially prone to erosion. These characteristics also keep yields low and diminish returns to investments in soil conservation. Thus a downward spiral of low production and low investment is easily set into motion as these marginal lands are taken out of their traditional uses (forest, long fallow, rangeland, etc.) and put under more intensive cultivation.

As anticipated, lands that are rented-in (a riskier context for investment) provide farmers with less incentive to invest in soil conservation. But price variation has no significant effect on conservation investments.

Larger farms tend to make fewer conservation investments and use fewer organic inputs than do smaller farmers. This may confirm that credit (with land as collateral) is not important to these investments. Large holders also have more land under fallow and thus may feel less pressured to protect the soils of their operational holdings. It may also be that larger holders are not compelled to take conservation measures to meet daily food and cash needs. Many small holders, on the other hand, appear to recognize that such investments are vital to their livelihoods, even in the short run. Thus, pressure to intensify farming practices is lower for larger holders than for small holders.

Nonfarm income as a liquidity source for investments (hiring labor, buying materials) exerts a positive effect on conservation investments.

Value of agricultural production and wealth in livestock have a significant effect on conservation investments. More livestock and agricultural production are also linked to greater use of organic inputs and higher C-value crops. It is likely that these associations are mutually reinforcing, and that wealth is not the only relevant factor to consider. Farms with livestock, for example, will use more organic inputs not simply because they are wealthier, but because they have a steady supply of manure.

No household characteristic has a significant effect on investments. The knowledge variable appears to have little effect on conservation investments when measured as an aggregate of all four types of investment, as we do here. However, Clay and Reardon, using the same data, show that some conservation practices are positively affected by this knowledge, while others are not.[43] In particular, farmers who have had greater exposure to conservation and fertility-enhancing technologies are more apt to plant hedgerows than are other farmers. However, this is not true for other investments. The difference may emerge because, unlike grass strips and ditches, the use of hedgerows to control soil loss is a relatively new technology for Rwandan farmers, and its application is less widespread. As the extension service is an important vehicle for dissemination of this

technology, it is perhaps for this reason that the positive effects of farmer knowledge are greater for hedgerows than for other, more traditional conservation investments.

Use of Inputs: Logistic Regression Results

Table 2 shows unexpectedly that agricultural profitability is a modest yet significant disincentive to the use of both organic and purchased inputs. As expected, non-agricultural wage rates exert a negative effect on investments, again perhaps because of competing nonfarm opportunities.

More fallow means lower use of organic inputs and fertilizer, thus confirming the substitutability of fallow and inputs use for restoring soil fertility.

Fields higher on the slope are more likely to receive organic inputs, but purchased inputs are as likely to be applied to fields in the valley as at the summit. Thus, farmers treat short-term investments such as purchased fertilizer, differently from those that have a longer-term impact (organic matter).

Also as expected, steeper slopes are less likely to receive either organic matter or purchased chemical inputs, because of runoff.

As anticipated, for the use of organic inputs, lands that are rented-in provide farmers with less incentive to invest, as the risk of appropriation is greater. However, the use of purchased inputs is not affected by ownership rights. Since the effects of purchased inputs such as fertilizer and lime tend to be more immediate, typically lasting for only one growing season at a time, renters are as likely as owners to make this form of investment. Price variation (short term risk) discourages the use of both organic and purchased inputs.

Larger farms are less likely to use organic inputs than are smaller farmers (as they are a means of intensification); again, larger farmers also have more fallow which substitutes for the application

of organic matter. By contrast, larger farmers are more likely to use purchased (chemical) inputs. Unlike conservation investments and use of organic inputs, which can be made using either household or hired labor, purchased inputs require cash. The greater liquidity of the larger farms enables them to use fertilizer, lime, and other purchased inputs to help improve yields, particularly on cash crops such as potatoes and coffee.

As expected, farmers with more nonfarm income are more likely to use inputs, particularly purchased inputs. Despite low overall use rates for fertilizer, lime, and other purchased inputs, Figure 3 shows that farms in the higher non-farm income categories are about twice a likely as the lower nonfarm income groups to use these inputs.

Farms with greater agricultural output and livestock are more likely to use organic inputs (they have more manure).

Knowledge of conservation and productivity-enhancing technologies is a positive and significant determinant of farmers' use of purchased inputs.

7. Conclusions

This research contributes to the general debate concerning what are referred to here as the labor-led and capital-led paths to sustainable agricultural intensification. We address the questions of whether and why particular types of farm households situated in a given agroclimatic and policy context, and facing similar incentives to intensify, take the capital-led intensification path. Specifically, we focus on the determinants of smallholder investments in soil conservation capital and the use of improved inputs such as fertilizer and organic matter in Rwanda—a setting in the East African highland tropics characterized by rapid population growth and land degradation.

Our analysis of survey data from a nationwide sample of farm households in Rwanda provides empirical confirmation of two sets of conclusions, both of which have clear implications for external

donor programming, and for the broader "relief to development" trajectory that the international donor community envisions for post-crisis Rwanda.

First, the structure of landholding is an important conditioning link between population pressure and the intensification paths taken by farmers. Land tenure, slope, fragmentation, years of cultivation, share of holdings under fallow, and size of holdings are important determinants of farmer investment strategies. In general, investments in soil conservation and fertility are greater on land owned (not rented) by farmers, where slopes are of medium steepness, where land is less fragmented and younger, and among smaller farmers and those with little land in fallow. Thus, apart from the obvious need for political stability in this war-torn country, our work shows that farmers need confidence in the longer term through secure land tenure. This means reducing the risk of appropriation, and the right to transact land. Enhancing farmer access to the land market will require reform of existing and antiquated land laws.

Second, household-level intersectoral links—specifically, "reverse linkages," where nonfarm income affects farm investment—enhance the capacity of households to follow the capital-led intensification path. Nonfarm income as an important source of own liquidity, in this setting of underdeveloped credit markets, is important for households to by materials, to buy animals and to by labor, all of which are needed for sustainable intensification. It can also provide a "buffer" by allowing farmers breathing space to make long-term investments in higher-yielding and cash-earning perennials. Nonfarm activities also increase the demand for crops through downstream production linkages. And as an alternative source of income it can reduce pressure on the land, enabling households to meet food needs through market access rather than subsistence.

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Endnotes

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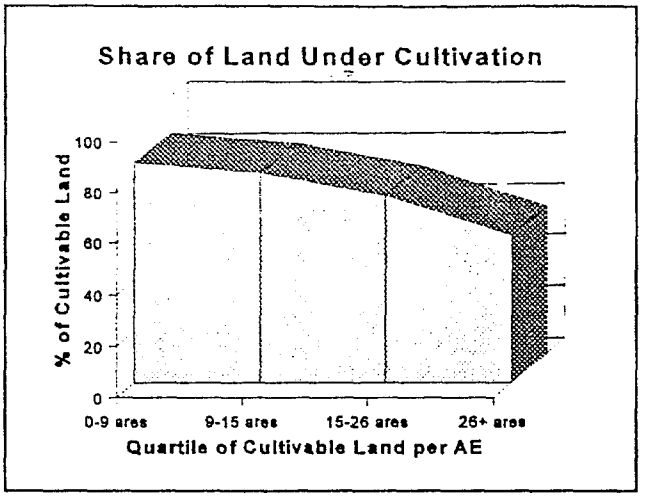

Figure 1

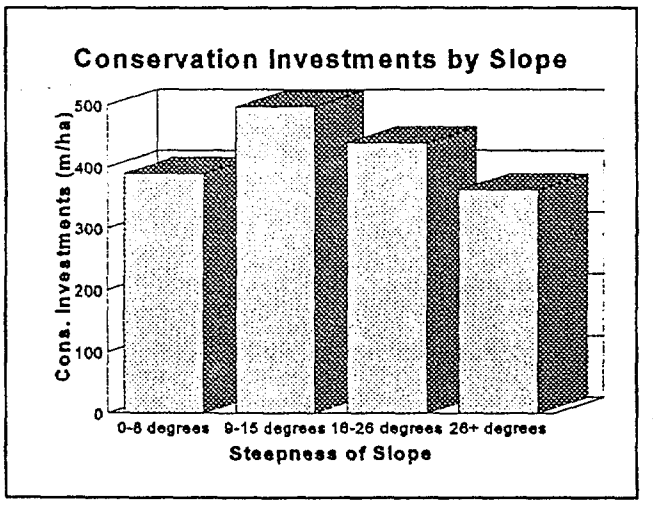

Figure 2

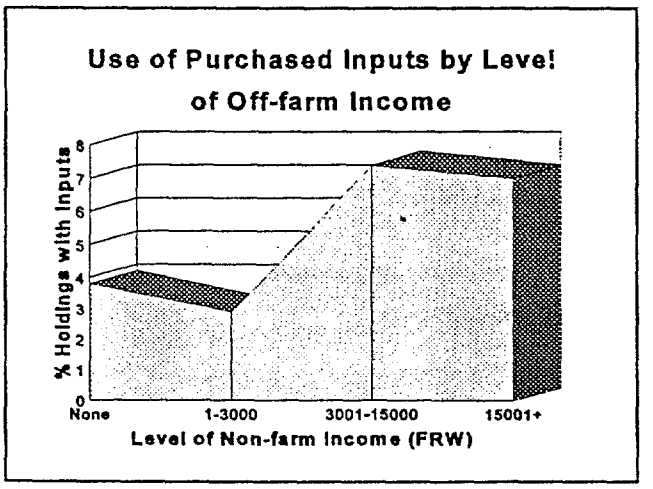

Figure 3

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Table 1
Land Use/Conservation Investments/Inputs Model Variables*

Model Variables	Overall Mean or Percent	Coefficient of Variation	Level of Observation Parcel = 5,596 HH = 1,240 Pref = 10
1. Land Use/Conservation Investments/Inputs			
A. Land Use (C-value)	.16	0.43	Parcel
B. All Conservation Investments (m/ha)	424	1.18	Parcel
Grass Strips (m/ha)	205	1.34	Parcel
Anti-erosion Ditches (m/ha)	161	1.68	Parcel
Hedgerows (m/ha)	56	2.86	Parcel
Radical Terraces (m/ha)	1.17	25.20	Parcel
C. Organic Inputs (% using)	69.5%	--	Parcel
D. Purchased inputs (% using)	4.9%	--	Parcel
2. Independent Variables			
A. Monetary Incentive to Invest			
Agricultural profitability index	1.00	0.31	Prefecture
Agricultural wage (140FRW = 1$US)	100	0.10	Prefecture
Non-agric. wage (140FRW = 1$US)	216	0.35	Prefecture
B. Physical Incentive to Invest			
Share of operational holdings under fallow (ha)	0.17	1.47	Parcel
Slope (degrees)	16.7	0.64	Parcel
Location on slope (1=highest, 5=lowest)	3.11	0.33	Parcel
Distance from residence (min. on foot)	7.41	2.14	Parcel
Years cultivating parcel	22.2	0.66	Parcel
Size of parcel (ha)	80	1.03	Parcel
Annual rainfall (mm)	1,214	0.14	Prefecture
C. Risk of Investment			
Ownership rights (% leased)	8.0%	--	Parcel
Price variation (CV of ag prices, 1986-92)	0.25	0.20	Prefecture
D. Wealth and Liquidity Sources			
Landholdings owned (ha)	.83	0.95	Household
Non-farm income (140FRW = 1$US)	11,120	3.24	Household
Value of livestock (140FRW = 1$US)	10,768	1.81	Household
Value of agri. production (140FRW = 1$US)	22,150	0.83	Household
E. Other Household Characteristics			
Number of adults (aged 15-65)	2.64	0.54	Household
Dependency ratio (econ inactive/econ active)	121	0.74	Household
Literacy of head of household (% literate)	50.3%	--	Household
Knowledge of conserv/prod techniques	3.59	0.55	Household
Age of head of household (years)	45	0.33	Household

*Summary statistics reported at the parcel level are for all holdings under cultivation or fallow (thus excluding pasture and woodlot).

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Table 2
OLS and Logistic Regressions: Land Use/Investments/Inputs Model

Independent Variables	LandUse/Investments/Inputs			
	Land Use (C-value) (OLS)	Conservation Investments (m/ha) (OLS)	Organic Inputs (Logistic)	Purchased Inputs (Logistic)
Correlation Matrix: LandUse,Investmentsand Inputs				
Land use (C-value index)	1.00	--		
Conservation investments	.05**	1.00	--	--
Organic inputs	-.18**	.21**	1.00	--
Purchased inputs	-.02	.06**	.11**	1.00
OLS and Logistic Regressions				
A. Monetary Incentive to Invest				
Agricultural profitability index	-.15**	.12**	-.02*	-.07**
Agricultural wage in prefecture	.06**	.09**	.02*	.08**
Non-agricultural wage in pref.	-.06**	-.16**	-.04**	-.10**
B. Physical Incentive to Invest				
Share of of holdings under fallow	-.14**	-.04**	-.11**	-.06**
Slope (degrees)	-.08**	-.04**	-.06**	-.05**
Location on slope (1=summit, 5=valley)	.09**	-.18**	-.12**	-.02
Distance from residence	.05*	-.04**	-.21**	.04*
Years operated	-.07**	-.00	.02*	.00
Size of parcel	-.05**	.03	.22**	.11**
Annual rainfall	-.07**	.07**	.00	.11**
C. Risk of Investment				
Ownership rights (1=own, 2=lease)	.19**	-.07**	-.19**	.00
Price variation (1986-92)	-.06**	.01	-.02*	-.03*
D. Wealth and Liquidity Sources				
Landholdings owned	-.04	-.23**	-.15**	.04*
Non-farm income	-.03*	.06**	.03*	.09**
Value of livestock	.04*	.05**	.07**	.00
Value of agricultural production	.04**	.04**	.07**	.00
E. Other Household Characteristics				
Number of adults (aged 15-65)	.02	.05	.04	.02
Dependency ratio	.02	.00	.00	.00
Literacy of Head of Household (0=no, 1=yes)	-.03*	.00	.00	-.07**
Knowledge of conserv/prod technologies	-.08**	.00	-.00	.03*
Age of head of household (years)	.02	.01	-.04**	.00
R^2 or % Correct prediction	.13	.14	82.3%	94.7%

*Sig T ≤.05 **Sig T ≤.01

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