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Promoting Food Security in Rwanda Through Sustainable Agricultural Productivity:

Meeting the Challenges of Population Pressure, Land Degradation, and Poverty

by

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This work is dedicated to the fond memory of Laurence Uwamariya.

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NOTE:

Jaakko Kangasniemi and Thomas Reardon were the lead authors for Chapter 3 on yield patterns. Some of the material for this chapter is based on Kangasniemi's forthcoming thesis. Much of the chapter also appeared as a DSA working paper by Uwamariya, Kangasniemi, and Reardon in November 1993. Fidele Byiringiro was the lead author on Chapter 4 for yield determinants. Most of the material for this chapter is based on Byiringiro's 1995 thesis. Dan Clay was the lead author for Chapter 5 on the determinants of long-term changes in productivity. Dan Clay, Jaakko Kangasniemi, and Tom Reardon were the lead authors on Chapter 6 for soil conservation investments and input use determinants. Some of the material for this chapter is based on Kangasniemi's forthcoming thesis.

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EXECUTIVE SUMMARY

PROMOTING FOOD SECURITY IN RWANDA THROUGH SUSTAINABLE AGRICULTURAL PRODUCTIVITY: Meeting the Challenges of Population Pressure, Land Degradation, and Poverty

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INTRODUCTION

The horror of genocide and civil war have turned the world's attention to Rwanda over the last year. But before and beyond that conflict, there was hunger and the slow, grinding poverty of smallholder agriculture meeting with severe land scarcity and degradation.

This report is about reversing the spiraling decline of the land and the economy in rural Rwanda. Three things conspire to accelerate this decline: unsustainable land use practices (intensifying land use without sufficient investment in soil fertility and land improvement), insufficient nonfarm employment, and rapid population growth. We focus on the forces behind productivity decline in Rwandan agriculture. The report examines how erosion, organic input use, soil conservation investments, use of fertilizer and lime, and land use strategies affect productivity. We then examine what determines farmers' productivity and conservation investments.

The results are based on collaborative research between the Rwandan Ministry of Agriculture (MINAGRI) and Michigan State University. The data derive from a detailed farm-level survey, one of the most comprehensive in Africa, conducted by the Division des Statistiques Agricoles (DSA/MINAGRI). The survey covered a nationwide random sample of 1248 households, and was undertaken over 11 years, from 1984 to 1994. DSA has been, and we hope will be again, one of the national treasures of Rwanda.

Our key findings are that Rwandan farmers need to sustainably intensify their farming by protecting the soil against erosion, and by enhancing soil fertility through the use of organic matter (manure and mulch), and chemical fertilizer, and lime. Without more input access and use, inevitable intensification of farming, as holdings grow smaller, will be based only on adding more labor and cropping more intensely, both of which will degrade the soils and lead to greater hardship. Where farmers are now making these investments, we report successes. We find success is often predicated on confidence in the future (owning one's land), knowledge from extension services, cash and labor resources from off-farm earnings, holding livestock that provides manure, and planting perennial cash crops.

The contributions of this report are: (1) in underscoring and focusing on priority strategies and questions regarding the many issues that have come in and out of development debate in the highland tropics of Africa, and (2) in the systematic application of detailed, nationwide survey data to these key questions. Moreover, the report points to the great value of excellent national agricultural statistics services and national capacity to analyze data and provide insights for policy debate.

This summary reviews (1) the problems and promise of Rwandan agriculture, (2) study findings regarding determinants of productivity, land use, soil conservation investments, and use of inputs, and (3) policy and strategic implications.

PROBLEM AND PROMISE

- Rwanda's rate of population growth is still among the world's highest (above 3.0 percent annually).

- Rwanda's average rural population density of 574 inhabitants per square kilometer of arable land is the highest in Africa. Most arable land is under cultivation.

- Per-capita food production in Rwanda is declining, having dropped by 25 percent from 1984 to 1991.

- Half of the surveyed farmers reported declining productivity.

- Half of Rwanda's farmland suffers from moderate to severe erosion.

- Farm sizes are very small—averaging 0.83 hectares per household—and getting smaller with increasing rural population. Land is unequally distributed by smallholder African standards. Use of fragile lands on steep slopes is expanding, and fallow periods are growing shorter.

- DSA/MINAGRI data for 1984-1991 show that, except for maize, yields of all major crops (bananas, beans, sweet potatoes, cassava, sorghum, maize, and coffee) have declined. There has been a strong decline in the yield of tubers, the main source of calories for the poor.

- FAO data supports the DSA data on overall productivity decline. They show that Rwanda lost much of its yield superiority to similar countries in the region during the 1980s—falling behind in cassava, maize, and sweet potato, and, in comparison to some neighbors, in coffee.

- Rwanda still has, however, comparatively high yields in its main cash crops—white potatoes, sorghum, coffee, and tea. Moreover, despite the yield declines of the 1980s, bananas and sweet potatoes still can produce large quantities of calories per hectare. These crops, together with maize (that has much potential for higher yields), hold promise either as food or cash crops.

YIELD PATTERNS

- Inter-zone differences in land productivity are substantial for specific crops, and for crops in the aggregate. The extremes are the two western zones, with the Northwest producing twice as much per unit of land as the Southwest.

- Compared to larger farms, smaller farms have higher yields (60-95 percent higher, depending on the crop), higher marginal value products of land, and lower labor productivity.

- Coffee and bananas (the key cash crops, and crops that protect the soil from erosion), and cassava yield better on smaller farms (with cropping more intensive in labor). The smaller the farm, the more land is allocated to bananas and coffee. Smaller farmers prefer potatoes (sweet and white) to cassava, however, as the former have higher yields (per hectare) in caloric terms. Bananas and white potatoes provide the highest returns to labor.

YIELD DETERMINANTS

- Smaller farms produce much more (in value terms) on each additional hectare of land than what is paid for a hectare of rented land. This implies land market constraints (access to renting and acquiring land).

- By contrast, smaller farms produce much less (in value terms) for each additional day of farmwork than it costs to hire a worker for a day. This implies that labor is "bottled up" on smaller farms and that there are constraints to access to labor market opportunities in the agricultural and nonagricultural sectors.

- Erosion greatly reduces land productivity. On very eroded farms an additional hectare produces 21 percent less than on farms with little erosion. This loss rises to 36 percent for farms with a low share of high-value cash crops (bananas and coffee) and a low share of cultivated area to which fertilizer or organic matter has been applied.

- Soil conservation investments (bunds, terracing, grass strips) greatly increase land productivity. Farms with a relatively high level of soil conservation investments have 25 percent greater land productivity than those with a low level, all else being equal. The gain is as high as 33 percent for farms with a high share of low-value crops (food crops, annuals) and high erosion.

- Cash cropping raises land productivity in terms of monetary value. Increasing the share of farm output coming from high-value cash crops (bananas or coffee) strongly benefits smallholders' incomes and land productivity (by 50 percent). The yield gains from shifting to cash crops are clearly highest for those with better farm conditions, i.e., with low levels of erosion and high use of fertilizer and organic matter.

- Expanded use of fragile lands on steep slopes and shorter fallow periods are driving down land productivity over the longer run, farmers report.

DETERMINANTS OF LAND USE, SOIL CONSERVATION INVESTMENTS, AND USE OF INPUTS

Land Use

Farmers' land use (in terms of erosivity) tends to be *less erosive* (more protective):

- on steeper slopes where rainfall is high, land is more protected where cash perennials (bananas and coffee) and woodlot are grown.

- on owner-operated (not rented) plots in which households have higher confidence in the long term.

- regardless of farm size. Farm size does not affect the erosivity of land use, except for farms located above 2000 meters (25 percent of Rwandan farmland). Most small farms manage to protect the soil through increased cultivation of bananas and coffee, but these perennials do not grow well in high altitudes. More erosive annual crops are grown instead.

- where there is more nonfarm income and a higher off-farm wage. Both reduce the erosivity of land use, probably by taking pressure off the farmer to "mine" the land with annuals for food security.

- with extension. Farmers' knowledge of conservation- and productivity-enhancing technologies is strongly and significantly associated with less erosive forms of land use.

Soil Conservation Investments

Soil conservation investments (grass strips, bunds, terraces, etc.) *increase* with the following:

- more profitable agriculture

- higher rainfall (the threat of runoff)

- less land in fallow

- plots being higher on the slope or on slopes of medium steepness

- owner-operated (not rented) plots

- smaller farms

- more nonfarm income (enabling farmers to make more investments)

- extension (especially for non-traditional types of investments).

Use of Organic Matter and Purchased Inputs

Use of improved inputs—organic matter (manure, mulch, etc.)—and purchased inputs (fertilizer and lime) *increases* with the following:

- less steep slopes (because of runoff)

- owner-operated land (not rental) for organic inputs, which are perceived as having long-term effects. This is not the case with fertilizer and lime, which are perceived to have short-term effects, and are applied to owned and rented fields alike.

- more stable prices (less price risk)

- smaller farms, which use more organic matter (as they have less fallow), and larger farms, which use more fertilizer and lime, probably because they are more able to afford them.

- more nonfarm income, which increases the use of purchased inputs among larger farmers (this implies a credit constraint). Nonfarm income is also important to smaller farmers, probably because it enables them to maintain traditional extensive practices (fallowing, etc.), and purchase food when necessary.

- the presence of more livestock (hence more manure), particularly among larger farmers. More nonfarm income also increases livestock ownership among larger farmers (as savings).

- extension (especially for fertilizer use).

STRATEGIC AND POLICY

IMPLICATIONS

In 1992 the Rwandan government announced its strategic policy goals to raise and sustain rural food security: (1) to increase farm productivity and profitability, (2) to combat soil degradation, and (3) to diversify rural household incomes to increase purchasing power and reduce pressure on the land (Commission Nationale d'Agriculture, 1992). In addition, although interest in productivity was traditionally focused on food self-sufficiency for Rwanda, interest in recent years has turned to increasing the output of products that have promising prospects in intra-regional trade.

These rural food security objectives depend on farmers' **sustainable intensification** of production. Growth of agricultural output must keep pace with rapid population growth, and is necessary to build trade ties in the region and abroad. This will require greater use of improved inputs.

What are the priorities for increasing the use of improved inputs? There are limits to the gains made by merely intensifying cropping by adding labor and increasing crop densities—this will exhaust the soil in short order. Rather, we have identified the following priority strategies:

- Greatly increase the use of organic matter (with mulch from perennials, manure from animals, and green manure from windbreaks).

- Greatly increase the use of fertilizer and lime (through local production and imports).

- Maintain and increase soil conservation investments such as bunds and terraces to protect input applications and fight erosion.

We have learned that farmers will not and cannot greatly increase the use of these key inputs and investments without certain conditions being present:

- Farmers need restoration of confidence in the short-term after four years of civil war. Without **political stability** it will not be possible to expect productivity investments.

- Agriculture needs to be profitable from the output price side and the input cost side. We find that the drop in coffee prices reduced investment, and the high cost of fertilizer made coffee growing unaffordable for many.

- The general conditions of stability and profitability are, however, necessary but not sufficient conditions. More specific policies and programs are needed to enable farmers to make the investments once the general conditions are in place.

- Our work shows that farmers need confidence in the longer term through **secure land tenure**. This means reducing the risk of appropriation, and giving households the right to transact land. This will require a **reform of the land laws**.

- Farmers need **knowledge** regarding productivity and conservation practices; we show that **extension** has been, and can be, an effective tool for technology dissemination in Rwanda.

- Farmers need **cash income** to buy materials, animals, and labor for productivity and conservation measures. Key sources of cash are **nonfarm activities** and **cash cropping**. Nonfarm activities also increase the demand for crops through downstream production linkages. Alternative income sources also reduce pressure on the land. These can be promoted through **nonfarm microenterprise programs**.

The presence of the appropriate conditions will spur the demand for improved inputs. Programs and policies should be ready to increase their supply. We believe that the findings presented in this report have clear implications for external donor programming, and for the broader relief-to-development trajectory that the donors envision for post-crisis Rwanda.

- **Relief-to-development**: After the war, foreign assistance and government programs need to include building the base of productive assets—perennials and livestock—the stocks of both of which have been reduced by conflict and neglect. Using disaster relief to rebuild herds, and focusing on animal diseases and stabling infrastructure will help. Building stocks of perennials and livestock will increase mulch and manure availability and increase farmer wealth, as well as protect against erosion in the case of bananas and coffee.

- Study and promotion of the **fertilizer/lime subsector** are needed. The focus should be on **constraints to private sector input marketing**. Government regulations and licensing requirements that inhibit fertilizer imports should be examined and potentially eased or eliminated. Extension is needed to promote use of fertilizer and lime on food crops, not just cash crops.

- **Credit**: Many smallholders suffer from severe cash constraints when trying to buy inputs and make investments. Our findings encourage further study of institutional options that will make secondary town and rural banks, perhaps along the lines of the Grameen bank, more accessible to farmers.

- There needs to be more livestock, as well as a shift from extensive to intensive livestock husbandry. Losses from four years of civil war, plus disease and loss of pasture, have decreased herds rapidly over time—hence decreasing manure availability. Livestock stabling and disease control technologies are areas where extension and project programming could have a major impact on productivity.

- Rwanda has underinvested in the use of **green manuring** and other agroforestry practices—despite successful on-farm trials.

- **Integration of fodder and crop production strategies** is poorly developed in Rwanda, by Asian standards. Its promotion would increase manure availability.

- Technological research is needed on **intensification of intercropping and mixed cropping techniques** that increase output, incorporate cash perennials, and increase crop density while still protecting the soil.

- Land rental and absentee landholding effectively lower investments in land productivity. **Revision is needed in land policies and traditional practices** that impede land transactions and contribute to productivity decline, such as laws prohibiting land sales.

- Government and donor programming in the population/health sector must **incorporate environmental and productivity issues** into their strategies for population control. Improved food security and environmental conditions can be used to help "market" population control.

- The Rwandan Ministry of Agriculture has expressed interest in relating productivity research results to strategies for specialization by region, to increase the overall national output and better position Rwanda for intra-regional trade. Our report makes some crop-specific suggestions for zone-level promotion of crops. Moreover, such promotion can be linked to processing infrastructure and input delivery system investments by the government and private firms. We stop short, however, of making strong recommendations concerning area-specific specialization from our diagnostic results. These results are reported at the zone level, which is often broader than the niche area for a given product. Moreover, Rwandan farmers diversify risk and take advantage of micro eco-niches at present, and there needs to be more research on the crop mix objectives and decisions of farmers (the subject of a forthcoming thesis from this project).

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PREFACE

One of the more tragic periods in human history began abruptly on the night of April 6th, 1994, when Rwanda's president, Juvénal Habyarimana, was assassinated. During the subsequent months of ethnic reprisals and counter-reprisals, hundreds of thousands of innocent men, women, and children were brutally murdered in their homes, and in schools and churches where they sought refuge. Millions more fled the country, to be jammed into the misery of refugee camps hastily assembled in bordering states.

Information for the research reported here was collected prior to this horrifying tragedy. By late 1994, a new government had been installed, and, with assistance from international relief agencies and the United Nations, Rwanda had begun the painful process of rebuilding its fractured society and battered agricultural economy. Many refugees had returned to their homes and their meager landholdings; but over two million remained behind in Zaire, Tanzania, and Burundi. At this writing, in mid-1995, there is still much uncertainty, suspicion, and pervasive fear among the people of this small, beautiful country.

We believe, however, that in time, order will be restored, families will be reunited, and peace will find a way. And, very quickly, as they must, farmers will go back to their fields and engage once more in the struggle to survive. Many of the same economic challenges present before the war will be there. To be sure, some of the specific circumstances affecting land management practices are forever altered. However, the underlying conditions that shape the relationships of Rwandans to their land (and that shape, as well, the relationships of Rwandans to each other) will not have changed. The pressures of over-population, land scarcity, erosion-prone topography, lack of export capital, abject rural poverty, and the threat of drought and famine are realities that will not go away.

CHAPTER 1

INTRODUCTION

1.1. Research Problem

Per-capita food production in Rwanda is declining. Over the period 1984-1991, the kilocalories produced by Rwandan farmers dropped from 2,055 per person per-day to 1,509 (see Figure 1.1). Part of this per-capita decline can be accounted for by Rwanda's high rate of population growth and extremely limited access to land, with an average population density of 574 people per-square-kilometer of cultivable land—the highest in Africa.

The overall volume of food produced in Rwanda today is smaller however, than in 1984. There have been good years and bad years during this period, yet the trend is unmistakable. In 1984, Rwandan farmers produced over 3,900 billion kilocalories of food (eight major crops); by 1990 this figure had declined to 3,604 billion kilocalories.

The production of coffee, Rwanda's most important cash crop, has not offset lower food production, so the overall agricultural output is also declining. Rwandan coffee output has declined over the past five years, along with a decline in world coffee prices, thus contributing to lower export earnings. Data reviewed in this report show a decline in selected crop yields over time, consistent with aggregate figures.

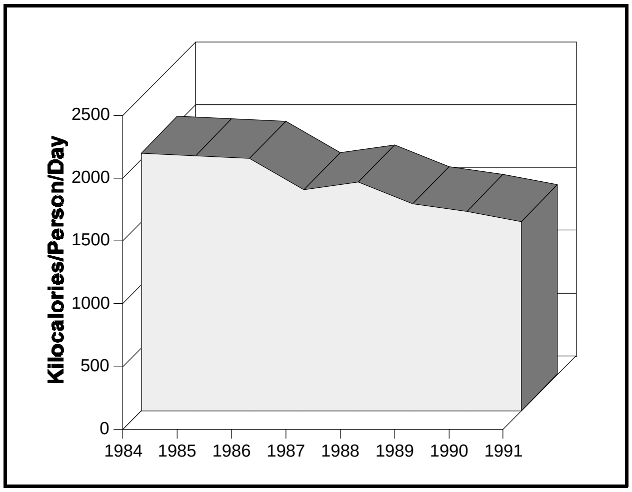
Farmer observations (in a 1991 survey by the DSA—Division des Statistiques Agricoles) are equally telling. When asked about changes in the productivity of their land, farmers reported that on 48.7 percent of their holdings, land productivity is declining. Farmers reported that on another 37.5 percent, yields have not changed, and on only 13.8 percent are their yields improving.

Moreover, DSA data show that production per-unit of land (average land productivity or yield) has declined from 1984 to 1991 for all major crops except maize. (Details are presented in Chapter 3.) Particularly alarming is the strong downward trend for tubers, the main provider of calories, especially for the poor.

Thus, if past trends foreshadow the future, as they so often do, Rwanda's agricultural and food security outlook is marked by uncertainty. Agriculture, as practiced in Rwanda today, is not sustainable for the long term. The rate of population growth is also expected to remain high, doubling today's population in less than 25 years.

Rwandan policymakers are aware of the alarming trends in agricultural productivity. The presidency formed a National Agricultural Commission (CNA) in 1991 to formulate a rural development and food security strategy. They listed the key immediate and long-term food security challenges to be: (1) reverse the decline in agricultural productivity; (2) stop and reverse soil degradation; and (3) provide alternative, off-farm income sources to smallholders to reduce pressure on the land and increase food purchasing power (CNA, 1992). The CNA estimated that half the country's farmland suffers from moderate to severe erosion.

Figure 1.1. Food Production per Person-Day



Source:
Computed from MINAGRI data.

Though Rwanda may never return to the days of food self-sufficiency, reversing the trend toward lower productivity is essential. Sustainable economic growth in Rwanda depends on a stable and resilient agricultural sector. Continued land degradation means lower rural incomes and economic decline. Controlling soil erosion and improving soil fertility are the keys to this economic growth. Our approach in this study places heavy emphasis on household level data and analysis. We thus give special attention to on-farm land use and investment, at the expense of related off-farm land management issues such as deforestation, watershed management, and park protection. Understanding farmers' strategies for land management, which include household-level investments in soil conservation and fertility enhancements on the one hand, and patterns of land use on the other, is where we begin.

1.2. Gaps in Knowledge and Study Objectives

Before one can begin to devise strategies that will help Rwandan farmers halt the trend toward declining agricultural productivity, one must first address a set of related questions concerning the nature and determinants of this decline. These questions are listed below and are the focus of the present study. The conceptual and empirical analyses presented in the following chapters are designed to help fill in these significant gaps in policymakers' and policy analysts' understanding of agricultural productivity in Rwanda, and guide us toward a policy framework through which viable solutions can be achieved.

a. What are the patterns of land and labor productivity in Rwanda? How do these vary by agroecological zone? By crop? How do Rwandan productivity levels compare with those of other countries in the region?

b. What are the determinants of land and labor productivity? In particular, what are the impacts of farm size (and hence demographic pressure), farm input use, livestock husbandry, soil degradation, land use and landholding changes, soil conservation investments, and the nonfarm income strategies of farm households?

c. What are the determinants of farm input use (especially fertilizer and organic inputs) and investment in soil conservation measures on farms?

d. What kinds of incentive policies and programs will promote sustainable land management and productivity enhancement?

1.3. Data and Methods

The Division des Statistiques Agricoles (DSA) of the Rwandan Ministry of Agriculture maintains one of Africa's more comprehensive data sets on rural households. The data examined in the present report are drawn primarily from this longitudinal data base covering approximately 1200 farm households. DSA (formerly known as SESA, or the Service des Enquêtes et des Statistiques Agricoles), was established in 1992 under funding from USAID/Rwanda. In 1983/84, SESA conducted Rwanda's first nationwide agricultural survey. Under continued USAID funding from 1984 to 1994, the DSA evolved into a large and experienced agricultural statistics and research unit, a major player in Rwanda's agricultural policy arena.

The data from the baseline farm survey, as well as from DSA supplemental surveys (in particular, the 1991 survey of agroforestry and land productivity), are the main data sets used in the present analysis, and are described in more detail in Chapter 2.

1.4. Approach and Layout of the Report

The report proceeds as follows. Section 1.5 lays out the key terms and concepts used in this report. Chapter 2 describes the data and agroecological zones analyzed. Chapter 3 describes patterns in average land and labor productivities using data from 1989-91. Chapter 4 examines average- and marginal-value products by farm size and land quality category, and explores the determinants of productivity using a cross-section from 1991. Chapter 5 examines determinants of the long-term changes in farm productivity reported by farmers, and their causes, as perceived by farmers. Chapter 6 examines determinants of organic and chemical inputs use and soil conservation investments, as well as land management practices—variables that are found to be key determinants of land productivity. Chapter 7 concludes the report and presents policy and program implications.

1.5. Terms and Concepts

"Productivity" is a measure of the output derived from a standard unit of input; it shows how efficient the producer is. That efficiency is conditioned or determined by the technology, the level of use of the input, and levels of use of complementary inputs. For example, land productivity is the average output per unit-of-land-used, and is conditioned by the use of that land, fertilizer, and other inputs. It is also conditioned by other characteristics of the farm, the household, and the household's milieu—soil quality, rainfall, the relative price of labor, and so on.

Average productivity is the total output divided by the level of use of one of the inputs used (e.g., total cassava produced divided by total land used for cassava production). This is often called "yield," but we use "average land productivity" and "average labor productivity" to highlight the input. *Marginal productivity* is the additional output (at the margin) produced by an additional unit of input used (e.g., how much *more* cassava an additional hectare of land will produce, say, beyond the average land used), conditioned by the same set of factors noted above. To compare across goods, to compare with factor prices, or to aggregate over goods, productivities are commonly valued at the output price. The marginal product of land, multiplied by the price of the good, produced by that additional unit of land, is the *marginal value product of land.*

Farm productivity measures can be defined with any number of crops in the numerator—from one to all. When there are two or more crops, they are aggregated using output prices as weights. Likewise, there can be one or more inputs in the denominator, again summed by weighting each input by its price. When a single input is used (with one or more outputs) one has *partial factor productivity*. Although not used here, when all the crops on a farm are in the numerator and all the inputs in the denominator, one has an index of *the total factor productivity*.

If the producer is economically rational and there is no constraint on the use of an input, the farmer should operate at the *economic optimum*, i.e., where the marginal-value product equals the factor price. At the optimum, the ratio of the marginal-value product of the input to the price of that input is equal to one. Thus, if the ratio is higher than one, the farmer is applying too little of the input; conversely if the ratio is less than one, he/she is using too much. For example, if the marginal-value product of seed, is above its price, that means the farmer can efficiently use more seed (as marginal return falls until marginal value equals the seed price), but for whatever reason (such as credit limits), farmers are constrained in their access to seed.

Moreover, if there is efficiency of allocation of a given input, theory tells us that the marginal-value product of an input for one or more crops should equal the marginal-value product for any other crop a farmer grows. If they are not equal, there is either a factor access constraint (e.g., there are limits to the type of land on which coffee can be grown), a non-optimal behavior due to risk (say, safety-first behavior), or a rotation constraint. Thus, farmers could be faced with a situation where they earn more on each additional hectare if they put the land under coffee or bananas, but cannot do this because of limits on the availability of land suitable for cultivating these crops. Consequently, they may put their available land under beans, sweet potatoes, or some other mix of crops.

In this document we work with the above concepts and measures. Average productivities are simply calculated using the average output divided by a given type of input used by farms of a given type (e.g., labor in the upper quartile of farms). Calculation of marginal productivities requires estimation of production functions.

The production function is output explained by use of variable inputs (labor, land, fertilizer, and pesticides), fixed or quasi-fixed inputs (land), and other conditioning factors such as soil erosion. Given an estimate (from that function) of the marginal effect of labor, on total output, for example, one can examine how this marginal impact changes when there are different levels of the conditioning factors (such as how much more productive an additional unit of land is, given a higher rate of erosion).

One can then ask what determines the use of inputs and conditioning variables—including policy and other household-level determinants such as nonfarm income and adult literacy. Thus, through the production and input use functions, one can trace how price and non-price variables, themselves influenced by policy, determine productivity levels.

CHAPTER 2

DATA, RESEARCH PROCEDURES, AND HOUSEHOLD CHARACTERISTICS

2.1. Data and Research Procedures

The data examined in this report came mainly from a nationwide stratified-random sample of 1,248 farm households (operating approximately 6,500 parcels) surveyed by the Division des Statistiques Agricoles (DSA) of Rwanda's Ministry of Agriculture.[1] The DSA survey ran from 1983 to mid-1994, and was Rwanda's primary source of agricultural statistics during that decade.

The baseline survey gathered data on crop and livestock production, household income and expenditures, land use and management, demographic characteristics, and sundry other topics. Complementing the baseline survey were a series of one-time supplemental surveys focused on specific topics.

Our analysis of agricultural productivity in Rwanda draws on both the baseline survey and on the agroforestry/soil productivity supplemental survey. Crop production, area (land use), and crop densities are among the more important baseline variable sets we examine; each is described below. Information on reported changes in soil productivity and on conservation and soil fertility investments was gathered by the agroforestry add-on survey. In that survey, interviews with heads of households and/or their spouses were conducted over six weeks beginning in June 1991. The survey instrument treated both household-level variables (such as knowledge of conservation practices) and parcel-level variables (such as soil conservation investments, land tenure, and steepness of slope). These data were merged with data from the baseline survey.

2.1.1. Crop Production

DSA's crop production data are based on weekly recalls. DSA supplied sample farmers with standardized, graduated buckets that were used to measure production and transactions. The quantities harvested were measured or estimated by respondents, and reported to the enumerators who visited each farmer weekly.

2.1.2. Land Area and Crop Densities

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[1]The complete sample frame includes a total of 1,248 households. However, due to military/political tensions in the prefecture of Byumba, along the Uganda border, interviewers were unable to conduct fieldwork in the region, and 8 (0.6%) of the 1,248 sampled households had to be omitted from this study. Sampling weights have been adjusted accordingly.

Fields were measured by enumerators once per season, at a time when annual crops were well established and visible in the fields. Since intercropping is common, enumerators estimated the planting densities of each crop in each field (relative to those on pure fields). These densities were then used to compute the field area occupied by each crop grown in that field.

Although estimating crop densities is somewhat subjective, it is essential for estimating yields. Under the procedures used in this study, a typical *mixed-cropped* banana/bean field, say, with 66 percent density for bananas and 33 percent density for beans, is divided so that two-thirds of the area is allocated (in the yield calculations) to bananas and one-third to beans. If only bananas were considered and the entire area were allocated (in calculations) to bananas, the banana yield of this field would be about 33 percent lower. Since the output of beans from this field would still be measured along with beans produced elsewhere on the farm, ignoring the area from fields like this would overestimate bean yields. Thus, in general, land allocation to crops that are mostly grown as minor crops in association with other major crops would be underestimated, and the yields overestimated, whereas the yields of the dominant crops (e.g., bananas) would be underestimated.[2]

Since most crops are harvested throughout the year, land use changes continuously. Cross-sectional measurement of land use is thus only a one-time-per-season sample that roughly approximates land use over the full six-month season. Households that harvested crop X at the beginning of the season and planted crop Y just before land use was measured, may have low or zero yields for crop Y, even though there was no crop failure, and exceptionally high yields for crop X even though its yield may have been normal. Although we do not have any reason to suspect that this data collection procedure introduces any statistical bias, we acknowledge that our household yield data may be more variable than similar data from countries where growing seasons and harvest periods are more uniform. Despite potentially higher variances, the relatively large number of households in the current sample (1,248) helps us achieve an acceptable level of statistical reliability.

2.1.3. Yields

Although yield (i.e., average land productivity, as defined in Section 1.5) is frequently expressed in units of output-per-unit-of-land, one should always keep in mind that output is a flow and yield is the sum of that flow over a specified period. Although this sounds obvious, much confusion is created by not being explicit about, or consistent in, the periods used. The common practice is to express yields-per-growing-period for annuals and per-year for perennials. Unfortunately, this rule is not clear for crops that are somewhere between annuals and perennials (e.g., cassava). In Rwanda, the annual reports of the DSA express yields-per-six-months

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[2] In the field, enumerators estimate densities relative to the normal densities of purely-cropped fields in the region. These densities are then standardized so that they add up to 100 percent. For instance, the 66/33 banana/bean field mentioned in the example may have been estimated by the enumerator to have a 80 percent density for bananas and 40 percent density for beans.

(season) for annuals, per-12-months (year) for bananas and coffee, and per-18-months (estimated average growing period) for cassava. In practice, the DSA collected data on production through weekly interviews.

In DSA's annual statistical reports, national yield estimates are computed by summing the estimated production and area figures over the two seasons, dividing, and then multiplying by 1 (for annuals), 1/2 (for perennials), or 3/2 (for cassava) to get the estimates in the common forms: per-season for annuals, per-year for perennials, and per-18-months for cassava. Note that this procedure weights by seasonal land use, giving more emphasis to the season when the crop is more important.

In this report, a somewhat different approach is taken. To ease comparisons among the crops, all yields are expressed in kilograms-per-hectare per-six-month season. As above, the procedure weights by seasonal land use. Unless otherwise stated, the yield estimates are averages over the six seasons of 1989-1991.

2.1.4. Weighting

Because the household-level data presented in this study are based on a stratified random sample, they have been weighted according to their probability of selection. Some of our analyses are based on data collected at the parcel level. Parcel-level data have been proportionally weighted according to parcel size, as well as for the household's probability of selection, thus eliminating any over-representation of smaller parcels and under-representation of larger parcels.

2.2. Household Characteristics and Patterns of Land Management

2.2.1. Household Characteristics

Rapid population growth and declining agricultural productivity affect the livelihoods and survival of millions of rural households throughout Sub-Saharan Africa. Perhaps nowhere else have these effects been deeper or created greater hardship than among the farm population of Rwanda, where over 93 percent of the population is rural, and almost all rural households are engaged in agriculture (Government of Rwanda 1982). Farm production is oriented toward subsistence: beans and sorghum, supplemented by sweet potatoes, cassava and peas, are the principal directly-consumed food staples. Bananas, used mainly for brewing banana wine, are also important to farm households both as a source of calories and for sale. Coffee and tea are important cash crops for some farmers and important sources of foreign exchange for the nation. Rwanda's agricultural system is labor intensive; hoes and machetes are the main farm implements.

The 1992 Demographic and Health Survey shows that Rwanda has a total fertility rate (TFR) of 6.2 live births per woman. Though declining (down from a TFR of 8.5 a decade ago; ONAPO

1994), the rate of population growth is still among the world's highest (above 3.0 percent annually). Small in land per-person, Rwanda's average rural population density of 574 inhabitants per-square-kilometer of arable land is the highest in Africa. Virtually all the arable land is now being used for agriculture. The nutrition of the Rwandan population is poor. Growth retardation among young children (3-36 months), for example, is reported to have a 45 percent prevalence rate, one of the highest in the world (Grosse et al. 1995).

The daily agricultural wage during the 1990/91 agricultural year averaged 100 Rwandan francs (RWF) (.71 $US) per-day in Rwanda, with relatively little variation across prefectures (see Table 2.1). The non-agricultural wage was twice as high—it averaged 216 RWF (1.54 $US)—but showed greater regional variation. Agricultural output, measured as the total regional gross[3] value of production per hectare of cultivable land, is standardized at 1.0 and shows considerable variation over regions, from .46 to 1.58. Regional price variation, an indicator of the relative risk of investment, is measured as the coefficient of the variation of monthly market prices over 1986-92 for the six major crops grown in Rwanda, combined in a weighted average, based on the relative importance (in production) of each crop at the regional level. There is substantial monthly and yearly price instability in Rwanda: The lowest regional price coefficient of variation is 24 percent and the highest is 39 percent.

Off-farm income (wages from labor for others on-farm and in nonfarm businesses, and income from own nonfarm businesses) is an important part (about one-third) of a household's total income. Approximately 69 percent of households earn some off-farm income, but it tends to be highly concentrated in the highest quartile and has a Gini coefficient of .83. Both skilled and unskilled off-farm employment is heavily concentrated in building construction. Income from carpentry, masonry, and tile manufacturing is key. Women tend to be employed in basket weaving and making clothing. There is a small but significant segment of the rural population involved in higher-paying professions. These include small business owners and traders, and government employees such as functionaries and teachers (Clay et al. 1990).

Landholdings owned and operated by households are very small, averaging only 0.83 hectares (ha.) per-household, and .21 ha. per-adult-equivalent (AE). Farm holdings are fragmented into many smaller plots. Most landholdings are owner-operated; 8 percent are rented.

Livestock husbandry is an integral part of the farming system, but the progressive conversion of pasture into cropland in recent decades has caused a reduction in the average household livestock production, and a parallel decline in manure available for improving soil fertility (Rwamasirabo et al. 1991). Most households own a few small ruminants; less than a quarter own cattle. Seventy-six percent of all households have some animals; the top quartile of livestock ownership own 45 percent of all the livestock; the Gini coefficient for livestock

[3]Due to very low farm input purchases.

Table 2.1. Sample Characteristics and Patterns of Land Use, Conservation Investments, and Inputs Use

Characteristics	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)	424.00	1.18	Parcel
Grass Strips (m/ha)	205.00	1.34	Parcel
Anti-Erosion Ditches (m/ha)	161.00	1.68	Parcel
Hedgerows (m/ha)	56.00	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. Other Characteristics			
A. Macroeconomic Characteristics			
Agricultural Profitability Index	1.00	0.31	Prefecture
Agricultural Wage (140FRW = 1$US)	100.00	0.10	Prefecture
Non-Agricultural Wage (140FRW = 1$US)	216.00	0.35	Prefecture
Price Variation (CV of agricultural prices, 1986-92)	0.25	0.20	Prefecture
B. Ecological Characteristics			
Share of Operational Holdings under Fallow (ha)	0.17	1.47	Household
Slope (degrees)	16.70	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
Size of Parcel (ha)	80.00	1.03	Parcel
Years Cultivating Parcel	22.20	0.66	Parcel
Annual Rainfall (mm)	1,214.00	0.14	Parcel
C. Household Characteristics			
Ownership Rights (% rented in)	8.0%	--	Prefecture
Landholdings Owned (ha)	.83	0.95	Parcel
Non-Farm Income (140FRW = 1$US)	11,12.00	3.24	Household
Value of Livestock (140FRW = 1$US)	10,768.00	1.81	Household
Value of Agricultural Production (140FRW = 1$US)	22,150.00	0.83	Household
Number of Adults (aged 15-65)	2.64	0.54	Household
Dependency Ratio (econ inactive/econ active)	121.00	0.74	Household
Literacy of Head of Household (% literate)	50.3%	--	Household
Knowledge of Conservation/Productive Techniques	3.59	0.55	Household
Age of Head of Household (years)	45.00	0.33	Household

Computed from MINAGRI/DSA survey data.

among livestock owners is only .27. The average value of household livestock holdings is 10,768 FRW, or approximately 77 $US (for comparison, a quarter of the average household annual income).

Only 17 percent of the cultivated holdings are kept under fallow. Fields tend to be on slopes averaging about 16.7 degrees, and annual rainfall is high (approximately 1,200 mm). Taken together, these factors provide strong incentive for farmers to take appropriate measures aimed at controlling soil loss. There is a strong variation among households (coefficient of variation of 0.55) in their self-reported degree of knowledge regarding various soil conservation and productivity-enhancing practices.

2.2.2. Patterns of Land Management

We focus on four aspects of land management: land use, conservation investments, organic inputs use, and purchased inputs use. Their levels and distribution are shown in Table 2.1, and are discussed below.

Land Use: Erosivity of land use is measured using C-values. The C-value index is a well-known measure that 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.

The C-values we use are based on field work undertaken in the Kiambu and Murang'a districts of the Kenya highland (Lewis 1985), and a pilot study of soil loss in Rwanda (Lewis 1988).[4] Among crops commonly grown in Rwanda, C-values vary from .02 and .04 for coffee and bananas, to .35 and .40 for maize and sorghum. In general, perennial crops, pasture, fallow, and woodlot all have low (less erosive) C-values. Annual crops, particularly grains, have high (more erosive) C-values. Tubers and leguminous crops tend to have values in the middle range. The average C-value for cultivated holdings in Rwanda is .16, a composite of many forms of land use and crop mix.

Conservation Investments: Conservation investments were measured in meters and recorded separately for each parcel of land operated by the sampled households. There is great variation among Rwandan farm households in the degree to which they invest in soil conservation

[4] Some of these values differ greatly from those published in the United States. For example, the C-value of .45 found for tobacco in Rwanda is significantly larger than it is in U.S. This is the result of the differences in agricultural practices between the heavily-subsidized, commercial tobacco production in the U.S., and small, farmer-produced tobacco for home consumption and local sale in Rwanda.

measures. Although hedgerows are planted and maintained in only 22.6 percent of the holdings, anti-erosion ditches are installed in 47.8 percent, and grass strips are found in 60.3 percent of all land holdings. The mean lengths of such investments over all households are 56, 161, and 205 meters per-hectare, respectively. Radical terraces can also be found in Rwanda, but these are relatively rare; only 1.4 percent of farm households have invested in radical terrace construction. No data are available with which to compare the relative effectiveness of the four types of investment. Radical terraces, similar to those found in parts of Asia, are thought by some to be superior to the other forms of investment. However, given the lack of data and the rarity of radical terraces, we do not give any one type of investment greater weight than the others. For our present purposes of description and modeling determinants, we have summed the four types of conservation investments into a single, aggregate measure (meters per hectare). Over three-quarters of the cultivated farm holdings in Rwanda receive some form of conservation investment. Among those that do, we find that investments average 555 m/ha (424 m/ha for all households).

Use of Farm Inputs: Because we hypothesize that there are differences in the determinants of organic and purchased inputs, we treat the two separately. Organic inputs consist of compost, manure, mulch, and green manure, and are applied to 69.5 percent of cultivated holdings. Purchased inputs include chemical fertilizer and lime, and are applied by just 7.4 percent of the households to an even smaller proportion (4.9 percent) of cultivated holdings.

Difficulties inherent in obtaining precise data on quantities of inputs applied at the parcel level have limited our information on input use to a dichotomous, yes-no response for each parcel operated by the household. At the household level, data are available on expenditures for fertilizer and other inputs. Data on household expenditures for fertilizer are incomplete because the Rwandan government has provided fertilizer for free or for a small fee for several years for promotion purposes. The only stipulation on this fertilizer was that it be used exclusively on coffee and potato fields. Thus, we treat data on purchased fertilizers cautiously, arguing that these figures are indicative only of the amounts used.

Chemical fertilizers and pesticides are used primarily in Rwanda on cash crops, notably coffee and potatoes, and, to a lesser extent, vegetables. Potatoes and vegetables respond particularly well to these inputs, and these crops have high prices that provide a high return on investment. Vegetables are produced near cities (Kigali and Butare) and are sold primarily in those markets. We surmise that greater liquidity, resulting from the sale of cash crops and off-farm income, is what enables farmers to purchase fertilizer. This is examined in more detail in later chapters.

2.3. Agro-Ecological Zones

There are three regional classification schemes that are used for various purposes by researchers and policy-makers in Rwanda. All three are based on differences in soils, altitude and rainfall, and as such also show marked differences in cropping patterns, farm size, livestock ownership, and other important household and regional characteristics. The first was developed by

Delepierre (1974), and divides the country into 12 agro-ecological regions. More recently, the CNA has expanded this number to 18. The CNA classification scheme draws upon a more comprehensive data base, particularly in soil characteristics, and has been useful for targeted, commune- and secteur-level development projects. A third classification scheme (Clay and Dejaegher 1987) has been devised to capture the major delineating characteristics of the first two, while summarizing these differences in just five zones that can be used effectively for national-level socioeconomic (rather than purely agronomic) analysis. The five-zone classification is judged to be the most suitable for our purposes, because it both highlights important socioeconomic differences and because the smaller number of zones enhances statistical reliability. Some of the defining characteristics of these zones are described below and in Table 2.2.

Northwest: This zone comprises the prefecture of Gisenyi, and parts of Ruhengeri and Kibuye. It has mostly volcanic, fertile soils that are highly susceptible to erosion. Its high altitude means the area has abundant rainfall and cooler temperatures. Major cash crops are coffee, white potatoes, and pyrethrum. Few bananas are grown at elevations above 2,000 meters. Staple food crops include potatoes, maize, sweet potatoes, and beans. The Northwest includes both temperate highlands with fertile and/or recently cleared volcanic soils, and well-watered lowlands by Lake Kivu. Much of the zone is very densely populated, and the typical agricultural working day is longer than elsewhere in Rwanda.

Southwest: The Southwest region comprises Cyangugu, the southern part of Kibuye, and the western part of Gikongoro prefectures. It is characterized by high altitudes, steep slopes, and high rainfall, with concomitant soil erosion and soil acidity problems. Soils have a high proportion of clay, and range from poorly to moderately suitable for agriculture. A substantial but diminishing part of the Southwest zone is covered by a natural, "protected" forest. Major cash crops are bananas and coffee. The most important food crops are beans, sweet potatoes, taro, and cassava. Soils are poor, and sometimes degraded and acidic on the steep slopes of the Zaire-Nile divide; soils are fertile on the coast of Lake Kivu. Although not as densely populated as the Northwest, the pressure on resources is higher in the Southwest, which is the poorest zone in Rwanda. The zone is not self-sufficient in food and depends on imports from Zaire and Burundi.

North-Central: This zone covers parts of Ruhengeri, Byumba, and Kigali. It is a region well known for its high mountains, very steep slopes, and susceptibility to erosion. Major cash crops are bananas and coffee, with some highland areas specializing in potatoes and wheat. Food staples include sweet potatoes, beans, sorghum, and maize. The zone is less densely populated than the South-Central Zone, and some northern and eastern parts have been agricultural frontier until recently. Agroclimatically, it is quite similar to the South-Central Zone.

Table 2.2. Characteristics of Agro-Ecological Zones

Zones	North-West	South-West	North-Central	South-Central	East	Rwanda
Altitude *(m)*	2,000	1,950	1,920	1,740	1,570	1,820
Rain *(mm)*	1,150	1,490	1,030	1,220	870	1,150
Erosion *(tons/ha)*	6.9	8.0	4.7	3.6	2.1	4.7
Farm Size *(ha)*	0.8	1.3	1.2	1.1	1.4	1.2
Income *(1000 RWF)*	49.6	30.1	51.1	33.6	63.1	47.1
Output *(1000 RWF)*	36.8	20.6	31.2	25.8	57.7	36.1

South-Central: This zone encompasses much of the prefectures of Gitarama, Butare, and Gikongoro. It has sandy-loam soils, and serious degradation. Soil fertility ranges from very poor to moderately suitable for agriculture. It is a region of well-watered marshes, which allow a third cropping season. Major cash crops are bananas and coffee, while favored staples are beans, sweet potatoes, cassava, and sorghum. The South-Central Zone includes the historical center of the country, and much of it has struggled with high population densities for a long time. Emigration to other parts of Rwanda, farmers' subjective assessments, and yield levels suggest that what was once considered prime agricultural land has become degraded during the past decades.

East: This zone corresponds to the entire prefecture of Kibungo, and the eastern parts of Kigali and Byumba. It is a region with gentle slopes and relatively low altitude. Rainfall is lower here than in the higher elevation zones to the west. Because it is drier, this eastern plateau was traditionally reserved for pastoral uses. Though it is densely settled today, farms are still larger here than in the older, western zones that became occupied several generations earlier. Households in this region rely principally on bananas (one-third are cooking bananas for food) and coffee as cash crops, and sorghum, beans, and cassava as major staples. Drier and warmer than the rest of Rwanda, the East was Rwanda's last agricultural frontier.

In sum, the two western zones have the highest altitude and thus receive the most rain. These zones were also the first ones settled because of their rainfall and relatively fertile soils. As one moves east into the central zones and then to the eastern plateau, altitude and rainfall, along with soil fertility, drop off; this is perhaps the main reason they were settled later than areas to the west. Yet, today, soils in the east are more productive because they are not as "farmed-out" as the western soils.

CHAPTER 3

PATTERNS OF AGRICULTURAL PRODUCTIVITY IN RWANDA

3.1. Introduction

As a basis for the analyses that follow, this chapter provides a general description of land and labor productivity in Rwandan agriculture. We start with an overview of the principal crops grown by Rwandan farm households, then compare the country's five agroclimatic zones in terms of overall and crop-specific land productivity. We also probe the question of how regional differences in yields are reflected in cropping patterns. In turn, we focus on how land scarcity affects productivity, a central theme of this report, given Rwanda's high and increasing population density. We discuss trends in land productivity over time, and then compare Rwanda's yields and trends with those of Burundi and Tanzania, and other neighboring countries. The chapter concludes with an analysis of labor productivity in Rwanda, comparing returns to labor by agro-ecological zone, farm size, and crop.

3.2. National Patterns in Land Use and Yields

Two-thirds of the cultivable land in Rwanda is cultivated. The rest consists of fallow land, pasture, and woodlot. The distinctions among the three non-cultivation uses are not always clear, since livestock is grazed mostly on fallow land, but sometimes on woodlots. The primary difference between fallow and pasture is that fallow lands have been cultivated in the past and will likely be cultivated again at some time in the future, while pasture neither has been nor will be cultivated.

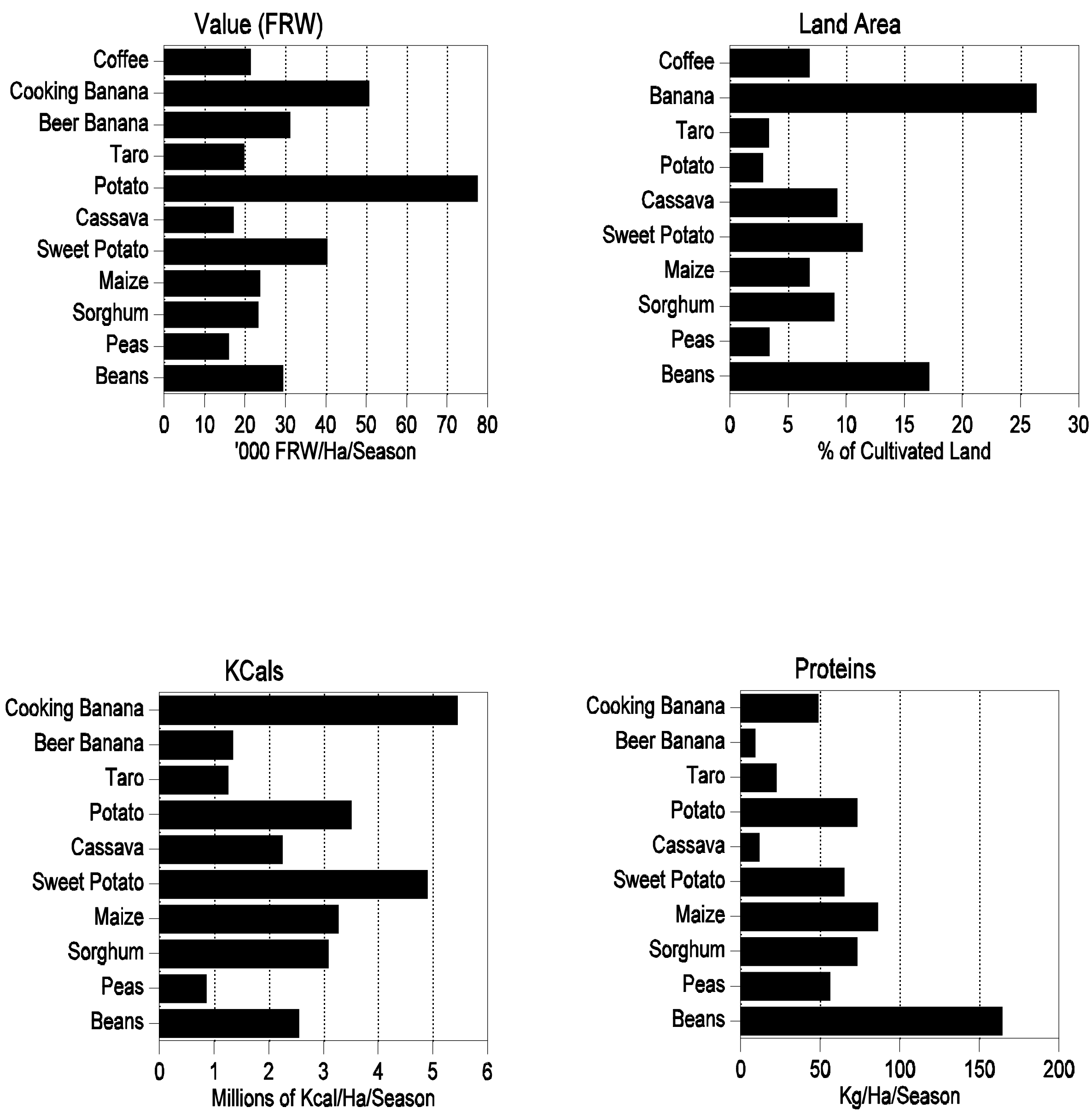
Half of Rwanda's cultivated fields are intercropped, and 56 percent of these grow bananas in association with food crops such as beans, sorghum, and sweet potatoes. Intercropping appears to be a response to land scarcity, as it is practiced more often by households with relatively little land per-person. Less intercropping occurs in high-altitude areas, where few or no bananas are grown.

In terms of shares of cultivated land, the main crops are bananas (26 percent), beans (17 percent), sweet potatoes (11 percent), cassava (9 percent), sorghum (9 percent), and maize (7 percent). In the following paragraphs we discuss each of these crops in detail (also see Figure 3.1a).

3.2.1. Bananas

Bananas are the most important crop in Rwanda, covering one-fifth of the agricultural land and accounting for one-third of the market value of crop production. Some 38 percent of the cultivated area is planted in bananas, either purely (11 percent) or in association with other

Figure 3.1a. Value (FRW), Land Area, Kcals and Proteins in Rwanda



Source: Computed from MINAGRI/DSA survey data, 1989 -1991.

crops. When land in intercropped fields is proportionally allocated to bananas and the other associated crops such as beans, sweet potatoes, and sorghum (according to crop density), the share of cultivated land in Rwanda allocated to bananas comes to 26 percent.

Furthermore, bananas would be the single most important provider of calories if more than two-thirds of the bananas grown were not beer bananas, which lose three-quarters of their calories when brewed into banana beer (also known as banana wine). While eating beer bananas is possible, it is not common, except after extreme harvest failures.

Cooking bananas are eaten by nearly all Rwandans, but less so by the poorest, who get more calories if they instead exchange bananas for cassava or use their land to grow sweet potatoes. As farmers they may still prefer bananas, but then their first choice is usually to grow beer bananas, brew beer, and exchange the beer for tubers. Banana beer, of course, is an expensive source of nutrients and although all groups drink it, especially during festivities, the poorest households sell much of the beer they produce (see Riley Miklavcic 1995).

Cooking bananas require lands that are rich in organic matter, so they are generally grown around the compounds, where household wastes accumulate. Beer bananas are less demanding, but in similar conditions would generally grow better than cooking bananas. Fruit bananas that are currently a minor crop can grow reasonably well even on quite degraded lands. Our yield data refer to the aggregate category "bananas," because although DSA's production figures are split among the three banana types, the land use data are not.

Bananas grow relatively well in most of Rwanda, with the exception of the upper elevations of the Nile-Zaire Divide that crosses the two western zones. At high altitudes (> 2000 meters), bananas not only grow poorly but their sugar content is low, which means that more bananas are needed to brew the same amount of beer.

Farmers can manage their banana fields with varying degrees of labor intensity. Dense, pure-stand banana groves do not require much labor, but the farming practices needed for higher yields are relatively labor-intensive. Well-managed banana fields require more labor than most other crops. Consequently, while the fourth quartile of farmers (the largest) produce more than half of their bananas in pure stands, households with little land per-person and few off-farm opportunities to sell their labor normally intercrop their bananas, especially in the East.

3.2.2. Sweet Potatoes

Sweet potatoes are the single most important source of calories for Rwandans. Sweet potatoes have more calories per-kilogram than potatoes or cooking bananas, and yield more than four thousand kilograms per-hectare in most of the country. Except for high-altitude areas, where potatoes grow best, only bananas can produce more calories per-hectare than sweet potatoes.

While the production of bananas and potatoes is relatively labor-intensive, sweet potato production is not. Sweet potatoes are, however, less demanding of soil quality and moisture. In valleys, sweet potatoes are grown in sole stands. On hillsides, intercropping with beans, sorghum, cassava, and other crops is common.

Sweet potatoes are the main staple for most rural Rwandans. They are particularly important for poorer households and in the central part of the country.

3.2.3. Cassava

Cassava yields cannot match those of sweet potatoes in any region, but cassava has three other advantages. First, it can grow on lands that are too degraded for other crops. Second, cassava requires little moisture, stores well in the ground, and can act as a reserve crop to feed people during droughts. Third, little labor is needed to grow cassava. Although cassava requires more work during the first few months than sweet potatoes, the remaining year or more of the growing period is almost effortless.

For Rwandan consumers, cassava provides cheaper calories than any other food crop. The low price makes it affordable to even the poorest households.

3.2.4. White Potatoes

White potatoes are Rwanda's only highly commercialized crop (apart from coffee). They are grown mostly on the northwestern volcanic highlands, where they rely heavily on pesticides. Elsewhere, potatoes are a minor, low-yielding subsistence crop. Nationally, less than three percent of the country's cultivated area is allocated to potatoes.

Due to the weekly pesticide applications, potatoes demand more labor than do other tubers. In the prime potato-growing area, they are a cheap, staple food for rural households. Elsewhere, potato prices are relatively high, especially considering their low caloric value; consumption by rural households is thus quite low. The main market is Kigali, the capital city, where potatoes are a major staple.

3.2.5. Sorghum and Maize

Sorghum is grown primarily for an input to beer brewing; maize is grown primarily for direct consumption. With favorable conditions, maize yields more than sorghum, but in drier areas, sorghum does better. At the national level, neither cereal produces yields that can compete with sweet potatoes or bananas in terms of calories, beans in terms of proteins, or any of these crops (or potatoes in the highlands) in terms of market value.

Both cereals require less labor than bananas or coffee, but need more labor than sweet potatoes or cassava. Except for the high-altitude areas where maize is often grown in sole stands, both are commonly intercropped, most frequently with beans.

3.3. Yields and Land Use by Zone

3.3.1. Aggregate Average Land Productivity

Aggregating production by price or caloric value and dividing it by the total cultivated area gives us two estimates of aggregate <u>average</u> land productivity in each zone. While production per-unit-of-cultivated-area is the most commonly used yield measure, it does not show how land productivity can increase when farmers cultivate a larger share of their cultivable holdings.

Figure 3.1b shows that inter-zone differences in land productivity are substantial for specific crops, while Table 3.1 shows the same, but for crops in the aggregate. The extremes are the two western zones, with the Northwest producing twice as much per unit of land as the Southwest.

In the Northwest, monetary returns to cultivated land are roughly 40 percent, and caloric yields nearly 30 percent, above the national average. When all cultivable land is taken into consideration, monetary returns to the land are 60 percent and caloric returns nearly 50 percent above the national average.

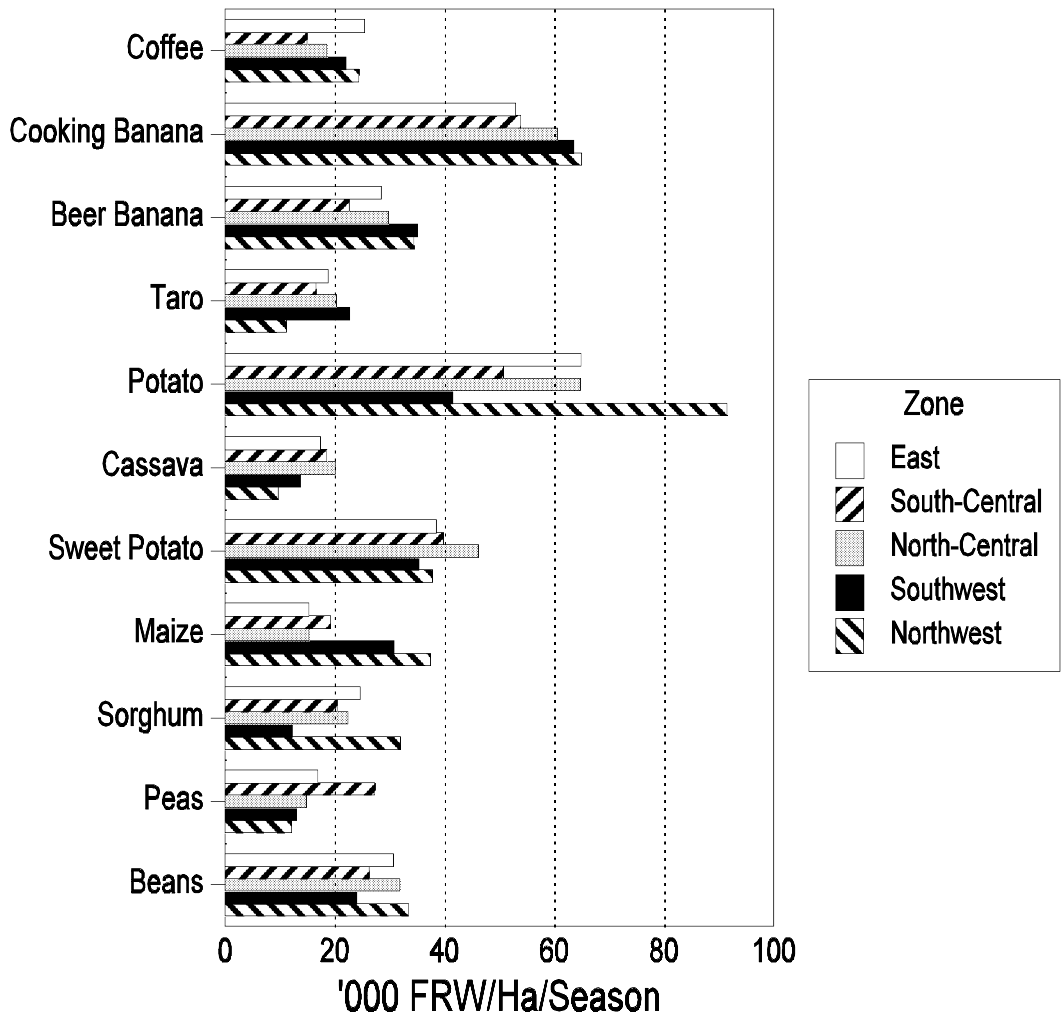
The yield gap is wider when all cultivable land is considered, since in the Northwest more than three-quarters (77 percent) of the cultivable land is cultivated, while the share is only two-thirds nationally.

In the Southwest, degradation has reduced yields and forced households to rely on fallowing to restore fertility, and allocate some degraded lands to pasture and woodlots. Only 56 percent of the cultivable land is cultivated here. Returns to land are low on every measure, but particularly so when the non-cultivated lands are accounted for.

In the North-Central Zone, returns to the land are close to the national average. In the South-Central Zone, which covers both degraded acidic hillsides comparable to those in the Southwest and more fertile banana-producing areas comparable to the North-Central Zone, land productivity is between the two.

In the East, land productivity is comparable or superior to that of the rest of the country. This area is drier and less densely populated than the national average. However, with population growth, cultivation has expanded at the expense of pasture, fallow, and woodlots. Crops now cover 74 percent of the cultivable area, which is a larger share than the national average. Since abundant fallow no longer serves to explain why each hectare in the East produces more than elsewhere, despite receiving less rainfall and labor than the national average, the following hypothesis can be posited. The East is less degraded because fallow land was abundant in the past, because the landscape is slightly flatter and less erodible, and because the cropping patterns emphasize more perennial crops (bananas and coffee) that are less degrading and erosive than the main annual food crops. Less degraded land means

Figure 3.1b. Value in FRW by Crop and Zone



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Table 3.1. Land Productivity by Zone (FRW/Ha)

Zone	Market Value (Thousands of FRW)		Food Energy (Millions of Kcal)	
	Cultivable Land	Cultivated Land	Cultivable Land	Cultivated Land
Northwest	32.6	42.5	2.6	3.4
Southwest	14.3	25.5	1.0	1.9
North-Central	20.1	31.2	1.7	2.7
South-Central	17.9	27.0	1.5	2.3
East	22.1	29.9	2.0	2.7
Rwanda	20.3	30.1	1.7	2.6

Source: Computed from MINAGRI/DSA survey data, 1989 - 1991. * All numbers refer to production per-hectare per-season.

higher yields, controlling for other factors. It is also likely that because the East was settled more recently, soil degradation is not as advanced there as it is in the Central and Western zones.

3.3.2. Average Land Productivity by Crop and by Zone

While inter-zone differences in aggregate average land productivity provide a useful summary, crop-specific comparisons are needed to examine comparative yield advantages among the zones. Below we also explore the extent to which land allocation seems to be compatible with these yield advantages. Of course, cropping patterns depend on many other things beside relative yields, which is why we study their determinants in detail elsewhere (Kangasniemi, forthcoming). However, relative yields are an important factor in determining cropping patterns, and the reason for our focus on yields here. The zone-specific findings discussed in this section are drawn from Figure 3.1b (see page 20) through Figure 3.1.e.

Northwest: The high-altitude volcanic areas of the Northwest Zone constitute Rwanda's main white potato production area. A favorable climate, combined with research and extension that makes improved varieties and pesticides available to farmers, have raised potato yields to eight tons per-hectare, four times as high as elsewhere in Rwanda. Despite relatively high transportation costs, potatoes have become the main cash crop for the high-altitude Northwest, are for sale and home consumption, and cover some 13 percent of the zone's cropped area.

Compared to white potatoes in the Northwest Zone and sweet potatoes in other regions, sweet potato yields in the Northwest are mediocre; cassava yields are also low. However, sweet potatoes are more nutritious than potatoes so their mean yields in caloric terms can match those of potatoes in the zone. Outside the white potato production area, sweet potatoes are the main food crop, as in most other parts of the country.

Maize also produces better yields and is more important in the Northwest than elsewhere. In contrast, sorghum, which also has relatively high yields, is less popular than in the other zones. Apparently it cannot compete with maize, which yields more whether measured in kilograms, calories, grams of protein, or market value.

Northwestern bean and pea yields are close to the national average. This is not enough to make beans and peas attractive cash crops in the Northwest, but due to their high protein content and ability to fix nitrogen, which then also benefits other crops, both are important subsistence food crops.

Peas provide far less food or cash value than do beans; yet their popularity lies in the fact that pea fields are in effect "half-fallows." In the western regions of Rwanda, peas are commonly grown as a last crop before a fallow period, with very low labor input. Consequently, they are grown mostly by the larger farmers who still can afford to hold land in fallow.

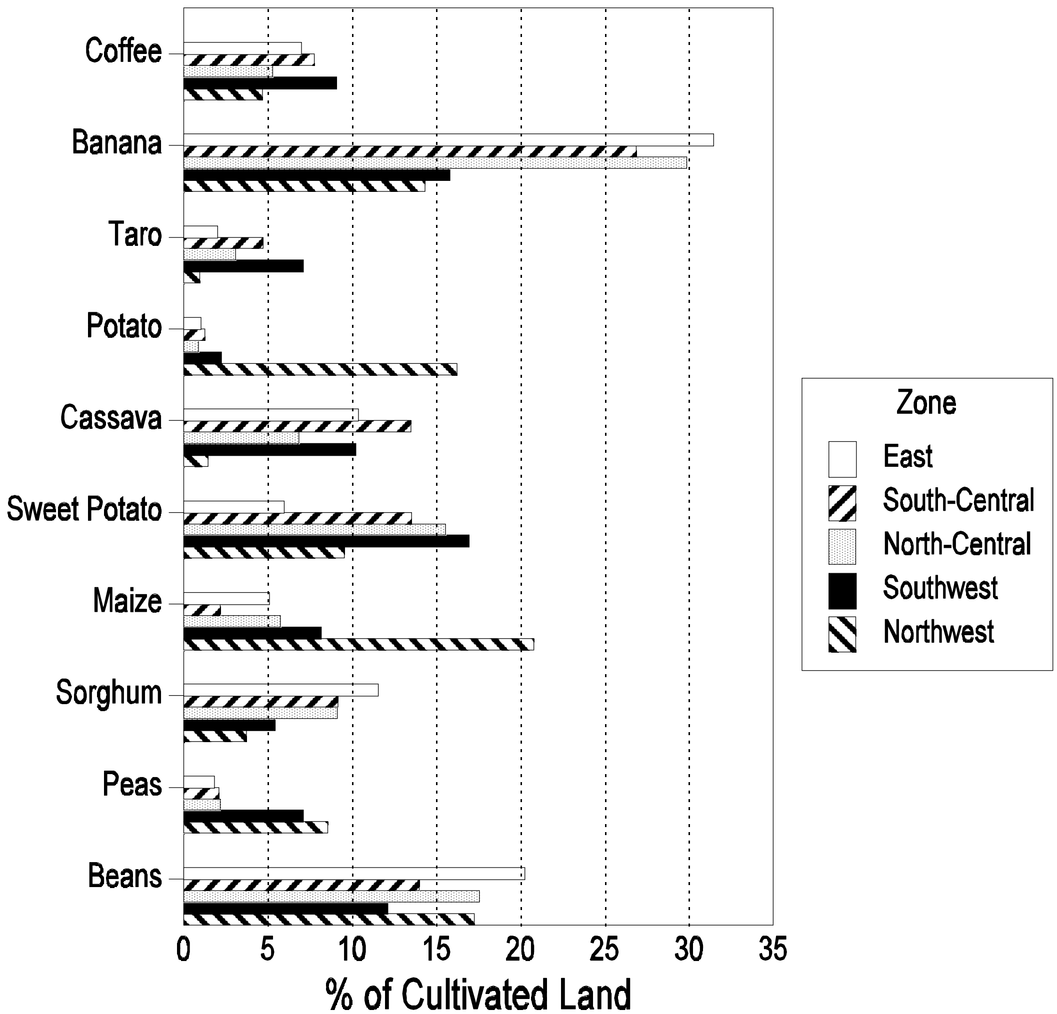
Few bananas are grown in the high-altitude areas of the Northwest. In the remainder of the zone, both the yields and the importance of bananas are roughly comparable to the rest of the country. As elsewhere, bananas can be attractive either as a high-yield food crop or as a cash crop.

Coffee yields are highest in the Northwest, yet less land is allocated to coffee there than in most other parts of the country. In the high-altitude areas, coffee cannot match potatoes as a cash crop, and in the low-altitude areas, beer bananas bring farmers much more cash than coffee. However, both of these "superior" cash crops are bulky, and households located long distances from roads and/or markets may be better off growing coffee.

Southwest: This zone relies strongly on tubers other than white potatoes. Sweet potatoes yield less here than in other zones but they are second only to cooking bananas in caloric yields, and they cover a larger share of cultivable land than elsewhere. Cassava's tolerance for the poor soils of the Southwest explains why cassava is popular in this zone despite low yields. The third important tuber is taro, which yields well when compared to other zones but does not shine as a good provider of calories or proteins.

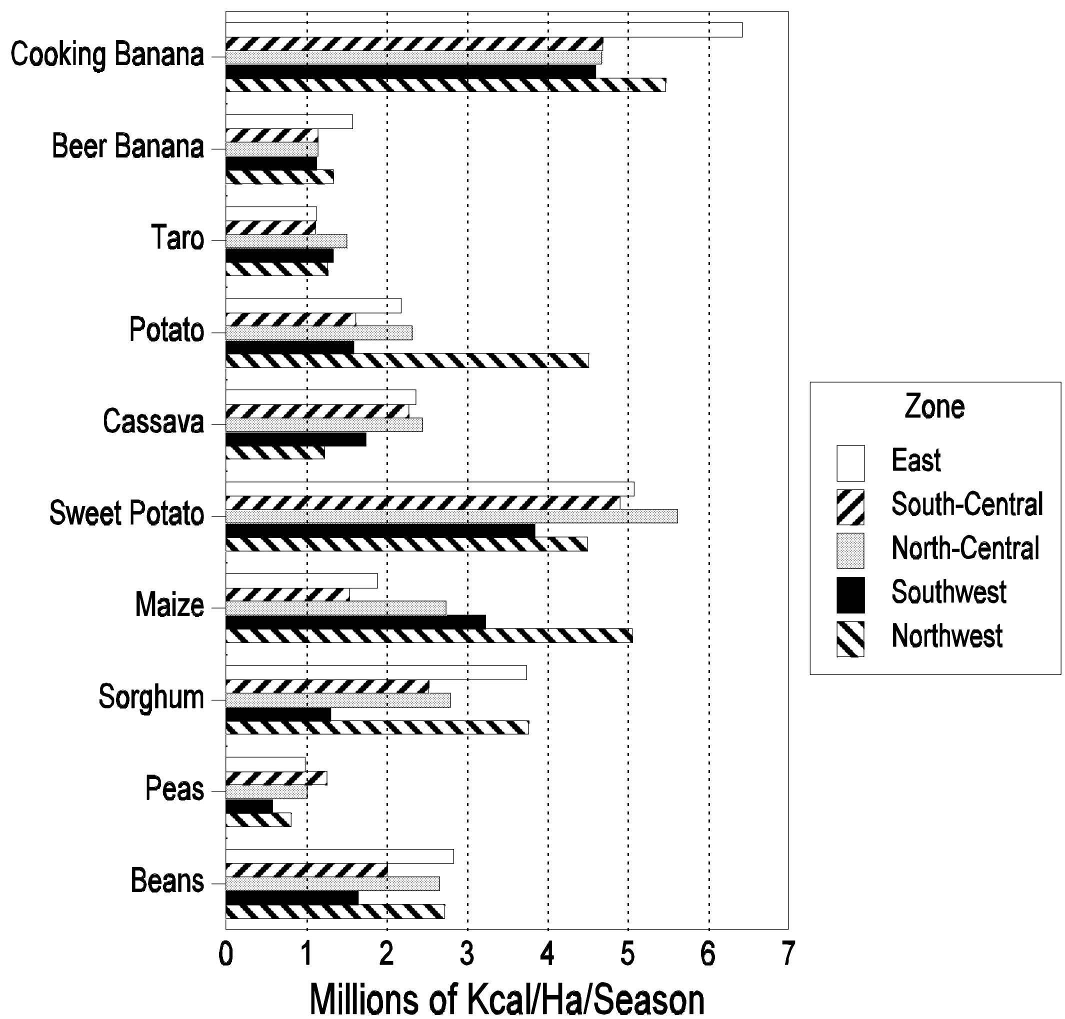
Beans resemble sweet potatoes in that, while yields are low compared to other zones, they compare favorably to other crops in terms of nutritive value (proteins in this case). But beans are less perishable and less bulky to transport (higher ratio of value per volume) than tubers. Moreover, beans do not grow well on poor soils. Consequently, instead of allocating much land to beans, farmers in the Southwest rely on imports from Zaire.

Figure 3.1c. Land Area by Crop and Zone



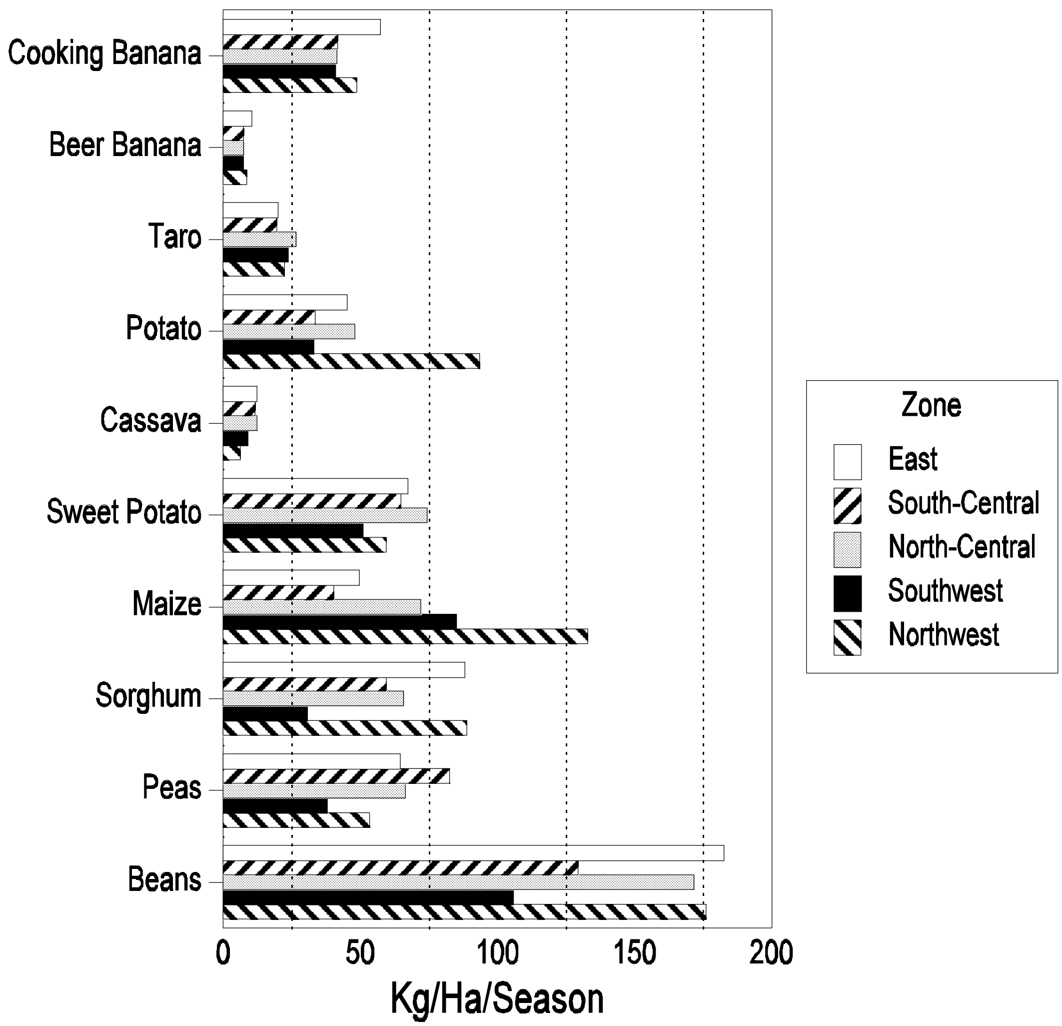
Source: Computed from MINAGRI/DSA survey data, 1989 - 1991

Figure 3.1d. Kcals by Crop and Zone



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Figure 3.1e. Proteins by Crop and Zone



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Sorghum is another crop with a regional yield disadvantage in the Southwest Zone, due to sizable imports, and a small share of land allocated to it. Yields are not just lower than elsewhere but also are low in terms of nutritive value, especially when compared to maize, which produces relatively high yields and claims a sizable portion of land in the Southwest.

Although peas yield much less than beans everywhere, and in the Southwest less than elsewhere, almost as much land is allocated in this zone to peas as to beans. To be sure, taste preferences play a role, but the main explanation is the same as in the Northwest: Peas are "half-fallows" that precede real fallows and require very little labor, while fixing some nitrogen.

As in the Northwest, parts of the Southwest are so high that banana yields are low and few bananas are produced. On the shores of Lake Kivu, bananas grow well, and are a superior food and cash crop.

To pay for their bean and sorghum imports, farmers in the Southwest rely on coffee and off-farm work on tea plantations and elsewhere. Coffee yields are above the national average, and more land is allocated to coffee here than elsewhere. However, coffee appears not nearly as attractive a cash crop as beer and cooking bananas—though the situation may be different on the steeper slopes at higher altitudes where bananas do not thrive and where the erosive impacts of tubers and beans are severe.

South-Central: As in the Southwest, tubers other than white potatoes are the main food crops in the South-Central Zone. Sweet potatoes have the highest caloric yields, but almost as much land is allocated to cassava, which is less sensitive to land degradation.

Beer bananas, cooking bananas, and fruit bananas are important food and cash crops. Despite yields that are slightly below the national average, bananas provide the highest monetary returns to the land, and cooking bananas also produce almost as many calories per-hectare as do sweet potatoes. Apparently as a consequence of this, almost one-fifth of the zone's cultivable land is allocated to bananas.

Maize yields are much lower than sorghum yields, which is reflected in land shares. Both bean yields and the share of land allocated to beans are somewhat below the national averages, and apparently because of this, beans are imported to the zone.

Pea yields are high when compared to other zones, but their land share is low. The explanation is that the role of peas in the rotation is different; the Northwestern practice of growing peas in the transition phase when the degraded land is left for fallow is not used here.

Coffee yields in the South-Central Zone are far below the national average, but the share of land allocated to coffee is above the average. To some extent, coffee may not (or no longer) be grown by farmers as a matter of choice. Until recently, government regulations stated that farmers were not allowed to cut down coffee trees (there is evidence that this was very unevenly enforced). By January 1994, many farmers in the South-Central Zone had abandoned their coffee trees, and in 1989-91, when our data were collected, this may have begun already—although some had begun to expand their plantations; hence the trend was ambiguous (Rwalinda et al. 1992).

North-Central: Nutritionally, tubers are as important in the North-Central Zone as in the South-Central Zone, although a slightly smaller percentage of cultivable land is allocated to them. This is possible because North-Central lands are less degraded, sweet potatoes yield more there, and more area allocated to tubers can be planted in sweet potatoes than in lower-yielding cassava and taro.

Banana yields are comparable to those in the South-Central Zone and, if used for food rather than for beer, can match those of sweet potatoes in terms of calories. As cash crops, both cooking bananas and beer bananas are clearly more attractive than coffee. This may have contributed to the small share of land allocated to coffee, although, as elsewhere in Rwanda, administrative decisions have probably also played some role.

Bean yields are substantially higher than in the South-Central Zone, and more land is allocated to this crop. As a food crop, beans are attractive due to their superior production of proteins, but they also match sorghum, maize, and cassava in terms of caloric yields. The cash value of beans exceeds that of coffee and sorghum, but does not come close to that of bananas.

A small part of the zone is included in the white potato-growing area, which makes the yields higher than elsewhere outside the Northwest, but the bulk of the zone is in a low-yielding potato deficit area, where prices are high. Combining these two results suggests that potatoes would be a highly attractive cash crop in this region, but are still not grown for this purpose by most of the farmers in the zone.

While maize yields clearly exceed those of sorghum in the two western zones, and the reverse is true in the South-Central Zone, the two cereals produce roughly the same yield in the North-Central Zone. Neither can match bananas, beans, or coffee as cash crops, or sweet potatoes, cooking bananas, or beans as food crops, but they do provide variety to the diet, and roughly one-tenth of the zone's cultivated land is allocated to them, in approximately equal proportions.

East: Bananas grow better in the East than elsewhere and provide higher yields than any other crop, both in terms of calories and cash value, than any other crop. Almost one-quarter of the cultivable land in the zone is allocated to bananas.

Sorghum produces better yields than maize, and more land is allocated to it here than elsewhere, but since land is relatively abundant and the main maize-producing region is distant, some maize is also produced in the East.

Bean yields are high compared to other zones, and beans are very attractive in terms of protein content. As cash earners, they cannot match bananas, but because of risk considerations and transportation constraints, they are also grown for sale. Pea yields are close to the national average, with relatively little land allocated to peas.

Sweet potato yields are not much lower than elsewhere, but their land share is substantially below the national average. While caloric yields of sweet potatoes are high, justifying subsistence production, smaller shares of the land of the (relatively large) farms are needed. Yields, expressed in terms of market value, cannot match those of bananas; thus sweet potatoes have not made much progress as a cash crop.

Cassava is also grown as a subsistence crop; mean yields for the zone cannot match those for the sweet potato, but it grows well in areas that are too dry for sweet potatoes, is less vulnerable to drought, and its tubers store well in the ground, thereby serving as a good reserve crop. Finally, it requires very little labor after the first season. It appears that as a consequence of these factors, more land is allocated to cassava than to sweet potatoes.

In monetary terms, white potato yields in the East appear attractive, but this is due solely to high regional prices. Compared to the Northwest, yields are very low, and when the cost of pesticides and/or the risk of crop failures caused by pests are taken into account, the attraction largely disappears. Consequently, little land is allocated in the East to white potatoes.

Coffee has been a required crop on the government-organized settlements (*paysannats*), which explains why the relatively large farms of the East allocate roughly the national percentage of their cultivable land to it. This implies that on a typical farm, coffee requires more work in the

East than elsewhere. Since yields in terms of market value are far below those of bananas, one would expect attempts to divert labor from coffee. That coffee yields are still relatively high suggests that, holding constant regional differences in management, coffee *might* produce much better in the East than it does elsewhere—although at present it produces best in the western zones.

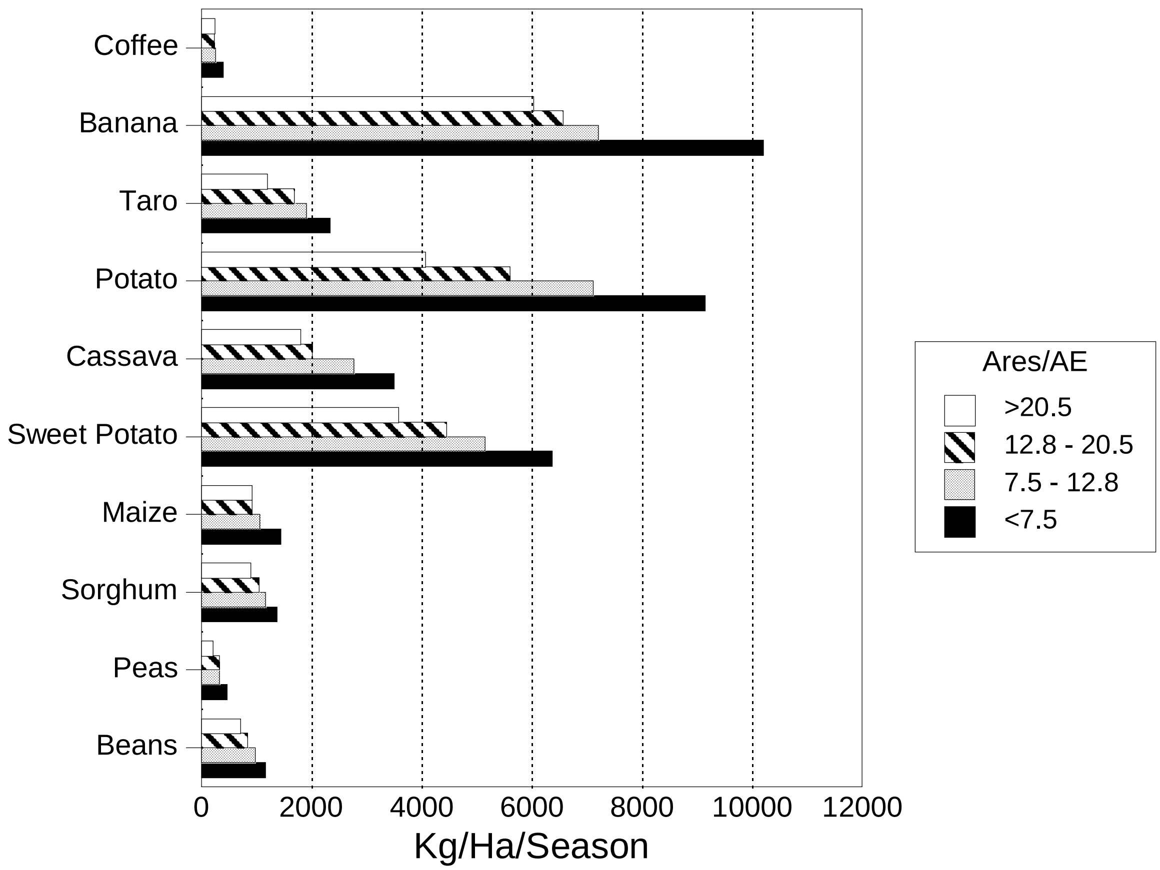
3.4. Land Scarcity and Land Productivity

In this section, we examine how yields are related to land scarcity. We define land scarcity in terms of cultivable land per-adult-equivalent and divide households into four quartiles based on how many ares (1/100s of a hectare) of cultivable land per-person they operate. Cultivable land is defined to include pastures and woodlots.

We use the terms 'small farmers' and 'Q1' (for quartile 1) to refer to households with less than 7.5 ares of cultivable land per-person. Similarly, our terms 'large farmers' and 'Q4' refer to households with more than 20.5 ares of cultivable land per person. "Large" here is a relative term, as these farmers might be considered small farmers in less densely farmed countries. 'Q2' includes households with 7.5-12.8 ares, and 'Q3' is composed of households with 12.8-20.5 ares per-person.

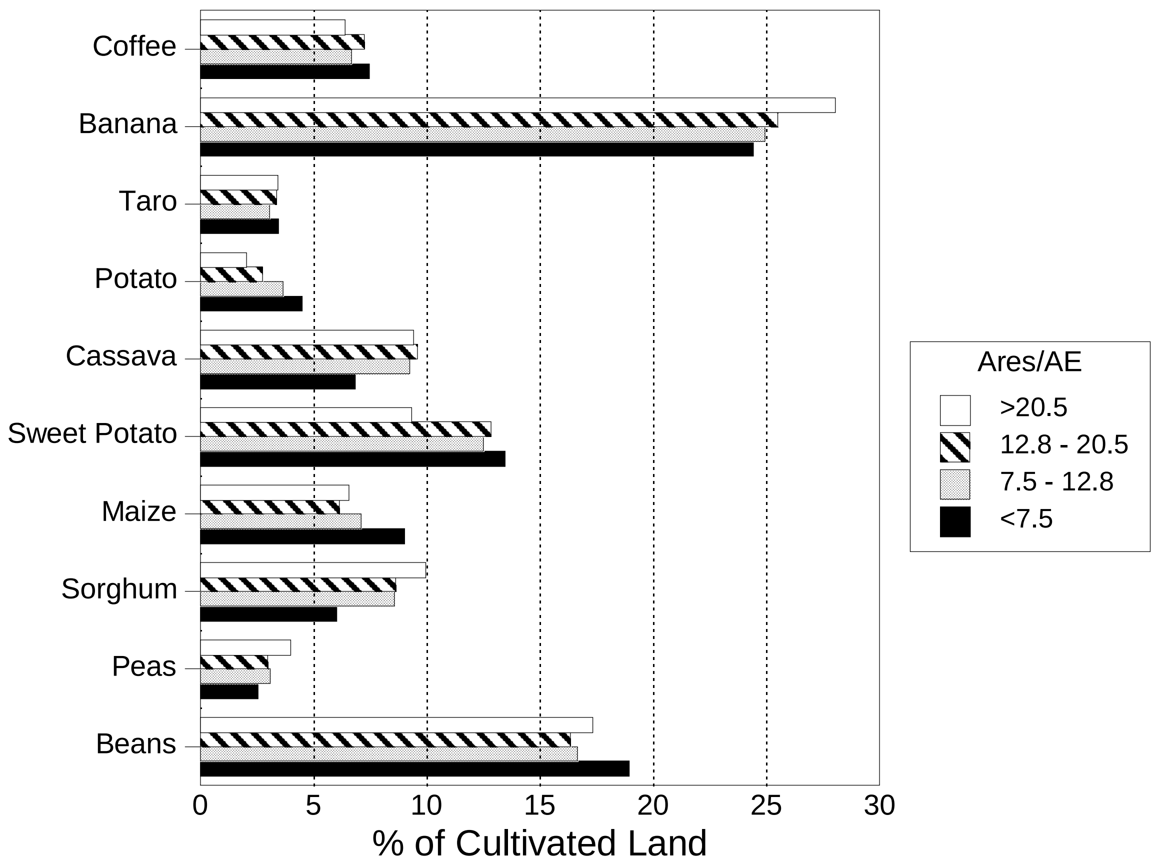
Figure 3.2a shows that all ten major crops yield considerably more on small than on large farms in Rwanda. At the national level, the pattern is so clear that only two minor exceptions can be seen to the pattern that a more land-scarce quartile has a higher yield than a less land-scarce quartile. For each crop, the yields of small farmers are 60-95 percent higher than those of large farmers. Coffee, cassava, and banana appear most responsive to extra labor, showing yields on small farms that are at least 50 percent above national average.

Figure 3.2a. Yields of Major Crops by Farm Size Quartile (Ares/Adult Equivalent)



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Figure 3.2b. Land Area in Major Crops by Farm Size Quartile (Ares/AE)



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Due to their high yields on small farms, bananas and coffee are even better cash crops for small farmers than for large farmers (Figure 3.2b). Not surprisingly, both are also allocated a larger share of small farmers' land than of large farmers' land. Controlling for agroclimatic zone would show an even stronger association. This is because bananas are unusually productive and hence popular in the East where farms are relatively large, thereby dampening the otherwise strong negative correlation between farm size and area cultivated in bananas within zones.

In contrast, cassava is no more popular on small farms than it is on large farms. The reason is that, despite its better response to the additional labor that small farmers can supply, its yields remain behind those of sweet potatoes and white potatoes in terms of calories and behind yields of beans in terms of proteins. Consequently, these three crops, along with maize (the highest-yielding cereal), rather than cassava, are the ones that become more important as farms grow smaller.

To make room for the highest-yielding food and cash crops, small farmers allocate less land to fallow, pasture, and woodlot, as well as to lower-yielding crops such as cassava, peas, and sorghum.

The above comparisons do not control for land quality. Where land productivity has restricted population growth in the past, population can be expected to be denser and farms smaller than in the areas where land is more productive. On the other hand, the opposite is true in much of Rwanda, where the easy-to-clear hillsides have been under cultivation for centuries, and the harder-to-work valleys have been cleared only recently. Though the valley lands tend to be more productive than the steep slopes (according to our data on farmer perceptions), they have their own problems with acidic soils, which have forced their use as pasturelands in the past.

Unfortunately, good measures for land quality are not available, although a reasonable proxy is developed for use in Chapter 4. In this report we will proceed by controlling for the agroclimatic zone, knowing that both yields and population density are high in the Northwest.

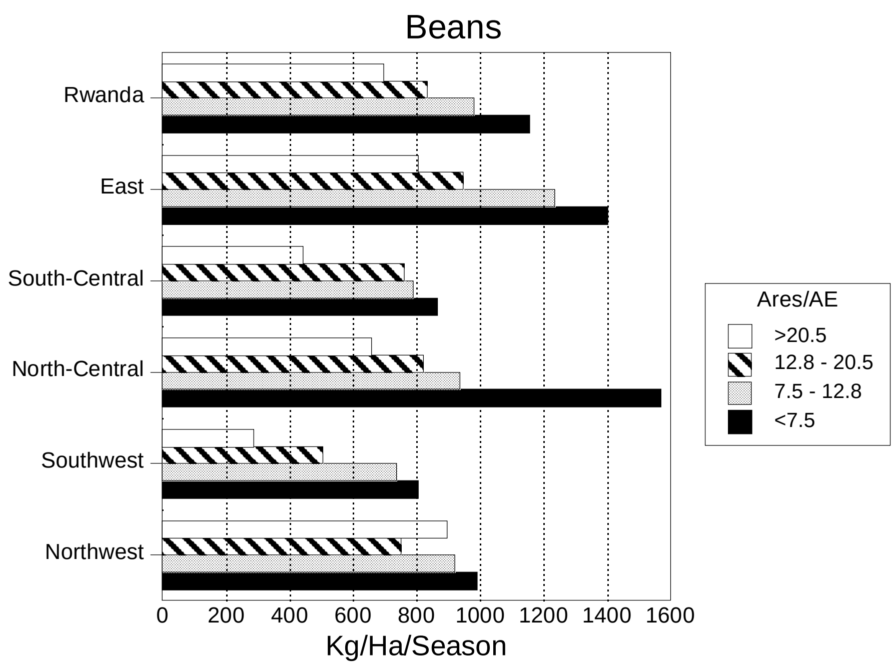
Since yield data tend to be highly variable, comparisons based on a relatively small number of observations could be easily dominated by random variation. Consequently, we restrict our discussion to the five major crops that are grown throughout Rwanda, where we have the largest number of observations.

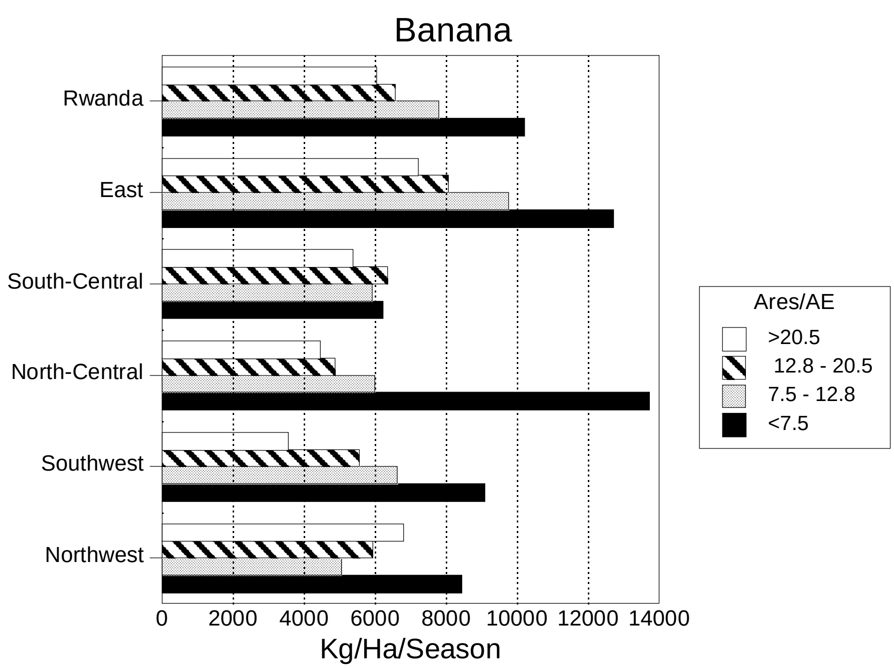
Figure 3.3 shows that controlling for zone does not weaken the relationship between land scarcity and bean yields, except in the Northwest. One possible explanation is that in the Northwest, many of the larger farms are located on the fertile volcanic highlands, some of which have been cleared for cultivation only recently. Another partial explanation is that since the regional population density is high in the Northwest, larger farmers hire more labor than elsewhere.

Banana yields (Figure 3.3) show a less consistent picture, presumably reflecting land quality changes ignored in this report. We can, however, rule out the possibility that inter-zone variation causes the relationship observed at the national level. Overall, yields are highest in the East, where many of the large farmers are located. The figure suggests that small farmers in the South-Central Zone cultivate degraded lands not well suited to bananas or many other crops.

Coffee yields show the national pattern (small farms yield better than large farms) in three of the five zones, with the reverse being true in two zones. Presumably this is an indication of small farmers neglecting coffee trees that they legally cannot cut down, but were not interested in carefully managing due to low prices. In the three zones, coffee still appears to

Figure 3.3. Beans and Banana Yields by Farm Size (Ares/AE) and Zone





Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

be an attractive cash crop for small farmers with few off-farm opportunities, even though it is the most labor-intensive crop of all. In the South-Central Zone and even more so in the East, many small farmers appear to have abandoned their coffee trees, and DSA's land use data show that some of them have started to grow food crops among the coffee trees, which hurts coffee's roots and may contribute to the low yields noted.

Sweet potato yields are positively correlated with land scarcity even when controlling for agroclimatic zone. For the Northwest we can present only the relatively high yields on the small farms, since in this zone, larger farms are few and mostly located at higher altitudes, where white potatoes are the crop of choice.

Maize is the only one of the five major crops that does not show any clear association between land scarcity and yield, after the variation for agroclimatic zones is held constant. In other words, the correlation at the national level is shown to be spurious, caused by the fact that maize yields well in the Northwest where most farms are small. On the other hand, if large farms in the Northeast do indeed have better lands than small farms, as we hypothesized above, then the standard pattern might re-emerge if we controlled not just for inter-zone, but also for intra-zone variation in land quality.

In sum, although we have not controlled for possible differences in land quality, four of five major crops show positive correlations between land scarcity and yield (that is, small farms have better average land productivity). In other words, additional family members help their households produce more, although not enough to keep the per-capita availabilities constant. We return to the marginal productivities of land and labor in Chapter 4.

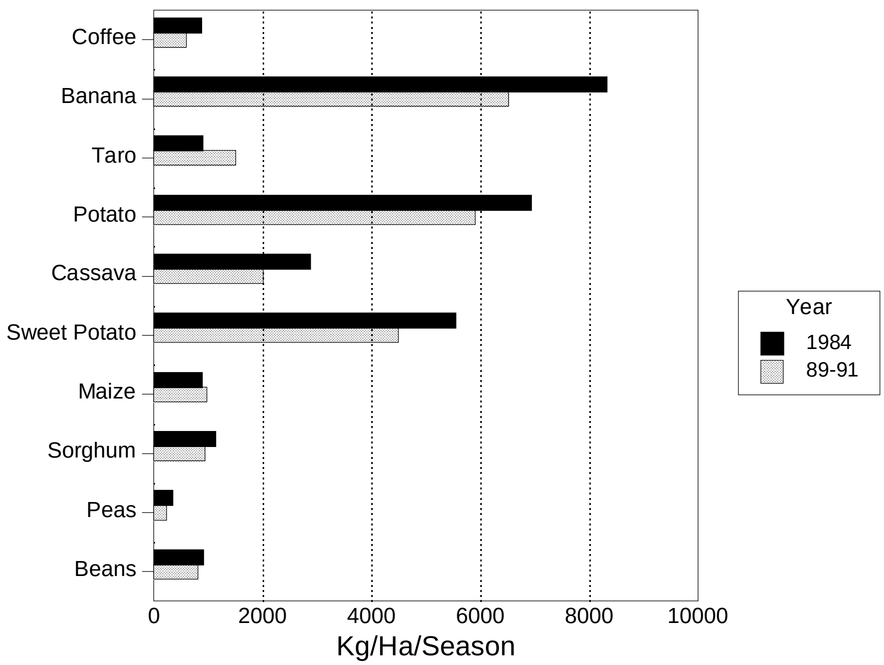
3.5. Trends and Cross-Country Comparisons

In this section, we first examine the evolution of yields since 1984 using DSA's data set. We then compare the trend of yields in Rwanda to those in neighboring countries. Since fully comparable nationwide agricultural survey data are not available for all of the neighboring countries, we use the data compiled by the United Nations Food and Agriculture Organization (FAO), presented in its Production Yearbooks. We also compare FAO's estimates to those of the DSA, and discuss reasons for the differences.

3.5.1. Yields Since 1984 Based on DSA Data

Comparisons of DSA data for the 1984 agricultural year and for the mean of agricultural years 1989-1991 show that, except for maize, the yields of all major crops have declined (Figure 3.4). Though benchmark data are available only for 1984 (no multi-year averages), the fact that 1984 was considered to be a modest drought year suggests that the observed decline in production between 1984 and 1989-91 was real, and possibly even understated. Particularly alarming are the strong downward trends for tubers, the main providers of calories, especially for the poor.

Figure 3.4. Evolution of Yields (1984-1991)



Source: Computed from MINAGRI/DSA survey data, 1984, and 1989 - 1991.

Coffee yields have also declined. A possible reason for this is the declining price of coffee during the late 1980s and early 1990s. The declining real producer prices of coffee during 1989-1991 reduced returns to land and labor in coffee production, encouraging those with better alternatives to focus their efforts elsewhere.

In the case of bananas, part of the decline in yields was caused by expansion of the area under bananas by more than one-fourth between 1984 and 1990. This expansion increased the share of young bananas that have not yet produced at all, or produce below their full capacity.

In the case of beans, part of the decline in yield can be attributed to pest problems that were unusually serious in 1989-1991. Although the data for agricultural years 1992 and 1993 were not available for analysis, our field observations suggested that both bean yields and the area under beans recovered after 1991.

While we have reason to believe that banana, bean, and coffee yields declined at least to some extent for specific reasons, the data also point to an alarming decline in overall land productivity. This occurred despite the rapid expansion of the agricultural labor force that, other things being equal, should have raised yields by enabling better weeding, more timely planting, etc. The unavoidable conclusion is that other things have not stayed equal. The discrepancy between cross-sectional results, suggesting that additional hands do increase production, and the longitudinal findings that they have not done so in the 1980s, amounts to quite strong, indirect evidence of the serious degradation of Rwandan agricultural lands. More direct evidence of the impact of land degradation on agricultural productivity is presented in Chapter 4, and of farmer-reported changes in land productivity in Chapter 5.

3.5.2. Comparing DSA and FAO Yield Data

The DSA production, area, and yield data used above are based on detailed farm surveys. In these surveys, land use is measured and its allocation among crops is estimated seasonally, with crop production measured by weekly recalls.

For international comparisons, the standard data base is that of the United Nations Food and Agriculture Organization (FAO). FAO publishes data provided by member governments. In the case of Rwanda, these estimates are made at the Ministry of Agriculture using past estimates, reports from local authorities, and expert opinions, including those formed by crop-cut estimates from Rwanda's national agricultural research institute (ISAR), in addition to the DSA survey data.

FAO Production Yearbooks are not very explicit about how their reported yields are defined. According to our reading, FAO production figures are annual, and the harvested area includes fields under perennials only once, whereas fields under annual (seasonal) crops can be included as many times as they are harvested. We further assume that FAO's reported cassava yields refer to an assumed average growing cycle of 18 months.

With these interpretations, FAO's yield estimates are substantially above those of DSA for nearly all major crops (see Table 3.2); we cannot compare the figures for bananas, however, as FAO yearbooks do not report data for bananas in Rwanda. FAO's 1989-1991 mean yield estimates for maize, sweet potatoes, cassava, and coffee are 20-30 percent above those of DSA's estimates; for the other crops, FAO's figures are 10-20 percent above DSA's. Only bean yields are the same from the two sources.

The true yields may lie somewhere between the two estimates. Experts knowledgeable in the crop survey methods used by DSA generally think that there is a small downward bias in the production estimates, as some small quantities of harvest are forgotten or not reported. On the other hand, the method preferred by agricultural research organizations, crop-cut estimates from small plot samples, is vulnerable to an upward bias. Unless great care is taken to choose representative samples, crop-cuts tend to be taken from better-than-average plots, and from higher-yielding areas within selected plots.

Even if there was a slight upward bias in the FAO yield estimates, it does not invalidate longitudinal comparisons as long as the error remains constant over time. Assuming this is the case, we will use FAO's numbers to look at trends over a slightly longer period of time.

Table 3.2. Comparison of Land Productivity (Kg/Ha) Using DSA and FAO Data

Crop	DSA (1989-91) (Kg/Ha)	FAO (1989-91) (Kg/Ha)
Beans	838	808
Peas	272	580
Sorghum	1,016	1,150
Maize	1,010	1,274
Sweet Potato	4,527	5,960
Cassava	2,185	2,870
Potato	6,102	6,744
Banana	6,788	*
Coffee	256	350

Sources: MINAGRI/DSA survey data, 1989 - 1991; and FAO Production Yearbook, Vols. 45 (1991) and 46 (1992).
* Information not available in FAO reports.

Several adjustments have been made to FAO figures to ensure comparability with the DSA figures:
Cassava: FAO figures were divided by 3, since they are for 18 mos.; DSA figures are for 6 mos.
Coffee: FAO figures were divided by 2, since they are for 12 mos.; DSA figures are for 6 mos.

Comparing the mean yields of two three-year periods ten years apart (1979-81 and 1989-91), we get a picture of Rwandan crop yields that is almost as alarming as that painted by DSA’s survey data for sweet potatoes, cassava, and coffee. The yields of white potatoes and sorghum have not declined according to FAO, and bean yields have increased. For maize, both data sets show yield increases. Although FAO's estimates are not as dire as DSA's, they agree that food production has not kept pace with population growth, and that the yields of some major crops have actually declined.

3.5.3. Inter-Country Comparisons Using FAO Data

The problem with inter-country comparisons is that the methods and definitions used by the governments may differ. However, FAO seeks to standardize the methods and definitions, and in any case there is no better available data set for international comparisons. We discuss only the main food crops and coffee, assuming that measurement problems make the comparisons for minor crops too suspect.

We compare Rwanda to its four neighbors—Uganda, Tanzania, Burundi, and Zaire—and to Kenya, which, although without a shared border with Rwanda, is close and includes densely-populated highlands that compare favorably to Rwanda's. Of these six countries, only Kenya has had any substantial agricultural modernization with industrial inputs and improved varieties. Zaire has the lowest population density and an agriculture with almost no industrially-produced inputs. Population densities in Tanzania and Uganda are also far below Rwandan levels, but Tanzania resembles Kenya in that a significant portion of the population lives on the densely-populated highlands. Burundi is most comparable to Rwanda, although its population density is also somewhat below that of Rwanda.

Note, however, that low population density does not necessarily mean that farmers can cultivate large fields. Instead, it often means that they can afford to restore fertility with long fallows, have consequently higher yields, and need not weed much or cultivate very large areas to feed their families. This explains why (at least according to the FAO data) Tanzania has less cultivated and permanently cropped land per-person than Rwanda or Burundi.

Sorghum yields in Rwanda are comparable to those in Burundi and are above those in Kenya, Tanzania, and Zaire (see Table 3.3). Yields are substantially higher in Uganda, despite declines in the 1980s. Yields have also declined in Zaire, but have increased in Tanzania and Burundi, while remaining stagnant in Rwanda.

Maize yields are the lowest (722 kg/ha) in Zaire, twice as high in Tanzania and Uganda, even higher in Kenya, and slightly below Ugandan levels in Rwanda and Burundi. Yields have increased in the 1980s in Rwanda, Burundi, Tanzania, and above all in Kenya, while they have stagnated in Uganda and declined in Zaire. The rapid increases in Kenyan maize yields can be attributed to agricultural modernization, and along with lessons learned from Zimbabwe and Zambia, suggest that similar increases are possible (though not necessarily economically attractive) in Rwanda with the use of chemical fertilizer and other modern inputs.

Bean yields are highest by a wide margin in Burundi, followed by Rwanda and Uganda, with much lower yields reported for Tanzania and Zaire. In the 1980s, Tanzania partially closed the gap with Burundi and Rwanda, both of which have also seen some increases according to FAO. In contrast, yields in Uganda and Zaire have declined.

Table 3.3. Cross-Country Yield Comparisons Using FAO Data

	Yield (Kg/Ha) per Season					
Crop	Rwanda	Burundi	Tanzania	Uganda	Zaire	Kenya
Beans	808	1,074	640	812	580	*
Peas	580	568	318	547	660	*
Sorghum	1,150	1,153	941	1,486	637	964
Maize	1,274	1,285	1,446	1,374	722	1,684
Sweet Potato	5,960	7,154	2,067	4,131	4,955	10,955
Cassava	2,870	3,760	3,440	2,840	2,554	3,063
Potato	6,744	7,154	6,861	6,857	4,771	4,922
Coffee	350	406	213	311	189	317

Source: FAO Production Yearbook, Vols. 45 (1991) and 46 (1992) .
* Information not available in FAO Report.

Sweet potato yields are many times higher in Kenya than in Tanzania, and about twice as high as in Zaire and Uganda. Rwanda and Burundi are between the two extremes. While the FAO's (and the DSA's) estimates suggest that sweet potato yields have declined by one-fourth in the 1980s in Rwanda, even more in Tanzania, and significantly in Uganda also, yields in Burundi and Kenya have increased. Since sweet potatoes are usually intercropped, the area under them is notoriously difficult to estimate, which may call into question the validity of these estimates. Nevertheless, the differences are startling, and since sweet potatoes are the most important food crop in Rwanda, understanding why these differences occur would be valuable.

Cassava yields appear to have declined dramatically in Rwanda in the 1980s. Though the FAO's very high estimate for 1979-81 is perhaps questionable, the FAO's picture for Tanzania is somewhat similar. Over the same period, yields stayed at a constant, high level in Burundi, in Kenya at a somewhat lower level, and have increased in Uganda and Zaire from much lower levels. Overall, the FAO data on these important subsistence tubers suggest that fields in Rwanda and Tanzania have degraded, while Burundi and Kenya have somehow managed to avoid such a decline.

White potato yields vary substantially among countries, but have stayed remarkably constant over time in all countries, except Kenya, where they have declined. In the tropics, potatoes grow well only in highland areas, and in Rwanda they are the only crop heavily dependent on pesticides. According to the FAO, yields are high in Rwanda, Tanzania and Uganda, and low in Burundi.

Coffee yields in Rwanda matched those in Burundi and Kenya in the early 1980s, but over the past 10 years, yields in Burundi have increased while Rwanda and Kenya have seen yields decline. At a lower level, the same happened with Tanzania and Uganda. These two countries started at the same level, but by the end of the decade, yields in Uganda had increased by one-fourth while those in Tanzania had declined. Zairian coffee yields are the lowest of all. Since coffee yields depend heavily on how carefully farmers mulch and manage their coffee trees, declining yields in Rwanda, Kenya, and Tanzania suggest that incentives for coffee production have declined, while the opposite has been true in Burundi and Uganda. Zaire's low yields suggest that production there is "extensive," with land availability not posing a significant constraint to Zairian farmers.

In sum, according to the FAO data, Rwanda lost much of its yield superiority during the 1980s. Not only did Rwanda's initially high cassava yields fall below that of most of its neighbors, Burundi also surpassed Rwanda in maize, sweet potato, and coffee yields, Kenya increased its lead in maize and sweet potato yields, Tanzania out-yielded Rwanda in cassava, and closed part of the gap in sorghum and bean yields, and Uganda did the same in sweet potato and coffee.

While comparisons using DSA's data for the years 1984 and 1990 paint an even more dire picture, FAO's data suggest that Rwanda not only performed poorly, but that it also did worse than any of its neighbors. Its food security clearly deteriorated as the yields of all its main food crops either declined or grew much more slowly than the population, in a context where little new land can be brought under cultivation. Particularly alarming are the figures showing collapsing yields of sweet potatoes and cassava, since growing more tubers has been the traditional way of feeding more people on small farms.

However, Rwanda still has comparatively high yields in its main cash crops—white potatoes, sorghum, coffee, and tea. Moreover, despite the yield declines of the 1980s, bananas and sweet potatoes can still produce large quantities of calories per-hectare. These crops, together with maize, that has great potential for higher yields, hold promise either as food or cash crops.

3.6. Labor Productivity

Survey data on labor use are difficult and expensive to collect. The DSA data set used in this report has no observations on labor allocation either between cropping and non-cropping activities, or among crops. The only DSA labor data are: (1) demographic data—numbers of persons, including their sex and age, in the household (from which we derive numbers of adult equivalents), and (2) labor transactions (sales and purchases) in the farm and nonfarm sectors. Combining (1) and (2) gives us rough estimates of the hours available to agriculture, other non-market activities, and leisure.

To derive estimates of agricultural labor productivity, we make several assumptions about how much time rural Rwandans allocate to agriculture. Our assumptions were developed by Laurence Uwamariya, DSA agronomist:

- The agricultural working day is six hours, except in three prefectures. It is seven hours in Byumba, eight hours in Gisenyi, and nine hours in Ruhengeri.

- Each week has five working days.

- No agricultural work is done in July, and farmers work half-time in January, February, June, and August. The exceptions are Byumba, where farmers work only one-third of their normal hours in August, and Kibungo, where they do no agricultural work in August.

Note that the assumptions we have used do not depend on farm size. In other words, we assume that an absence of land to work does not make farmers work more (or less). That is, we assume that if farm size per-available-worker declines by one-half, per-hectare-labor-use exactly doubles.

With these assumptions, we have calculated the average returns to labor in crop production by zone, farm size quartile, and crop. Our estimated average returns to labor in Rwandan agriculture were 10.3 Rwandan francs (US$.07) per hour in 19889-1991. In terms of purchasing power, this corresponds to approximately 588 grams of beans (1784 kcals), or 2320 grams of sweet potatoes (2508 kcals).[5]

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[5] Excerpt from Uwamariya et al. 1993 (translated):

Calculations for labor input by crop derived as follows:

Farm labor time by season (hours): not having data on the number of days or hours of labor time dedicated to farm activities, we needed to estimate them, by season and by prefecture, using the following assumptions.

1. The seasons start and end at the same time in all regions. Season A starts in September and ends in January, and season B starts in February and ends in August.

2. The labor day is:

    - 6 hours in the prefectures of Butare, Cyangugu, Gikongoro, Gitarama, Kibuye, and Kigali
    - 7 hours in the prefecture of Byumba
    - 8 hours in the prefecture of Gisenyi
    - 9 hours in the prefecture of Ruhengeri

3. There is no farmwork in July. Farmers work half-time in January, February, June, and August in the prefectures of Butare, Cyangugu, Gikongoro, Gitarama, Kibuye, Kigali, Ruhengeri, and Gisenyi; they work one-third time in August in Byumba. In the prefecture of Kibungo, farm work is negligible in August.

Labor allocation by crop: (hj/ha):

Estimates of labor time by crop came from "l'Etude de l'Université Nationale du Rwanda (UNR) sur les coûts de production et politiques des prix agricoles et de l'élevage au Rwanda." Their data came from a survey undertaken from March 1986 through May 1987 in the 12 agroclimatic regions of the country, with 40 "secteurs" of data used. These represent a national farm average; the data are expressed in man-days of 8 hours per-hectare and per-season (hj/ha/saison).

The calculations were applied to the crop years 1989, 1990, and 1991.

Weighted averages:

The number of adult equivalents by household of the "total labor force by household" was estimated from data on demographic characteristics of the DSA sample for the 1990 Season A. Without considering the sex of household members, we divided the population in the three categories according to age. Persons greater than or equal to 15 years old and below 60 represent 1 adult laborer. Those from 6 to less than 15 represent 0.25 adult laborers. Those over 60 also represent 0.25 adult laborers. The total labor force is the sum of the persons thus weighted.

Hours of available family labor time were calculated by multiplying the total number of adult laborers per-household by the labor time per-season.

The hours of available family labor time, plus hired labor time, minus family labor time sold, equal the available labor time per-household.

The coefficient of labor allocation per-crop was calculated as follows: the area under each crop is multiplied by the number of adult laborer days per-hectare needed to produce the crop, estimated by the UNR per-season. For example: UHAR = HAR*209; UHAR represents the number of hours required per-hectare to produce beans.

The total number of hours required over all crops (UTOT=UHAR+UPOIS+...) gives the total labor time in agriculture.

We divide the labor time allocated to each crop by the total farm labor time to obtain the "coefficient of allocation of labor by crop." For example, CHAR = UHAR/UTOT; char represents the share of labor in beans.

Overall labor productivity (FRW/hour): The input costs are subtracted from the total value of the crops (quantity of output times price), and we divide the latter value by the total number of available labor hours per-household.

Labor productivity per-crop (FRW/hour): By dividing the value of the output of each crop by the product of its coefficient of labor allocation and the total available labor time by household, we obtain labor productivity per-crop. For example, PTHAR = VHAR/(CHAR*HMOAG), and PTHAR represents the labor productivity of beans in FRW/hour.

Assumptions:

- All family members work at the same intensity on all crops.
- The price of crop *i* is the same in all regions.
- The labor times by crop estimated by the UNR (the national average in mandays per-hectare per-season) are applicable.
- Farm inputs are minor in the calculations.
- Purchased seed is not subtracted from the gross value of the crop output to obtain net output.
- Labor time allocated to pastoral labor, forestry, and food processing are not subtracted from the total labor time available to the household.

3.6.1. Regional Differences in Labor Productivity

By a wide margin, labor productivity is highest in the East, where yields are above the mean and farms are relatively large (Figure 3.5). While the fertile Northwest with its volcanic highlands and the fertile banana region by Lake Kivu ranks first in land productivity, high population density and longer work days mean that, in this zone, returns to labor hours are estimated to be only slightly above the national average. The North-Central Zone is close to the national average both in land and labor productivity. Returns to labor are lowest in the Southwest and South-Central zones, the two zones where yields are dismally low.

The result of monetary returns to labor being some 50 percent higher in the East than they are in Rwanda's southern zones is compatible with the fact that much of the migration inside Rwanda during the past decades has been from the South to the East (Clay et al. 1990).

3.6.2. Labor Productivity and Land Scarcity

Not surprisingly, we find that labor productivity declines dramatically with increasing land scarcity (Table 3.4). At the national level, returns to labor hours are twice as high in the most land-abundant quartile as in the most land-scarce quartile. However, part of this is explained by the fact that farms are largest in the East, where returns to labor are unusually large. Within zones, the differences among the quartiles are somewhat smaller, except for the South-Central Zone, where the smallest quartile does particularly poorly.

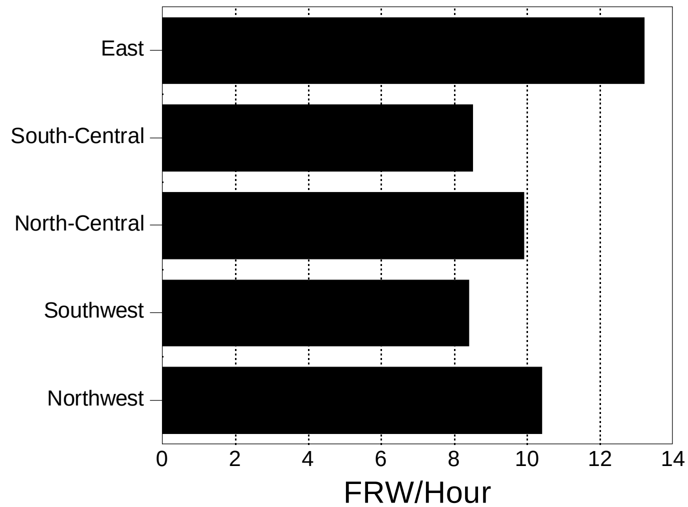
Moreover, the collapse in labor productivity seems to accelerate with land scarcity. Differences among the three least land-scarce quartiles are small compared to those between them and the most land-scarce quartile. In the Southwest, returns to cropping labor appear unusually low for the quartile with the largest farms, presumably in part because their lands are degraded, and in part because we may have overestimated the allocation of labor to cropping by households that own much livestock.

Since the land scarcity quartiles are based on national rather than zone-by-zone rankings, inter-zone comparisons in effect control for land scarcity (at least within each of the three lowest quartiles). The lowest quartile, for instance, includes households with less than 7.5 ares of agricultural land per-person. That returns to labor are above the national average in the smallest quartile in the East reflects, above all, that labor sales are made possible by the strong effective demand for labor in this zone. Returns to labor are unusually low among the smallest households in the South-Central Zone, where a dearth of effective demand for labor leaves the most land-scarce households with few productive uses for their labor.

3.6.3. Differences in Labor Productivity by Crop

Since no data are available on how the surveyed households allocated their labor among the crops, we allocated the estimated number of cropping labor hours based on the amount of land under each crop and the estimated relative labor-intensities of each crop. The latter are adapted from an earlier cost of production study conducted by the National University of

Figure 3.5. Labor Productivity (FRW/Hr) by Zone



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

Table 3.4. Mean Labor Productivity (FRW/Hour) by Zone and Landholdings per-Adult-Equivalent

	Landholding Quartiles (Ares/Adult Equivalent)				
Zone	<7.5	7.5-12.8	12.8-20.5	>20.5	Total
Northwest	12.6	18.4	25.4	24.8	20.8
Southwest	12.0	21.6	20.8	16.4	16.8
North-Central	17.8	14.8	22.6	24.2	19.8
South-Central	9.4	15.4	20.0	22.4	17.0
East	21.4	19.4	23.6	32.4	26.4
Rwanda	13.4	17.0	22.6	26.8	20.6

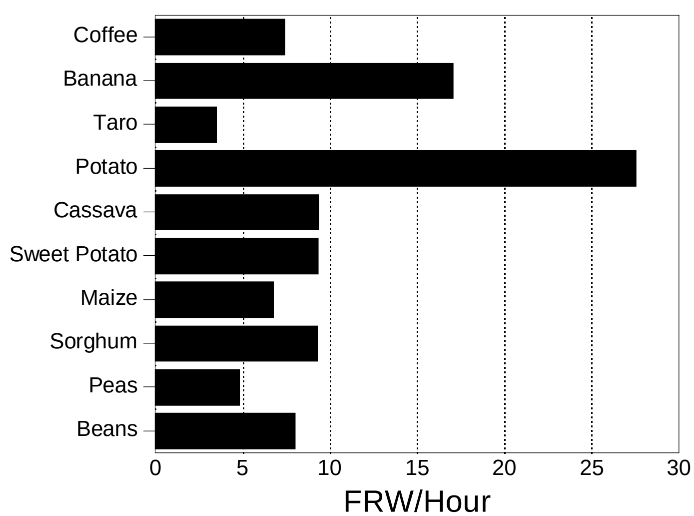
Computed from MINAGRI/DSA survey data, 1989 - 1991.

Rwanda. Due to the many assumptions needed to arrive at the crop-specific estimates of labor productivity, they should be regarded as suggestive only.

The results suggest that bananas and white potatoes provide considerably higher returns to labor than do other crops (Figure 3.6). This result is compatible with other observations. In the case of white potatoes, the finding is consistent with the overwhelming popularity of potatoes among all four farm size quartiles in the region where they grow well, and where the necessary pesticides are available. Similarly, bananas are grown by small and large farms alike, and between 1984 and 1990 the area under bananas increased by more than one-fourth.

The other main crops—coffee, cassava, sweet potato, maize, sorghum, and beans—all provide roughly comparable returns to labor. This, together with the results presented on land productivity (Figure 3.1a, page 16), explains why the crop mixes are so similar across farm size quartiles (Figure 3.1b, page 20). None of the major crops provide a combination of high returns to land and low returns to labor, which would be the likely characteristics of crops that large farmers avoid but which land-poor farmers are forced to grow. Also the opposite—the crop that needs little labor but much land and is appealing to large farmers—is missing.

Figure 3.6. Labor Productivity (FRW/Hr) by Crop



Source: Computed from MINAGRI/DSA survey data, 1989 - 1991.

CHAPTER 4

DETERMINANTS OF FARM PRODUCTIVITY IN RWANDA

4.1. Introduction

Farm-level research on patterns and determinants of productivity in Africa during the 1960s and 1970s focused mainly on sample stratification based on farm characteristics. Farm size, use of animal traction, access to credit, use of new seed varieties, land tenure status, and income were among the more important characteristics examined (Eicher and Baker 1982).

Since the 1960s, soils have degraded and erosion has become a major environmental problem in many developing countries. Access to land has become increasingly constrained in areas formerly thought land abundant, factor and credit markets have structurally changed, and land markets have developed. Now most countries are confronting important issues relating to (a) land degradation, (b) land productivity, and (c) growing land constraints. The linkages among these factors are particularly under-researched, yet important in areas of Africa such as Rwanda, where land constraints and land degradation are serious and growing problems.

This chapter explores the determinants of agricultural productivity in Rwanda using household-level data from the 1991 agricultural year. We contribute to productivity determinants research in Africa through an analysis of how farm size, erosion, and soil conservation measures affect productivity.

4.2. Hypotheses and Approach

The above strategic research issues give rise to two related hypotheses in the context of Rwanda.

(1) Hypothesis: Average and marginal land products will rise as the size of farm decreases.

Much of the empirical productivity research in developing countries in general has focused on the relationship between farm size and productivity. Most of this work has been in Asia; very little has been undertaken in Africa. Research in Asia has often found an inverse relationship. For example, work in India (Bardhan 1973; Deolalikar 1981; Rao and Chotigeat 1981) shows that small farms have higher land productivity but lower labor productivity (as they use more labor-intensive techniques). This evidence has been important in the land reform debate in developing countries, supporting the smallholder whose labor/land ratio is higher, and who uses land more intensively.

Research in Africa on productivity has often been crop-specific, and has usually focused on larger and/or commercial farms. Relatively few studies have analyzed the relationship between farm size and productivity in the smallholder sector. (Ellis (1993) reviews these studies.) Recent studies include Blarel et al. (1989), Carter and Wiebe (1990) in Kenya, Barrett (1994) in

Madagascar, and Adesina et al. (1994) in Cote d'Ivoire. The Kenya and Madagascar studies confirmed the Asian findings of an inverse relationship between farm size and productivity. Blarel et al. found that the marginal product of capital in maize-bean cultivation in Kenya falls as farm size increases, while the marginal product of labor starts low, due to intensive labor use on small farms, and rises with farm size. Carter and Wiebe found similar patterns for wheat in Kenya, citing the constraints faced by smallholders in access to capital and by largeholders in access to labor as causes. Barrett found an inverse relationship in Madagascar, and noted that, in an environment of price uncertainty, differences in the households' marketable surplus explain the inverse relationship between farm size and productivity, where small farms are price-risk averse. He did not assume labor market imperfections or differences in the quality of land, cropping patterns, or village-level effects.

However, empirical research has found that this relationship depends on how much non-labor inputs are used as a substitute for labor by large farmers. Adesina et al., in Northern Côte d'Ivoire, found that large rice farms have greater land productivity than small rice farms. The difference is attributed to differences in technology use between small and large farms, as a consequence of public policy. Large farms were given preferential access to inputs, credit, and research. Research in Asia has found a similar qualification: Rao and Chotigeat (1981) showed that in India, land and labor have a negative effect on the elasticity of the gross value of output per-unit of land, while capital has a positive effect. The net effect depends on which of the two is greatest. Larger farms that employ more hired labor, more fertilizer, high-yielding varieties, and improved plows and tractors, tend to have greater land productivity.

Ellis (1993) and Barrett (1994) reviewed four explanations for the inverse relationship: (a) There is a dual labor market; largeholders face the market wage, while smallholders face a virtual wage or opportunity cost of labor that is lower than the market wage. Small farms apply labor until its marginal value product becomes a fraction of the market wage; the greater labor-to-land ratio means higher yields (Feder 1984). (b) There may be decreasing returns to scale, although most production studies in developing countries show constant returns to scale. (c) Smallholders may crop available land more intensively, whereas large landholders may underuse land, leaving more fallow or planting less densely. (d) Zone-specific characteristics, such as soil quality or price risk, can affect the yield-size relationship perceived in an aggregate sample (covering more than one zone). For example, a zone with better soils might attract more people, giving rise to smaller farms with better yields than in other zones.

We expect that one or more of the explanations above apply to rural Rwanda, and thus expect the inverse relationship to hold.

Using marginal productivity analysis based on production functions, we examine (c), showing that smaller farms crop more intensively, and (a), that marginal value products differ from market factor prices, indicating constraints to access to inputs, and hence economic inefficiency. Tests of this proposition have been rare in Africa, the exceptions being Carter and Wiebe (1990) and Adesina et al. (1994) for Cote d'Ivoire. Non-African research on the subject includes Bravo-Ureta and Evenson (1994) for Paraguay.

(2) Hypothesis: Land degradation strongly reduces land productivity; conversely, soil conservation investments raise land productivity.

The direction of these effects seems to be a matter of common sense, but the empirical importance of the effects has rarely been examined in developing countries outside of experimental situations, particularly in Africa. For India, Bhalla and Roy (1988) and Bhalla (1988) incorporated the effect of land quality in their analysis of the inverse relationship between farm size and productivity. Land quality was proxied by soil type, color, and depth in the absence of data on soil fertility.

An additional issue is whether one should expect the effects to differ between small and large farms. This will depend on whether small farms have more degraded soils than large farms. If the soils of smaller farms are more degraded, this will offset the potential inverse relationship of farm size and productivity.

Our preliminary assumption was that smaller farms indeed have more degraded soils in Rwanda, where increasing population pressure is reducing farm size and pushing farmers onto the fragile "extensive margins," of hillsides, characterized by thin and erosion-prone soils (von Braun et al. 1991; Clay 1995). We then analyzed erosion per hectare (measured by methods described in Section 4.2) over farm size terciles (reported in Table 4.1), and found that erosion does not differ significantly across farm size strata. This is at first surprising, but is partially explained by the fact that smaller farms have also been farmed for fewer years, are much more fragmented into small plots, and have twice as many meters per-hectare of soil conservation infrastructure. Thus, as these smaller farms age and there is little opportunity to shift cultivation to fallow areas and let cropped areas rest, the short- to medium-term strategies of soil conservation investment will slow degradation but not fully offset it. In the longer term, one would expect degradation to be more severe on smaller farms (thus mitigating the inverse relationship between farm size and land productivity).

In sum, in the short- to medium-term, we expect that degradation will not have a differential productivity effect on smaller farms, and that the land quality effect will not fully offset the expected inverse relationship between farm size and land productivity.

4.3. Model

We start with a production function relating output to inputs (labor, land, fertilizer) and other "conditioners" such as land quality:

Value of Output = f(Land, Labor, Capital, Conditioners) (1)

Table 4.1. Farm Characteristics by Farm Size

Farm Size Tercile

	<.58 ha	.59-1.45 ha	>1.45 ha	Total	Coeff. of Var.
Output (RWF[a])	21.6	34.3	52.6	36.3***	0.9
Yield (RWF/ha)	74.4	42.1	26.1	47.4***	1.1
Labor (days/ha)	1251	557	271	689.0***	1
Land (cultivable ha)	0.34	0.83	2.38	1.19***	0.8
Fields (no. per ha)	13	7	3	8.0***	0.8
Farm Age	17.9	18.4	20.8	19.1***	0.7
Erosion (est. in T/ha)	4.3	4.7	4.6	4.5	1.1
Soil Conservation (m/ha)	672.8	414.1	344.6	477.2***	1.5
Inputs Share	68.1	66.2	68.1	67.5	0.4
Fertilizer Use (kg/ha)	0.08	0.07	0.08	0.08**	14
Distance (min)	8.25	9.08	11.65	9.70***	1.1
Rented Land (percent)	9.9	10.0	5.6	8.50**	1.9
Share High-Value Crops	0.34	0.32	0.36	0.34**	0.7
Stratum's Share Land	0.1	0.22	0.68	1.0	n.a.
GINI Coeff. for Land				0.3827	n.a.

Source: Compiled from MINAGRI/DSA survey data, 1990. n.a.: not applicable
[a] .71 RWF = US$ 1 in 1990.
Strata means are significantly different at: **5 percent, and ***1 percent.
Table 4.1 Definitions:
Output: Value of gross agricultural production in thousands RWF.
Yield: Value of gross agricultural production per hectare (in thousands of RWF).
Labor: Available labor for the household in person-days per hectare (total family labor + labor hired - labor sold). Labor is standardized into adult equivalents (AE): 1 for adults (aged between 16 and 60) and .25 for children (between 6 and 15) and seniors (above 60).
Fields: (FRAGMENT in regressions.) Number of fields on farm.
Farm age: Average number of years of cultivation of fields.
Erosion: USLE estimated average annual soil loss in tons/hectare.
Soil conservation: Total length of anti-erosion devices per-hectare.
Inputs share (FERTSHARE in regressions): Share of farm area on which organic or chemical inputs are applied.
Distance: Average distance from residence to plot in minutes.
Rented: Percentage of operational holding rented.
Share HVC: Share of high valued crops (bananas and coffee) in total agricultural output value.
Proportion of Land per-Stratum: Cumulative amount of land per-stratum.

From the levels of the variables and the estimated coefficients, we compute marginal value products (MVP) of the inputs. The MVP is the change in output associated with an incremental change in the use of an input. The MVP of input X is in turn conditioned by use of X, by use of other inputs, and by "conditioners," such as the degree of erosion. The MVP is used in Section 4.4 for three purposes related to testing our two hypotheses: (a) to show how the marginal productivity of land changes over landholding strata; (b) to show how land productivity is conditioned by soil degradation; and (c) to examine whether the MVP is equal to the marginal factor cost (input price) to determine whether use of that input is efficient, or somehow constrained.

4.4. Data

The data used here come principally from a nationwide stratified-random sample of 1,240 farm households (operating 6,464 plots) interviewed in 1991 by the Agricultural Statistics Division (DSA) of Rwanda's Ministry of Agriculture. Two surveys were conducted: (1) the baseline survey, which enumerated production and other activities of the sample every week over the year; and (2) the Agroforestry survey, which enumerated soil conservation measures taken by households. See Chapter 2 for additional detail.

The baseline survey provides information on outputs and inputs. Missing, however, are the following categories of information: (a) allocation of own and hired labor to specific crops, and total household labor differentiated between cropping and other activities, and (b) allocation of purchased inputs (fertilizer, pesticides, lime) to fields or crops. The Agroforestry survey provided data on soil characteristics and soil conservation investments, but no direct estimates of soil erosion.

4.5. Regression Specification

The regression specification is as follows:

$$\text{OUTPUT} = f(\text{LABOR, LAND, FERTSHARE, FRAGMENT, AGEFARM, EROSION, DISTANCE, SHAREHVC, TENURE, NORTHWEST, SOUTHWEST, NORTHCENTRAL, EAST}) \qquad (2)$$

OUTPUT is the aggregate value of production of a farm. While our data show allocation of land to specific crops, we lack household observations on labor and fertilizer allocation per-crop. Moreover, most Rwandan farms allocate an important share of their land to mixed cropping. Thus, we specify output as an aggregate (over crops) in cash value terms (the sum of each crop's physical output weighted by the market price prevailing at harvest in 1990).[6]

Bardhan (1973) notes, however, that such aggregation overlooks the effect of crop-composition of output, and the marginal value product gives more weight to farmers producing crops that have higher prices than does the marginal physical product. We address this problem by controlling for crop mix (discussed below).

[6] Prefecture-level market prices for Rwanda's major crops were collected monthly by the Ministry of Planning.

Variable inputs are LABOR, LAND, and FERTSHARE. LABOR is expressed in person-days per-hectare, and is an aggregate of hired and own labor. It is considered predetermined because it is mainly own labor, which was proxied by household size in adult equivalents.

LAND is expressed in hectares (of cultivated land). It is also treated as exogenous because it consists almost entirely of owned land (see Section 4.6), and landholdings are set by traditional land rights. Rwanda lacks a competitive land market for the transfer of land.

All farmers use hoes and machetes as basic farm tools; animal traction is not used. There is extremely little use of chemical fertilizer, lime, and pesticides (see Section 4.6). Soil fertility is maintained principally by fallow and use of manure. Our data set lacks information on the quantities of manure used. As a rough alternative, and with the assumption that parcels are homogeneously fertilized, a proxy variable, FERTSHARE, is used: The share of cultivated area on which any of the following are used: organic matter, chemical fertilizer, lime, or pesticides. Though pesticides are not fertility-enhancing inputs like chemical fertilizer and lime, their effect is to increase agricultural output in the short term, and they are thus grouped for purposes of this study with fertilizer and lime as "purchased inputs." The present regression specification combines organic and purchased inputs into a single aggregate indicator (FERTSHARE) of variable capital inputs. Moreover, very little fertilizer or pesticide is used.

There are several variables that control for farm characteristics. FRAGMENT reflects fragmentation — the number of plots per-hectare. The more plots, the more time the farmer spends moving around the farm, and the more inefficient the operation. DISTANCE reflects the average (over farm plots) time the farmer travels from the household to the plots; greater distances mean less efficient operation.

AGEFARM is the average (weighted by plot size) of the number of years since cultivation began on currently-farmed plots; older plots are expected to be less fertile, all else being equal.

EROSION is the average annual soil loss in tons/ha per-farm. It is calculated using the Universal Soil Loss Equation, (USLE; Morgan 1986; Hudson 1981). The USLE provides an estimate of the long-term average annual soil loss from parcels of arable land under various cropping conditions (Hudson 1993), and is specified thus:

$$\text{Erosion (plot-level)} = R \times K \times L \times S \times C \times P \qquad (3)$$

where: R is the index of rainfall and runoff; K is the soil erodibility index reflecting the susceptibility of a soil type to erosion; L is the length of the plot (compared to a standard field of 22.6 meters); S is the slope of the plot relative to a standard (9 percent); C is the C-value, the ratio of soil loss on a plot under a standard treatment of cultivated bare fallow compared to the soil loss expected from the crop mix and cropping practice used on the current plot; P is the soil conservation practice factor, which is a ratio comparing the soil loss of the plot (given soil conservation measures used thereon) with that from a field with no conservation practice. (See Chapter 2 for details on the USLE.)

The following data from the baseline dataset, plus secondary data, were used to measure the above USLE variables: (a) for R, we used average annual rainfall data for the 78 *secteurs* in which our sample households resided; (b) for S, we used plot slope data; (c) for the C value we used baseline data on crop mix; (d) for L (plot length) we used the square root of the plot area (with the simplifying assumption that the plots are square); (e) for K we used secondary data on the soil types for the 12 zones from which our sample was drawn; and (f) for P (conservation practices) we used DSA Agroforestry data on meters per-hectare of soil conservation infrastructure used (grass strips, anti-erosion ditches, hedgerows, and radical terraces).

Land TENURE is the percentage of cultivated area rented per-household. It reflects effort disincentive because we expect that farmers invest less effort in improving rented plots.

Our proxy for crop mix (the need for which is discussed above) is the share of high value crops (SHAREHVC), bananas and coffee, in the gross value of output.

Dummy variables are used to capture the effects of agroclimatic zone. The five zones are NORTHWEST, SOUTHWEST, NORTHCENTRAL, SOUTHCENTRAL, and EAST. They differ by rainfall, altitude, soil quality, and crop mix/vegetative cover. In general, the western zones are rainier and higher in altitude, with soils that have been farmed much longer than those farther to the east. (See Chapter 2.)

4.6. Functional Form and Estimation Methods

Most production studies in Africa have used linear or log-linear functional forms (Eicher and Baker 1982); few have used more complex forms. Linear and log-linear forms are criticized for being too restrictive, as they do not allow analysis of interactions among variables. We favor the translog (transcendental logarithmic), a flexible functional form. Lau (1975) recommends the translog when there is relatively high substitutability among inputs; Antle and Capalbo (1988) and Nakamura (1984) recommend its use because it is general and flexible, and enables the use of few parameters to model behavior without imposing restrictions on the function. The general form of the translog production function is:

$$\ln y = \beta_o + \Sigma_i \beta_i \ln X_i + \Sigma_j \beta_j Z_j + \Sigma_i \Sigma_i \beta_{ii} \ln X_i \ln X_i + \Sigma_i \Sigma_j \beta_{ij} \ln X_i Z_j + \beta_k D_k \tag{4}$$

where βs are coefficients, *i* inputs, *j* conditioning factors, and *k* dummy variables. Applied to our variables this becomes:

$$\ln(\text{output}) = \beta_o + \beta_1 \text{lnLABOR} + \beta_2 \text{lnLAND} + \beta_3 \text{FRAGMENT} + \beta_4 \text{AGEFARM} + \beta_5 \text{EROSION} + \beta_6 \text{FERTSHARE} + \beta_7 \text{DISTANCE} + \beta_8 \text{SHAREHVC} + \beta_9 \text{TENURE} + \beta_{10} \text{lnLABOR*lnland} + \beta_{11} \text{lnLABOR*EAST} + \beta_{14} \text{lnLAND*AGEFARM} + \beta_{15} \text{lnLAND*EROSION} + \beta_{16} \text{lnLAND*FERTSHARE} + \beta_{17} \text{NORTHWEST} + \beta_{18} \text{SOUTHWEST} + \beta_{19} \text{NORTHCENTRAL} + \beta_{20} \text{EAST} + u \quad (5)$$

In an initial specification of the model, we included soil conservation investment as a regressor, but found that they were highly correlated with EROSION, and thus dropped investments; we brought them back into the analysis by relating MVP of land and labor to levels of soil conservation investment on the farm, as discussed in Section 4.8.

The retained regressors successfully passed the test for exogeneity.[7]

4.7. Patterns

Table 4.1 (page 48) shows patterns in output, inputs, conditioning factors, and other household characteristics, compared across terciles of farms grouped according to farm size: smallest, averaging .34 ha.; middle, .83 ha.; largest, 2.38 ha. The latter is still far below average holdings in Sub-Saharan Africa. Note the seven-fold difference in landholding between tercile averages; 68 percent of the land is held by the largest tercile, only 10 percent by the smallest. The Gini coefficient is .40.

Output increases and yield declines as one goes from the smallest to the largest terciles. The overall yield (in value terms) of the average farm in the largest tercile is one-third that of the smallest-farm tercile. The yield advantage is mainly due to a greater labor use per-hectare: the smallest tercile applies four times more labor per-hectare than the largest tercile.

Compared to the largest-tercile farms, the smallest-tercile farms: (a) are four times as fragmented (indicated by number of plots per hectare); (b) have been farmed fewer years; (c) have plots clustered closer to the domicile; (d) have a higher share of land rented (10 percent compared to 6 percent for the largest); (e) have only slightly less eroded soils; (f) have twice as much soil conservation investment per-hectare (measured in meters of own-built infrastructure per-hectare); (g) use the same (very small) amount of chemical fertilizer; and (h) have about the same proportional value of output coming from the high-value crops of coffee and bananas (also crops with low erosive impact).

4.8. Results and Discussion

Table 4.2 shows the production function regression results. Labor and land have positive, significant effects; their full effect can be ascertained, however, only by assessing these sole effects together with the interaction terms, which is done below in our discussion of marginal

[7] We used the procedure set out in Rivers and Vuong (1988).

Table 4.2. Translog Production Function Estimates[a]

Variable[b]	Coefficient	Standard Error
(1) LABOR	0.54***	(0.13)
(2) LAND	0.36**	(0.19)
(3) FRAGMENT	-0.002	(0.002)
(4) AGEFARM	- 0.003**	(0.001)
(5) EROSION	0.04*	(0.07)
(6) FERTSHARE	0.007	(0.006)
(7) DISTANCE	0.003	(0.002)
(8) SHAREHVC	2.73***	(0.91)
(9) RENTED	0.001	(0.001)
(1)*(2)	0.02	(0.03)
(1)*(5)	-0.01	(0.01)
(1)*(8)	-0.31	(0.15)
(1)*NORTHWEST	0.31	(0.09)
(2)*(5)	-0.01	(0.007)
(2)*(6)	- 0.001***	(0.001)
(2)*(8)	0.07	(0.1)
NORTHWEST	- 1.22**	(0.53)
SOUTHWEST	-0.07	(0.06)
NORTH-CENTRAL	0.18***	(0.05)
EAST	0.42***	(0.06)
Constant	6.56***	(0.76)
Adj. R^2	0.53	

Source: Estimated with MINAGRI/DSA survey data, 1990.
[a] The dependent variable is the logarithm of gross value of output in 1990 agricultural production in RWF.
[b] Definitions of variables: as in Table 4.1.
***Significant at 1 percent.
**Significant at 5 percent.
*Significant at 10 percent.

value products. Farm age has a significant negative effect, as expected. Fragmentation has the expected sign but is not a significant factor. Share of rented land is not significant. Erosion's direct effect (after controlling for its indirect effects) is unexpectedly positive, but not significant. The share of coffee and bananas (high-value crops) have, as expected, a strong effect on the value of aggregate output.

Table 4.3 shows average and marginal value products of land and labor (calculated taking into account direct effects and interaction effects). The average and marginal value products of land (respectively, AVP, or yield, and MVP) decrease as the farm size increases, as hypothesized. AVP and MVP of labor increase with farm size, again, as expected.

Nevertheless, Ellis (1993) and Bhalla (1988) noted that an observed inverse relationship between land MVP or AVP and farm size can depend on the partition of farms into different strata (i.e., the definition of stratum cut-off points). To test the robustness of our finding, we specified the following function quadratic in land:

$$\text{MVP (land; labor)} = \beta_o + \beta_1\text{LAND} + \beta_2\text{LANDSQUARED} + \beta_3\text{EROSION} + \beta_4\text{FERTSHARE} + \beta_5\text{SHAREHVC} + \beta_6\text{NORTHWEST} + u \qquad (6)$$

Table 4.4 shows the regression results for Equation 6. They confirm the inverse relationship between farm size (LAND) and the MVP of land, and the positive relationship for the MVP of labor. The relationships are U-shaped. EROSION has a strong negative effect on land, and also on labor productivity (though not significant). Application of fertilizer and organic matter improves land productivity but not labor productivity; this is normal, as fertilizer is land-replacing, not labor-replacing, in this farming system.

Figure 4.1 shows the MVPs of land and labor, and compares them with factor prices--the market wage rate and the land rental rate. Observe that the smallest farms apply labor until the labor MVP is only a fraction of the market wage--going from about one-third of the wage (for the smallest farms) to about two-thirds for the largest farms. This implies a lower opportunity cost of labor on smallholder farms than that reflected in the agricultural wage, probably because of constraints on access to that labor market as well as nonagricultural employment opportunities.

By contrast, the land MVP is much higher for the smaller farms than land rental rates (proxy for market price of land), indicating constraints on access to land. The land MVP and the rental rate are much closer on larger farms, but still indicate land scarcity. These results are similar to those found by Carter and Wiebe (1990) for labor and capital on wheat farms in Kenya.

We then control for farm size and vary each of the key conditioning variables (holding the others fixed) to see how marginal impacts change. The results are shown in Table 4.5 part a; various combinations of changes and stratifications are shown in Table 4.5 parts b-e.

First, when erosion increases from 1 to 8 tons/ha (the average is 4.55 tons/ha) Table 4.5a shows that the MVP of labor decreases by 14 percent. Furthermore, the land MVP decreases 21 percent. Table 5.b shows that as the share of high value crops and improved input use

Table 4.3. Marginal and Average Factor Products

Farm Size (terciles)	Labor MVP	Labor AVP	Land MVP	Land AVP
<.58 ha	38.3	64.2	25.2	74.4
.59-1.45 ha	46.8	76.8	20.6	42.1
>1.45	67.5	95.7	9.0	26.1
Total	52.5	81.6	17.5	47.4
Factor Price	100		7.5	

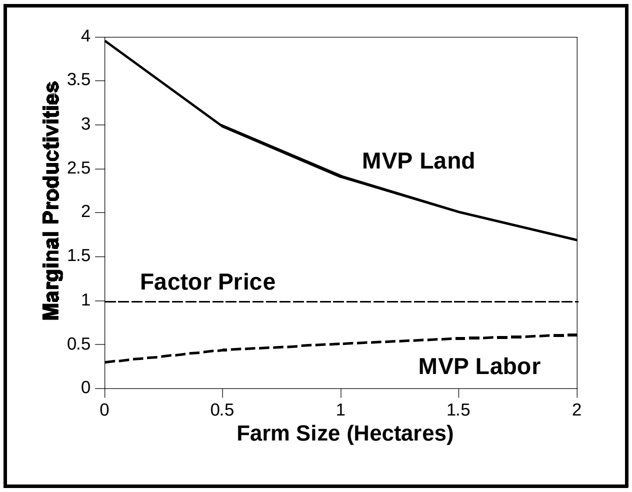
Source: Estimated with MINAGRI/DSA survey data, 1990.
The Marginal Value Product (MVP) and the Average Value Product (AVP) of labor are expressed in RWF/person-days.
Factor prices (wage of labor and rental price of land) were derived from the data. The wage rate is for one day of labor. They are median values.

Table 4.4. Regression of Marginal Value Products of Land and Labor on Farm Size and Farm Characteristics

	MVP of Land		MVP of Labor	
Variables	Coefficient	Std Error	Coefficient	Std. Error
LAND	-10,423.1***	(969.5)	19.71***	(7.11)
LAND²	905.4***	(133.2)	-1.98*	(0.98)
EROSION	-746.5***	(122.5)	-1.23	(0.90)
FERTSHARE	54.2***	(19.4)	0.04	(0.14)
SHAREHVC	22,086.0***	(2901.1)	41.76*	(21.28)
NRTHWEST	11,082.6***	(1730.9)	37.88***	(12.70)
Constant	19,225.2***	(2128.9)	14.86	(15.62)
Adj. R^2	0.23		0.02	

Estimated from MINAGRI/DSA survey data, 1990.
*** significant at 1 percent; ** significant at 5 percent; * significant at 10 percent.

Figure 4.1. Marginal Value Product of Land and Labor by Farm Size



Source: Computed from MINAGRI/DSA survey data, 1990.

Table 4.5. Percentage Change of Marginal Value Product of Land and Labor

4.5.a. Variation of one conditioning factor while holding other variables constant

Moving from..	MVP of Labor (percent change)	MVP of Land (percent change)
.. Small Farms to Large Farms	38	-36
.. Low Erosion to High Erosion	-14	-21
.. Low to High FERTSHARE	4	15
.. Low to High Share of High Value Crops	34	49
.. Low Soil Conservation Investment to High	4	25

Table 4.5.b. Impact of change from low to high erosion for various farm categories

Moving from Low to High Erosion	MVP of Labor (percent change)	MVP of Land (percent change)
Low SHAREHVC Low FERTSHARE	-20	-36
Low SHAREHVC High FERSHARE	-22	-32
High SHAREHVC Low FERTSHARE	-15	-22
High SHAREHVC High FERTSHARE	-14	-19

Table 4.5.c. Impact of change from low to high FERTSHARE for various farm categories

Moving from Low to High FERTSHARE	MVP of Labor (percent change)	MVP of Land (percent change)
Low EROSION Low SHAREHVC	3	11
Low EROSION High SHAREHVC	11	27
High EROSION Low SHAREHVC	4	16
High EROSION High SHAREHVC	9	33

Table 4.5.d. Impact of change from low to high share of high value crops (bananas/coffee) for various farm categories

Moving from Low to High Share	MVP of Labor (percent change)	MVP of Land (percent change)
Low EROSION Low FERTSHARE	39	58
Low EROSION High FERTSHARE	49	92
High EROSION Low FERTSHARE	29	39
High EROSION High FERTSHARE	42	67

Table 4.5.e. Impact of change from low to high soil conservation investment for various farm categories

Moving from low to high soil conservation investment	MVP of Labor (percent change)	MVP of Land (percent change)
Low EROSION Low FERTSHARE	1.3	20
Low EROSION High FERTSHARE	1.2	18
High EROSION Low FERTSHARE	1.5	26
High EROSION High FERTSHARE	1.4	23
Low SHAREHVC Low FERTSHARE	1.6	30
Low SHAREHVC High FERTSHARE	1.6	26
High SHAREHVC Low FERTSHARE	1.2	19
High SHAREHVC High FERTHSHARE	1.2	17
Low EROSION Low SHAREHVC	1.5	24
Low EROSION High SHAREHVC	1.1	16
High EROSION Low SHAREHVC	1.8	33
High EROSION High SHAREHVC	1.3	20

Source: Computed from MINAGRI/DSA survey data, 1990.

(FERTSHARE) increase from the average, the erosion impact on the land MVP can fall to as low as 19 percent, and when there are both a low share of high-value crops and low FERTSHARE, the loss from erosion can be as high as 36 percent. These latter types of farmers have the greatest combination of incentives to invest in erosion control infrastructure. As smaller farms do not have more eroded soils on average than larger farms, the erosion effect does not offset the inverse relationship between yield and farm size, as hypothesized.

Second, increasing soil conservation investment on-farm (here, meters per-hectare of soil conservation infrastructure) from 345 to 673 meters/hectare (the average is 477 meters/ha.) increases the land MVP by 25 percent and labor MVP by 4 percent. Table 4.5e (page 59) shows that when comparing over farms using the criteria of erosion and FERTSHARE (holding all else constant), the farms that benefit most (and logically so) are those with high erosion and low FERTSHARE (with a 26 percent increase in land MVP); those that benefit least are those with low erosion and high FERTSHARE (only 18 percent).

Also in Table 4.5e (page 59), comparing share of high-value crops in output and FERTSHARE, we find that those with the lowest share of high-value crops but low FERTSHARE stand to gain the most—30 percent. Two forces are at play here; lower value crops provide a lower payoff per-extra-kilogram produced than do high-value crops, but the latter tend to be crops with low C-values, and hence already protect the soil. Thus the lowest payoff is to households with a high share of coffee and bananas that already have a high FERTSHARE (17 percent). At the bottom of Table 4.5e we similarly find that those farms with the greatest impact on land productivity of any farms have high erosion and a low share of high-value crops—33 percent.

Third, Table 4.5a (page 57) shows that by increasing the share of land on which fertilizer or organic matter is applied from 40 percent to 90 percent (the average is 67 percent), the labor MVP increases by 4 percent and land MVP by 15 percent. Table 4.5c (page 57) shows that with high erosion and a high share of high-value crops, the gain to land MVP can be as high as 33 percent. Thus, these types of farmers have the greatest combination of incentives to use fertilizer and organic matter; with low erosion and a low share of high-value crops, the gain can be as little as 11 percent.

Fourth, increasing the share of farm output from high-value cash crops (bananas or coffee) from 15 percent to 54 percent (the average is 34 percent), the labor MVP increases by 30 percent and land MVP by 50 percent. These cash crops improve smallholder incomes. Table 4.5d (page 58) shows that the gain from shifting to cash crops is clearly highest for those with better farm conditions, i.e., with low erosion and a high use of improved inputs. Those gaining the least have highly eroded soils and use few improved inputs.

4.9. Conclusions

This chapter tested the hypotheses that (a) small farms have better land productivity than larger farms, (b) soil erosion strongly reduces land productivity; and (c) soil conservation investments strongly improve land productivity. If smaller farms had more eroded soils than larger farms, the effects of erosion would be to diminish any gains in productivity obtained through greater intensification. However, we find that smaller farms do not have more eroded soils (in the short- to medium-term at least) than larger farms, because they use more soil conservation measures. We found four sets of key results.

First, we found a strong inverse relationship between farm size and average and marginal land productivity, with the opposite being true for labor productivity. For smaller farms, the marginal value product of land is above the rental price of land, implying factor use inefficiency and constraints on land market access. By contrast, for larger farms the value product and rental price are nearly equal. The findings for labor were the inverse: the marginal value product of labor for smaller farms was well below the market wage, while they were nearly equal for larger farms. This implies that there are constraints on access to labor market opportunities for the smaller farm households.

Second, land productivity on very eroded farms is 21 percent lower than on farms with little erosion. The most extreme case is for farms with a low share of high-value cash crops (bananas and coffee) and a low share of cultivated area on which fertilizer or organic matter has been applied. The loss of productivity on these farms is 36 percent.

Third, on average, farms with a relatively high level of soil conservation investments have 25 percent greater land productivity than those with few of these investments. The biggest gainers from such investments are farms with a high share of low-value crops (food crops, annuals) and high erosion; they gain 33 percent (relative to the average). Those that gain the least are households with a high share of perennial cash crops and low erosion.

Fourth, increasing the share of farm output coming from high-value cash crops (bananas or coffee) strongly benefits the incomes of smallholders, with land productivity increasing by 50 percent. The yield gains from shifting to cash crops are clearly highest for those with better farm conditions, i.e., those with low erosion and high use of fertilizer and organic matter.

There appears to be a degree of substitutability between perennial cash cropping and soil conservation investments. But the catch is that getting a strong farm yield and income effect from cash cropping requires that the land be less eroded to begin with, and that farmers be able to use substantial quantities of improved inputs (fertilizer and organic matter).

Many small farms already have quite eroded soils, and this erosion has a very harmful effect on land productivity, reducing yields up to one-third. Thus, general programs and policy efforts which encourage and enable farmers to make soil conservation investments will yield significant returns in productivity.

Though small farms tend to use land more efficiently than larger farms, the productivity of smaller farms is constrained by constrained land markets. This implies that attention to reform of land markets is needed, particularly in areas where farms are small and land is scarce.

CHAPTER 5

DETERMINANTS OF LONG-TERM PRODUCTIVITY CHANGE AS REPORTED BY FARMERS

The previous chapter examined what cross-section survey data on production, input use, and capital investment show concerning the determinants of productivity in Rwanda. This chapter examines the same question from a different perspective. Here we examine results from the 1991 Agroforestry survey, where farmers were asked what long-term changes they had observed in land productivity and fertility, and what they thought drove these changes. The chapter starts with a discussion of the patterns in reported productivity change, then focuses on the observed determinants of reported change in a cross-section analysis.

5.1. Patterns of Long-Term Changes in Productivity as Reported by Farmers

In the 1991 Agroforestry Survey conducted by the DSA, farmers were asked what changes they had observed over time in the productivity of each plot on their farm. They were first asked whether they had observed change (either improvement or decline) in the productivity of their soil since first having cultivated the plot. Then they were asked whether the change was small, moderate, or large. Thus, our measure of change in soil productivity is a seven-point scale from "large decline" to "large improvement."[8] Table 5.1 reports a decline in productivity on 48.7 percent of the cropland, 37.5 percent showed no change, and improvement was reported for only 13.8 percent.

What determines these changes? Soil conservation investments such as terraces and hedgerows are found as often (about 84 percent of the time) in holdings that have improved in productivity as they do in holdings that have declined (see Table 5.2). Holdings that have shown no change are less likely to have received conservation investments. This may mean that farmers do not adopt conservation practices unless they see a decline in productivity. In some cases the investments pay off and improve productivity; in other cases, fields with conservation investments continue to decline, either because the investments are not accompanied by increased use of improved inputs and fallow, or because the investments are too small to redress years of decline from overuse, steep slopes, and other causes.

[8] Note that the survey did not enumerate *when* the changes in productivity reported by the farmers occurred—whether before or after the application of improved inputs or soil conservation investments, acquisition of livestock, and so on. Because our analysis focuses on observed change in productivity over time, questions of temporal sequencing and causal ordering become especially apparent. Thus, we assume that the predictor variables have not changed over time, e.g., that a large farm today was a large farm in the past, even before changes in productivity may have occurred. Admittedly there may be cases where this is not actually the case, but the occurrence of this error is random and will not bias the results. At worst, our reported measures of association will be slightly lower as a result.

Table 5.1. Farm Holdings Classified by Level of Change in Productivity Reported by Farm Operators

Reported Level of Change in Soil Productivity	Percent of Land Area	N=
Large Decline	21.5	1,203
Moderate Decline	13.3	745
Slight Decline	13.9	777
No Change	37.5	2,101
Slight Improvement	4.5	253
Moderate Improvement	5.8	322
Large Improvement	3.5	194
Total	100.0	5,699

Source: Computed from MINAGRI/DSA household survey data, 1989.

Table 5.2. Change in Soil Productivity by Conservation Investments, Use of Inputs, and Land Use

Independent Variable	Change in Soil Productivity: Declining	No Change	Improving	Total
Conservation Investments				
No Investments	16.0	36.9	15.9	23.8
Investments	84.0	63.1	84.1	76.2
Gamma	-0.24			
Significance	≤0.01			
Use of Organic Inputs				
Not Used	24.4	44.0	15.6	30.5
Used	75.6	56.0	84.4	69.5
Gamma	-0.12			
Significance	0.03			
Use of Purchased Inputs				
Not Used	92.9	97.3	96.6	95.1
Used	7.1	2.7	3.4	4.9
Gamma	-0.38			
Significance	≤0.01			
Land Use (C-values)				
.0000 - .1000	15.2	23.1	13.4	17.9
.1001 - .1800	50.2	39.4	48.3	45.9
.1801 - .2300	20.1	20.8	26.2	21.2
.2301+	14.5	16.7	12.1	15.0
Significance	0.85			
Gamma	0.00			

Source: Computed from MINAGRI/DSA household survey data, 1989.

Findings are similar for the use of organic and purchased inputs; on fields that showed no change in productivity, fewer inputs were used. Organic input application was highest in fields that are improving over time—improvements that may result from input use. Conversely, fertilizer and lime are most commonly placed on fields that have shown a long-term decline.

Also, as Figure 5.1 shows, purchased inputs are used 86.5 percent of the time, along with soil conservation investments and organic inputs. Hence fertilizer and lime are rarely used alone; farmers may add them when the effects of the other measures are judged inadequate. Moreover, farmers may find that fertilizer and lime work best along with organic inputs, and soil conservation investments help prevent these inputs from washing off during heavy rains.

Table 5.2 (page 64) also indicates that land use and observed change in soil productivity are unrelated. Declining productivity occurs both on fields with high C-values (usually annual crops) as well as on fields planted in more protective perennial crops. To better understand why erosivity of land use and productivity decline show no association, we return to this finding in our discussion of Ordinary Least Square (OLS) results in Section 5.4.

5.2. Comparison of Improving and Declining Holdings

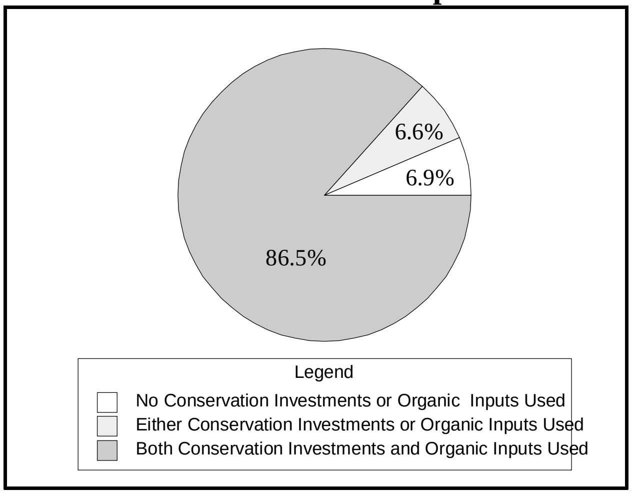
The above findings suggest that soil conservation investments and fertility-enhancing inputs, at least as currently practiced by Rwandan farmers, provide no guarantee of longer-term sustainability. There are holdings that receive investments and inputs of all types yet continue to decline. Yet there are other holdings that show long-term improvement in productivity with no conservation investments or inputs at all.

Table 5.3 gives us a clue as to why some of these seemingly anomalous cases exist. Physical characteristics of the holdings, combined with household-level differences, are crucial to understanding the conditions under which productivity will improve or decline over time.

Columns 1 and 2 show some of the physical and household characteristics of parcels that have received both conservation investments and organic inputs. Holdings in column 1 have improved, while holdings in column 2 have declined, despite farmer investments. Comparison of these columns shows that physical differences between improving and declining parcels are as expected, but are not large. Declining parcels are slightly steeper, have been cultivated longer, and are in higher rainfall areas. The more important differences are socioeconomic. Among holdings that receive conservation investments and organic inputs, those that have improved over time are on farms that have much more livestock and off-farm income (compared to farms with declining quality of plots).

Columns 7 and 8 show the opposite end of the spectrum—plots that receive no conservation investments and no organic inputs. Most of these holdings are reported to have declined in productivity but 18.8 percent actually improved. Relative to declining fields, improving fields tend to: (a) be in flat valley bottoms (and fields with declining productivity in more sloped land). Fields in the valley bottoms probably benefit from silt and fertilizer run-off

Figure 5.1. Use of Purchased Inputs With and Without Other Investments/Inputs



Source:
Computed from MINAGRI/DSA household survey data, 1989.

Table 5.3. Comparison of Parcels (Weighted by Size) According to Presence of Anti-Erosion Investments, Use of Oganic Fertilizer, and Farmer Observations of Change in Productivity Over Time

Independent Variables	Anti-Erosion Investments				No Anti-Erosion Investments				Total
	Organic Fertilizer		No Organic Fertilizer		Organic Fertilizer		No Organic Fertilizer		
	Improving (1)	Declining (2)	Improving (3)	Declining (4)	Improving (5)	Declining (6)	Improving (7)	Declining (8)	
Slope	18.20	18.6	14.7	18	9.2	15.3	3.7	18.1	17.8
Location on Slope	2.81	2.93	2.99	3	3.19	3.37	4.45	3.42	3.01
Distance from Household	2.60	2.6	23.3	12.3	14.3	5.2	39.1	19.7	6.4
Years of Cultivation	21.60	26.1	18.3	23.4	13.7	23.9	9.6	19.5	23.7
Rainfall (mm)	968	1,150	945	1,088	926	1,239	800	1,268	1,112
Land Tenure (% Leased by HH)	5.70	2	5.8	16.9	5.8	1.5	12.1	17.9	8
Total Holdings Owned by HH	182	156	124	127	111	118	220	167	157
Percent of HH holdings in fallow	0.14	0.14	0.13	0.2	0.11	0.24	0.42	0.27	0.16
HH Livestock Ownership (FRW)	35,009	21,528	9,012	17,033	12,629	18,050	10,670	14,101	22,038
Household Off-farm Income (FRW)	41,623	16,708	18,707	9,305	22,135	9,499	13,938	10,497	19,396
Purchased Inputs (% with)	4.20	9.20	0.00	0.00	1.60	6.30	0.10	2.60	6.30
HH Prod. for Home Consump (FRW)	33,617	30,031	34,505	25,014	35,741	23,706	11,720	27,583	29,446
Household Labor	3.56	3.34	2.74	2.8	2.61	2.85	2.98	3.02	3.25
Knowledge of Prod Techniques	2.72	2.29	3.29	2.5	3.57	2.25	0.91	2.26	2.39
Number of cases	594	1,915	53	375	56	146	67	289	3,495

from surrounding slopes; (b) be farther from the residence; (c) have been cultivated for fewer years; (d) be in areas of lower rainfall; and (e) be on larger farms (with more fallow).

Thus, Table 5.3 (page 67) shows that conservation strategies adopted by farmers are many and varied, and their effectiveness depends on where farmers live, the physical characteristics of their holdings, and the households' socioeconomic characteristics.

The above comparison of extremes (those with anti-erosion investments and improved input application, versus those with neither) highlights the differences between what can be called the traditional approach to land management and an approach that has evolved in response to social, economic, and ecological exigencies. The key to the traditional approach was more land—extensification—which enabled farmers to maintain soil fertility through longer fallows. This has nearly disappeared in Rwanda, except in low-rainfall areas, particularly in the eastern plateau where farms are larger and younger, and where slopes are not as steep. Conservation investments and fertility-enhancing inputs are now a necessity for most Rwandan farmers. But not all farmers can make these investments, at least not enough to reverse the long-term decline in productivity.

In addition, soil conservation investments and improved inputs are necessary but not sufficient for long-term improvement in productivity. The latter has come to depend additionally on the integration of livestock into the farming system and a source of off-farm income. The importance of livestock and off-farm income for improved long-term productivity varies according to farm size. Livestock have little impact on reported changes in productivity for farms in the smallest quartile of farms (see Table 5.4). As farms grow, so does the importance of livestock to increasing productivity. Among the largest quartile, holdings that are improving are located on farms with 36 percent more livestock than is the case for holdings that are declining.

Why does the presence of livestock enhance productivity more for larger farms than smaller ones? There are two interrelated reasons. The first is that the ratio of livestock-to-land increases slightly with farm size. The largest quartile of farmers own 11 percent more livestock per-hectare than the smallest quartile. The second is that larger landholders may be more effective than small ones at returning animal manure to the soil. This is because farmers with more land are able to graze their livestock on their own fallow lands, thereby returning nutrients directly to the soil. By contrast, the absence of fallow land on the smaller farms requires manual transportation and distribution of animal manure. Sometimes livestock are permanently stabled in Rwanda, which eases the collection of manure, but more often, smallholders must graze their animals along roadsides and on other public and private lands. Manure collection from these more distant locations for application on the farm is uncommon. In time, however, Rwandans may come to adopt this practice, as it is done in densely populated areas of Asia. There is little public land (commons) set aside specifically for grazing livestock in Rwanda. The commons, along with private pasture have all but disappeared over the past two decades. Public lands along paved roads and other public areas remain, but are small and inaccessible to most farmers.

Table 5.4. Value of Household Livestock and Off-Farm Income by Farm Size and Farmer Observations of Change in Productivity Over Time

Farm Size Quartile and Change in Productivity	Value of Household Livestock (FRW)	Household Off-Farm Income (FRW)	N=
Low Quartile			
Improving	5,457	15,695	153
Declining	5,680	6,246	686
2nd Quartile			
Improving	11,432	21,399	173
Declining	12,918	6,955	661
3rd Quartile			
Improving	25,910	14,794	190
Declining	19,322	15,587	754
High Quartile			
Improving	59,019	74,677	253
Declining	43,799	30,852	624

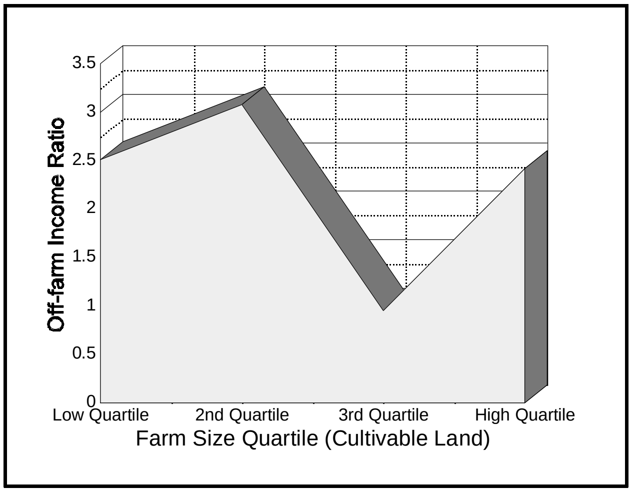
Source: Computed from MINAGRI/DSA household survey data, 1989.

By contrast, off-farm income tends to improve long-term productivity for both smaller and larger holders, but less so for those in the third quartile (see Figure 5.2). Further analysis (not shown in the tables) suggests that larger landholders strongly tend to invest off-farm income in livestock and fertilizer, unlike smallholders. Among larger farmers, there is a strong correlation between off-farm income and both livestock ownership and fertilizer use. But among smallholders no such correlation is found. For smallholders, off-farm income is apparently important to improved productivity for other reasons, perhaps because the cash can be used to purchase food, thus permitting them to maintain some of the less intensive traditional practices for improving productivity, such as fallowing.

5.3. Population Growth, the Structure of Landholding, and Changes in Productivity Over Time

The impact of demographically-induced land scarcity on long-term agricultural sustainability is a major concern for Rwandan policy-makers and farm families who have seen their holdings shrink with each successive generation. Though fertility rates in Rwanda appear to

Figure 5.2. Off-Farm Income Ratio for Holdings with Improving vs. Declining Productivity



Note: This figure compares improving holdings with declining holdings in terms of the off-farm incomes earned by households operating the holdings. The comparison is shown as a ratio (improving over declining) and is reported for farm size quartiles.

Source: Computed from MINAGRI/DSA household survey data, 1989.

have "turned the corner" during the past decade and are now slowly declining, basic principles of population growth ensure that the county's population will continue to grow for many years. Conservative growth estimates suggest that Rwanda's population will double in 20 to 30 years.

Population pressure affects soil productivity indirectly, principally through its effect on the structure of landholding—the physical and social properties that define farmers' relationship with their land. We focus on six key properties—five physical, one social—that change under demographic pressure: farm size, farm fragmentation/dispersion, fragility (slope), years of cultivation, and land tenure (use/ownership rights). As discussed in Chapter 2, farm sizes are decreasing, while fragmentation, fragility, the age of farms, and land rental are all increasing. Here we ask how these changes affect long-term trends in land productivity, as well as how these trends affect the farmers' land use strategies and investments in soil conservation and inputs use?

Though some of these demographically-induced changes in the structure of landholding have been amply demonstrated in previous research, others are as yet untested hypotheses. We do know that steadily rising demographic pressure has reduced the average farm holding in Rwanda by 12 percent over a period of just five years (DSA 1991), and farmers are finding it increasingly necessary to piece together holdings by renting parcels of land. Indeed, in 1991, Rwandan farmers rented-in 7.83 percent of their operational holdings compared to only 5.37 in 1983—a 57 percent increase over eight years. In comparing land tenure among Rwanda's farm size quartiles, we also find that the lowest quartile rents-in twice as much land (in terms of share of holding) as those in the highest quartile. Households under the most severe land constraints are compelled to meet their needs through lease agreements.

Similarly, land scarcity has compelled farmers to cultivate fragile, steep-slope holdings. In Rwanda's fertile Northwestern region, where the potential for agricultural productivity is high, the expansion of agriculture onto marginal lands is already resulting in serious slope failures (slumps and landslides) (Nyamulinda 1988). The increase in degradation on hill slopes will eventually lead to excessive deposition in the valley bottoms—conditions now reported to be common in Burundi (Mathieu 1987) and which, over time, can cause flood damage and destruction of lowland crops (Clay and Lewis 1990).

In summary, though farm size, fragmentation/dispersion, fragility, years of operation, and tenure are different dimensions of the structure of landholding in Rwanda, they are closely associated in that they all are driven in large part by demographic pressures. In recent decades, population growth has meant greater land scarcity. In turn, farmers must now feed their families from smaller holdings than those operated by their parents. And they must cultivate slopes once thought to be too steep and fragile to farm. The disappearance of virgin holdings means a rise in the average age of holdings, and, for those landholdings under the greatest pressure, their holdings must be supplemented by renting small, distant parcels from others (usually through seasonal payments either in cash or in kind).

5.4. Determinants of Productivity Change: Regression Specification and Results

To examine the determinants of productivity change, the cross-section regressions specified in Table 5.5 were estimated using stepwise OLS. In the first step, measures of land management, such as conservation investments and use of inputs, were introduced. In the second step we introduced ownership rights, farm size, fragility and other key structure-of-landholding variables to assess their impact independent of conservation investments. The third step controlled for the range of exogenous variables described earlier. They are grouped into the following four categories: household wealth, demographic characteristics, macro-economic variables, and agroclimatic variables.

Regression results are reported in Table 5.5. Application of organic inputs is the only land management practice that positively significantly affects long-term improvement in soil productivity. The use of purchased inputs shows a small but significant negative correlation with productivity change. This finding reflects the short-lived impact of purchased inputs, and the observation made in the preceding section that Rwandan farmers tend to apply these inputs, possibly as a last resort, on fields that have declined in productivity despite conservation investments and the use of organic inputs.

Table 5.5. Optimal Least Square Stepwise Regressions – Structure of Landholding and

Change in Land Productivity

	Change in Land Productivity		
Independent Variables	Step 1	Step 2	Step 3
A. Land Management			
Conservation investments	-.02	.00	.02
Organic inputs	.09**	.14**	.14**
Purchased inputs	-.05**	-.07**	-.04*
Land use (C-value index)	-.00	-.02	.00
Share of of holdings under fallow	.01	.00	.02
B. Structure of Landholding			
Ownership rights (1=own, 2=lease)		-.02	-.05**
Size of landholdings		.11**	.03
Distance from residence		.11**	.10**
Size of parcel		.07**	.01
Slope (degrees)		-.15**	-.04*
Location on slope (1=summit, 5=valley)		-.03	.00
Years operated		-.20**	-.23**
C. Exogenous Variables			
Household Wealth			
Value of livestock			.09**
Non-farm income			.02
Value of agricultural production			-.03
Demographic Characteristics			
Number of adults (aged 15-65)			-.00
Dependency ratio			.02
Literacy of household head (0=no 1=yes)			.08**
Knowledge of conserv/prod technologies			.09**
Age of head of household (years)			.11**
Macro-economic			
Agricultural profitability index			.08**
Mean agricultural wage in prefecture			-.04
Mean non-agricultural wage in pref.			.13**
Price variation (1986-92)			.09**
Agro-climatic			
Mean annual rainfall			-.10**
R^2	.01	.10	.16

*Sig T ≤.05 **Sig T ≤.01

Source: Computed from MINAGRI/DSA household survey data, 1989.

Conservation investments and land use practices do not show a significant influence on change in productivity in this OLS regression. However, a subsequent analysis of variance shows that the interaction effects of conservation investments and slope, and C-values and slope exert a strong effect on productivity changes. In other words, the effect of conservation investments and land use emerges only in combination with the steepness of the slope. As Figure 5.3 demonstrates, for example, conservation investments have a negative association on gentle slopes, but become increasingly important to productivity changes as the slope increases. Among fields in the steepest slope quartile, productivity is far more likely to increase when conservation investments are present.

In short, the structure of landholding affects productivity changes. As expected, fields (a) on steeper slopes, (b) that are older, and (c) that are rented, are more likely to be declining in productivity. Fields nearer the residence also tend to be declining in productivity, probably because they are cultivated more intensively. Though farm size is important at step 2, its impact disappears at step 3, once the exogenous variables are brought into the equation.

Consistent with the findings presented above, productivity is enhanced by holding livestock because of manure use. Off-farm income shows little direct effect on productivity changes, but, as shown earlier, it has an indirect effect, since it is an important source of liquidity for conservation investments and the purchase of inputs. Knowledge of conservation investments and fertility-enhancing technologies, literacy of the head of household, and age of the head of household all contribute to improved productivity over time.

5.5. Farmers' Perceptions of Causes of Changing Productivity

For each plot reported to be either improving or declining in productivity, farmers were asked their opinions about the primary causes for the change. The results are shown in Figure 5.4. Sixty percent of the farmers claimed that their plots are declining in productivity because they are over-cultivated (beyond their prime), or because they are unable to apply fertility-enhancing inputs to them. Few respondents (subjectively) attributed declining productivity to soil erosion, unless it is on very steep slopes and, we surmise, unless it is visible. However, earlier analyses (Chapter 4) showed that soil loss is (objectively) a major factor in productivity loss.

As the primary reason for productivity improvement, 70 percent of the respondents specified the application of fertility-enhancing inputs. Use of fallow in the rotation is mentioned as a distant second. It is not surprising that conservation investments are rarely seen as the cause of improved productivity, since in Rwanda their usual purpose is to help arrest the decline by slowing soil loss. Improving productivity requires a biological, nitrogen-fixing change. Some types of conservation investment, notably agroforestry practices, such as the planting of living fences that produce green manure, can contribute in both ways, but are rare in Rwanda.

Figure 5.3. Improvement in Productivity by Slope and Conservation Investments

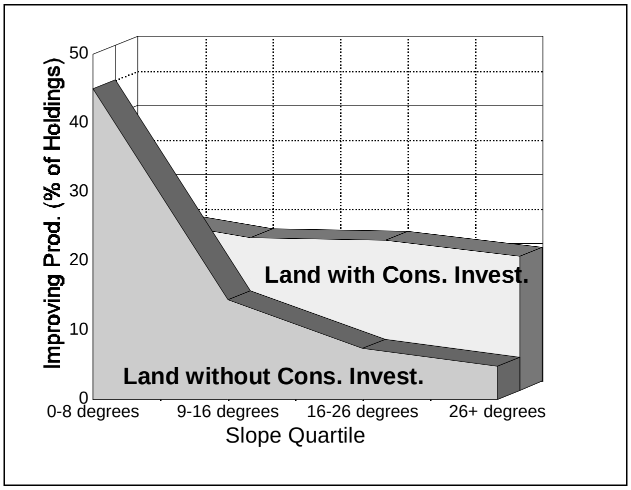
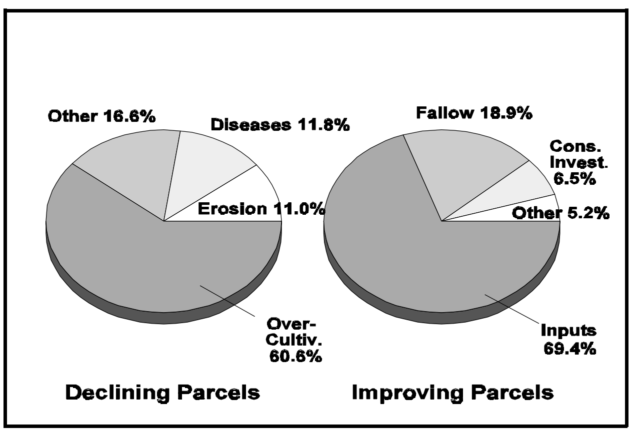


Figure 5.4. Farmer Opinions about Causes of Changing Productivity



Source: Computed from MINAGRI/DSA household data survey, 1989.

5.6. Conclusions

Farmers report that on nearly half of the cultivated land there has been a long-term decline in yields.

Agricultural productivity has been harmed to the extent that population pressure has resulted in (1) less stable land use rights, i.e., land rental rather than ownership, (2) expanded use of fragile lands on steep slopes, and (3) longer periods of use (shorter fallow periods). The findings also show that the presence of livestock on the farm and off-farm earnings, for both the largest and smallest holders, leads to improved productivity. Soil conservation investments on steep slopes, as well as farmer education (both for literacy and productivity/ conservation techniques) also have significant payoff.

Most farmers perceive overuse of land as the villain in the productivity decline, and use of organic and purchased inputs as the way to reverse the trend. Soil conservation investments are also seen as necessary to help arrest the decline, but not sufficient to lead to improvement.

CHAPTER 6

DETERMINANTS OF LAND USE, CONSERVATION INVESTMENTS, AND INPUTS USE

6.1. Introduction

Problems of poverty, land scarcity, and degradation were present in Rwanda before the recent atrocities of genocide and civil war, and they are equally apparent today. Smallholders are still poor, degradation has continued, and, we surmise, food security is as great a problem as ever. This chapter 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 (Nwafor 1979). But in recent decades, rapid population growth has 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, particularly those owning little land or with large families, rent land; and (5) fallow periods have become shorter, with longer cultivation periods.

Consequences of more intensive farming and farming on steep slopes are declining fertility and the high incidence of soil loss due to erosion. Rwanda's National Agricultural Commission (CNA 1992) estimates that half the country's farmland suffers from moderate to severe erosion. Farmers report that the productivity of nearly half their holdings has declined in recent years from degradation (Chapter 5 here and Clay 1989). Chapter 4 of this report shows that erosion severely reduces farm yields.

Hence, farmers have found it imperative to invest in soil conservation measures, anti-erosion infrastructure such as grass strips, anti-erosion ditches, hedgerows, and radical terraces. Three-quarters of the DSA surveyed households have one or more of these improvements in their fields, though across households there is great variability in investment per-hectare.

In her seminal work, Boserup (1965) outlined a number of technology and investment paths to agricultural intensification that farmers follow in the wake of increased land constraints and demand for land—conditions that result from population growth, increased demand for agricultural products, or reduced transportation costs (Boserup 1965; Pingali et al. 1987). 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 and organic matter), and capital that helps land improvement. Boserup identified 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), tractors for contour plowing, and similar land improvements (pp. 113-114). She also noted that "[b]oth 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..." (p. 113). Hence, she envisioned both the push of demographic pressure and the pull of policy and market factors.

Empirical research on production intensification in Africa has illustrated the two intensification paths initially described by Boserup, and here termed the labor- and capital-led paths. Several studies have categorized the agricultural systems in certain regions where demographic pressure has pushed farmers to intensify along these paths. Matlon and Spencer (1984) noted that the capital-led path is more sustainable and productive in fragile, resource-poor areas. Lele and Stone (1989) categorized 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 termed "policy-led"). They maintained that the labor-led path (which they termed the "autonomous model") had not led to land productivity growth in Sub-Saharan Africa, and that policy-led intensification was needed so that land quality and productivity would be maintained and even enhanced as cropping was 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 (Matlon and Spencer 1984). This danger is at its maximum in the East African highland tropics, which are characterized by heavy rainfall and steep slopes. In this setting, the capital-led path of intensification that incorporates soil conservation investments with the use of organic matter and fertilizer produces higher yields that are much more sustainable. By contrast, farm households that follow only the labor-led path in that setting are in 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 agricultural 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. (1987) examined how costs and returns to intensification by use of animal traction can be categorized according to economic and physical characteristics of agroclimatic zones. Smith et al. (1993) and Freeman (1994) examined the nature of intensification in maize production at locations with differential access to infrastructure, technology, and prices.

Much less empirical research, especially in Africa, has addressed the issue of what specifically 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- 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 (1993), who focused on the effects of land tenure on land improvements in Rwanda, and Lopez-Pereira et al. (1994), who studied the same effects for the hillsides of Honduras.

We address this gap in research using farm survey data from Rwanda. Our contribution is twofold. First, we add an empirical analysis of these two paths 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 been usually 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—in enhancing the capacity of households to follow the capital-led path. (b) We address the subject of landholding structure that recent literature (e.g., Place and Hazell 1993) has brought to center stage. Here we examine the links between demographic pressures, changes in the structure of landholding, and, in turn, the technology paths taken by farmers; and (c) We show the links between the shift to high-value, perennial, cash crops, and the choice of the capital-led intensification path.

The chapter proceeds as follows. First, we describe how soil conservation investments, fertility-enhancing inputs, and protective land use patterns figure into the farmers' strategies for land management in Rwanda. Second, we examine inter-household variations in these practices as a function of plot, household, and the following regional variables: (a) economic incentives, (b) household characteristics, (c) structure of landholding, and (d) ecological attributes of farm plots. Because these investments require substantial household outlays of labor and cash, we approach the subject with an investment/adoption model.

The rest of the chapter proceeds as follows: Section 6.2 discusses our general model. Section 6.3 discusses the specific variables and our hypotheses. Section 6.4 describes the data used and regression specification. Section 6.5 describes patterns in the model variables. Section 6.6 presents and discusses the regression results, and Section 6.7 concludes.

6.2. General Model

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

We follow the literature on firm- and farm-level investment theory (see Christensen 1989, or Feder et al. 1985 and 1992), and model farm-level investments as a function of four sets of variables:

Investment =

f (1) net financial returns, (2) physical returns,
(3) riskiness, and (4) wealth and cash sources (1)

In general, the better the return to the activity for which the investment is made, the greater the investment. The greater the risk (from price and rainfall instability, which Feder et al. (1992) termed "confidence in the short term" or from insecurity of land tenure, hence the risk of appropriation of capital, which they termed "confidence in the long term"), the lower the investment for risk-averse farmers (Newbery and Stiglitz 1981).

Incentive can be great but capacity low, however, so income and wealth (in terms of human capital, cash and labor sources) are important general determinants of such investments. In theory, one's own liquidity is important to include in the function where the credit market is underdeveloped or absent, which is generally the case for these sorts of investments in the tropical highlands of East Africa.

6.3. Explanatory Variables and Hypotheses

The above general model explains investment in terms of the (dis)incentives facing farm households, and the resulting capacity of households to undertake the investments.

Table 6.1 shows the regression specification, reproduced as follows:

Land Use (C-value, reflecting erosivity) = 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 6.1, and include the following: (A) *monetary incentives to invest*: agricultural profitability, farm wage, nonfarm wage; (B) *physical incentives to invest*: fallow, slope, location on slope, distance from residence, plot size, and rainfall; (C) *risk of investment*: ownership rights (rent or own), years of operation, price variation over the last six years; (D) *wealth and liquidity sources*: farm size, nonfarm income, livestock value, crop output value; (E) *other household characteristics*: adults, dependency ratio, literacy of head, knowledge of conservation practices, age of head. Note that some variables are classed for simplicity as either incentive or capacity variables, but are actually both (an example is farm size).

Table 6.1. 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$US)	100	0.10	Prefecture
Non-Agricultural Wage (140FRW = 1$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 Agricultral Production (140FRW = 1$US)	22,150	0.83	Household
E. Other Household Characteristics			
Number of Ddults (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). Parcel-level summary statistics may differ slightly from those aggregated and reported in other chapters at the household level. Source: Computed from MINAGRI/DSA household survey data, 1989.

6.3.1. Net Monetary Incentives to Invest

Profitability: We expect better returns to agriculture to unambiguously lead 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 the one hand, better returns off-farm mean competition with on-farm investments. 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-demanding ways, such as perennial crops, fallow, and pasture—ways that are also less "mining" of the soil.

Costs of Investment: This is also reflected in the farm labor wage (as farm labor is used to build the on-farm infrastructure).

6.3.2. 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 is greater. As with slope steepness, declining 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 (Clay and Lewis 1990). Only woodlots seem to have not suffered, thanks to a strong government campaign aimed at replanting, as well as woodlot maintenance at both the household and communal levels.

Declining fallow appears to be linked with 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 (Clay and Magnani 1987; Loveridge et al. 1988). Tubers have a higher caloric value than other crops, and tend to grow relatively well in poorer soils (Gleave and White 1969), 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 (Lewis 1985) and in Latin America (Ashby 1985), tubers have been associated with accelerated soil loss.

Slope Steepness and Location: Steeper slope (particularly where the 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 also discourage the use of fertilizers and organic matter because of runoff.

The issue of field slope has become more important with increased population density. The steepest areas have traditionally been reserved for pasture, woodlots 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 in recent decades has obliged many farmers 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 the steepness of the slope and in hillside location (i.e., upper, middle, 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" is the geographic dispersion of plots. We measure this by average *distance* (in terms of time) farmers must walk to their plots, rather than just the number of parcels or the size of the parcels.[9] Chapter 4 showed that smaller farms are much more fragmented than larger farms.

We expect that as fragmentation increases and plots are more dispersed, farmers will have less incentive to make land improvements because of higher travel/transaction costs. Moreover, more distant parcels are often at the base of a 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 pressures; 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, 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 being equal, it will be a sign of soil fatigue, perhaps a disincentive to investment.

Rainfall: Greater rainfall is expected to lead to less erosive land use practices and more soil conservation investments. This is discussed further below in the section concerning the slope of the plots.

6.3.3. Risk of Investment

Land Tenure/Use Rights: This is what Feder et al. (1992) termed "confidence in the long term." Our hypotheses, based on conceptual reasoning, are straightforward. We expect farmers to make fewer longer-term land improvements, such as bunds and terraces, on holdings rented-in with short-term use rights. Such holding arrangements are risky, since landowners can take back the land, which thereby discourages investments by tenants. Empirical evidence for similar contexts is mixed, however. For a smaller sample in Rwanda (in three prefectures: Butare, Gitarama, and Ruhengeri), Blarel (1989) and Place and Hazell (1993) found farmers tended to invest less in rented land. Migot-Adholla et al. (1990) showed that in Ghana, plots owned or under long-term use rights were more likely to be improved (fertilized, mulched, irrigated, or have trees planted on them) than those under short-term use rights such as rental. But for Kenya they

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[9] In the regressions, we do not include number of parcels because that variable is highly correlated with farm size.

found the relationship between tenure and land improvements was weak—because farmers feel secure in their ability to continuously cultivate rented plots.

Moreover, we expect, as Cook and Grut (1989) found, that rented holdings will tend to be used for annual crop production, rather than for more protective perennial crops and woodlots, whose value is returned over a longer time period.

Price Risk: This is classified by Feder et al. (1992) as a variable affecting "confidence in the short term." This usually reflects rainfall variability in Rwanda, and we expect it to be a disincentive to investment.

6.3.4. 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 landholders are better able to spare land to set aside for anti-erosion measures, for fallow, or for pasture or woodlot. Largeholders tend to be wealthier, and so have more cash to hire labor and buy inputs for land improvements (Grabowski 1990).

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

Farmers with smaller landholdings have greater incentive to improve their land, as they are more dependent (*ceteris paribus*) on less land than farmers with larger holdings (Boserup 1981; Ehui et al. 1992). Boserup (1965) maintained that as population density increases and land becomes scarce (farms grow smaller), fallow periods must be shortened and technologies must be adopted that are intensive in factors that substitute for land. Maro (1988) showed that increased population density in highland Tanzania has led to agricultural intensification using irrigation in one area and terracing of steep slopes in another area.

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 (Cook and Grut 1989). Applying more labor to a given unit of land and planting more densely, however, 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 intensification path will deplete Rwanda's soils in the longer run.

However, the "ceteris paribus" assumption in the above paragraph has allowed us to ignore only for a moment what we must now recognize: Small farmers are driven to diversify incomes off-farm to manage risk in fragile resource settings—risk that is an incentive to diversify their asset portfolios and incomes to deal with an uncertain environment (Binswanger 1986; Robison and Barry 1987).

In sum, smaller farmers are compelled on the one hand to make these investments because they depend more on their small plots, they can fallow less so need to seek intensification strategies, and have more labor per-hectare to use for land improvements. But on the other hand, the very smallness of their farms and the riskiness of their environments mean that the desire is stronger to divert resources to diversify their incomes. The cash from these off-farm activities, however, 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 one's own liquidity sources (such as off-farm income and crop sales) will be critical to on-farm investments (Reardon et al. 1992). Moreover, even where the credit market is functioning but underdeveloped, Reardon and Vosti (1992) contended that the least likely investments to receive credit are conservation measures.

Thus, we posit no clear hypothesis about the effect of nonfarm income on agricultural investments. 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.

6.3.5. 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. Furthermore, the more educated the household members, and the better trained they are in land conservation practices, the more we would expect them to make investments and manage resources carefully.

6.4. 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 the 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 sets 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) that were interviewed in 1991 by the Agricultural Statistics Division (DSA) of Rwanda's Ministry of

Agriculture. Interviews with the 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 our present purposes, we integrated this data with data sets on farm and livestock enterprise management from the Ministry's national longitudinal survey from the same sample of households. This survey was described in greater detail in Chapter 2.

6.5. Data Patterns

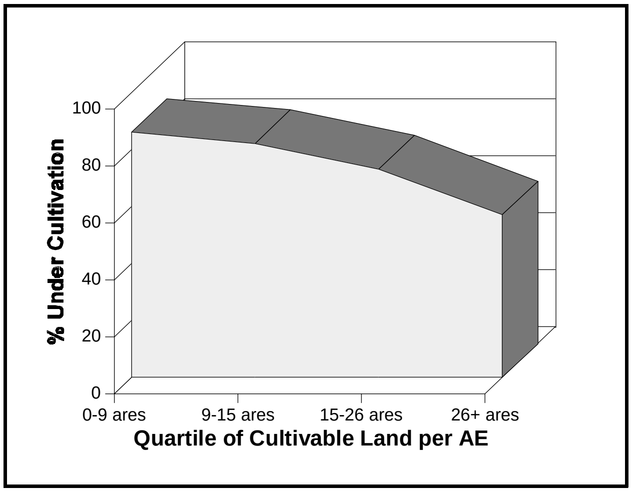
Though most of the model variables were discussed in Chapter 2, they are grouped and listed here (Table 6.1, page 80) according to the model specified above. It is important to note that for purposes of the present analysis, many of the summary statistics in Table 6.1 are reported at the plot level (as indicated). These figures may differ slightly from those reported at the household level in earlier chapters. 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), but there is great variation over parcels (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 all 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 farmers hold a greater share of land in fallow than do smaller farmers. Figure 6.1 shows that the quartile of households with the 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 one's own business income) constitute on average about one-third of households' total income, and about two-thirds of all surveyed 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.

Figure 6.1. Share of Cultivable Land under Cultivation



Source: Computed from MINAGRI/DSA household survey data, 1989.

6.6. Regression Results and Discussion

This section examines the determinants of land management strategies in Rwanda. Ordinary Least Squares (OLS) and logistic (logit) regressions on soil conservation investments, fertility-enhancing input use, and land use (C-values) are estimated using the variables described above and in Chapter 2 of this study. The regressions explaining C-values and conservation investments are run using OLS.[10] 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.

6.6.1. Land Use Determinants

As expected, the 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

[10]Because the OLS regressions are estimated using plot-level observations, estimates are weighted according to parcel size, as well as for the household's probability of selection.

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.

Steeper slopes and more rainfall mean lower C-values, as expected—farmers are choosing more protective land uses for steeper slopes and hillsides than in the valleys. 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 (1990) argued, farmers have not grown their more protective crops (bananas and coffee) on the very steepest slopes. 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) on land they rent than on land they own. Additionally, 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. Moreover, the association could be due to cash crop profits being invested in nonfarm business. More livestock translates into more erosive land use, but the reason why this occurs 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 number of adults in a household, nor dependency ratio show 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. This finding comes as no surprise given that, as shown in Figure 3.2b (page 30), crop composition does not differ much over farm size categories.

Kangasniemi and Reardon (1994) explored in more detail the issue of the difference in C-values between 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. They took 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 (see Figure 6.2 here). They found 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

Figure 6.2. Percent of Cultivated Land with Many Trees, by Size of Holdings in Ares/AE

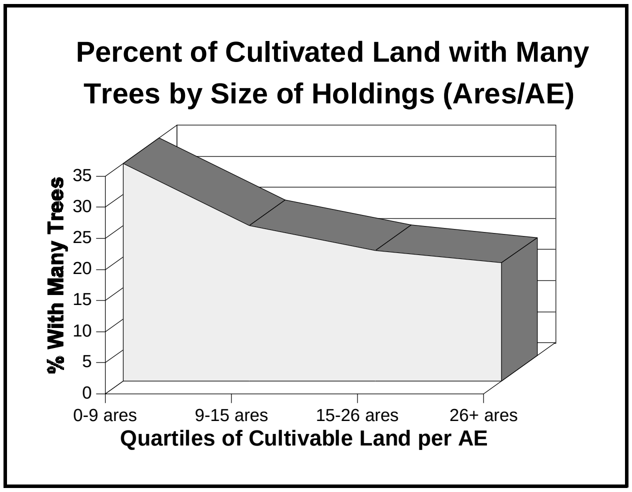


Figure 6.2

Source: Computed from MINAGRI/DSA household survey data, 1989.

sustainability of Rwandan agriculture, small farmer strategies in the short- to medium-term have, overall, offset the inevitable impacts of population growth on the land.

However, Kangasniemi and Reardon also found that above 2,000 meters altitude, which covers one-fourth of Rwanda's agricultural area, land use practices are highly erosive and becoming more so with population growth. The explanation lies in the fact 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 than bananas in that area, 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 showed 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 the larger war against erosion. How crops are managed is another story. 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 nearly universal mulching previously. Some observers of Rwandan agriculture predicted some years ago that as the availability of organic matter from previously uncultivated valley bottoms and other areas declined, mulching would decrease (Jones and Egli 1984). 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 neglect these trees, 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 the 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.

6.6.2. Conservation Investments: OLS Results

Table 6.2 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 is found 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 their efforts 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.

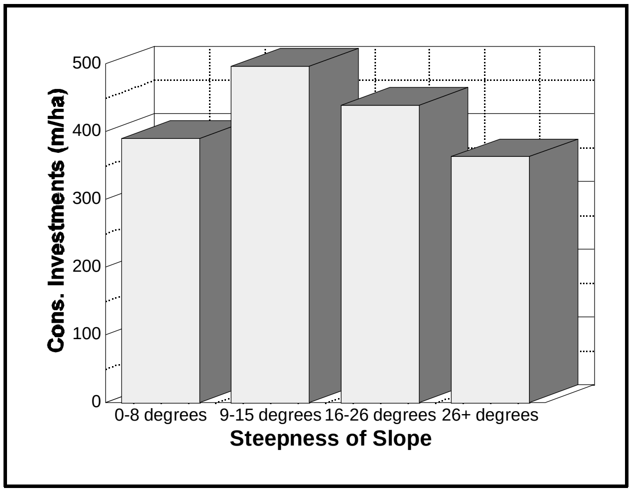
The relationship between conservation investments and field slope is complex. Though the OLS regressions in Table 6.2 show a small but significant negative association, closer examination of the relationship between slope and conservation investments (see Figure 6.3) shows that farmers invest most heavily 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 (Pingali and Binswanger 1984), as

Table 6.2. OLS and Logistic Regressions: Land Use/Investments/Inputs Model

Independent Variables	Land Use (C-value) (OLS)	Conservation Investments (m/ha) (OLS)	Organic Inputs (Logistic)	Purchased Inputs (Logistic)
Correlation Matrix: Land Use, Investments and 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 prefecture	-.06**	-.16**	-.04**	-.10**
B. Physical Incentive to Invest				
Share 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'
Source: Computed from MINAGRI/DSA household survey data, 1989.

Figure 6.3. Conservation Investments by Slope



Source: Computed from MINAGRI/DSA household survey data, 1989.

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 landholders tend to make fewer conservation investments and use fewer organic inputs than do smaller farmers. This may confirm the hypothesis that credit (with land as collateral) is not important to these investments. Largeholders 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 landholders are not compelled to take conservation measures to meet daily food and cash needs. Many smallholders, on the other hand, appear to recognize that such investments are vital to their livelihoods, even in the short-run. Thus, the pressure to intensify farming practices is less for larger landholders than for smallholders.

Consistent with our expectations, nonfarm income as a liquidity source for investments (hiring labor, buying materials) exerts a positive effect on conservation investments.

The value of agricultural production and wealth in livestock have significant effects on conservation investments. More livestock and agricultural production are also linked to greater use of organic inputs and production of 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 also 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 (1994), using the same data, showed that some conservation practices are positively affected by this knowledge, while others are not. 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. This 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.

6.6.3. Use of Organic Matter and Purchased (Chemical) Inputs: Logistic Regression Results

Table 6.2 (page 90) 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, the steeper the slope of the plot, the less likely it is 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.

Farmers with more land 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 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 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 the low overall use rates for fertilizer, lime, and other purchased inputs, Figure 6.4 shows that farms in the higher nonfarm income categories are almost twice as 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.

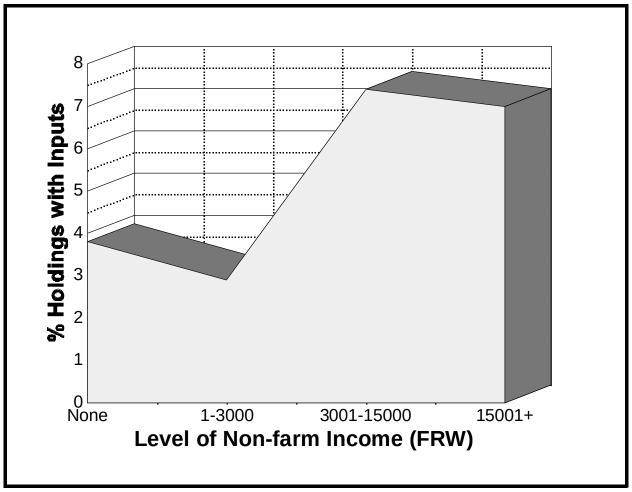
6.7. Conclusions

Regarding land use determinants (in terms of erosivity), our key findings are as follows: (1) There is a fortunate coincidence between better earnings from key cash crops (bananas and coffee) and lower erosivity of land use. (2) The steeper the slope and the more rainfall, the less erosive are land use choices (coffee, bananas); the inverse is true for rented plots, about which households have lower confidence in the long-term. (3) More nonfarm income and higher off-farm wage both reduce the erosivity of land use, probably by taking the pressure off the farmer to "mine" the land with annuals for food security. (4) Extension counts—farmers' knowledge of conservation and productivity-enhancing technologies is strongly and significantly associated with less erosive forms of land use.

Regarding determinants of investments in soil conservation, our key findings are as follows: (1) The more profitable agriculture is, the more farmers invest in soil conservation. (2) Farms with less land in fallow make more investments. (3) Farmers make more soil conservation investments in holdings that are located higher on the slope, where erosion has historically been the most severe, and on slopes of medium steepness (steep enough to need anti-erosion measures, but not so steep as to discourage investment). (4) Farmers invest less in rented-in land. (5) Smaller farmers make more investments. (6) Farmers with more nonfarm income make more investments, as they have more liquidity of their own with which to buy materials and hire labor. (7) Use of extension services promotes non-traditional types of investments.

Regarding determinants of the use of organic matter (mulch, manure, etc.) and purchased inputs (fertilizer, lime), our key findings are: (1) Organic matter substitutes for fallow. (2) Inputs are less likely to be used on steeper slopes because of runoff. (3) Rented land receives fewer organic inputs. The effects of fertilizer and lime are more immediate, however, so confidence in land use rights in the longer term does not affect their use. (4) Price variation (short term risk) discourages the use of both organic and purchased inputs. (5) Smaller farmers are more likely to use organic matter (as they have less fallow), but larger farmers are more likely to use fertilizer and lime, probably because they are more able to afford them. (6) Farms in the higher nonfarm income categories are about twice a likely as the lower nonfarm income groups to use purchased inputs. This implies a credit constraint.

Figure 6.4. Use of Purchased Inputs by Level of Non-Farm Income



Source: Computed from MINAGRI/DSA household survey data, 1989.

(7) Farmers with more livestock use more manure. (8) Farmers that receive extension services are more likely to use fertilizer.

In general, then, we find: (1) Having insecure land use rights (rental) discourages longer-term investments (such as soil conservation measures, planting perennials, and using manure and mulch), but does not discourage measures with short-term effects, such as fertilizer use. (2) Nonfarm income, an important source of one's own liquidity in this setting of underdeveloped credit markets, is important for undertaking substantial outlays for soil conservation investments and input purchase, and apparently acts as a "buffer" that allows farmers breathing space to make long-term investments in perennials.

The Rwandan government seeks to achieve the following policy goals: Improve food security through increased farm productivity and profitability, combat soil degradation, and diversify rural household incomes (Commission Nationale d'Agriculture 1992). In addition, long-term reform of the land market is on their agenda. We believe that the above results lend empirical support to the mutually-reenforcing nature of these aims. Our conclusions should also be important to external donor programming, as they imply that, under certain circumstances, projects aimed at developing nonfarm enterprises by farm families can indirectly promote sustainable intensification and soil conservation on-farm. Moreover, increasing the extension service's emphasis on new and appropriate conservation measures has clear payoffs at the farm level, and also increases the compatibility of the above policy goals.

CHAPTER 7

IMPLICATIONS

7.1. Introduction

The horror of genocide and civil war have turned the world's attention to Rwanda over the last year. But before and beyond that conflict, there was and will be hunger and the slow, grinding poverty of smallholder agriculture pitted against severe land scarcity and soil degradation.

This report is about reversing the spiralling decline in rural Rwanda. Three things conspire to make up this decline—unsustainable land use practices (intensifying land use without sufficient investment in soil fertility and land improvement), insufficient nonfarm employment, and rapid population growth.

We focus on the forces behind productivity decline in Rwandan agriculture. The report examines the following four sets of questions.

a. What are the patterns of land and labor productivity in Rwanda? How do these patterns vary by agroecological zone? By crop? How do Rwandan productivity levels compare with other countries in the region?

b. What are the determinants of land and labor productivity? In particular, what are the impacts of farm size (and hence demographic pressure), farm input use, livestock husbandry, soil degradation, land use and landholding changes, soil conservation investments, and the nonfarm income strategies of farm households?

c. What are the determinants of farm input use (especially fertilizer and organic inputs) and investment in soil conservation measures on farms?

d. What kinds of incentive policies and programs will promote sustainable land management and productivity enhancement?

The research is based on collaboration between the Agricultural Statistics Division of the Rwandan Ministry of Agriculture (DSA/MINAGRI), and Michigan State University (MSU) in the context of the MSU Food Security II Cooperative Agreement with USAID.

The data used in the research derive from a detailed farm-level survey, one of the most comprehensive in Africa, conducted by DSA/MINAGRI. DSA has been, and we hope will be again, one of the national treasures of Rwanda.

The DSA baseline survey covered a nationwide random sample of 1,248 households (operating 6,464 plots), and was undertaken over 11 years, from 1984 to 1994. The survey enumerated production and other activities of the sample every week over the course of a year. Most of the report focuses on data collected from 1989-1991. The baseline data were supplemented with data from the DSA Agroforestry survey, which enumerated soil conservation measures taken by sampled households in the baseline survey, as well as reported changes in long-term productivity and perceived determinants of these changes.

Our *key findings* are that Rwandan farmers need to sustainably intensify their farming by first protecting the soil against erosion, and then enhancing soil fertility through the use of organic matter (manure, mulch, etc.), chemical fertilizer, and lime. Without more input access and use, as holdings grow smaller, the inevitable intensification of farming will be based only on adding more labor and cropping more intensively (the labor-led path), both of which will degrade the soils and lead to greater hardship. The labor-led path can appear to be successful in the short-term, but in the long-term it undermines the natural resource base of agriculture—with predictable yield consequences. Where farmers are now making these investments, we report successes. We find that success in following the capital-led path is often predicated on confidence in the future (owning one's land), knowledge from extension services, cash and labor resources from off-farm earnings, holding livestock to provide manure, and planting perennial cash crops.

The rest of this chapter discusses (1) trends in Rwandan agriculture and performance thereof, particularly with respect to yields, (2) study findings regarding the determinants of productivity, (3) study findings regarding the determinants of land use, soil conservation investments, and use of inputs, and (4) policy and strategic implications.

7.2. Trends and Problems

Rwanda's rate of population growth is still among the world's highest (above 3.0 percent annually). Their average rural population density of 574 inhabitants per-square-kilometer of arable land is the highest in Africa. Most arable land is under cultivation.

Under this demographic pressure, farm sizes are very small, averaging 0.83 hectares per-household—and getting smaller with the increasing rural population. Land is unequally distributed by smallholder African standards. Use of fragile lands on steep slopes is expanding, and fallow periods are growing shorter.

Chapter 3 examined trends in aggregate, zone-level, and farm stratum (by farm size) patterns in average land and labor productivity. The evidence presented confirms that per-capita food production is declining in Rwanda—from 1984 to 1991, it dropped by 25 percent. Half of the farmers surveyed report declining productivity. Half of Rwanda's farmland suffers from moderate to severe erosion. DSA/MINAGRI data for 1984-1991 shows that, except for maize, yields of all major crops (bananas, beans, sweet potatoes, cassava, sorghum, maize, and coffee) have declined. There has been a strong decline in yields of tubers, the main source of calories for the poor. FAO data supports the DSA data on this overall productivity decline, showing that Rwanda lost much of its yield superiority to similar countries in the region during the 1980s—falling behind in cassava, maize, sweet potato, and (to some countries) in coffee.

Rwanda still has comparatively high yields in its main cash crops, however, white potatoes, sorghum, coffee, and tea. Moreover, despite the yield declines of the 1980s, bananas and sweet potatoes still can produce large quantities of calories per-hectare. These crops, together with maize (that has a strong potential for higher yields), hold promise either as food or cash crops.

Inter-zone differences in land productivity are substantial for specific crops, and for crops in the aggregate. The extremes are the two western zones, with the Northwest producing twice as much per-unit-of-land as the Southwest.

Compared to larger farms, smaller farms have higher yields (60-95 percent higher, depending on the crop) and marginal value products of land. Labor productivity on smaller farms is lower than on larger farms.

Coffee and bananas (the key cash crops, and crops that protect the soil from erosion) and cassava yield particularly better on smaller farms (with cropping more intensive in labor). The smaller the farm, the more land is allocated to bananas and coffee. Smaller farmers, however, prefer potatoes (sweet and white) to cassava, as the former have higher yields (per-hectare) in caloric terms. Bananas and white potatoes provide the highest returns to labor.

7.3. Determinants of Productivity

Chapter 4 examined cross-sectional survey data on production, input use, and capital investment, focusing on how these factors affect productivity in Rwanda. It tested the hypotheses that (a) small farms have higher land productivity than large farms, (b) soil erosion strongly reduces land productivity, and (c) soil conservation investments strongly improve land productivity. If smaller farms had more eroded soils than larger farms, the effects of erosion would be to diminish any gains in productivity obtained through greater intensification. However, we find that smaller farms do not have more eroded soils (in the short- to medium-run at least) than larger farms because they use more soil conservation measures. We found four sets of key results.

First, we found a strong inverse relationship between farm size and average and marginal land productivity, with the opposite being true for labor productivity. For smaller farms, the marginal value product of land is well above the rental price of land, implying factor use inefficiency and constraints to land market access. By contrast, for larger farms the value product and rental price are nearly equal. The findings for labor are the inverse: The marginal value product of labor for smaller farms is well below the market wage, while they are nearly equal for larger farms. This implies that there are constraints to access of labor market opportunities for the smaller farm households.

Second, land productivity on very eroded farms is 21 percent lower than on farms with little erosion. The most extreme case is for farms with a small share of high-value cash crops (bananas and coffee) and a small share of cultivated area to which fertilizer or organic matter has been applied. The level of productivity on these farms is 36 percent lower than on farms with little erosion.

Third, on average, farms with a relatively high level of soil conservation investments have 25 percent greater land productivity than those with few of these investments. Farms with a high share of low-value crops (food crops, annuals) and high erosion gain the most from these investments; they have 33 percent higher productivity than the average. Those that gain the least are households with a large share of perennial cash crops and low erosion.

Fourth, increasing the share of farm output coming from high-value cash crops (bananas or coffee) strongly benefits incomes of smallholders, with land productivity increasing by 50 percent. The yield gains from shifting to cash crops are clearly highest for those with better farm conditions, i.e., those with low erosion and high use of fertilizer and organic matter.

There appears to be a degree of substitutability between perennial cash cropping and soil conservation investments. The catch is, however, that getting a strong farm yield and income effect from cash cropping requires that land be less eroded to begin with, and that farmers be able to use substantial quantities of improved inputs (fertilizer and organic matter).

Chapter 5 also focused on land productivity, but from a different perspective. Here we examined farmer-reported data on the long-term changes observed in land productivity and fertility, and farmers' perceptions about the causes of this changing productivity. This chapter also examined some of the key linkages between population pressures and declining agricultural productivity, specifically those linkages involving demographically-induced changes in the structure of landholding.

Emphasis was placed on five important landholding variables of profound importance to farmers in Rwanda, i.e., tenure arrangements (ownership versus use rights), size of holdings, geographical dispersion of holdings, fragility (steepness of slope), and years of operation. Previous studies and current findings reveal that population pressure in Rwanda has been accompanied by dramatic changes along several of these landholding dimensions. More than ever before, farmers must rent the land they operate, their holdings have radically diminished in size, and they see little alternative to farming the steep and fragile slopes once held almost exclusively in pasture, woodlot, and fallow. These factors have had a measurable impact on changes in agricultural productivity as reported by farmers. Less stable land use rights (i.e., land rental rather than ownership), expanded use of fragile lands on steep slopes, and longer periods of use have all contributed to a decline in soil productivity over time.

Farmers reported that on nearly half of their cultivated land there has been a long-term decline in yields.

Off-farm income is shown to improve productivity for the largest and smallest farms, but not for those in the middle. Larger holders often convert off-farm earnings into purchased inputs. By contrast, we speculate that smallholders benefit from off-farm income, not because it is used to purchase inputs, but because it tends to be used to purchase food. In turn this takes pressure off the land and allows farmers to maintain some of the less intensive agricultural practices to restore productivity, such as fallowing.

Livestock ownership translates into improved productivity, especially for largeholders. This is due to little loss occurring in the cycling of nutrients on large farms, since livestock graze on owned land kept in pasture and fallow. Smaller holders must transport manure from wherever livestock are grazed or stabled in order to recapture its beneficial effects on soil fertility. Transporting manure is not a common practice in Rwanda, and would lead to some loss of nutrients even where it is practiced.

Soil conservation investments on steep slopes, as well as farmer education (both for literacy and productivity/conservation techniques) also have a significant payoff.

Most farmers perceive overuse of land as the villain in the productivity decline, and use of organic and purchased inputs as the way to reverse the trend. Soil conservation investments are also seen as being necessary to help arrest the decline, but not sufficient to lead to improvement.

7.4. Determinants of Land Use, Soil Conservation Investments, and Use of Inputs

Chapter 6 examined the determinants of agricultural intensification, i.e., what drives land use, soil conservation investments, and the use of inputs.

Regarding land use determinants, our key findings are as follows. (1) There is a fortunate coincidence between better earnings from key cash crops (bananas and coffee) and lower erosivity of land use. (2) The steeper the slope and the more rainfall, the less erosive are land use choices (coffee, bananas). The inverse is true for rented plots, over which households have lower confidence in the long-term. (3) More nonfarm income and a higher off-farm wage both reduce the erosivity of land use, probably by taking the pressure off the farmer to "mine" the land with annuals for food security. (4) Extension service use counts—farmers' knowledge of conservation and productivity-enhancing technologies is strongly and significantly associated with less erosive forms of land use.

Regarding the determinants of soil conservation investments, our key findings are as follows. (1) The more profitable agriculture is, the more farmers invest in soil conservation. (2) Farms with less land in fallow make more investments. (3) Farmers make more soil conservation investments in holdings that are located higher on the slope, where erosion historically has been the most severe, and on slopes of medium steepness (steep enough to need anti-erosion measures, but not so steep as to discourage investment). (4) Farmers invest less in rented-in land. (5) Smaller farmers make more investments. (6) Farmers with more nonfarm income make more investments, as they have more liquidity of their own with which to buy materials and hire labor. (7) Extension services use reinforces non-traditional types of investments.

Regarding the determinants of organic input use (mulch, manure, etc.) and purchased inputs (fertilizer, lime, pesticides), our key findings are as follows. (1) Organic inputs substitute for fallow. (2) Inputs are less likely to be used on steeper slopes due to runoff. (3) Rented land receives fewer organic inputs. The effects of fertilizer and lime are more immediate, however, so confidence in land use rights in the longer-term does not affect their use. (4) Price variation (short-term risk) discourages the use of both organic and purchased inputs. (5) Smaller farmers are more likely to use organic matter (as they have less fallow), but larger farmers are more likely to use fertilizer and lime, probably because they are more able to afford them. (6) Farms in the higher nonfarm income categories are almost twice as likely as the lower nonfarm income groups to use these purchased inputs. This implies a credit constraint. (7) Farmers with more livestock use more manure. (8) Farmers that receive extension services are more likely to use fertilizer.

In general, then, we find: (1) Having insecure land use rights (rental) discourages longer-term investments (such as soil conservation measures, planting perennials, and using manure and mulch), but does not discourage measures with short-term effects, such as fertilizer use. (2) Nonfarm income, an important source of one's own liquidity in this setting of underdeveloped credit markets, is important for undertaking substantial outlays for soil conservation investments and input purchase, and apparently acts as a "buffer" that allows farmers breathing space to make long-term investments in perennials.

7.5. Strategic and Policy Implications

In 1992 the Rwandan government announced its strategic policy goals to raise and sustain rural food security. These were: (1) increase farm productivity and profitability, (2) combat soil degradation, and (3) diversify rural household incomes to increase purchasing power and reduce pressure on the land (Commission Nationale d'Agriculture 1992). In addition, although interest in productivity was traditionally focused on food self-sufficiency for Rwanda, interest in recent years has turned to increasing the output of products that are promising prospects for intra-regional trade.

Government and donor attention is focused now, and will be for some time, on the immediate problems of the displaced, relocation, refugee camps, and disease and hunger occasioned by the four years of civil war. But in the medium-term, the government and donors will need to turn their attention back to the food security goals highlighted in the previous paragraph to ensure long-term survival and development in Rwanda's countryside. We hope that the findings of this report and their implications will be taken into account in present efforts to move from "relief to development," and serve as strategic guideposts in agricultural policy debate thereafter.

The contributions of this report are in: (1) underscoring and focusing on priority strategies and questions among the many issues that have come in and out of development debate in the highland tropics of Africa, and (2) the systematic application of detailed, nationwide survey data to these key questions. Moreover, the report points to the great value of excellent, national agricultural statistics services and the national capacity to analyze data and provide insights for policy debate.

In the medium- to long-run, attaining rural food security objectives in Rwanda, and in the highlands of East Africa in general, depends on farmers' sustainable intensification of agricultural production. Growth of agricultural output must keep pace with the country's rapid population growth and is necessary to build trade ties in the region and abroad. This will require greater use of improved inputs.

What are the priorities for increasing the use of improved inputs? There are limits to what can be accomplished by merely intensifying cropping by adding labor and increasing crop densities—this labor-led path to intensification will not stop soil degradation in the long-run. Rather, we have identified the following priority strategies. First, farmers need to invest in and maintain soil conservation measures such as bunds and terraces to protect input applications and fight erosion. Second, the use of organic matter (with mulch from perennials, manure from animals, and green manure from windbreaks) and fertilizer/lime needs to be greatly increased.

7.5.1. The Right Conditions

We have learned that farmers will not and can not greatly increase the use of these key inputs and investments without certain *conditions* being present.

First, it is clear that after four years of civil war, farmer confidence needs to be restored. Without political stability it will not be possible to expect productivity investments.

Second, agriculture needs to be profitable from both the output price side and the input cost side. We find that the drop in the coffee price reduced investments in coffee, and the high cost of fertilizer made it unaffordable for many.

The general conditions of stability and profitability are, however, necessary but not sufficient. More specific policies and programs are needed to enable farmers to make investments once the general conditions are in place.

Third, we find that farmers need confidence in the longer-term through secure land tenure. This means reducing the risk of appropriation, and increasing their right to transact land. This will require reform of the land laws. The implications of political stability on land tenure and productivity are discussed again below in the following section.

Fourth, farmers need knowledge of productivity and conservation practices; we show that extension services have been, and can be, an effective tool for technology dissemination in Rwanda.

Fifth, farmers need cash income to buy materials, animals, and labor—for productivity and conservation measures—which can be expensive relative to a single year's crop income. Key sources of cash are nonfarm activity and cash cropping. Nonfarm activities also increase the demand for crops through downstream production linkages. Alternative income sources also reduce pressure on the land. These can be promoted through nonfarm microenterprise programs. It will also be useful to address the development of rural credit institutions.

7.5.2. Strategic Priorities

The presence of the appropriate conditions will spur demand for improved inputs. Programs and policies should be ready to increase the supply, accessibility, and use of inputs, and to encourage conservation investments. We believe that the findings presented in this report have clear implications for external donor programming, and for the broader relief to development trajectory that the donors envision for post-crisis Rwanda.

Access to Organic Inputs: "Relief to development" strategies of donors and Rwanda's new government need to include building up the base of productive assets—notably livestock and perennial crops.

We have already referred to the decline in manure availability (per-hectare) caused by the disappearance of pasture land and livestock. Though small ruminants, especially goats, seem to be increasing in number, there has been a significant decline in the number of cattle raised. When measured in Tropical Livestock Units (TLU), the overall trend has been downward, both in aggregate numbers and per-hectare (Rwamasirabo 1991). There appear to be several constraints to the greater use of animal manure.

a. The first constraint is that Rwandan farmers have not made sufficient use of available livestock intensification technologies. For example, the great majority of livestock owners still graze their animals away from home, often on public lands. Permanent stabling technologies for cattle, goats, and sheep are used by approximately 25 percent of the households (Rwanda 1986). Though low, this figure is a considerable improvement over the 5 percent permanent stabling rates reported in 1984. We see the slow shift to more intensive livestock technologies as a shortcoming of local research and extension services. The technologies exist and have been applied successfully in other countries, but need to be more aggressively adapted and disseminated in Rwanda.

b. The second constraint, which is tied to the first, is that Rwandans do not collect animal manure for application on the farm, as is done in China and other Asian countries. This represents a significant loss in valuable organic matter, particularly for small farmers who tend to graze their livestock on public lands. On-farm handling of manure can also be improved. Under current practices the nitrogen content of manure is diminished due to exposure to the sun.

c. The third constraint is that, by international standards, livestock mortality rates are very high (Rwamasirabo 1991). East Coast fever and other preventable diseases are the primary causes.

Research and extension programs need to focus on alleviating these constraints. Building stables, integrating fodder and crop production, and the use of hedgerows to grow fodder are all areas for potential improvement. Fodder-banana-hedgerow interactions deserve high priority in the national agricultural research and extension services agenda.

Local research on livestock diseases and veterinary services should also be given priority by Rwanda's new Ministry of Agriculture and in donor programming. This is another area where relief to development funds could have a significant payoff.

In short, the necessary shift from extensive grazing to intensive livestock husbandry was well on its way in Rwanda by 1990. But losses from four years of civil war have left many households without a source of manure. Using disaster relief to build and refill stables, and to focus on animal diseases will help. Research and extension services on fodder crops, manure handling, and disease control technologies deserve priority attention.

Access to Fertilizer and Lime: The supply of purchased inputs is also constrained. There have been numerous small projects designed to increase the supply and use of fertilizer in Rwanda, but these have primarily relied on government fertilizer imports and subsidies. Private sector imports have been constrained by government regulation and licensing requirements.

The study and promotion of the fertilizer/lime subsector are needed. The focus should be on constraints to private sector input marketing. Government regulations and licensing requirements that inhibit fertilizer imports should be examined and potentially eased or eliminated.

Extension services are also needed to promote the use of purchased inputs for food crops, and not just for cash crops.

Many smallholders suffer from severe cash constraints to buying inputs and making investments. Our findings encourage further study of institutional options to make rural and secondary town banks and other sources of credit more accessible to farmers, perhaps along the lines of the Grameen bank.

Soil Conservation: Soil conservation in Rwanda is still a long way from what has been achieved in Nepal, Peru, the Mandara Mountains of Cameroon, and other regions where mountain agriculture prevails. Unfortunately, there are few lessons that could be learned from Rwanda's neighboring states. In Zaire, Uganda and Tanzania, problems of land scarcity have been far less intense and more localized than in Rwanda; all are relatively land-rich and less mountainous. Burundi, on the other hand, has much in common with Rwanda, but it too is still looking for answers. Recent reports from the Machakos district of Kenya, however, offer a sign of encouragement that the downward spiral can be reversed (Tiffen et al. 1994). Much of Rwanda has a population density similar to that of Machakos, though much of the success in Machakos appears to have been due to urban proximity—in combination with cash cropping and agricultural support services. We also find that the latter two factors affect soil conservation investments in Rwanda.

Rwanda's long campaign to increase farm-level conservation investments should be reconstituted and upgraded with new and varied technologies that have been successful in Kenya's Machakos district and other regions of the East African highlands. Controlling soil loss through conservation investments has been shown here to be a necessary condition to improved productivity. Priority should be placed on research and extension services that make options available to farmers (rather than the coercive, state-enforced system employed in the past).

Rwanda has underinvested in the use of green manuring and other agroforestry practices. The integration of trees into cropping systems, for example, has not yet been extended very far in Rwanda, despite the successes of on-station research trials (Yamoah et al. 1987). Green manure is applied to less than two percent of the farm holdings, and hedgerows are grown on just 22.7 percent of all holdings.

Technological research is needed on intensification of inter- and mixed-cropping techniques that increase output and crop density, and incorporate cash perennials, but protect the soil. Moreover, research on conservation investments in the context of the watershed is needed, including collective action to promote household investments.

Land Tenure: Land rental agreements and absentee landholding effectively lower investments in land productivity, including conservation investments and the use of inputs. Revision is needed in land policies and traditional practices, such as laws prohibiting land sales, that impede land transactions and contribute to productivity decline.

This report has shed empirical light on the particular intermediate linkages through which mounting demographic pressure affects land degradation, and in so doing, has broadened our spheres of policy action. One of the most important intermediate linkages examined is land tenure, which is affected by population pressure and, in turn, has been shown to affect land management strategies. In short, the data show that farmers seldom invest in land they do not own. More rented land means fewer investments. We surmise that population change affects the growth of the rental market in two ways.

First, land scarcity has compelled each successive generation of households to look beyond the boundaries of their family holdings. Renting from others, often in distant locations, is one way farm households meet the need to augment their operational holdings.

Second, there is evidence that absentee landholding has increased along with the growth of Rwanda's urban centers. In fact, we contend that the reason why land rentals in the South-Central Zone are higher than elsewhere is because of the relatively large urban populations (Kigali, Butare, and Giterama) in this zone.

Landholding and the maintenance of rural roots are fundamental to Rwandan cultural heritage, and are responsible for much of the country's absentee landholding. Though no firm figures exist on the extent of absentee landholding in Rwanda, even a casual conversation with a random group of rural-born men living in Kigali will reveal that most still own land in their home communities. Furthermore, most of these men say that they intend to return to their land some day, either in their retirement or sooner, when times get tough.

These cultural patterns are compounded by the country's social, political and economic instabilities, particularly in Rwanda's urban areas. Landholding is a safety net for many whose livelihoods and social standing in the city are insecure. The tragic events of 1994 have doubtless sent many thousands of urban families back to the land, and reinforced in almost every Rwandan's mind the importance of maintaining these ties. Thus, instability leads to absentee landholding, which, in turn, is a disincentive to conservation and fertility investments.

Instability can even deter investments among rural owner-operators whose title to land may be uncertain, and among those whose uncertainty moves them to avert risk by placing their accumulated wealth into more liquid assets. Cash, livestock and other goods can be easily transported and exchanged in times of crisis, such as drought or war. By contrast, investing in their land means that farmers must sacrifice a degree of liquidity. The risk can be significant during times of uncertainty, as millions of Rwandans, the majority of whom are still living in refugee camps in Zaire, Tanzania, and Burundi, can affirm.

Thus, a policy environment that reduces the risk (perceived or real) of appropriation of landholdings must be a priority concern. This is true not only from a human rights perspective, which has been the focus of much recent attention, but also from a natural resource management point of view. To date, little thought has been given to how the political events of the 1990s have affected Rwanda's natural resource base.

Even in times of peace and relative stability, however, policies and local custom may be doing more harm than good in terms of land management practices. Though further study is necessary, we hypothesize that the belief that the land is the property of all Rwandans, along with current legal restrictions on the sale and ownership of land, tend to discourage the sale and purchase of land while encouraging the land rental market. In addition, because land rental is a disincentive to conservation and fertility investment, policies and beliefs that impede land transactions contribute to degradation and productivity decline.

To be sure, in many areas, laws prohibiting land sales are not enforced. Land sales do occur in Rwanda, though there appears to be significant regional variation in the regularity of such transactions. Evidence of this variability is suggested by the finding that proportionately four times as much land is acquired through purchase in the Northwest Zone than in the South-Central Zone. What accounts for these differences? To what degree are they attributable to Rwanda's land laws? These are important policy questions that will need to be addressed by members of the new Rwandan government as they seek to stimulate agricultural production and improve its long-term sustainability.

Regional Specialization: The Rwandan Ministry of Agriculture has expressed interest in relating productivity research results to strategies for specialization by region, to increase overall national output and better position Rwanda for intra-regional trade. Our report makes some crop-specific suggestions for zone-level promotion of crops. Moreover, such promotion can be linked to processing infrastructure and input delivery system investments by the government and private firms. We stop short, however, of making strong recommendations concerning area-specific specialization from our diagnostic results. These results are reported at the zone level, which is often broader than the niche area for a given product. Moreover, Rwandan farmers diversify risk and take advantage of micro eco-niches at present, and there needs to be more research on the crop mix objectives and decisions of farmers (the subject of a forthcoming thesis from this project by Kangasniemi).

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