Input Use and Conservation Investments among Farm Households in Rwanda: Patterns and Determinants

by

Daniel C. Clay*
Valerie Kelly**
Edson Mpyisi***
Thomas Reardon ****

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*Institute of International Agriculture, Michigan State University, East Lansing, MI 48824
**Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824
***Food Security Research Project, Rwanda Ministry of Agriculture, Animal Resources, and Forests
****Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824

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1. Introduction

One of the Government of Rwanda's key post-war policy objectives has been to increase agricultural productivity and ensure food security by promoting a transition from semi-subsistence production and marketing practices to intensive production and highly commercialized agricultural markets. The government wants farmers to increase land and labor productivity through the use of modern inputs, thereby generating substantial surpluses which can be sold to pay for inputs and generate increases in farm incomes.

From the 1960s well into the 1980s there was a strong government and donor commitment to a low-external input approach to Rwandan agricultural production. This was coupled with a desire on the part of the government to remain as self-sufficient as possible with respect to inputs used and food consumed, keeping imports to a minimum and relying on local production to the greatest extent possible (CNA 1991). Until the early 1980s, research and extension efforts focused almost exclusively on soil conservation technologies (animal and green manures for maintaining soil nutrients and organic matter, use of locally produced travertin and lime to control soil acidity, and use of radical terraces, ditches, hedgerows, and grass strips to control erosion. For many years little attention was given to improved seed/fertilizer technologies and the conventional wisdom was that Rwanda's soils and crops were not very responsive to inorganic fertilizers.

Unfortunately, decades of rapid population growth have brought about dramatic changes in the traditional agricultural system and the ability of Rwanda's low-external input agriculture to meet growing food demand: (1) farm holdings have become smaller due to constraints on land availability; (2) holdings have become more fragmented; (3) cultivation has pushed onto bottom lands and fragile margins on steep slopes previously held in pasture and woodlot; (4) many households now rent land; (5) fallow periods have become shorter, and cultivation periods have grown longer (Clay 1995).

A consequence of farming more intensively (without replenishing nutrients and organic matter) and farming on steep slopes is the high incidence of soil loss due to erosion, and along with it, declining soil fertility. Rwanda's National Agricultural Commission estimates that half the country's farmland suffers from moderate to severe erosion (CNA 1992). Clay (1995) reports that farmers observe a decline in the productivity of nearly half their holdings due to land degradation. Byiringiro (1995) show that erosion severely reduces farm yields in Rwanda. Ford, citing research results in the steeply sloped Ruhengeri zone of Rwanda, notes that four-fifths of the sampled farmers have observed declines in the productivity of their soil; Ford (1993) also notes that soil loss from erosion has been high in the zone and is the most serious threat to the agricultural resource base. May (1995) finds that demographic pressure is driving soil degradation in Rwanda. Given these multiple examples of declining soil quality, it is not

surprising that aggregate production statistics from 1984-1991 show a decline in yields per hectare for all crops but maize (Clay et al., 1995).

There is growing evidence that improvements in farming practices focused on soil conservation (such as bunding, mulching, agroforestry, and alley cropping), while important, cannot by themselves reverse the trend in declining yields because they are limited in supplying adequate amounts of plant nutrients to increase and maintain yields (Weight and Kelly 1999) Neither can manure (notably animal and green manures) be produced in sufficient quantities to achieve current and future production goals, especially given the decimation of livestock herds that occurred in 1994 and the traditional extensive livestock husbandry practices. It is apparent that Rwanda needs to promote alternative approaches to increase agricultural productivity. Introducing alternative approaches, however, does not exclude continued promotion of traditional anti-erosion technologies and the application of manure, compost and other organic matter. Instead, there is a need to combine these traditional measures with improved inputs such as fertilizers, pesticides, and herbicides. Despite the high cost of fertilizer, farmers' poverty, their small land holdings, and the semi-subsistence nature of farming. Substantial increases in the use of inorganic fertilizer must be part of Rwanda's agricultural strategy in order to provide food for a rapidly growing population.

Increasing the use of improved seed/fertilizer technologies on food crops is not a new idea in Rwanda, but it remains an elusive goal. From 1980 until 1994 an important program of fertilizer trials and demonstrations was carried out with the assistance of the FAO and other donors. By the time the program closed in 1994 a substantial body of data had been collected on fertilizer response for various crops and regions of the country and a set of official fertilizer recommendations was published and promoted by the extension services. In the mid-1980s a government parastatal was created to import and distribute subsidized fertilizer for food crops. Despite the change in the official view of inorganic fertilizer (from undesirable to desirable), on-farm use remained extremely low (generally less than 4000 MT/year, equivalent to 1-2 kg/ha). Compare that to an average for Sub-Saharan Africa of 9 kg per hectare in 1995 (Weight and Kelly, 1998), and 83 kg per hectare in all developing countries in 1993 (Heisey and Mwangi, 1997). Aggregate fertilizer use in Rwanda in 2000 is not substantially different than it was in 1994 when the input parastatal was replaced by a fertilizer import program (managed by the European Union) that made supplies of DAP, 17-17-17, and urea available to private sector dealers, farmers' associations, and various government and NGO projects. As the government enters the 21st century, it is still struggling to develop policies and programs that will stimulate the use of productivity enhancing inputs, such as inorganic fertilizers, to complement the substantial investments that farmers have already made in adopting low-external input practices

2. Objectives, Data, and Methods

The research presented in this paper focuses on the question of what determines a farm family's investments in agricultural intensification and their land use patterns. Particular attention is given to conservation investments, use of organic matter, purchases of chemical inputs, and the

link between land use practices and soil erosion. Developing a better understanding of what factors influence these types of farm decisions and the relative impact they have on investments is a first step toward developing better policies and programs to promote agricultural modernization. We address the research question using pre-war (pre 1994) farm survey data collected under the Rwanda Food Security Project by the Agricultural Statistics Division (DSA) of Rwanda's Ministry of Agriculture. The data are drawn from a nationwide stratified-random sample of 1,240 farm households (operating 6,464 plots) interviewed in 1991.

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 plot-level variables (such as land conservation investments, land tenure, and steepness of slope). The input use data are for 1991 (the year of the cross-section), and the soil conservation investments are reported as meters per hectare of improvements on the parcels at the time of the one-shot Agroforestry survey in 1991. To complete the data set for present purposes, we integrated these data with those on farm and livestock enterprise management from the Ministry's national longitudinal survey on the same sample of households.

Section 3 presents the analytical approach used (explaining farm level investment in terms of the incentives facing farm households and the capacity of households to undertake investments) and briefly describes the models developed. A general description of the Rwandan farming context, with particular attention being given to levels of conservation and input investments and levels of variables reflecting incentives and capacity to invest, is presented in Section 4. Results of regression analyses are used in Section 5 to describe the most important determinants of the four different types of agricultural intensification discussed. Section 6 examines the implications of the model results for the design of policies and programs to support the government's current objectives for agricultural intensification.

3. Conceptual Framework and Model

Use of improved technologies in general, and soil conservation technologies in particular, needs to be understood as major investment decisions by farmers. Farmers must make difficult decisions about how best to allocate scarce resources between consumption (e.g., food, education, health, housing) and production ends. For farmers in Subsaharan Africa who use recommended doses, fertilizer purchases can represent the largest single input expenditure for a production season. As investing in agricultural intensification implies foregoing other consumption and/or investment opportunities (at least temporarily), farmers are likely to pose two basic questions before making such an investment: (1) Will it be profitable? And (2) Can I afford it?[1]

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[1]This paragraph draws on a similar discussion inYanggen et al. 1998.

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Factors that influence profitability can be thought of as the "incentives" to adopt a particular technology. We find it useful to consider two key categories of incentives: monetary and physical. Monetary incentives are those associated with the profitability of agriculture in a zone (e.g., output prices, input prices, access to markets, prevailing wages for agricultural and nonagricultural activities). In general, higher output prices, lower input prices, better market access, and lower wages/incomes from competing nonfarm opportunities provide positive monetary incentives for agricultural investments. Physical incentives are those associated with farm and plot characteristics (size and location of plot, amount of fallow, fragmentation of plots, slope, rainfall, etc.). Our hypothesis is that farms are more likely to invest in soil conservation and improved inputs if they are under greater stress (more fragmented plots, less fallow) but possess land that can be improved (good location on slopes and/or slope not too steep, plots not too fragmented or far from the residence, and acceptable levels of rainfall).

Risk is a factor that can alter a farmer's perception of both monetary and physical incentives. For example, an investment will become riskier and incentives will decline if a farmer is not sure that he will be able to recover the full benefits of a particular investment (e.g., applying manure to a rented field). Similarly, volatile, unpredictable output prices can reduce incentives as farmers will be uncertain of their ability to recover their investment costs by selling surplus production. In general, a higher return (reflected in financial or physical incentives) on investment will stimulate a higher rate of investment. Conversely, greater risk leads to lower investment for risk-averse farmers. Feder et al. (1985) break risk into two categories, risks (such as from price or rainfall instability) affecting "confidence in the short term," and risks (such as insecure land tenure) affecting "confidence in the long term."

Whether farmers can afford to invest in soil conservation or agricultural intensification depends on their capacity to acquire and correctly use improved technologies. Capacity improves when financial capital (fixed assets, cash and/or credit) increases, permitting farmers to invest more, and when levels of human capital (nutrition, health, education, management skills) are higher, as this enables farmers to use improved technologies efficiently. Thus, wealth, broadly defined to include cash for purchases, human capital, and own-labor sources for "home production" of capital goods, constitutes a major determinant of such investments. The level of financial and human capital is often correlated with farm characteristics such as farm size, farm population, and location. In theory, household liquidity is especially important where the credit market is underdeveloped or absent (the case in Rwanda and elsewhere in the tropical highlands of East Africa).

We set out a general model for farm investments that reflects the conceptual framework summarized above and the literature on firm and farm-level investment theory (Christensen 1989, Feder et al. 1992, Feder et al. 1985). Farm investments are viewed as functions of five sets of variables:

> Investment = f (financial incentives, physical incentives,
> risk, wealth, agro-socio-economic context)

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The dependent variables are land conservation investments (represented by meters per hectare of conservation investments such as grass strips, radical terraces, ditches, hedgerows); organic inputs (a dummy variable indicating use/non-use of composting, manure, green manure, or mulch); chemical inputs (a dummy variable indicating use/nonuse of fertilizer, pesticides, or lime); and land use erosivity (represented by the C-value).

An unusual aspect of the models developed below is that they model investment/adoption at the parcel rather than at the household level. Most models designed to explain the determinants of investment/adoption use zone and household level data to answer the question: What explains whether the farm household invests in or adopts a particular technique. These types of models do not deal with the degree of adoption; even if a technology is used on a very small portion of cultivated land the household is classified as an adopter.

The modeling question applied to Rwandan data is: What explains investment/adoption for each parcel on the farm. In other words, the model design takes into account that adoption/investment decisions are not made uniformly for the entire farm. In attempting to answer this question, the models use zone, household, and parcel-level characteristics.

Another unusual characteristic of the specification of these models is the richness of the data base and thus the degree of disaggregation possible. Few adoption/investment models are able to cover all five categories of explanatory variables and the four outcome variables identified above. Such models require not only detailed information on farmers' input and conservation investments, but also a broader set of data 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 context, data, and disaggregated regression specification are discussed next.

4. The Rwandan Farming Context and the Specification of the Regressions

The purpose of this discussion is to describe the general farming context in Rwanda and to discuss in detail the full range of variables used in the regression findings reported in Section 5. The overall importance of agriculture in Rwanda is illustrated by the fact that 93% of Rwanda's population live in rural areas and nearly all rural households earn an important share of income from farming.

Table 1 presents summary statistics on land use (C-value), conservation investments, use of organic inputs, and use of chemical inputs. These variables represent the four indicators of land use and investment for which regression findings are presented in Section 5. Numbers presented are average parcel-level values or percentage of parcels benefitting from a particular type of input. Coefficients of variation are reported to illustrate variability around the means.

The land use index (C-value) measures soil erosivity. As the C-value falls, so does the erosivity of land use. Land use is fairly non-erosive on average (with a C-value of .16) though variation across parcels is moderately high (the ratio ranges from a low of .01 to a high of .4; the coefficient of variation is .55). Controlling for production techniques, the C-value reflects crop mix. Erosivity is higher for some crops than others—lowest for bananas (.04) and increasing gradually for beans (.19), manioc (.25), sorghum (.35) and maize (.40).[2]

The land use model explicitly reflects choice of an outcome (level of erosivity), but is also modeling a decision about choice between cash perennial crops and annual crops which are either cash or subsistence crops. The decision is based on two sets of objectives (controlling for physical, cultural, and economic constraints): (1) to reduce erosion, which is a long-term objective that requires short-term (crop) choices and (2) to maximize returns to land and labor, which is a short-term objective that requires a short-term choice of crops with high returns. We have thus modeled this "dual variable" as a function of variables that reflect incentives related to the long-term objective of controlling erosion (e.g., steeper slopes of fields should spur investment in perennials to control runoff), and of variables that reflect short-term profitability considerations (e.g., the price of bananas relative to sweet potatoes).

The parcel-level average of all land conservation investments combined is 438 meters per hectare. There is, however, great variation across parcels (coefficient of variation of 2.12). Grass strips are most common, followed by anti-erosion ditches, then hedgerows, then radical terraces. Ditches and terraces are the most labor- and equipment-intensive to build and maintain, and grass strips the least. Hence, the abundance of grass strips can be explained by the relative ease of their installation. About half (49 percent) of the parcels receive organic matter (some combination of compost, animal manure, green manure, or mulch) , but very few (2 percent) receive chemical inputs (some combination of fertilizer, lime, or pesticides).[3]

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[2] The C-value index reflects the overall protective quality of crops. It is defined as "the ratio of soil loss from an area with a specific cover and tillage practice to that from an identical area in tilled continuous fallow," (Wischmeier and Smith 1978),

For any given field, the crop cover, canopy, and tillage practices can vary throughout the year. C-values represent the average soil loss ratio resulting from these factors over the growing season. They must be obtained empirically, as planting and tillage strategies of specific crops vary over farming systems. For this reason, the use of the standard published C-values, based largely on farming practices in the United States, should not be used in Third World countries without first being evaluated.

We use region-specific C-values, based on field work undertaken in the Kiambu and Murang'a districts of the Kenya highland (Lewis 1985 and 1988).

[3] Only .08 kgs/ha of fertilizer are used per hectare in rural Rwanda; this is substantially less than is used in cash-cropping areas of highland Kenya and Uganda (Byiringiro 1995).

To provide more detail on patterns of investment and input use, we calculated (not shown in Table 1) the shares of farmland (measured in hectares)[4] receiving land conservation measures, organic matter, and chemical fertilizer. Only 15% of Rwandan farmland is being cultivated with traditional intensification in which farmland receives no external inputs or conservation investments. Conversely, intensification using all three types of improvements (conservation investments, organic inputs, and chemical inputs) accounts for only 4 percent of farmland. Most farmland falls between the two extremes.

Table 1 shows that there are a number of statistically significant correlations among the indicators of land use and investment examined. The largest correlation coefficient (-.25) is between organic inputs and the erosivity index, suggesting that farmers reduce organic inputs as the erosivity of farming practices increases. The second largest coefficient shows a positive relationship (.10) between organic inputs and conservation investments, suggesting that as conservation investments increases farmers are more willing to apply organic inputs. There is a positive (.09) correlation between organic and inorganic inputs as well as between conservation investments and chemical inputs (.05), indicating in each case that the two categories of investments are used more frequently as complements than as substitutes. These correlations are important—particularly in the case where the coefficients are larger—because programs to promote one type of investment will probably have spillover effects on the other types.

Table 2 presents summary statistics on a wide range of variables hypothesized to influence the indicators of land use and investment presented in Table 1. These explanatory variables are presented in five broad categories reflecting : (1) monetary incentives, (2) physical incentives, (3) risk factors, (4) farmer's capacity to invest, and (5) the sectoral context in which farmers are operating. Some of these summary statistics are reported at the parcel level, while others are reported at the household, sector, or prefectural levels (levels are indicated in the right-hand column).

Among the monetary incentives we report four prefecture-level indicators of prices and wages and two measures of market access. The agricultural profitability index is the average value product of labor per prefecture, calculated using aggregated sample household data, valued at market prices. Across all prefectures the average is 96 RwF with a minimum of 59.6 RwF in Kibuye and a maximum of 178.8 in Kibungo. The distance variables represent the transactions costs of getting production to markets; these costs are not reflected in market prices. On average, farmers in all sectors covered live 4.4 kilometers from the nearest market; the nearest paved road is reported to be an average of 21 minutes away by foot (with a relatively high CV of 1.06).

The non-agricultural wage can be thought of as the opportunity cost of working on one's own farm. The average value of the non-farm wage (205 RWF) is about double that of the profitability index for agriculture–suggesting that those who are able to earn non-agricultural incomes are getting a higher return to their labor. The impact that the non-agricultural wage

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[4] We used share of farmland rather than share of households because many households use inputs on only a small share of their land and it would be misleading to classify them as following capital-led intensification.

might have on soil quality and investment is ambiguous. Better returns off-farm will compete for both labor and investment capital that could be used in agriculture. This is not necessarily bad, as labor and cash diverted to off-farm uses might reduce pressure on the land by providing cash to purchase food or encouraging less intensive land use patterns requiring less labor (perennial crops, fallow, pasture). Greater off-farm income could also promote investments to improve soil quality because more cash is available.

Crop prices are hypothesized to affect land quality and investments through the incentives they create for soil conserving crops (perennials such as coffee and bananas) versus more erosive crops (such as cereals and beans). Given the cross-sectional nature of the data base, we are only able to look at how differences in banana and sweet potato prices across prefectures affect investment (changes in the relative prices of crops across time would also be expected to affect investment behavior).

The physical characteristics reported at the parcel level include average years operated (18), average parcel size (0.18 ha.), average distance from house measured in walking time (11 minutes), and average slope (13 degrees). Farm/household level characteristics include average share of land in fallow (14%), wood lots (7%) and in pasture (2%). For each of these variables the coefficient of variation is extremely large—a reflection of the highly variable capacity of farmers to leave some part of their land uncultivated. Figure 1 shows that differences in shares of uncultivated land are highly correlated with farm size: the quartile of smallest farms (ranked by arable land per adult equivalent) cultivates 86% of their arable land (with 14% being in fallow, wood lot, or pasture), whereas the quartile of largest farms cultivates only 57% (with 43% being in wood lots, permanent pasture, and fallow). Also measured at the farm level is the Simpson farm fragmentation index (0.64). The Simpson index is a quantitative indicator of how fragmented farm holdings are, combining the number of parcels in a farm and their relative size. Annual rainfall, measured at the sector level, is high (1140 mm) and should therefore provide an incentive for conservation investments (to reduce erosion from runoff) and input use.

Risks factors likely to influence incentives are the percent of parcels rented in (20% of all parcels are rented) and the percent of price variation during the 1986-92 period (19%).

Variables reflecting assets and capacity to invest show that the average household owns .91 hectares and about 12,600 RwF worth of livestock; it earns about 12,300 RwF from crop sales and 17,600 RwF from off-farm activities. The distribution of land holdings is uneven with a seven-fold difference in land per person between highest and lowest landholder quartiles. Nonfarm income (wages from hired agricultural and non-agricultural work plus own-business income) constitutes 59% of total income; about two-thirds of households earn some nonfarm income. The latter is a breakdown not shown in Table 2. Most households own a few small ruminants; less than a quarter own cattle. Households have on average 2.77 adults of working age (15-65) and a dependency ratio of 1.23 indicating that for each working age adult (15-65 years) in the household, there are 1.23 non-working age dependents (<15 or >65 years). Household heads are 46 years old on average, 80% male, and 49% literate. The variable representing knowledge of conservation/ production practices is a summation index across a set

of practices such as knowledge of recommended fertilizer use packages and measures to intensify livestock production. The average value of the knowledge index (2.85 of a possible 9 points) is relatively low and varies a lot over households.

Secteur-level variables (secteurs are the primary sampling units of about 16 households each) reflect the general context in which farmers are making their land use and investment decisions. Our nation-wide sample of 1,240 households is comprised of 78 "secteurs." We aggregated household observations for each of the four land use and investment variables across the households in each secteur to create secteur-level variables. These secteur-level variables can be used to represent: (1) social and administrative conditions in the immediate area; (2) "imitation effects"; and (3) positive externalities of neighbors' undertaking land protection measures. Kerr and Sanghi (1992) argue, using examples from watersheds in India, that these types of secteur effects should have a positive impact on a given household's investments. The average values of the secteur-level variables do not differ substantially from the overall averages based on parcel level data. The extremely high coefficient of variation (1.86) on the chemical inputs variable, which has an average of .04 kg, suggests that the share of area receiving chemical inputs is highly variable across secteurs.

5. Determinants of Land Use and Conservation and Input Investments: Model Results

Regression results are listed in Table 3. Columns represent the different models estimated. Dependent variables used as column headings. The explanatory variables are listed in rows and grouped into the five categories described above. Some variables are classed for simplicity as either incentive or capacity variables, but in practice are often both (an example is farm size). These models were run with observations for 1240 households and 5460 parcels rather than with the full set of survey data. The households that were eliminated from the sample did not have a complete set of data for all variables used in the models.

Given the panel nature of the data (multiple parcel-level observations for each household), we attempted to control for the panel effect by using the random effects GLS, Tobit, and Probit models available in STATA. GLS results for the land use model did not show a significant panel effect, so we report the OLS results. The xttobit estimation for conservation investments went through 40 iterations without producing results, so we reverted to the regular Tobit model. The organic and chemical input models estimated with STATA's xtprobit proved to be unstable (quadchk routine) using xtprobit, so we report the regular probit results. Given our inability to control for panel effects in all but the land use model, the coefficients for the conservation and input models may include a panel effect.

Statistics presented at the bottom of Table 3 show that although all four models were statistically significant (F or chi square tests highly significant) the explanatory power is very poor for the conservation investments model (pseudo R square of .02) and mediocre for the other three (adjusted or Pseudo R square in the .25 range). Our hypothesis was that the extensive set of variables used in the models, coupled with a parcel rather than a household level of analysis,

would capture the complexity of the many factors affecting the farm investment decision process in Rwanda and thereby provide us with greater explanatory power than the more typical investment/adoption models that focus on household level analysis and a smaller set of variables. The latter part of this hypothesis— that we would achieve greater explanatory power—is not supported by the low R-square statistics. The complex nature of household decision making was, however, confirmed by the large number of statistically significant coefficients. An analysis of these coefficients provides us with insights about the relative impact that changes in the many statistically significant explanatory variables are likely to have on investment and adoption decisions.

As approximately half of the field-level observations used in the conservation investment model showed zero investment, we estimated a Tobit model. Surprisingly, 11 of the 32 explanatory variables were statistically significant, but because of the extremely low R square for the model, we do not interpret any of the individual coefficients.

For the other three models, all had many statistically significant variables (21/32 for the organic inputs model, 16/32 for the land use model, and 9/32 for the chemical inputs model). The coefficients on the variables are generally quite small, with few coefficients large enough to suggest that the associated variable could be used as an effective policy instrument. In other words, large changes in input use and land use erosivity will probably require programs that work on a wide range of factors simultaneously rather than programs targeted to change one or two of the statistically significant determinants.

Organic inputs were used on 49% of the fields included in the model. The model predicts correctly use/non-use of organic inputs for each field correctly only 74% of the time, with better results predicting use (79% correct) than non-use (68% correct). Comparing the relative sizes of one unit changes in the explanatory variables on the probability of using organic inputs, the most influential variables are:

- the price variability indicator (more variability reduces probability of use 0.85),
- the secteur-level pattern of organic input use (higher secteur-level use increases the probability of use 0.67),
- the area a household has in pasture land (higher percent of land in pasture decreases the probability by 0.57),
- farming rented vs. owned land (renting reduces the probability of using organic inputs 0.39).[5]

Chemical inputs were used on only 2% of the fields included in the model. The overall model predictions were 92% correct, but of the 129 fields that received chemical inputs only 12 were

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[5]Numbers reported in parentheses are the dF/dx calculated by STATA. They represent the impact on the probability of adoption/use of a one unit change in the explanatory variable, except for the case of dummy variables where the change in probability is calculated using a change from 0 to 1 in the value of the dummy variable.

predicted correctly–i.e. many of the model errors were false predictions of non-use. Among the statistically significant coefficients, the ones that have the largest impact on the probability of use are:

- the secteur-level use of chemical inputs (positive effect on the probability of use 0.08);
- the price variability indicator (negative impact on probability 0.09).

The land use ratio (C-Value) ranges from 0.01 to 0.4 in the data. The OLS model explains only 22% of the variability in the ratio with the secteur level land use variable having the largest standardized coefficient, followed by the dummy variable for renting/owning the field, and the categorical variable indicating the location of the field on the slope. Although these variables are highly significant and have larger standardized coefficients than the other variables, the impact of even large changes in the values of the variables has only a very small impact on the ratio. The predicted value of the ratio is .15 evaluated at the sample means. Changing the dummy variable indicating rented vs owned land from 1 (rented) to 0 (owned) reduces the predicted value of the land use ratio from 0.20 to 0.14. Similarly, reducing the secteur-level land use ratio from its mean of .13 to the 5th percentile value of .09, changes the ratio from .15 to .12.

A general observation about the set of four models viewed as a whole is that the variables in the 'physical incentive to invest' and 'investment risk' categories are more likely to be significant (63% of coefficients in each group are significant) than variables in the 'wealth/capital' and 'monetary incentive to invest' categories (32% and 29% of coefficients in each group are significant). One possible interpretation of this result is that declining productivity (due to erosion, nutrient depletion, etc.), coupled with the need to meet most household food security objectives from own production (due to poorly developed agricultural markets), are pushing farmers to invest in soil enhancing technologies regardless of short-run commercial incentives reflected in the prices, wages, and profitability indices. It is also possible, however, that the indicators of monetary incentive selected for the model do not adequately reflect indicators of monetary incentives used by farmers when making investment decisions[6] or that parcel-level choices are better explained by parcel-level variables (used only in the physical characteristics and risk categories of variables) than by household, secteur, or prefecture level variables.

Table 3 reveals that two of the 'physical characteristics' variables (slope and size of plot) are statistically significant in all four models. Four of the 'physical characteristics' variables (share of holdings in woodlot, share in pasture, location of the plot on the slope, and distance of the plot from the residence) are statistically significant in three of the four models. Although the impact of changes in these variables is quite small within each model, the impact on the overall effort to

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[6] This is an area where future research could have important payoffs. Our model specification assumes that farmers use market prices to evaluate returns to investments. In situations where much of production is home consumed, farmers may be using different criteria to evaluate investment returns. Learning more about which criteria are used and how they are used would improve government's ability to design effective programs to promote input and conservation investments.

improve soil fertility and reduce soil degradation and erosion will be larger if a change in the determining factor influences several outcomes at once.

Model results show that larger parcel size has a small but positive impact on the use of both organic and chemical inputs. This reflects the tendency of Rwandan farmers to invest first and foremost in fertility of their banana parcels, usually the largest parcel, on which the residence enclosure is also located.   The same variable also has a positive impact on meters/ha of conservation investments and helps reduce land use erosivity (lowers C-value). Slope of the plot also plays an important role in decision making. As the slope of the plot increases, conservation investment also increases and land use choices become less erosive (C-value declines). Steeper slopes, however, are associated with lower probabilities of input use, reflecting farmers' concern that fertilizers are more likely to be washed away if applied on steeper slopes unless anti-erosion investments have been made.

A plot's location on the slope and its distance from the farm residence have significant coefficients in all the models but that of chemical input use. When we replaced the 5-category variable (1= location on the summit and 5 = location in the valley) by dummy variables representing levels 2-5 (level 1 being captured by the constant), we found that levels 4 and 5 tended to have a different impact on the dependent variable than levels 2 and 3.[7] Conservation investments decline markedly as one moves from the summit to the valley, reflecting the greater need to prevent erosion on the higher areas of the slopes. There is a similar pattern with organic inputs–the probability of using them declines as the plot location moves from the summit to the valley. This pattern probably reflects the fact that animals are stabled near the residence which is located closer to the summit than the valley. Given the labor required for transporting manure, fields closer to the residence are more likely to benefit than those further away. In the land use equation, we find that farmers use more erosive crops/practice on plots near the valley (levels 4 and 5). This makes sense because these fields are less likely to suffer harm than fields near the summit.

A larger share of holdings in wood lots is associated with a greater probability of using organic inputs, a lower probability of using chemical inputs, and less erosive land use practices on cultivated plots. A larger share of holdings dedicated to pasture is associated with less conservation investment, a lower probability of using organic inputs, and less erosive use of cultivated plots. It is not clear how the share of wood lot and pasture land is influencing decisions about investments and adoption, because some of these results appear counter-intuitive.

A plot that is located further from the residence or one that is rented receives less conservation investment, is less likely to benefit from organic inputs, and has a more erosive cropping pattern. All three of these significant relationships suggest that a farm on own land and/or with cultivated

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[7] Coefficients for the slope location dummies are reported as a subset under the results for the categorical slope location variable in Section B of Table 3. All other coefficients reported are from the models run with the categorical variable.

plots close to the residence is more likely to engage in practices that promote soil fertility and conservation.

A larger farm size tends to make farmers less aggressive in terms of soil fertility and conservation measures, presumably because their need for productive land is less acute. An increase in farm size decreases conservation investment and use of organic inputs, while increasing erosive land use practices.

The last variable that has a significant impact in three of the four models is the secteur level use of chemical inputs. This variable is associated with a higher probability that chemical inputs will be used, a lower probability that fields in the secteur will benefit from organic inputs (i.e., chemical inputs may be substituting for organic inputs rather than acting as complements), and more erosive land use practices. The variable has no significant impact on conservation investments.

6. Policy and Research Implications

Three of the variables that had either a relatively large impact on one or more of the dependent variables. These determinants include land ownership (versus rental), parcel size, and parcel distance from the residence. All of these variables are ones that are directly affected by current government policies to resettle families and develop villages. We found that increasing the distance of a parcel from the residence resulted in a statistically significant decrease in conservation investments, decrease in the use of organic inputs, and an increase in the erosivity of land use patterns. Smaller parcels were also less likely to benefit from conservation investments and inputs, while reflecting higher rates of erosion.

These results have implications for the government's current policy of "villagization." This policy is a well-intentioned effort to provide housing for those who were without it after the war and to stimulate the development of commercial centers in rural areas. It has, however, the unfortunate impact of substantially increasing the distance between farm parcels and residences. Our results suggest that it is unlikely that the villagization program will encourage agricultural intensification and improved conservation practices if villagers are not living close to their fields. Although the impact of villagization on parcel size is not known, this is another factor the program should take into account as it evolves and changes are made to improve its ability to stimulate agricultural productivity growth and commercialization.

Although larger parcel sizes encourage investment and intensification, larger farm size does not. The coefficients on the farm size variables are relatively small, however, so it will be important for those designing agricultural policies in Rwanda to keep in mind that at present it is the smaller, rather than larger, farm that contributes to conservation investments and soil-fertility improving input use.

Results associated with the rent/own dummy variable confirm that Rwandan farmers need confidence in the longer term through secure land tenure. This means not only helping farmers to farm their own rather than rented land by legalizing land transactions, but also by reducing the risk of appropriation—which in recent years has been extremely high. Enhancing farmer access to the land market will require reform of existing and antiquated land laws.

Recent developments on land-related issues in Rwanda have been encouraging. The importance of land issues to the government is clearly evidenced by the formation of a new Ministry of Lands and Settlement created in February 1999. The government has a proposal for new land regulations which will be going before cabinet/parliament in the near future. The proposed new regulations are aimed at addressing the ambiguity created by current land laws where land rights are governed by two sets of laws depending on whether the land is registered. Currently, registered lands (found mostly in the urban areas) are governed by written land laws and are officially titled. Unregistered lands are governed by customary law and all belong to the state and have no property titles (laws of July 11, 1960 and March 4, 1976, Book II Civil Code).

The present system provides farmers only limited security against the risk of appropriation, thereby creating a direct, though sometimes subtle disincentive to investment in the land. While in some areas farmers circumstances and customary law may provide enough security over property to justify long-term improvements, in other areas and depending on a given household's position in the community, the farmer will be cautious about how he/she invests. The new regulations are aimed at ensuring land tenure to an individual and facilitating land transactions. On April 17, 1998 a commission headed by the Prime Minister to study the question of land rights stated that "land should not belong to the state... since this is contrary to the country's principle of liberalisation. Land should belong to the individual (*umuturage*). This will encourage one to use land as a profit generating economic instrument." (Ministry of Agriculture, Livestock, and Forests, *Avant Projet de Loi*, 1999).

Another potentially beneficial aspect of the proposed land laws are Articles 48-50, which vest in the individual the right to sell, lease, exchange, mortgage, or give away land without any government interference in these transactions (Ministry of Agriculture, Livestock, and Forests, *Avant Projet de Loi*, 1999). What makes this change so important is that it will have the dual effect of permitting farmers to recoup partially of fully their investments in the land at the time of sale, and of facilitating the sale of lands that might otherwise be leased. As this research has shown, leased land is far less likely to receive improvements than land that is owner-operated.

Another lesson from all four models is that secteur-level patterns of conservation and input use can serve as a stimulus for further promotion of adoption. Hence, if the general context in which farmers are making their land use and investment decisions favors conservation and investment, individual farmers will be more likely to move in the same direction. This implies that secteur-level investments in extension, markets, and infrastructure that get a few farmers moving in the right direction will have a 'multiplier' effect in helping spread adoption to others.

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The lesson for policy makers to take from this analysis is the complexity of conservation and input investment decisions. This complexity was highlighted by the large number of statistically significant variables in the models, each offering a small contribution to the overall decision to invest or not invest. Unfortunately, this implies that major changes in conservation and input investments will require attention to all of these factors, because no single factor is controlling enough to be used single-handedly as a major policy leverage instrument.

The patterns discussed in this paper reflect the situation in Rwanda at a point in time when farmers are just beginning to recognize the importance of conservation investments and input use. The 1994 war and the many changes in population and policies that have intervened since the war suggest that updating the data base on agricultural practices to identify patterns that have continued as well as changes that have taken place since the war will be important. Careful monitoring of the impact of villagization on production and conservation practices is necessary, so that policy makers will have access to information to help them adjust the program as it evolves. Further study of the impact that economic variables have on production decisions is also necessary, particularly given the current national objective of transforming Rwanda's agricultural sector from one based on semi-subsistence practices to one striving toward the development of a commercial sector. Model results showed many of the coefficients on economic variables (prices, income, human and physical capital) to be significant but the size of the coefficients to be very small. It is our hypothesis that the importance of these variables in determining conservation investments and input use will increase as Rwanda's agriculture becomes more commercial.

Much work remains ahead if Rwanda is to develop a modern, commercial agricultural secteur. We hope that the lessons that can be drawn from past research and experience such as that presented in this paper will speed the transformation process.

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Table 1. Dependent Variables: Parcel Level Correlations and Mean Values

Correlation Matrix	Conservation Investments	Organic inputs	Chemical inputs	Land use C-Value
Conservation investments (m/ha)	1			
Organic inputs (% parcels benefitting)	.10**	1		
Chemical inputs (% of parcels benefitting)	.05**	.09**	1	
Land use (C-Value)	0.01	-.25**	0	1

Descriptive Statistics	Means	Standard Deviation	Coefficient of Variation	No. of observations
Conservation investments (m/ha)	438205161561	9.28	2.12	5460
Grass strips		274e+13	1.34	
Anti-erosion ditches			1.68	
Hedgerows			2.86	
Radical terraces			25.20	
Organic inputs (% parcels benefitting)	49	50	1.02	5460
Chemical inputs (% of parcels benefitting)	2	1.5	6.36	5460
Land use (C-Value)	0.16	0.09	0.55	5460

Source: Estimated from survey data.

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

Table 2.   Explanatory Variables: Descriptive Statistics

Model Variables	Overall Mean or Percent	Coefficient of Variation	Level of Observation Parcel* = 5,460 HH = 1,146 Secteur = 78 Pref = 10
A. Monetary Incentive to Invest			
Agricultural profitability index (FRW)	96.3	.40	Prefecture
Non-agricultural wage in prefecture (FRW)	205	.34	Prefecture
Price of banana (FRW)	23.5	.12	Prefecture
Price of sweet potato (FRW)	14.7	.221	Prefecture
Distance to nearest market (km)	4.4	.32	Secteur
Distance to paved road (minutes)	20.8	1.06	Secteur
B. Physical Incentive to Invest			
Share of holdings under fallow	.14	1.16	Household
Share of holdings under woodlot	.07	1.55	Household
Share of holdings under pasture	.02	3.571	Household
Slope (degrees)	13	.73	Parcel
Location on slope (1=summit, 5=valley)	3.27	.36	Parcel
Farm fragmentation (Simpson)	.64	.33	Household
Size of Parcel (ha)	.18	1.79	Parcel
Distance from residence (minutes)	11	1.6	Parcel
Years operated	17.7	.86	Parcel
Annual rainfall (mm)	1140	.27	Secteur
C. Risk of Investment			
Dummy for rent/own land (% rented in)	20%	--	Parcel
Price variation (1986-92)	.19	.27	Prefecture
D. Wealth and Liquidity Sources			
Non-cropping income (FRW)	17,606	2.38	Household
Cash-crop income (FRW)	12,317	1.62	Household
Value of livestock (FRW)	12,582	1.68	Household
Landholdings owned (ha)	.91	.93	Household
Human Capital :			
Number of adults (aged 15-65)	2.77	.52	Household
Dependency ratio	1.23	.74	Household
Literacy of Head of Household (% literate)	49%	--	Household
Knowledge of conserv/prod technologies	2.85	.85	Household
Age of head of household (years)	45.9	.332	Household
Sex of head of household (% male)	80%	--	Household
E. Secteur-level Variables			
Secteur land use patterns (C-value)	.13	.19	Secteur
Secteur conservation investments (m/ha)	422	.50	Secteur
Secteur use of organic inputs (avg % area using)	.64	.22	Secteur
Secteur use of chemical inputs (avg % area using)	.04	1.86	Secteur

Source: Estimated from survey data.

Note: Summary statistics reported at the parcel level are for all holdings under cultivation or fallow (thus excluding pasture and wood lot).

Table 3. Estimated Coefficients and Significance

Independent Variables by group	Conservation Investments (m/ha) (Tobit)	Organic Inputs (Probit)	Chemical Inputs (Probit)	Land Use (C-value) (OLS-beta coef)
A. Monetary Incentive to Invest				
Agricultural profitability index	3.2**	.00	.00	-.01
Non-agricultural wage	-.58	-.00**	-.00	.02
Price of banana	-18.52	-.04**	-.06	.02
Price of sweet potato	22.25	.01	-.02	-.01
Distance to nearest market	37.14*	.05**	.10*	.01
Distance to paved road	1.21	-.00**	-.00	.05
B. Physical Incentive to Invest				
Share of holdings under fallow	-200.92	-.49**	-.56	-.06**
Share of holdings under woodlot	-55.88	.46*	-1.00*	-.04**
Share of holdings under pasture	-858.53*	**-1.46****	-.60	-.03**
Slope (degrees)	16.82**	-.01**	-.02**	-.02*
Location on slope (1=summit, 5=valley)	-350.92**	-.22**	.04	.11**
Level 5	-1594.59**	-.92**	.01	.03**
Level 4	-300.78**	-.55**	.00	.01*
Level 3	-67.05	-.38**	.01	.00
Level 2	130.29	-.20*	.01	.00
Farm fragmentation (Simpson Index)	-86.05	.08	.48	-.01**
Size of Parcel	3.15**	.01**	.01**	-.08**
Distance from residence	-5.86**	-.02**	.00	.04**
Years operated	3.12	.01**	.00	-.01
Annual rainfall	.02	-.00	- .00	.06**
C. Risk of Investment				
Share of landholdings rented in (0=own,	-275.61**	**-1.12****	-.01	**.26****
1=lease)	113.10	**-2.28****	**-4.37****	-.00
Price variation (1986-92)				
D. Wealth/Liquidity Sources and Human Capital	.00	.00**	-.00	-.00
Non-cropping income	.00	-.00	.00**	-.04**
Cash crop income	.00	.00**	.00**	.06
Value of livestock	-1.24**	-.00**	.00	.02**
Landholdings owned (ha)				
Human Capital :	-10.91	.01	-.08	.01*
Number of adults (aged 15-65)	.14	.00	-.00	-.00*
Dependency ratio	12.58	-.04	-.16	.01
Literacy of Head of Household (0=no, 1=yes)	8.66	.04**	.02	-.04
Knowledge of conserv/prod technologies	-1.26	-.01**	-.01*	.01
Age of head of household (years)	-36.82	.09	-.00	.02
Sex of head of household (0=male, 1=female)				
E. Secteur-level Variables	3759.82**	-..89	2.14	**.30****
Secteur land use patterns	1.97**	.00	.00	.01
Secteur conservation investments	171.34	**1.74****	.95	.01
Secteur use of organic inputs	607.38	-.62*	**4.75****	.05**
Secteur use of chemical inputs				
Adj R^2 (pseudo for Probit/Tobit models)	.02	.26	.25	.22
Prob. > chi square	.00	.00	.00	--
% observations correctly predicted	--	74	92	--

Source: Estimated from survey data.
Notes:
(1) *Sig T ≤.05   **Sig T ≤.01.
(2) Bold type indicates a variable with a relatively strong marginal impact on the dependent variable.
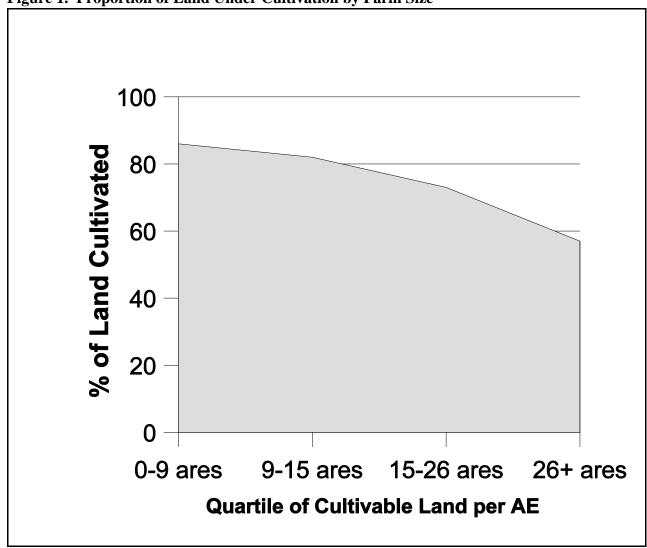(3) Positive coefficients are desirable for models 1-3 and negative coefficients for model 4.

Figure 1. Proportion of Land Under Cultivation by Farm Size