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Fighting an Uphill Battle: Population Pressure and Declining Land Productivity in Rwanda

by

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1. INTRODUCTION

How population growth and increasing land scarcity affect the well-being of agrarian societies has been a subject of considerable debate since the time of Malthus. To this day, proponents of Malthusian doctrine assert that population pressure will eventually reduce food surpluses, arrest agricultural development and lead to environmental degradation, starvation and other "positive checks" (Dupaquier 1983). In contrast to the Malthusian position is an hypothesis articulated in the works of Boserup (1965, 1981, 1985). She posits that conditions of resource scarcity, precipitated by long term population growth, will ultimately give rise to higher standards of living through agricultural intensification and improved productivity.

Empirical studies relative to densely populated regions around the world suggest that both of these perspectives are deficient. For every example of demographically induced agricultural development, a seemingly comparable situation exists where such change has failed to occur, and where the well-being of the rural population and their environment has actually declined. These ambiguous findings derive, at least in part, from a conceptual weakness in the Malthusian and Boserupian paradigms. Neither paradigm takes account of the intervening effects of a *changing structure of landholding*—changes in the fundamental relationships between farmers and their land (Clay, Guizlo, and Wallace 1994).

The research reported here draws attention to the structure of landholding as a set of mechanisms through which demographic changes in agrarian societies can alter the natural environment. These mechanisms, I believe, are especially important, for they constitute both the predominant social, as well as bio-physical, properties that define the relationships between farmers and their land. As such, they are central to our understanding of agricultural development processes and of why some farmers succeed, and some farmers fail, in their efforts to ensure the long-term sustain ability of their land holdings.

First, and perhaps the most obvious demographically-induced change in the structure of landholding, is that farm holdings generally become smaller as an ever-increasing number of households enter the agricultural work force and seek to derive their livelihood from this fixed resource base. Second, holdings tend to become more fragmented, not simply in the number of parcels operated but in the distances between parcels, as farmers look harder and farther for whatever bits and pieces of land may be available. Third, and closely tied to the second, land scarcity obliges farmers to cultivate marginal, less productive land previously held in pasture, rangeland, woodlot and forest. Fourth, many households, particularly those owning little land or with an abundance of family labor, find it necessary to expand their holdings by renting land from others. Fifth, since little new (virgin) land is brought into cultivation, the length of time under cultivation grows longer for holdings already in operation.

Thus, size of holdings, fragmentation/dispersion, fragility, and years of cultivation are among the more obvious physical attributes that differentiate one farmer's holdings from another's. Along the social dimension, land tenure (use/ownership rights) stands out above all others. Increasing population pressure and the ensuing competition for scarce resources precipitates a restructuring of these physical and social attributes of landholding. Although such demographically induced changes in the structure of landholding have drawn considerable research attention in and of themselves, my principal concern is with the impact of these changes on land degradation—notably on soil erosion and the depletion of soil fertility experienced in densely populated areas of the Third World. As shown in Figure 1, the effects of a changing structure of landholding occur indirectly through their impact on land management practices, including patterns of land use as well as investments in conservation technologies and productivity-enhancing inputs.[1]

By altering the bio-physical attributes of farm holdings, the farmer's ability and willingness to invest in the long-term sustain ability of his/her land can be compromised. The application of chemical nutrients, lime, mulch and other inputs to improve soil fertility are both costly and labor intensive. The same holds true for conservation technologies (e.g., terraces and hedgerows) and land use practices (e.g., increasing perennial crops) designed to help control soil loss. Unless farmers, particularly those in developing countries, can anticipate an economic return commensurate with their level of investment they will have little incentive to adopt such practices. One cannot assume that conservation investments will be attractive to farmers simply because those practices are known to protect the resource base (Reardon and Islam 1989). As more distant, steeper (less stable) and increasingly farmed under short-term lease agreements, cost-benefit ratios of conservation technologies will become even less favorable to the individual farmer—the net result being an acceleration of land degradation.

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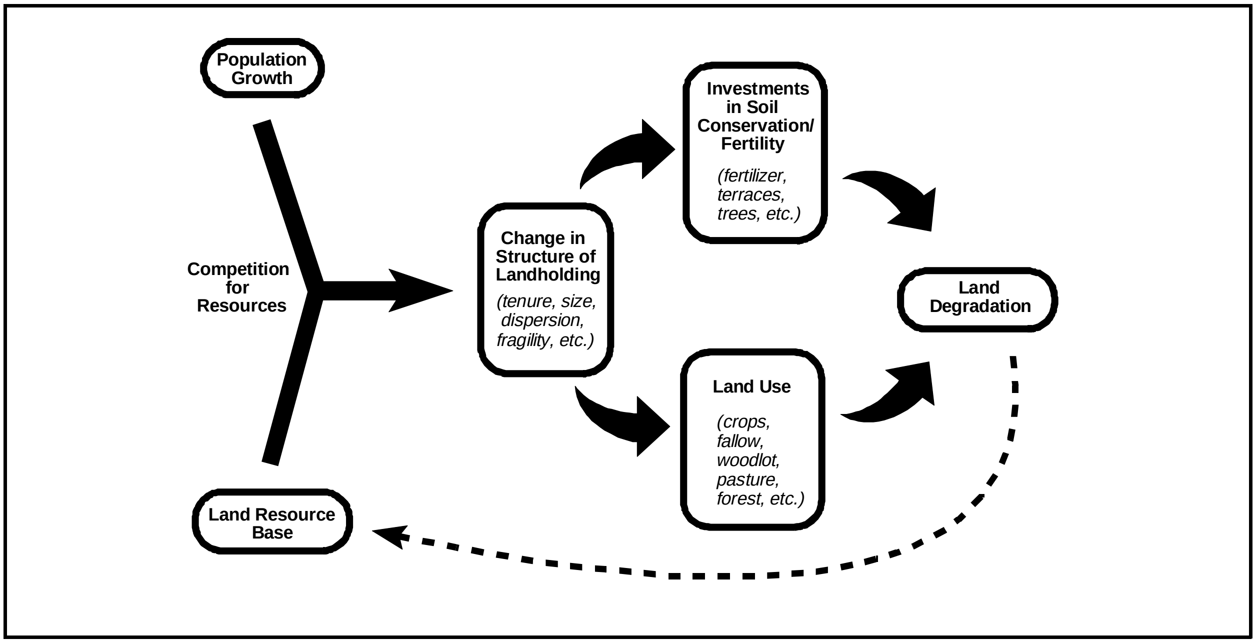
[1] This conceptual framework linking demographic pressure and land degradation through changes in the structure of landholding and land management is developed and discussed more fully in Clay, Guizlo, and Wallace (1994). I caution that the sequence of interrelationships presented in Figure 1 is far from a full accounting of the process of land degradation in low-income, agrarian societies. Such a model would be vastly more complex and comprehensive. It would have to give attention to other factors such as class structure, market forces, the availability and affordability of purchased inputs, and variations in fundamental agroecological conditions. Rather, in line with the stated purposes of this research, Figure 1 provides a framework for conceptualizing only that subset of relationships that helps us understand the critical paths of influence between population pressure and land degradation. This research is equally restricted in geographical scope, targeting problems of land degradation faced by populations of the developing world. My intention is not to downplay the environmental impacts of population dynamics on environmental degradation in industrialized countries, or the global implications of resource use by those nations. However, I do wish to recognize the extreme conditions of declining productivity and food shortage faced by the millions of rural households living in the world's predominantly agrarian societies.

Figure 1. **Conceptualizing how Population Pressure Affects Land Degradation Through Changes in the Structure of Landholding and Land Management (Land Use and Investments in Soil Conservation and Fertility)**



1.1. Focus on Rwanda

Rapid population growth and declining agricultural productivity affect the livelihoods and very survival of millions of rural households throughout SubSaharan Africa. Perhaps nowhere have these effects been deeper or have they created greater hardship than among the farm population of Rwanda, where over 93 percent of the people live in rural areas and where virtually all rural households are engaged in agriculture (Rwanda 1982). Farm production in Rwanda is oriented toward subsistence; farms average slightly less than one hectare of land (Rwanda 1987). Beans and sorghum, supplemented by sweet potatoes, cassava and peas, are the principal food staples. 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 basic farm implements. Livestock comprise an integral part of the farming system, but the progressive conversion of pasture into cropland has caused a reduction in average household livestock production, and a parallel decline in the amount of manure available for improving soil fertility (Rwamasirabo, Clay, and Weber 1991).

The 1992 Demographic and Health Survey reports a total fertility rate (TFR) of 6.2 live births per woman, down from 8.5 a decade ago (ONAPO 1994). Consequently, the rate of population growth remains exceptionally high (above 3.0 percent annually). Small in area relative to population, Rwanda's average rural population density of 574 inhabitants per square kilometer of arable land is the highest in Africa. Virtually all arable land is used for agricultural purposes.

My research focuses on Rwanda's changing patterns of landholding and how this has contributed to the degradation (declining productivity) of agricultural lands. Steep slopes and abundant rainfall are the norm, thus the tasks of field preparation and erosion control are uncommonly difficult for the country's many small holders. Rural population growth has reduced average farm holdings in Rwanda by 12 percent over a period of just five years (DSA 1991), and increasingly farmers are finding it necessary to rent parcels of land from their neighbors.[2] Rwandan farmers in 1991 rented in 7.8 percent of their operational holdings compared to only 5.4 in 1983. The smallest farmers (i.e., the lowest quartile) rent proportionally 2.25 times as much land as all others.

In similar fashion, 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 processes acting on hill slopes will eventually lead to excessive sedimentation in the valley bottoms—conditions now reported to be common in neighboring Burundi (Mathieu 1987) and which, over time, can precipitate flood damage and the destruction of lowland crops (Clay and Lewis 1990).

In summary, population pressure and concomitant land scarcity in Rwanda have in recent decades contributed to several important changes in the structure of landholding. In turn, I believe, these landholding changes have affected the ways in which farmers manage their land and, consequently, land productivity. How, specifically, does the structure of landholding affect land management? What are the repercussions for land productivity?

My study addresses these important questions in two parts. In the first part, I examine each of the major dimensions of the structure of landholding—how they are affected by population pressure, and how they are linked to changes in land management and degradation. The focus is on research findings and conceptual issues from SubSaharan Africa as well as from other regions of the developing world. In the second part, drawing upon nationwide household survey data in Rwanda, I examine the linkages between the structure of landholding and land degradation. In the Rwanda case study, I give special attention to the intervening effects of land management strategies, notably variations in farmer investments (in soil conservation and fertility) and in land use practices.

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[2] Data on the proportion of parcels held under lease agreements are reported in the analysis section of this paper.

2. CONCEPTUAL LINKAGES

Changes in the structure of landholding in Rwanda and in other Third-World contexts, has affected the ways in which farm households manage their land. In some areas, farmers have adopted new technologies (irrigation, drainage, soil conservation structures, etc.) in response to declining farm size, steeper slopes, and other landholding changes. In other areas, technology substitutions (e.g., chemical fertilizers in place of fallow periods or manure) have been the more common intensification strategy. Land-use changes also result from the restructuring of landholding, and often figure prominently in farmer strategies. Fallowing practices (amount and duration), cropping patterns (types of crops grown, multiple cropping, intercropping), pastoral practices, and agroforestry, are among the more important land-use changes observed. I examine the effects of each major dimension of the structure of landholding on land management and degradation below.

2.1. Land Tenure

Long-term use rights through ownership or lease are generally regarded as a necessary precondition for prompting farmers to invest in the improvement of their operational holdings, particularly for some of the more costly soil conservation practices such as terracing and bunding. Short-term use rights discourage investment since the long-term return is not guaranteed for the farmer, and is almost never passed on to his or her heirs. Cook and Grut (1989) report that the same argument may be especially cogent for investments in agroforestry, the returns to which are generally accrued over a longer time horizon. They caution that in parts of rural Africa the tenure issue may have more to do with customary rights over how land is used than with formal laws and regulations. Thus, it is not entirely clear whether improved land-tenure arrangements would motivate farmers to invest in agroforestry technologies for soil conservation.

Migot-Adholla, Hazell, and Place (1990) report that the investment behavior of farmers in Ghana is highly dependent upon the security of land tenure. Land parcels that are operated under ownership or long-term use rights are considerably more likely to be improved than those operated under short-term use rights. This was true not only for investments in fertilizers, mulching, and irrigation, but for investments in tree crops as well. By contrast, the relationship between tenure and land improvements among farmers in Kenya was found to be rather weak—probably because Kenyan farmers feel relatively secure about their ability to cultivate rented parcels on a continuous basis.

In 1988 the World Bank in association with Rwanda's Service des Enquêtes et des Statistiques Agricoles (SESA) conducted a study on the effects of land tenure on agricultural production in three prefectures in Rwanda: Butare, Gitarama, and Ruhengeri.[3] One objective was to ascertain how tenure arrangements influence farmer investments, and, in turn, how such investments affect crop yields. Consistent with the Ghana findings, Blarel (1989) found that Rwandan farmers are far more likely to invest in their own fields than in fields rented from others. Yet, despite the higher level of investment, yields on fields that farmers owned were significantly lower than on the fields they rented. One plausible interpretation is that the fields owned by farmers, though receiving inputs and physical improvements, are more seriously degraded (probably due to continuous cultivation) and thus less productive than fields over which they have use rights only. This interpretation is reexamined in the light of more recent findings presented in the following section.

Land-use patterns, like investments, often reflect the stability of use rights. Holdings operated under long-term use rights are more likely to be planted in perennial crops, used for wood production, or held in "long fallow" than is land that is shared or rented under short-term agreements. Again, if farmers are not assured of reaping the longer term benefits, they will use their holdings to maximize returns in the near-term. For example, the importance of tenure security has emerged in studies of indigenous agriculture in the Amazon region. Alcorn (1989) observes that traditionally, long-term use rights fostered a long-fallow agricultural system in the region. Newer settlers, however, have limited tenure security and thus have developed an extractive, short-term agricultural system that has resulted in rapid depletion of soil nutrients and increased erosion. Land-use controls that were important to the success of swidden systems in the region have broken down due to development policies emphasizing short-term economic growth at the expense of diversification and sustain ability (Schmink and Wood 1987).

2.2. Size of Holdings

The size of farm holdings can affect land management in numerous and sometimes inconsistent ways. Large-holders in traditional agrarian societies are generally in a better position than small-holders to maintain traditional fallowing practices and to set aside a portion of their holdings for pasture or woodlot—all land-use practices that help control soil loss and fertility depletion. Because these farmers also tend to be relatively wealthy, their liquidity enables them to invest in the kinds of inputs and improvements that will raise the productivity of their land in the long term (Grabowski 1990). Large holders are also better prepared to endure the short-term consequences of taking land out of production in order to create space for anti-erosion technologies such as grass strips, trees and bunds. Conversely, small farms in densely populated regions of the world are typically endowed with a relative abundance of labor which can be drawn upon for the construction and maintenance of terraces, bunds, hedgerows, drainage ditches, and other soil

[3] This study was conducted as a part of the same research initiative cited above (Migot-Adholla 1990) with reference to Ghana and Kenya.

conservation measures that require a significant and continuing supply of labor. Moreover, those with small holdings are often in greater need of careful management and the related improvements in productivity. Their lower level of production puts them closer to the margin and thus at greater relative risk should some of their land fail to produce adequate yields.

Relating to the latter point, Boserup (1965) maintains that as population density increases and land becomes scarce (farms grow smaller), fallow periods must be shortened, and levels of investment in productive technologies must increase if populations are to avoid the hardships of migration and/or a declining standard of living. Although Boserup uses length of fallow as the key variable in defining the degree of intensification, inputs such as fertilizers, irrigation, and soil conservation are examples of technologies that substitute for long fallow periods.

Empirical support for Boserup's paradigm has been reported by Maro (1988) who describes several changes in investment and land use which have occurred in Tanzania as a result of decreased farm size. Complex networks of irrigation channels form the basis for agricultural intensification in one area, while steep slopes have been terraced and brought into production in others. Further evidence is provided by Riddell and Campbell (1986) from their work in the Mandara mountain region of Cameroon, where high population densities and small farm sizes have made the development of intensive farming systems a necessity. Over time, farmers in the region have developed a complex farming system based on soil building strategies, integration of animal husbandry with cultivation, and soil conservation. Paradoxically, as more people leave the mountains to farm on the lowlands, problems of soil degradation have begun to emerge. A decline in population density due to out migration has curtailed the amount of labor available for the soil conservation and manuring activities—labor necessary for maintaining the productivity of the system. As Riddell and Campbell (1986) note: "Traditional technology that keeps tropical soils in near continuous production requires dense populations to ensure adequate labor. The Mandara material suggests that these systems collapse as soon as population density is reduced below some critical threshold."

Farms in Rwanda are shrinking in size as farmers continue to subdivide already meager holdings equally among their sons. Though the impact of this phenomenon on the degradation of agricultural lands has received little direct attention from the local research community, bits and pieces of indirect evidence exist which, at the very least, permit us to formulate a few initial thoughts on the question. In his search for an optimal distribution of land holdings, one that would maximize crop yields, Blarel (1989) found that farm size and crop yields in Rwanda were inversely related. Small-holders, it was reasoned, intensify their farm operations through more rigorous use of available family labor, a substitution toward higher-yielding crops, sowing seeds more densely, and growing more crops in association. While more intensive use of family labor has indeed hastened the use of terraces, living fences, mulching and other soil conservation technologies (Cook and Grut 1989), it seems unlikely that some of the other forms of intensification mentioned, particularly changes in plant densities, would be as likely to improve soil fertility. Quite to the contrary, without additional inputs or fallowing, such intensification will undoubtedly precipitate even greater depletion of the soil.

2.3. Dispersion/Fragmentation of Holdings

The World Bank Land Tenure Study also addressed the issue of land fragmentation (*morcellement*) in Rwanda and its impact on crop yields. It is important to note that fragmentation is distinct from the process by which farms become smaller over time due to the division of holdings among two or more children. I adopt the definition of land fragmentation employed by the World Bank (Blarel 1989), which emphasizes the "geographic dispersion" of land holdings. Large farms and small farms alike can be pieced together from many individual parcels. For purposes of understanding the structure of landholding in Rwanda, I am more concerned with the *distance* (time) farmers must travel on foot to work and improve their fields than with the number of parcels operated or the size of individual parcels.

Blarel reports that the dispersion of holdings has not had a negative effect on crop yields in Rwanda. Indeed, dispersed farms and parcels show higher yields overall than do consolidated farms. One suspects, however, that at least part of the reason why more distant parcels may be more productive is that, like parcels rented from other farmers (as suggested above), soil depletion and degradation through erosion is less advanced than on parcels that are owner-operated. More distant parcels are often located at the base of the hillside and in the valleys where the degenerative effects of soil erosion are less severe, and where lands have been brought into production more recently.

In the Anloga region of Ghana farmers are more apt to invest labor and capital in fields that are closer to the household residence, which is ordinarily built up on sand bars (Migot-Adholla, Hazell, and Place 1990). Because of the particular location of these fields vis-à-vis sand bars, they are more prone to damage from heavy rains and therefore require heavier preventative and reparative investment. Susceptibility to rain damage may be one important factor in the farmer's decision to invest in nearby fields. This pattern of investment, however, may also be a reflection of the "tyranny of space," or the additional costs incurred (time spent en route, energy required to haul materials, etc.) in improving less proximate parcels.

Despite potential advantages of greater agro-environmental diversity (Bently 1990), there may be good reason to believe that farm fragmentation inhibits farmers from enhancing productivity. The greater level of investment required and the relative risk of investing in distant parcels may diminish the incentives for certain types of conservation investments. Farm fragmentation, as a demographically induced change in the structure of landholding, is integral to our understanding of how population pressure can lead to land degradation.

2.4. Cultivation of Marginal (Fragile) Lands

Increasing cultivation of marginal lands and their subsequent degradation is a phenomenon common to densely populated countries around the globe (Gregersen, Oram, and Spears 1992). In many arid and semi-arid areas, and in most forest ecosystems in the tropics and semi-tropics, the problem is acute (Getahun 1991). Because off-farm opportunities are lacking, rural populations look to the process of ecological expansion—the exploitation of resources formerly outside of their immediate environments (Hawley 1950). Migration onto marginal lands, seen here as a significant change in the structure of landholding, is well recognized for its impact on the environment (Hecht 1985; Millikan 1992). The particular form of environmental degradation that results from movements onto marginal lands is quite context-specific. In Guatemala, for example, it is deforestation and watershed destruction; in Sudan, decertification and rangeland stress have followed changes in the management of fragile lands (Bilsborrow and DeLargy 1990). Whatever the case, as farmers/herders attempt to increase production in fragile areas, the dynamics of human-environment relationships in those areas change dramatically. How this shift onto fragile lands affects farmer investments and land use strategies in Rwanda, and how resulting problems of land degradation have emerged, are fundamental questions addressed in this study.

In situations where population growth and land scarcity have pushed farmers to occupy mid and upper slopes, erosion problems are particularly common. The characteristic 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 these marginal lands are taken out of their traditional uses (forest, long fallow, rangeland, etc.) and put under more intensive cultivation. Expansion of cultivation onto marginal lands has resulted in degradation largely because the traditional uses of these lands, notably rangeland, long fallow, and forest are less disruptive of the soil and its natural processes than are seasonal or annual cropping. Clearing these fragile areas of trees and vegetation for purposes of cultivation leaves the bare soils most vulnerable to accelerated erosion from both wind and water. Indeed, the maintenance of vegetative cover is one of the more effective means of controlling erosion in many environments.

The degree to which crops and other types of vegetative cover protect the soil in which they are grown from the effects of erosion varies greatly. Similarly, crops differ in the types and levels of inputs they require. As farmers' holdings decline in size, options for cropping become more limited, and when forced onto marginal lands, their choices become more limited still. Specific slope and soil characteristics of plots not only constrain the choices available to farmers, but also condition the effect of cropping patterns on land degradation. Land use and crop selection is a dynamic process affected by external structures and local conditions. Market and policy constraints affect farmers' decisions to grow crops or employ practices that may be ill-suited for environments that are new to them. As technologies change, or degradation occurs, farmers adapt by adopting practices suitable to new conditions or by moving into environments that may be even more fragile.

The confrontation between human subsistence needs and environmental conservation has became intense and pervasive in Rwanda. Deforestation and protection of the mountain gorilla population are issues that have recently received extraordinary international recognition. And these environmental concerns have grown in recent years because of ongoing political and economic instability. But for the average farm household, changes of more immediate and profound consequence include the cultivation of fragile lands once reserved for pasture and woodlot. 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. Immediately surrounding the household compound, they planted groves of bananas and other essential crops. Bananas have special significance in Rwandan culture because they are used for making a unique home-brewed beer which is served at virtually all formal and informal social gatherings, and is a principal source of income for a majority of farm households. Beyond the inner ring of bananas, a series of outer rings was customarily used to meet other nutritional needs of their households (Nwafor 1979, p. 59). The first such ring was farmed intensively with annual crops for both home consumption and sale. A bit farther down the hillside they grow coffee. Coffee is the country's principal export crop and as such is vigorously promoted by the government of Rwanda.

Beyond the coffee plots, the slope of the hillside was often at its steepest. Consequently, farmers traditionally reserve these areas for pasture and woodlots as well as for many of the less important crops (for which frequent fallow periods are commonly required). At the very outer rings, toward the base of the slope and in the swampy valleys—along ridges that are built up to facilitate water drainage, where farmers raise sweet potatoes and other vegetables to ensure a continuous food supply between harvest seasons.

Because of increasing land scarcity due to population growth, in recent decades many farmers have been obliged to depart from this traditional system. As the preferred lands along the upper slopes become occupied, more young farmers are facing the decision either to cultivate smaller and less fertile plots farther down the hillside or to migrate elsewhere in search of sufficient land resources. Similarly, land in fallow and in pasture have been declining because of the need to increase food production (Clay and Lewis 1990). Only woodlots seem not to have suffered over the past few years, thanks to a strong government campaign aimed at replanting and maintaining them at both the household and communal levels.

Though some of the lost fallow and pasture may be land that is converted into woodlot, it appears that households with insufficient land holdings are being forced to plant ever-increasing proportions of their holdings with sweet potatoes and other tubers (Clay and Magnani 1987; Loveridge, Rwamasirabo, and Weber 1988). These tubers have a higher caloric value than do other crops, and tend to grow relatively well in poorer soils (Gleave and White 1969), such as those commonly found on steeper slopes. But as annual crops they do not compare with the traditional uses of these slopes (i.e., woodlot and pasture) in their ability to control soil erosion. In fact, elsewhere in Africa (Lewis 1985) and in Latin America (Ashby 1985) annual crops are associated with accelerated soil loss.

2.5. Years of Operation

In the past, Rwandan farmers have been able to relocate to other areas of the country in response to growing demographic pressure. In particular, they moved to the country's drier, eastern provinces which were previously the exclusive domain of the country's pastoralist population. This movement was largely spontaneous, though it was also supported by the government through the organization of large settlement schemes called *paysannats*. In total, about 80,000 families were settled in *paysannats* during the 1960s and 1970s (Olson, Clay, and Kayitsinga 1989). Today, however, in the absence of unoccupied lands, farmers continue to cultivate the same holdings year after year and in increasingly intensive fashion. It may be reasonable to hypothesize that long-term cultivation will increase the likelihood of investment in a given parcel. However, all else equal, it will be a sign of soil fatigue.

Thus, though farm size, dispersion, slope location, years of cultivation, and tenure represent five different dimensions of the overall structure of landholding in Rwanda, they are indirectly associated with one another through their concomitant variation with changes in demographic pressure. Population growth in recent decades has meant greater land scarcity. In turn, farmers must now feed their families from smaller holdings than operated by their parents, must cultivate slopes once thought to be too steep and fragile to farm, and must supplement their meager holdings by renting small and distant parcels from others—presumably from those whose resource endowment exceeds the supply of family labor.

The analyses presented in the following section address two interrelated questions, which together comprise the locus of this research: How do these demographically induced changes in the structure of landholding affect farmers' land-use strategies and their investments in soil conservation and fertility? And how do these intervening land management variables in turn affect land productivity?

3. RWANDA CASE STUDY

3.1. Data and Research Procedures

The data analyzed in this paper derive from a nationwide stratified random sample of 1,240 farm households, undertaken as part of the 1991 Survey of Agroforestry in Rwanda.[4] Direct interviews with heads of households and/or their spouses, taking about one and a half hours, were conducted over a six-week period beginning in June, 1991. Interviewers collected information on a variety of topics. At the household level, interviewers asked questions about the use, marketing and problems associated with fuel-wood and other types wood products. For each parcel of land operated by the sampled households, they asked questions or took measurements relative to: land tenure, steepness of slope, location of the field on the slope, soil conservation methods used, the use of fertilizer and other inputs, number and species of trees planted, distance from the household residence, and crops grown.[5]

Changes in Productivity. Interviewers asked farmers series of questions about the changes they observed in the productivity of each parcel of land. Was soil productivity improving or declining? Were these slight, moderate, or large changes in productivity? Parcels were ranked along a seven-point scale of productivity change ranging from "large decline" to "large improvement." Table 1 shows, according to surveyed farmers, that the productivity of 48.7 percent of all cultivated farmland in Rwanda is declining, 37.5 percent has not changed, and only 13.8 percent has increased in productivity over time.[6] For purposes of the present research on change in productivity, the analyses presented in the following section focus only on parcels that have been reported to be either increasing or decreasing in productivity.

Land Use. Erosivity of land use is measured using C-values. The C-value index, a well-known measure that reflects the overall protective quality of crops, is defined as, "the ratio of soil loss

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[4] 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 eight (0.6%) of the 1,248 sampled households had to be omitted from this study. Sampling weights have been adjusted accordingly.

[5] Data on crops grown in each parcel were obtained several months earlier as part of DSA's seasonal area and production survey. Because of a small amount of farm household turnover, and changes in land holdings between the two periods of data collection, the number of parcels on which complete data are available is reduced from 6,464 to 5,798. A comparison of fields dropped from the sample with those retained shows no significant bias on the principal landholding characteristics examined in this study.

[6] Because these figures, and others presented in this analysis are based on data collected at the parcel level, they 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.

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 clearly vary from farming system to farming system for specific crops. 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. In the present study, the C-values used were 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).[7] 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 .14, a composite of many forms of land use and crop mix.

Table 1. Farm Holdings Classified by Level of Reported Change in Productivity Reported by Farm Operators

Reported Level of Change in Soil Productivity	Percent of Land Area	Number of Parcels
Large Decline	21.5	1203
Moderate Decline	13.3	745
Slight Decline	13.9	777
No Change	37.5	2101
Slight Improvement	4.5	253
Moderate Improvement	5.8	322
Large Improvement	3.5	194
Total	100.0	5699

[7] 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 the United States. This is the result of the differences in agricultural practices between the heavily subsidized commercial tobacco production in the United States, and small farmer production for home consumption and local sale in Rwanda.

Conservation Investments. Conservation investments were measured in meters and recorded separately for each parcel of land operated by sampled households. Rwandan farm households vary greatly in the degree to which they invest in soil conservation. Although hedgerows are planted and maintained in only 22.6 percent of holdings, anti-erosion ditches are installed in 47.8 percent, and grass strips are found in 60.3 percent of 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 all farm households have invested in terrace construction. No data are available by 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, no one type of investment is given greater weight than the others. For present purposes the four types of conservation investments are summed into a single, aggregate measure. Over three quarters of cultivated farm holdings in Rwanda receive some form of conservation investment. Among those that do, we find that investments average 555 m/ha.

Use of Farm Inputs. Because of hypothesized differences in the determinants of organic and purchased inputs, the two are treated separately in this analysis. 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 households to an even smaller proportion (4.9 percent) of cultivated holdings. Difficulties inherent in obtaining precise quantities of inputs applied at the parcel level has limited information on input use to a dichotomous, yes-no response for each parcel operated by the household.

3.2. Findings and Discussion

Steady growth of the land rental market in Rwanda, resulting from increasing demographic pressure, has raised concerns about potential land degradation. Conventional wisdom and overwhelming empirical evidence, some of which has been reviewed above, tell us that farmers generally invest more in fields they own than in fields they rent from others. Data presented here also support this assertion; Table 2 confirms that owner-operated parcels in Rwanda are much more likely to have received organic fertility-enhancing inputs, such as manure or compost, and to have been improved through the adoption of anti-erosion technologies, such as terraces and grass strips. The use of purchased inputs, too, is higher on owned land, but the difference is not statistically significant. Land use practices also favor owner-operated parcels as they tend to be under vegetative cover with relatively low (less erosive) C-values.

Paradoxically, despite heavier investments, Rwandan farmers do not report a significantly greater improvement in productivity on parcels they own than on parcels they operate as tenants. This may be due to the fact that owner-operated parcels have been cultivated over a longer period

(23.2 years on average), compared to only 10.7 years for holdings operated under lease agreements. The implication here is that the level of investment farmers are currently making in their own is necessary to compensate for the number of years of intensive cultivation and the loss of nutrients associated with this "mining of the soil," a problem identified as one of the major barriers to agricultural growth and sustain ability across the entire highland region of East Africa (Getahun, 1991). This may also help us understand why Blarel (1989) found higher yields on parcels operated under short-term use rights than under ownership rights.

As population grows and farms become smaller, what happens to soil productivity? Table 2 suggests that declining productivity is more of a problem for small and mid-sized farms than for those in the largest quartile. Large holders are more likely than small holders to invest in fertilizers and other inputs, yet they are less likely to take soil conservation measures such as constructing terraces and hedgerows. This may reflect the large holder's greater liquidity (needed particularly for purchased inputs) and ownership of livestock (to supply manure). Conversely, the small holder has a relative abundance of labor (needed for field improvements).

Land use practices, too, are associated with farm size. Small farms tend to have higher C-values since they place a much greater share of their holdings in annual crops. By contrast, large holders plant a greater proportion of their cultivated land in perennial crops such as bananas and coffee, which tend to be less erosive forms of land use. Large holders have greater flexibility in land use practices than do small holders, for whom the immediate demands of daily subsistence necessitate that nearly all holdings be intensively farmed rather than held in pasture, woodlot, fallow or other environmentally beneficial uses. Those with small operational holdings are able to compensate for less desirable land-use practices by focusing available family labor and scarce inputs on the production and conservation of a reduced number of fields.

The geographic dispersion of land parcels, another dimension of the structure of landholding, is here operationalized as the "distance" (in minutes, on foot) between parcels and the household residence. Competition for scarce land resources does not (yet) appear to be forcing Rwanda's smallest holders to travel to increasingly distant locations in search of land to supplement the family holdings. Since 1983, the average amount of time required to walk from home to field has remained steady at approximately 7.5 minutes.

Though apparently not affected by demographic change in Rwanda, the dispersion of holdings does influence farmer investments in soil fertility (Table 2). This finding is fully consistent with established theory and observation reported elsewhere. Farmers in Rwanda invest relatively little in holdings located more than a few minutes' walk from the household residence. This may be conditioned by the fact that distant fields are more likely to be operated under short-term use rights, but reflects the relatively high cost of transporting inputs and materials needed for soil conservation, as well as farmers' beliefs that their holdings in more distant locations have not yet reached the same degree of exhaustion as those in closer proximity.

Table 2. Conservation Investments, Land Use, and Reported Change in Soil Productivity by Structure of Landholding

Structure of Landholding	Organic Inputs Used *% of holdings*	Purchased Inputs Used *% of holdings*	Anti-erosion Improvements *(meters/ha)*	Land Use *(mean C-value)*	Change in Productivity of Soil *(mean score)*	Number of Parcels
Land Tenure						
Operated by Owner	73.2	5.0	429	.16	-1.26	5147
Operated by Tenant	26.8	3.7	366	.21	-1.20	448
Total	69.5	4.9	424	.16	-1.26	5596
Eta	*.27*	*.02*	*.03*	*.20*	*.01*	
Significance	*≤.001*	*.20*	*.01*	*≤.001*	*.65*	
Size of Farm						
Low quartile	68.1	2.8	528	.18	-1.46	1413
2nd quartile	66.2	2.7	456	.17	-1.29	1414
3rd quartile	73.7	5.1	409	.16	-1.37	1393
High quartile	69.8	9.2	298	.14	-.91	1376
Total	69.5	4.9	424	.16	-1.26	5596
Eta	*.06*	*.12*	*.17*	*.21*	*.11*	
Significance	*≤.001*	*≤.001*	*≤.001*	*≤.001*	*≤.001*	
Distance from Residence *(dispersion)*						
0 min.	93.0	7.4	474	.16	-1.37	2683
1-4 min.	67.7	3.4	433	.17	-1.10	970
5-12 min.	49.6	1.0	410	.17	-1.19	929
13+ min.	26.5	3.5	302	.17	-1.03	978
Total	69.6	5.0	426	.16	-1.25	5560
Eta	*.56*	*.11*	*.12*	*.12*	*.07*	
Significance	*≤.001*	*≤.001*	*≤.001*	*≤.001*	*≤.001*	
Steepness of Slope						
0-8 Degrees	68.2	3.8	390	.18	-.83	1584
9-15 Degrees	71.7	5.5	497	.18	-1.19	1387
16-25 Degrees	69.4	4.3	439	.16	-1.40	1457
26+ Degrees	69.1	6.6	363	.14	-1.60	1166
Total	69.4	4.9	424	.16	-1.26	5594
Eta	*.02*	*.05*	*.10*	*.21*	*.15*	
Significance	*.36*	*≤.01*	*≤.001*	*≤.001*	*≤.001*	
Years of Operation						
0-10 years	50.7	2.7	391	.17	-.84	1488
11-20 years	73.1	5.9	440	.16	-1.23	1450
21-30 years	81.9	7.3	438	.17	-1.13	1075
31-40 years	79.1	5.0	437	.15	-1.53	1554
41+years	68.8	1.8	423	.15	-1.87	
Total	69.3	4.7	424	.16	-1.26	5566
Eta	*.26*	*.09*	*.04*	*.11*	*.17*	
Significance	*≤.001*	*≤.001*	*.05*	*≤.001*	*≤.001*	

Farmers in Rwanda now occupy fragile lands once thought to be too steep and unproductive for cultivation. Formerly, farmers often held these slopes in pasture, but the demand for food from a rapidly growing rural population has caused many households to abandon livestock production in favor of crop production. In just 5 years, from 1984 to 1989, land held in pasture has declined from 10% to 4% of total operational holdings in Rwanda (DSA 1991). Although these steep slopes still have lower C-values than holdings on more level slopes, their degradation is reported to be the most severe of all. Farmers tend to apply more purchased inputs as slope increases, but not more organic inputs. Farmers are less likely to make field improvements on the very steepest slopes where relatively poor soils inhibit costly investment, and on gentler slopes, where the risk of soil loss is lower. Farmers tend to concentrate field improvements on slopes of medium steepness, where their cost effectiveness is the highest.

One of the most powerful determinants of fertility decline in Rwanda is the length of time the land has been cultivated. Table 2 shows that the most serious decline has occurred on holdings that have been cultivated for more than 30 years, and that fewer years of cultivation mean less decline. It is no surprise, then, that older fields tend to receive more organic and purchased inputs, as well as more conservation investments.

In viewing these patterns of investment more closely, however, the evidence suggests that farmers may be abandoning their oldest, most run-down fields. These fields may be past "the point of no return," i.e., a threshold beyond which the marginal return on investments in conservation and fertility diminishes, and thus discourages investment. What leads to this conclusion is that all three types of investment grow with years of cultivation through 30 years, but then decline for parcels cultivated for 31 or more years—parcels reported to have declined in productivity far more than those in any of the younger groups.

How does the structure of landholding influence degradation once the intervening effects of farmer investments and land use patterns have been controlled? And, alternatively, to what degree do such management decisions provide the intermediate mechanism through which the structure of landholding affects the degradation of holdings in this context of intense demographic pressure? The stepwise OLS regression model in Table 3 helps us respond to these important questions. The first step introduces, ownership rights, farm size, fragility and other key structure of landholding variables. The second step introduces measures of land management, such as conservation investments and use of inputs, in order to assess their impact independent of the structure of landholding.

Overall, the structure of landholding emerges as an important set of determinants of productivity change in Rwanda. As expected, fields located on steep slopes, those that have been operated for many years, as well as those on smaller farms, are more likely to be declining in productivity. Distance from the household residence is also an important factor; those in more proximate locations tend to be declining in productivity, probably because they are cultivated more intensively. Though land tenure is important at step 1, its impact disappears at step 2, once the land management variables are brought into the equation. Thus, the importance of land ownership is entirely accounted for by its effect on land management. Farmers invest in the land they own, which in turn improves productivity.

Findings reported in Table 3 also demonstrate that the application of organic inputs such as mulch and manure is the one management practice that exerts a positive and significant effect on long-term change in soil productivity. The use of purchased inputs shows a significant negative correlation with productivity change. This finding reflects the short-lived impact of purchased inputs and the fact that Rwandan farmers tend to apply these inputs, possibly as a last resort, to fields that have declined in productivity despite conservation investments and the use of organic inputs.

Table 3. OLS Stepwise Regressions: Structure of Landholding, Land Management, and Reported Change in Land Productivity

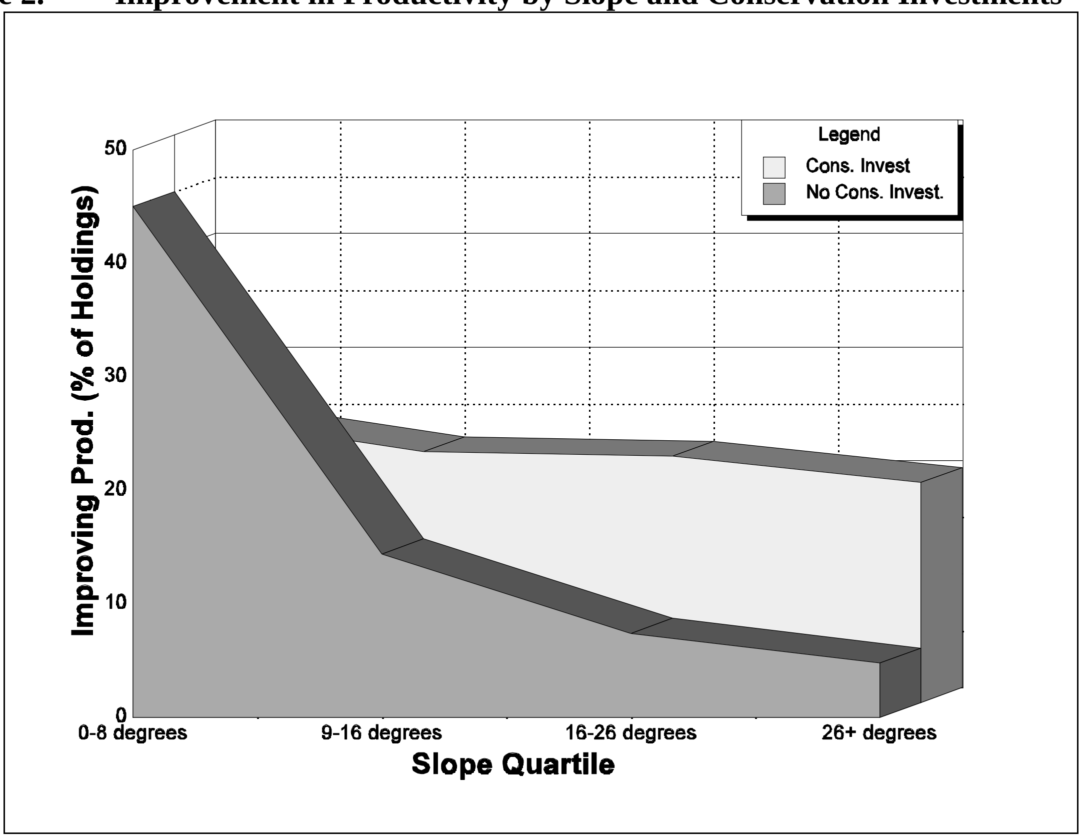
	Reported Change in Land Productivity	
Independent Variables	Step 1	Step 2
A. Structure of Landholding		
Ownership rights (1=own, 2=lease)	-.06**	-.02
Size of Land holdings	.15**	.15**
Distance from residence	.05**	.11**
Slope (degrees)	-.15**	-.15**
Years operated	-.19**	-.20**
B. Land Management		
Organic inputs		.16**
Purchased inputs		-.07**
Conservation investments		.01
Land use (C-value index)		-.02

*Sig T ≤.05 **Sig T ≤.01

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 exert a strong effect on productivity change. In other words, the effect of conservation investments emerges only in the combination with steepness of slope. As Figure 2 demonstrates, conservation investments have a negative association on gentle slopes, but become increasingly important to productivity change as slope increases. Among fields in the steepest slope quartile, productivity is far more likely to be increasing when conservation investments are present than when they are not.

In summary, the long-term sustain ability of Rwandan agriculture will be challenged by continued population growth and resource scarcity. Analyses presented in this section confirm that demographically induced changes in the structure of landholding exert an appreciable impact on reported changes in soil productivity. To the extent that population pressure has resulted in less stable land use rights (i.e., land rental rather than ownership), expanded use of more distant and fragile lands on steep slopes, and longer periods of use, it has been detrimental to agricultural productivity in Rwanda.

Figure 2. Improvement in Productivity by Slope and Conservation Investments



3.3. Conclusions and Study Implications

Population pressure has long been cited as one of the leading causes of environmental degradation in the Third World, but rarely does our understanding of the complex relationship between population and the environment extend beyond the most rudimentary level of generalization. We speak of how growing populations eventually exceed environmental "carrying capacities," often without giving even cursory recognition to the socioeconomic and physical mechanisms through which land scarcity translates into land abuse. But gradually, we are coming to realize that demographically induced problems of resource scarcity can not be solved simply by slowing population growth or by increasing available resources (Simmons 1988:152). While independent research efforts on both sides of the equation are vital, and are highlighted by numerous context-specific successes and failures, the particular *mechanisms* through which mounting demographic pressure affects land degradation must be spelled out with greater conceptual clarity and empirical detail. Understanding these intermediate linkages will vastly broaden our spheres of policy action in the struggle to conserve precious land resources in those areas of Africa, Asia and Latin America where rising population densities are threatening long-term environmental sustain ability.

The research reported here has endeavored to identify and explore a small set of these mechanisms, specifically those involving demographically induced changes in the structure of landholding—the particular pattern of social and spatial relationships observed between farmers and their land. Emphasis has been placed on five important landholding variables of profound importance to farmers in Rwanda: tenure arrangements (ownership versus use rights), size of holdings, geographical dispersion of holdings, fragility (steepness of slope), and years of cultivation. Previous studies and current findings reveal that population pressure in Rwanda has been accompanied by dramatic changes along several of these dimensions of landholding. More than ever before, farmers must rent the land they operate, family land holdings have radically diminished in size, and they see little alternative to farming the steep and fragile slopes that once were held almost exclusively in pasture, woodlot and fallow.

How have these changes affected the long-term sustain ability of farming in Rwanda? Traditional inputs such as compost, manure, and mulch, invariably go on fields owned by the farmers and especially on those located nearer to the family compound. The same principle holds for field improvements such as the installation of terraces, hedgerows, grass strips, and drainage ditches—rented fields and distant fields are largely ignored.

On owner-operated parcels, greater investment in conservation and fertility is seen by farmers as necessary to compensate for the detrimental effects of many more years of cultivation. Without these investments, owner-operated holdings would likely be far more degraded still. In general, the longer a field has been cultivated, the more conservation and fertility investments it will receive. Sure to raise concerns, however, is evidence that after 30 years or so, the level of investment by farmers levels off and begins to decline. Have these fields crossed a threshold in which declining returns to investments become a disincentive to further investment? Do limited resources eventually cause farmers to abandon completely these older holdings? What this means is that farmers are losing a difficult and deeply significant struggle; it means that their prize holdings, those they will pass on to their children, have been worked to the point where, under current circumstances, more investment makes little sense.

Providing incentives for farmers to plan for the long term is no easy matter. Innovative programs are needed. There must be incentive schemes, locally sponsored, that simultaneously extend viable technologies to farmers and encourage them to adopt those best suited to their own particular needs. The integration of trees into cropping systems, for example, has not yet been well extended in Rwanda, despite the reported successes of on-station research trials (Yamoah, Grosz, and Nizeyimana 1987). Green manure is applied to less than two percent of farm holdings, and hedgerows are grown on just 22.7 percent of holdings. Soil conservation in Rwanda is still a long way from what has been achieved in Nepal, Peru, the Mandara Mountains of Cameroon and in other regions where mountain agriculture prevails. Unfortunately, lessons to be learned from Rwanda's neighboring states are few. 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 policy makers there, too, are still searching for answers. Yet recent reports from the Machakos district of Kenya offer a sign of encouragement that the downward spiral can be reversed (Tiffen, Mortimore, and Gichuki 1994).

Rwanda may also have its "success stories." A shortcoming of the present study is that by focusing on changes in productivity across all parcels, most of which have either declined or remained the same, we have said comparatively little about those holdings which appear to have improved in soil productivity. Though relatively small in total area (13.8 percent of all holdings), a focused study of this segment of successful fields may offer some insight into the conditions and investments that will be required of Rwandan farmers over the long haul.

Further, we must caution that the present study has not addressed the "off-farm" issue of deforestation, which is closely tied to "on-farm" changes and is an equally menacing problem in Rwanda today. Indeed, a recent IFPRI publication, *Priorities for Forestry and Agroforestry Policy Research* (Gregersen, Oram, and Spears 1992), underscores the need to develop optimal land-use strategies for small-scale cultivators in wet tropical forest zones, and to address issues of population growth and distribution, shortened fallow periods, and opportunities for incorporating trees and other perennial crops into established farming systems.

Though we can learn much from the kinds of nationwide survey data examined here, our understanding of the constraints farmers face in the application of specific conservation technologies, and of indigenous knowledge and practices already in use, is rather limited. We have a fundamental need for supplementary information of a more qualitative nature on these important questions. Until more is known about how farmers in Third-World, agrarian contexts perceive the notion of resource conservation, and until incentives can be developed to encourage farmers to embark on longer-term strategies that meet their needs, from both environmental and family planning perspectives, the cycle of resource degradation and poverty will most assuredly intensify. Poorly equipped and faced with the daunting charge of producing more food from smaller and depleted holdings, and now scarred by the atrocities of civil war, one must conclude that Rwandan farmers today are not well placed to engage in long-range strategic planning for the environment. They are, indeed, fighting an uphill battle.

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