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MORE PEOPLE MORE TROUBLE:
Population Growth and Agricultural Change in Rwanda
(A Case Study of the Population-Agriculture-Environment Nexus)

by

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with assistance from
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ABSTRACT

Rwanda is a small, landlocked country which until mid-1994 had the highest population density of any country on the African continent. Until very recently, rapid population growth and high densities had been successfully accommodated in Rwanda with relative environmental stability. Agricultural production and population in Rwanda both increased at least 4-fold during the last half century. More recently, population growth has greatly outpaced food production, because of a lack of additional land to put into cultivation, an absence of improvement in farm technology, and decreases in soil fertility. As is argued in a companion paper, increased resource scarcity contributed to the violent conflict in Rwanda by exacerbating social tensions. Even without the severe disruption caused by the killing and the civil war, geographic isolation would be a major barrier to prospects for sustainable development in Rwanda based on nonagricultural employment. The chief lesson for population policy is that rapid population growth is unsustainable in regions which are geographically isolated and lack outlets through either emigration or nonagricultural exports. A corollary for natural resources management is that in addition to interventions in farming systems and resource conservation, facilitating access of rural populations to alternative sources of income may be important for maintaining environmental stability.

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Introduction

This paper is a case study on Rwanda of the Population-Agriculture-Environment Nexus in Sub-Saharan Africa (Cleaver and Schreiber, 1993). It was sponsored by the Africa Bureau of the U.S. Agency for International Development in conjunction with a study by Honadle, Grosse, and Phumpiu (1994) which incorporates a new literature review on this topic. Rwanda was selected for the case study because of its high population density, the highest of any country on the African continent, and because Rwanda has been a major recipient of assistance in the fields of agriculture and natural resources management. The Nexus study of Cleaver and Schreiber focuses on lowland areas of Africa characterized by customary land tenure and land-extensive shifting cultivation or transhumant pastoralism. In contrast, Rwanda is a mid-elevation environment with intensive, permanent cultivation and individualized land tenure.

After this study had been initiated, Rwanda was consumed during the middle of 1994 by a bloody conflagration. Many people have speculated as to responsibility of "overpopulation" in Rwanda for the events that have occurred there. However, a balanced treatment of this question requires a consideration of a variety of historical and political factors. We have prepared a parallel paper which focuses on the historical and demographic roots of the crisis and collapse of the Rwandan state (Grosse, 1994). That paper was prepared with the support of an analytical narrative of the historical and political dimensions of the Rwandan conflict provided by Jennifer Olson. Our analysis elaborates upon the following assessment of the Rwandan situation by J. Brian Atwood, administrator of the U.S. Agency for International Development and special envoy to Rwanda:

> The pyre of failed states is being fired by common fuels: long-simmering ethnic, religious and territorial disputes; proliferating military stockpiles built dangerously high during the Cold War; endemic poverty; rapid population growth; food insecurity; environmental degradation; and unstable and undemocratic governments. Pre-crisis Rwanda was the most densely populated country in Africa; per capita food production was in decline, land was in dispute, and political power was jealously guarded. Extremists exploited those volatile conditions, precipitating the orgy of genocidal violence that ensued.

To summarize the conclusions of our other paper, it is a safe judgement that demographic pressure contributed to the mix producing the Rwandan conflagration, but population variables by themselves cannot be held responsible. In a context of severely limited natural resources and domestic markets and an inability to draw upon external markets, population growth resulted in severe problems of subsistence. First, the increases in agricultural production in the previous decades resulted almost entirely from the expansion in cropped area. After 1980, stagnation in agricultural production resulted in large part from the lack of additional land that could be brought into cultivation. Environmental degradation aggravated the stagnation in agricultural production, although the extent to which land degradation was responsible is debatable. The second manifestation of demographic pressure which we believe contributed in important ways to the violent conflict was the desperation of young people, who lacked any realistic hope for being able to support themselves through gainful employment.

The title of the present paper acknowledges an intellectual debt to two recent volumes. Population Growth and Agricultural Change in Africa, edited by Turner, Hyden, and Kates (1993), balances the gloomy assessments often made about the potential of African agriculture to respond to increased population size. The editors have pulled together ten case studies of agricultural intensification in high population-density areas of Africa. They emphasize the fact that in each case agricultural production has increased with little severe environmental degradation (Hyden et al., 1993; Turner and Benjamin, 1994). This is especially true of highland environments such as Rwanda. Indeed, the volume includes an article on Ruhengeri prefecture in northwestern Rwanda by Robert Ford (1993), who served as a consultant in the preparation of our study.

The book More People, Less Erosion: Environmental Recovery in Kenya by Tiffen, Mortimore, and Gichuki (1994) has attracted attention with its optimistic assessment of changes in Machakos District in Kenya since the 1930s. This volume, along with a parallel report by English, Tiffen, and Mortimore (1994) has documented improvements in land conditions within the

highland part of the District which have occurred despite (or because?) of much larger population numbers. Many of the same positive elements are present to an important degree in mid-elevation areas in Rwanda. These include dramatic increases in total agricultural production, increased tree cover in populated areas, and stable land masses (little gullying or landslides). However, the parallel More People, More Trouble: part of our title acknowledges that Rwanda has been facing increasingly serious problems at the same time that its population has grown. The difference between rural Machakos and rural Rwanda in terms of their ability to absorb growing populations at rising standards of living primarily reflects the fact that Machakos is integrated into a larger economy with access to resources from outside the local system whereas Rwanda much more closely approximates a closed system (despite substantial amounts of foreign aid and export revenues from coffee). That is, the sustainability of agricultural intensification under high and rising rural population density may in large part be a function of ready access to markets and nonagricultural employment, which rural Machakos has enjoyed and rural Rwanda has not.

Analytical approach to population, agriculture, and environment connections

This section briefly summarizes the conceptual framework and critical review of the literature on population-agriculture-environment linkages presented in the first chapter of the report by Honadle, Grosse, and Phumpiu (1994). For more details and references, readers are referred to that report. In the "Discussion" section of the present paper we apply these points to the case of Rwanda. Our thesis is that some of these variables have contributed to the maintenance of stability in Rwanda, while others appear to have contributed to the chronic stress and ultimate rupture of the Rwandan equilibrium.

The major theme of our synthesis is that population-environment linkages are necessarily context dependent. Simple, linear models in which population is assumed to have deterministic consequences are not sufficiently complex to capture important aspects of reality. A variety of disciplinary perspectives maintain that human choices and strategies modify the effects of natural

processes, so that outcomes are variable. Different evolutionary strategies may lead to either successful accommodation of growing populations, with stable or rising living standards, or unsuccessful outcomes, with deteriorating environmental quality and falling living standards. These strategies include the choices of individuals as influenced by the political and macroeconomic context. In addition, physical factors may greatly modify the potential success of evolutionary strategies.

An important source of contextual variation in population-agriculture-environment outcomes is variation in the physical environment. This has at least two and possibly three aspects. The first and most obvious factor is that lands differ greatly in terms of their sensitivity to and resilience from degradation (Blaikie and Brookfield, 1987; Lewis and Berry, 1988; Turner and Benjamin, 1994). This owes partly to variations in the direct determinants of risk of soil erosion and degradation, including soil types, rainfall patterns, and steepness of slopes (Wischmeier and Smith, 1978). Nonetheless, we should be careful not to fall into ecological determinism, since sustainable agricultural development under fairly high population densities is technically feasible under almost all types of physical environments, including those with relatively poor soils and heavy, aggressive, rainfall (National Research Council, 1993; Weischet and Caviedes, 1993).

A comparison of ten case studies from African high population-density areas edited by Turner, Hyden, and Kates (1993) reveals the importance of physical factors given prevailing adaptive strategies. In each case where agricultural intensification had been relatively successful, soils were reported to be above average in quality and rainfall was either adequate in amount and distribution or there was an aquifer available for irrigation. The most problematic cases of decreasing soil fertility were all reported to have had relatively marginal soils. Interestingly, steepness of slopes seemed to be relatively less important, since some of the most successful areas involved cultivation of relatively steep slopes, although with anti-erosion terracing and cultivation of bush and shrub crops.

Other aspects of the physical environment must be considered jointly with the social environment, including the repertoire of economically useful plants which can be grown on different lands. It is increasingly being recognized that one of the most important determinants of environmental stability in tropical regions is the continuity and density of vegetative cover (Weischet and Caviedes, 1993; National Research Council, 1993). This can protect soils against erosion, leaching, mineralization of organic material, and inhibition of biological activity caused by excessive temperatures and rainfall. The physical and human environments interact in determining the feasibility and desirability of cultivation of perennial shrub and tree crops, which generally provide the best vegetative cover and hence minimize the risks of degradation.

An aspect of the physical environment which is strongly dependent upon political and economic factors is geographic location and integration into regional and global markets. No closed system is capable of supporting an indefinitely growing population. Only a system which is open in terms of movement of people or goods can fully adapt. One form of adaptation which is needed for a given area of cropped land to support a growing farm-based population is increasing specialization in production for the market with high levels of inputs (Boserup, 1965). Consequently, access to markets with elastic demand for agricultural produce and nonagricultural goods and to markets for science- and industry-based inputs is essential for rural societies to cope successfully with high population density.

Successful agricultural intensification also invariably involves major shifts of the work force into nonagricultural activities. Every case in which dense populations have succeeded in improving their living conditions in a sustainable way has involved increasing reliance on nonagricultural incomes (Hyden et al., 1993). Only integration into regional and world markets allows for rapid expansion of nonagricultural employment to absorb the labor no longer needed in agriculture. Consequently, geographic isolation caused by narrowly-drawn political boundaries, a location distant from dynamic economies, and poor transportation infrastructure can pose an almost insuperable obstacle to sustainable development under high and growing population

densities. It should be noted that this generalization does not constitute a form of ecological determinism, since such isolation is caused primarily by political and economic variables.

Public policies may provide crucial encouragement or inhibition of needed adaptive responses. Political and economic stability, which together promote investment by encouraging individuals to adopt long planning horizons, is a prerequisite for long-term sustainable development. Political stability may be a necessary condition, but it is by no means a sufficient condition. A political system which creates space for voluntary local organizations to mobilize adaptive responses on the basis of indigenous knowledge and social organization may be an important mediating response. Macroeconomic policies must minimize market distortions or failures rather than aggravating them, as through the protection of inefficient manufacturing industries. Governments which tax rural-based exporters and use the revenues to subsidize urban consumers may greatly slow down the endogenous processes of economic diversification and growth which would be expected to occur in response to population growth.

Public policies directed at rural primary producers may either help or hinder the maintenance of environmental quality. For example, restrictions on the ability of rural residents to sell fuelwood or charcoal to urban markets, usually intended to preserve woodlands, may have the inadvertent effect of discouraging planting or maintaining of trees by reducing their economic value (Dewees, 1993). Agricultural extension services often contribute to soil erosion by recommending practices which are inferior to indigenous knowledge, notably monocropping in place of intercropping. This is especially true of monocropping of seasonal plants, especially pure stands of cereals such as maize, which leave the soil bare during the first part of the rainy season. Even attempts at preventing soil erosion by mandating soil conservation practices may provide little or no benefit, because the measures promoted are often poorly adapted and inferior to indigenous localized practices.

The structure of landholdings may be an important influence on the adoption of the on-farm investments needed to protect soil quality and increase yields (Clay et al., 1994). It is generally agreed that individualized land tenure is much more supportive of such investments than are communal or lineage forms of control over land (Cleaver and Schreiber, 1993). While tenure systems in most densely-settled rural societies in Africa have over time evolved toward effective individualized tenure, this is not a universal phenomenon. Those areas which have not have tended to experience the worst environmental degradation. However, among those societies which have effectively given individuals or households permanent control over the same plots of land, variations in restrictions on land transfer or sale appear to be unrelated to the making of on-farm investments (Migot-Adholla et al., 1991; Place and Hazell, 1993).

Social organization may help determine whether and how fast populations make adaptive changes to cope with increasing population size. One aspect of this is gender relations. A greater degree of sharing of productive roles between men and women may stimulate a cooperative environment for making on-farm investments in trees, soil conservation, and maintenance of soil fertility. The existence of voluntary self-help organizations may also play a key role in these areas, as has been argued to be the case in Kenya (Tiffen et al., 1994).

Rwanda: Geographic, demographic, and historical background

Rwanda is a small, landlocked country the size of the state of Vermont located in the Great Lakes region of east-central Africa. Rwanda is of particular interest to many environmental specialists because of the biological importance of its few remaining tropical montane forests. In particular, the Volcanoes National Park, which sits astride the frontier with Zaire and Uganda, shelters the only sizeable population of mountain gorillas left in the wild (viz Gorillas in the Mist). Nonetheless, this review does not address the question of biological diversity. Our focus is on environmental degradation in terms of the sustainability of the natural resource base for economically productive activity (Abel and Blaikie, 1989).

With a land area of 26,338 km^2, Rwanda has had the highest population density of any country on the African continent, roughly 300 per km^2 in early 1994. The physiological density relative to inhabitable land was substantially higher. Some subnational areas within other African countries have as high or higher population densities, including southeastern Nigeria and the highlands of Kenya (Turner et al. 1993). One major difference is that residents of these densely-settled subnational regions have access to migration and employment opportunities outside of their densely-settled home regions, a safety valve which was lacking in the case of rural Rwanda.

The high population density of Rwanda represents a particular example of a more general type of adaptation found in African highland environments (Lewis and Berry, 1988). Lands located more than 1,500 meters above sea level comprise only 10% of the African land mass but contain 20% of its population (Roose, 1992). The relatively high population densities found in these environments typically reflect long-term successful adaptations to relatively intensive forms of cultivation, often involving permanent, year-round cultivation. Historical factors accounting for the relatively high population densities in these lands, including specifically Rwanda, involved protection from raiders and from tropical vector-borne diseases such as malaria and sleeping sickness, as well as relatively high soil fertility and moderate rainfall (Gourou, 1953). Geographic isolation actively maintained by strong precolonial states in Rwanda and Burundi also protected their populations from the nineteenth century epidemics of cholera and smallpox spread by traders, slave raiders, and European explorers (Gourou, 1953; Chrétien, 1987).

Most of the population of Rwanda lives at elevations between 1300 and 2300 meters above sea level. The relatively high elevation has provided Rwanda with a mild climate, especially given its location near the equator (between 1 degree 02 minutes and 2 degrees 50 minutes south latitude) (Sirven, Gotanegre, and Prioul, 1974). Mean monthly temperature varies from 21 degrees Celsius at lower altitudes in eastern Rwanda (e.g., Rusomo at 1322 m) to about 15 degrees in the higher altitude settled parts of Ruhengeri prefecture (e.g. Kinigi at 2250 m)

(Musema-Uwimana, 1983). Most of Rwanda receives rainfall averaging between 800 and 1400 mm per year, distributed between two rainy (and hence, growing) seasons.

Administratively, Rwanda is divided into 11 prefectures. Ten of these prefectures are predominantly rural and are named for their respective capitals. The remaining recently-created prefecture is Kigali-Ville, which consists of the capital city, Kigali. The northwestern prefectures of Ruhengeri and Gisenyi and the southwestern prefecture of Cyangugu have historical traditions and ecological characteristics which distinguish them from the "core" prefectures of traditional Rwanda, namely Butare, Gikongoro, Gitarama, and Kibuye. The remaining prefectures, Byumba in the north, Kigali in the center, and Kibungo in the southeast, traditionally had relatively low population densities, although population movements since the 1940s have largely evened out the spatial distribution of population in Rwanda (Prioul, 1981; Cambrezy, 1984; Sirven, 1984; Nzisabira, 1989; Bart, 1993).

Ecologically, Rwanda is divided into a number of natural zones, which do not correspond to administrative boundaries (Sirven, Gotanegre, and Prioul, 1974; Delepierre, 1975). The three largest ecological zones are the Zaire-Nile Divide (or Crest), the Central Plateau, and the eastern savanna. The Zaire-Nile Divide is an important natural feature, consisting of a mountainous chain running south to north close to the western edge of the country. The relatively steep slopes and higher elevations of this region have been colonized only during the course of this century and are subject to some of the most severe environmental degradation in the country. The Central Plateau, located to the east of the Divide, comprises the classical "land of a thousand hills" and has a long history of dense settlement at elevations between 1500 and 1800 meters. Finally, the relatively lowlying and flat grasslands of eastern Rwanda, including Kibungo prefecture and portions of Byumba, Kigali, and Butare prefectures, have only recently become densely settled (except for Akagera National Park) and are subject to relatively great climatic vulnerability.

Rwanda is one of the few countries in sub-Saharan Africa which was not an artificial creation of colonialism. The people of Rwanda speak a single language, Kinyarwanda, and comprise a single nationality, Banyarwanda, divided among three groups, Hutu, Tutsi, and Twa. A Tutsi monarchy which dominated the central part of Rwanda had expanded its control by the beginning of the colonial era to roughly the present boundaries of the country. The northwest (Ruhengeri and Gisenyi prefectures) did not come under effective central control until after 1900, with the assistance of German guns (Nyrop et al., 1969).

In the "scramble for Africa," Rwanda became part of German East Africa (with Tanganyika) from the 1890s until World War I. From 1916 until 1962, Rwanda was administered by Belgium together with neighboring Burundi, as the territory of Ruanda-Urundi. Both German and Belgian authorities found it expedient to rule Rwanda indirectly through indigenous authorities, thereby strengthening and rigidifying that system and setting the stage for later tragedy (Grosse, 1994). The authority of the Tutsi monarchy was extended into areas where it had previously not been effective, and in other areas the supposedly traditional exactions became much more extensive and oppressive (Guichaoua, 1989). At the end of the colonial era, between 1959 and 1962, Rwanda experienced a social revolution in which the Hutu majority (83% of the population) overthrew Tutsi chiefly and monarchical rule. The Belgian authorities cooperated with this movement and recognized the independence of the Rwandan Republic in July 1962.

Demographic growth during colonial rule is difficult to assess because of the lack of reliable population data before the 1930s (see Table 1). Estimates of the population of Rwanda around 1900 vary from 1 million (Nzisabira, 1989) to 2 million (Guichaoua, 1989). If, as seems plausible, the initial population was close to 2 million, the population at the beginning of the 1950s may have been no higher than half a century before. Eastern Rwanda appears to have become almost depopulated early in this century (Scaetta, 1932). Lwlying parts of Burundi were depopulated at this time by epidemics of disease brought by the Europeans and their African associates (Chrétien,

1987). Also, indigenous trade exchanges which were crucial for the balancing of food deficits, since few if any parts of Rwanda were completely self-reliant in food, were disrupted (Pottier, 1986). The consequence of disruptions was famine in affected areas, which spilled over into still other areas through mass migration of starving victims (Lugan, 1985; Pottier, 1986; Scaetta, 1932).

A series of devastating famines occurred in Rwanda during the late 1920s and early 1930s, and again during World War II (Lugan, 1985). The Belgian authorities decided that overpopulation and land degradation were largely responsible for the occurrence of these famines (Scaetta, 1932; Guichaoua, 1989; Bart, 1993). Responses by the authorities included institution of obligatory conservation practices, forced changes in cropping patterns, and organized emigration, as well as improvement of transportation and promotion of interregional exchanges (Leurquin, 1963; Vis, 1975). The authorities ignored their own role in the causation of famine, including taxation which was excessive in poor crop years and wartime procurement of food (Lugan, 1985; Guichaoua, 1989). As a result of widespread death and migration during the famine of 1943-44, the population of Rwanda is estimated to have fallen from 1,950,000 in 1942 to 1,500,000 in 1945 (Gatera, 1980; Nzisabira, 1989). This famine occurred during a period (1939-1945) in which exports from Rwanda increased seven-fold (Guichaoua, 1989). This famine was even more devastating than the better-known Great Bengal Famine of 1943 in British India which was similarly caused or aggravated by military procurement (Sen, 1981). We have discussed these historical famines at length because they do not support ecological deterministic hypotheses of famines being caused by overpopulation, environmental degradation, or climate.

The first reliable population estimate for Rwanda comes from the 1978 census, when the enumerated population was 4,819,317 (Sirven, 1984). Previous figures are estimates from various sources, including administrative sample "censuses" conducted in 1933, 1949, 1958, 1964, and 1970 (Sirven et al., 1974; Table 1). Given the imprecision for most of the estimates, they are rounded off to the nearest hundred thousand.

Table 1. Population estimates for Rwanda, various years

Year	Population total
1933	1.8 million
1949	1.9 million
1958	2.5 million
1964	3.0 million
1970	3.7 million
1978	4.8 million
1991	7.2 million
1994	7.9 million

Population growth accelerated after 1950, in part because of a reduction in the rate of migration to neighboring British territories because of improved conditions in Rwanda (Chrétien, 1978). Nonetheless, in 1959 there were 350,000 Rwandans resident in Uganda and another 35,000 in what is now Tanzania, the majority of whom were temporary migrant workers (Chrétien, 1978). In addition, perhaps 200,000 Rwandans had settled as farmers in northern Kivu (Leurquin, 1963; Sirven, 1984; Guichaoua, 1989). The organized settlement of Rwandan farmers in Kivu occurred mostly during the postwar period.

Following independence, population growth was even more rapid. A temporary reduction in population growth resulted from the exile of 150,000 to 200,000 Tutsi refugees between 1959 and 1965 (Chrétien, 1992). Mortality continued to decline during this period, while fertility either remained constant (ONAPO, 1994) or increased (May, 1993). The population growth rate was thought to be 2.6% per year, but the 1978 census revealed an intercensal growth rate of 3.6% per year (Hamand, 1982). The total fertility rate at the time was roughly 8.5 children per woman, the second highest in the world (Table 2).

Since the early 1980s, the rate of population growth in Rwanda has begun to decelerate. The population of Rwanda enumerated in the August 1991 census was 7.15 million (MINIPLAN, 1993). The intercensal growth rate from the 1991 census, compared to the 1978 census, is only

3.1%, well below the 3.7% rate which had been projected (MINIPLAN, 1993). The major explanation for the reduced population growth rate is a reduction in the rate of childbearing, which followed upon the establishment of Rwanda's national family planning program in 1981 (May et al., 1990). In 1992, 21.2% of women married or living with a man were reported to be practicing some form of birth prevention, including 12.9% currently utilizing a modern method of contraception (ONAPO, 1994). These data show that fertility rates have fallen at all ages, with fertility falling because of postponement of marriage, more women remaining outside of a union, and declining fertility within marriage. Rwandan farmers appear to be aware of the burden posed by large numbers of children and recognize the urgency of controlling family size (Ndiaye and Sofranko, 1994).

Table 2. Total Fertility Rate (TFR) estimates for Rwanda, various years. Sources: (MINIPLAN, 1993; ONAPO, 1994).

Year	TFR	Source of data
1978	8.6	Census [1]
1983	8.5	National Fertility Survey [2]
1991	6.0	Census (adjusted data) [1]
1992	6.2	Demographic and Health Survey [3]

Years covered by estimates:
[1] Previous 12 months
[2] Previous 3 years
[3] Previous 4 years

The reported 30% decline in the total fertility rate (TFR) in less than 10 years, from 8.5 during the 1980-82 period to 6.2 during the 1988-91 period (see Table 2), is one of the most rapid fertility declines that has yet occurred in sub-Saharan Africa. Retrospective data collected from the 1983 and 1992 survey samples indicate that fertility was essentially constant during the 1970s and began to decline around 1982, with the decline accelerating after 1986 (ONAPO, 1994). The 6.2 TFR estimate from the 1992 DHS survey appears to be more reliable than the

6.9 rate reported from the 1991 census covering essentially the same reporting period (ONAPO, 1994).

Rwanda remains one of the most rural nations in the world, although this is in part a statistical artifact. Officially, 95% of the Rwandan population was rural according to both the 1978 and 1991 censuses, which would seem to indicate little net rural-urban migration. However, it is recognized that these figures seriously understate the urban population in 1991 (MINIPLAN, 1993). This was in part because of a decision to deport large numbers of unauthorized residents from Kigali in late 1990. Rwanda is one of only a handful of countries in the world to require citizens to obtain residence and work permits in order to live in the capital city. Besides temporarily reducing the actual number of people in the capital, fear may have contributed to a disproportionately large undercount in the capital. Further, calculation of the urban population was restricted to the same 12 areas officially classified as urban before the 1978 census (MINIPLAN, 1993). It is acknowledged that many "rural" settlements had already assumed classically urban characteristics (see Sirven, 1984; Ford, 1990; 1994).

Trends in agricultural and livestock production in Rwanda

As a landlocked country with limited access to international markets, Rwanda has traditionally been largely self-sufficient in food production (Ntezilyayo, 1986). The dominant staple foods in contemporary Rwanda are beans and sweet potatoes, along with bananas (used in making a mildly alcoholic cider or "beer"), other root crops (cassava and potatoes) and sorghum and maize (see Table 3). The diet is reasonably balanced between energy and protein (mostly from beans), depending upon elevation, but is extremely low in dietary fat, which provide less than 10% of calories consumed (Musema-Uwimana, 1983; MINAGRI, 1992). Animal products are consumed in only small quantities in rural areas (Vis, 1975).

Over the course of the twentieth century, Rwandan diets and cropping systems have evolved in important ways. Dominant crops grown at the beginning of the century are reported to

have included sorghum and eleusine (finger millet) along with a variety of legumes, including beans and peas (Jones and Egli, 1984; Martin, 1987). Eleusine and peas were traditionally grown on fallow lands with low labor inputs and very low yields. As land has become more scarce, the cultivation of both of these crops has receded (Bart, 1993). Also, the Belgian authorities vigorously discouraged the system of growing eleusine by 'ecoubage', which entailed gathering grass into piles and burning them, as a form of soil fertilization. This exposed the entire field to serious soil erosion (Leurquin, 1963).

The major shifts in cropping patterns have been towards increasing reliance on bananas, maize, and root crops, especially sweet potatoes. Sorghum has partly been supplanted by maize for use as a cereal and by bananas for use in making beer. Maize has higher yields than sorghum, especially with the improved varieties distributed since the 1950s, but sorghum remains more common than maize (Leurquin, 1963). The increased cultivation of bananas in place of sorghum is reported to be because cultivation of sorghum was dependent upon fallowing, while bananas could be cultivated on a permanent basis on plots close to the household, fertilized by household wastes (Martin, 1987). However, it should be noted that bananas were already widely cultivated at the beginning of the colonial era (Sirven, 1984; Bart, 1993).

Beginning in 1931, Belgian authorities mandated that each farm family cultivate a certain area in root crops as a means of preventing seasonal food crises and famines (Vis, 1975; Martin, 1987). In most of Rwanda, the root crop of choice was sweet potatoes, with cassava grown only at the lowest elevations, and white potatoes at high elevations. Rwandan farmers have traditionally lacked on-farm crop storage, and root crops have the advantage of being able to be harvested at varying points. Further, root crops yield a much higher ratio of food energy (calories) per hectare compared to other crops, although with relatively low amounts of protein. This measure was quite successful, and by the 1950s, sweet potatoes had become the major source of calories in diets of families living below 2000 m elevation (Close, 1955; Leurquin, 1963; Vis, 1975).

The other major change in Rwandan agriculture has been the cultivation of export crops, almost all grown by smallholders. These crops constitute only 5% of cropped land in Rwanda, but are an important external source of liquidity (Bart, 1993). The dominant export crop is coffee, followed in high elevation areas by tea. The Belgians mandated the cultivation of coffee during the colonial period, which was a successful means of generating monetary revenue to cover the expenses of the colonial administration (Guichaoua, 1989). Past efforts at promotion of cinchona and pyrethrum were limited in success by the weakness of international markets (Jones and Egli, 1984).

The database on agricultural production trends in Rwanda before the first national agricultural household survey of 1984 is of uncertain reliability (Bart, 1993). Three periods can be distinguished. The first is the period from the end of World War II to independence in 1962. Little is known about this period, although indications are that food production increased at least as fast as population, and cash crop production more than doubled (Leurquin, 1963). More information is available for the following period, from the mid 1960s to the early 1980s. The consensus is that during this period agricultural production grew more rapidly than did population. Finally, the period since 1984 has been one of agricultural stagnation and increasingly severe periodic food crises occurring around a trend of declining per capita food production.

During the late 1940s, Rwanda's population was roughly 1.9 million (Table 1), roughly one fourth of the population as of the early 1990s. During the late colonial era numerous predictions were made that Rwanda would soon be on the brink of a Malthusian crisis, with mass starvation if the population continued to grow (Harroy, 1949; Tondeur, 1949). As various observers (Pagni, 1982; Lambert, 1982; Charlery, 1989; Guichaoua, 1989) have noted, subsequent population growth exceeded colonial-era projections, yet no such crisis occurred (at least until the 1990s). One consequence of the rapid expansion of agricultural production between the late 1940s and early 1980s was that many Rwandans became convinced that pessimistic predictions of

demographic imbalance could be ignored (Pagni, 1982). In retrospect, it is clear that this imbalance was postponed but not averted.

Between the early 1960s and the early 1980s, Rwanda was one of only three sub-Saharan African countries which succeeded in increasing total food production per capita (Harrison, 1987). This occurred through the exploitation of previously underutilized resources (Bart, 1993). This phenomenon validated the judgement of Gourou (1953) and Neesen (1956), who maintained that Rwanda at the time was not overpopulated, and that ample land remained to be put into cultivation. Gourou argued that the amount of area cultivated was constrained chiefly by scarcity of labor, not cultivable land, so that an increasing farm population could be accompanied by a proportional increase in cropped area and in production.

The increase in agricultural production in Rwanda from the 1960s to the early 1980s occurred primarily through an extension of cropped area. Uwizeyimana (1991) cites Mouchiroud (1988) as analyzing statistics for population and food production for Rwanda in 1966 and 1983. Average annual rates of increase were 3.5% for population (from 3.2 to 5.7 million), 4.0% for food production (from 2.3 to 4.7 million tons), and 3.9% for cropped area (from 308 to 615 thousand hectares). Average crop yields remained essentially constant, 7.5 t/ha in 1966 and 7.6 t/ha in 1983. These agricultural statistics are based on estimates cumulated from lower-level officials and are not fully reliable (Bart, 1993).

The expansion in cropped area occurred both within existing farms and through the extension of farms to new areas. Boserup (1965) distinguishes agricultural intensification, which results from increasing the frequency and intensity of cultivation of land already located within farming systems, and extensification, which involves bringing new land into cultivation. Intensification implies an increase in total production per unit of land within a farming system (see appendix in Honadle, Grosse, and Phumpiu, 1994). In the case of Rwanda, this occurred largely through reductions in fallow and on-farm pasture and an increase in the fraction of

available land under crops at any single point in time. As average farm size shrank, this was compensated by increasing production per hectare of landholdings, but without any increase in yields relative to cropped area.

The extension of cultivated area to areas outside the holdings of existing farms occurred in part through the colonization of higher elevation forests. This was partly spontaneous, and partly reflected officially-sponsored clearing of large portions of the few remaining natural forests in Rwanda (Nzisabira, 1989). The extension of cultivation also occurred as a result of the abolition of control by Tutsi chiefs over extensive areas of land previously reserved as pasture for their flocks of cattle (Nzisabira, 1989). Large areas of fertile but swampy valley bottomland, which had been reserved for dry season pasture, were drained and put into cultivation. Most dramatically, the drier, lowlying savanna areas in the south-center and southeast of Rwanda received large numbers of official and unofficial settlers from the hills (Cambrezy, 1984).

The post-independence period was also characterized by a continuation of trends towards expanded cultivation of root crops and bananas at the expense of cereals and legumes. Between 1966 and 1976, crop area and production of peas and sorghum stagnated in absolute terms, while area and production of white potatoes and sweet potatoes both increased by roughly 2.5-3.0 times. Cassava production also increased sharply (Cambrezy, 1984). Between 1967 and 1985, the share of food crops in planted area increased from 20% to 22% for bananas and from 14% to 19% for root crops, and decreased from 29% to 23% for cereals and from 37% to 35% for legumes (Bart, 1993). König (1993) reports that between 1966 and 1986 per capita production of tubers rose by 65% while per capita production of cereals fell by 25% and of legumes by 21%.

The exploitation of underutilized land during the post-independence years postponed for a few decades the crisis of imbalance between food production and population which had previously been predicted. By the end of the 1970s, hardly any cultivable land remained to be put into cultivation. Around this time, new projections were made which predicted that as a result of the

saturation of cultivable land. a sericus food crisis would hit Rwanda by the late 1980s or early 1990s. At the initiative of Prof. Henri Vis, the CEMUBAC service of the Free University of Brussels sponsored the development and application of a large-scale economic-demographic simulation model to eastern Kivu in Zaire and also to Rwanda. This "Kivu Montagneux" study was first prepared in 1976, was issued in 1979, and was finally published in 1986 (Wils, Tondeur, and Carael, 1986). It predicted a decline of 25% in per capita food availability in Rwanda by 1995. According to Vis (1986: personal communication), the projection results were taken very seriously in Rwanda, where they helped pave the way for the creation of a national population policy in 1981 (Hamand, 1982). However, the model made assumptions about decreases in soil fertility as a result of loss of fallowing which were criticized as being excessively pessimistic (Jones and Egli, 1984; Nzisabira, 1989; Moeyersons, 1989).

Another simulation model for Rwanda was prepared by Lambert (1982) which did not presume any decrease in soil fertility. Nonetheless, projections regarding decreases in per capita food availability were just as grim. Based on 1978 data, it was calculated that if food production remained constant, per capita food energy availability would decline from 1,956 kcal in 1978 to 1,745 kcal in 1985, 1,484 kcal in 1990, 1,264 kcal in 1995 and 1,080 kcal in 2000. Even with an optimistic set of assumptions about increased yields, it was calculated that energy production per capita would at best remain roughly constant until the year 2000.

The decreases in per capita food availability which had been projected to occur during the 1980s seem to have occurred largely as predicted. Whereas during the 1960s and 1970s, Rwanda was one of the top three performing countries in sub-Saharan Africa in increasing per capita food production, during the 1980s Rwanda was one of the three sub-Saharan African countries with the worst performances in terms of decreasing food production per capita (World Bank, 1992). Food production during the 1980s has stagnated in absolute terms and declined in per capita terms (Uwizeyimana, 1991). A comparison of data from the 1984 and 1990 farm household surveys in Rwanda (MINAGRI, 1992) indicates that the per capita availability of food energy

from domestic production fell by roughly 23% between 1984 and 1990 (Table 4). This is in spite of the fact that the 1984 harvest had been depressed relative to normal levels by localized problems of inadequate rainfall and crop pests (MINAGRI, 1991).

Table 3. Food crop production in Rwanda by crop year, 1984 to 1990. (Source: MINAGRI, 1992)

	1984	1986	1987	1988	1989	1990
Bananas	2,614,380	2,398,379	2,591,846	2,775,810	2,966,466	2,776,766
Beans & Peas	273,411	297,325	219,053	240,485	225,989	215,656
Sorghum	171,056	158,878	150,217	144,689	126,885	141,638
Maize	111,477	35,003	102,438	27,314	93,594	95,625
Cassava	324,208	361,899	389,592	358,925	310,550	265,191
Potatoes	251,371	241,466	180,988	170,044	238,605	283,673
Sweet Potatoes	730,926	861,904	799,286	878,557	771,460	817,740
Calories	3,915	4,124	3,750	3,992	3,730	3,710
Protein	99,170	106,234	86,651	94,002	86,748	86,212

As Tables 3 and 4 demonstrate, production trends varied markedly by crop. Decreases in total production were concentrated in cereals and legumes, continuing the long-term trends of stagnation in these crops. Production of beans and peas fell between 1984 and 1990 by 23.6% of the average 1984-1990 production level (from 111.5 to 87.9) (Table 4). Aggregating by crop type, production of cereals (sorghum and maize) fell by 17.4% (from 108.7 to 91.3). Banana production rose by 6% of the average (from 97.3 to 103.3). Root crops (sweet potatoes, potatoes, and cassava) also showed a modest increase in aggregate production, from 95.2 to 99.6. This reflected more substantial increases in both sweet potatoes and potatoes, offset by a sharp decrease in production of cassava (Table 4). The production of cassava has been seriously impacted by spreading crop pests, a problem which is not unique to Rwanda. The continued shift away from cereals and beans and toward root crops reflects both the higher caloric yields of root crops and their lower demands for soil nutrients (Clay and Magnani, 1987; Olson, 1992; König, 1993).

Compared to beans, cassava allows for 8 times as much food energy to be produced from the same area of land, although beans provide 16 times as much protein (König, 1993).

Table 4. Food crop production in Rwanda by crop year relative to average for 1984-1990 (= 100.0). (Source: MINAGRI, 1992)

	1984	1986	1987	1988	1989	1990
Bananas	97.0	89.2	96.4	103.0	110.4	103.3
Beans & Peas	111.5	121.2	89.3	98.0	92.1	87.9
Sorghum	114.9	106.7	100.9	97.2	85.2	95.1
Maize	100.5	121.7	92.3	114.7	84.0	86.2
Cassava	96.8	108.0	116.3	107.1	92.7	79.1
Potatoes	110.4	106.0	79.5	74.7	104.8	124.6
Sweet Potatoes	90.2	106.4	98.7	108.5	95.2	101.0
Calories	101.2	106.6	96.9	103.2	96.4	95.9
Protein	106.4	114.0	93.0	100.9	93.1	92.5
Pop. (thousands)	5,789	6,149	6,337	6,532	6,731	6,938
Kcal/Pop	111.2	110.3	97.3	100.5	91.1	87.9

As can be seen from Table 4, between 1984 and 1990 total food energy production in Rwanda is estimated to have fallen by 5%, at the same time that the population rose by 20%. Thus, the vast bulk of the decrease in per capita food energy availability from domestic production reflected the rise in the denominator (population) rather than a decrease in the numerator (production). A full consideration of the food security and nutritional situation in Rwanda requires consideration of food imports and other adjustments. Anthropometric measurements of preschool children can be a sensitive indicator of severe worsening of food security, yet the available data from Rwanda do not indicate any significant deterioration during this period.

Table 5 compares summary statistics of anthropometric measurements of 276 rural children ages 0-74 months measured during August-November 1983 as part of the National Budget and Consumption Survey (Schnepf, 1992) with those of 1939 rural children ages 0-60 months measured during November 1991 to January 1992 as part of the National Nutrition and

Food Security Survey (MINAGRI, 1993). Comparing the two sets of data, one is struck by the apparent absence of deterioration in nutritional status of rural Rwandan children during a period when per capita food supply is reported to have sharply deteriorated. This is a paradox which remains to be resolved. Von Braun, de Haen, and Blanken (1991) point out that child anthropometry in Rwanda may be more related to health status (and feeding practices) than to household-level food security, but their longitudinal data from a commune in Gisenyi prefecture demonstrate that food crises have a major effect on child anthropometry in that population.

Table 5. Prevalence of child malnutrition in Rwanda in 1983 and 1991-92 as indicated by proportions of preschool-age children with anthropometric values (z-scores) more than 2 standard deviations below the international (NCHS) reference. Sources: (Schnepf, 1992; MINAGRI, 1993).

Indicator	1983	1991-92
Height-for-age	53%	52.2%
Weight-for-age	30%	28.6%
Weight-for-height	5%	5.2%

One major adjustment by rural Rwandans to the decreasing domestic production of beans and sorghum has been increasing unofficial imports of both products from Zaire and Uganda (Pottier, 1986; Loveridge, 1988; Robins, 1991; MINAGRI, 1991). Loveridge (1988) estimates that in 1986 unofficial imports of bean and sorghum were equivalent to 14% of rural consumption of these two products. Thus, the approximately 34% decrease in per capita production of protein greatly overstates the decrease in per capita protein availability. It appears that there has been a deliberate strategy by Rwandan farmers to concentrate on higher value crops, notably bananas and coffee, and to buy increasing amounts of sorghum and beans from neighboring countries (Zaire, Uganda), where land is less scarce (Scott Loveridge, personal communication). These unofficial imports are financed in large part by the unofficial export of small livestock (Pottier,

1986), as well as banana cider (Loveridge, 1988). Unofficial trade in new and reconditioned products, especially used clothing, may also have been a major source of funds for unofficial food imports in Rwanda during the late 1980s (Loveridge, 1988).

The causes of the agricultural stagnation observed in Rwanda during the 1980s are multiple. The major factor in our opinion is the lack of additional land to put into cultivation. A comparison of data from the 1984 and 1990 national farm household surveys would seem to indicate otherwise, since there appears to be a paradoxical expansion of cropped area (Table 6; MINAGRI, 1992: 62). Total cropped area is reported to have increased between 1984 and 1990 by 13% during the first crop season and by 7% during the second crop season. The differences between the values reported for the two seasons in the 1990 crop year presumably reflect an acknowledged difference in sample composition between the two seasons, with average farm size lower by 6% in season B than in season A. As we will see below, a comparison of figures fromm the 1984 and 1990 surveys probably should not be taken as implying that the amount of land planted in crops actually increased.

Table 6. Data on land utilization in farm households in Rwanda, 1984 and 1990 crop years
Source: (MINAGRI, 1992).

	crop year and season (A and B) Area (thousands of hectares)				Percent change 1984-90	
	1984A	1984B	1990A	1990B	Season A	Season B
Cropped fields	691	712	783	782	13%	10%
Fallow	172	129	245	208	42%	61%
Pasture	108	114	56	40	-48%	-65%
Woodlots	106	102	147	111	39%	8%
Fallow & pasture	280	243	301	248	7%	2%
Total	1122	1111	1271	1178	13%	7%

According to the figures in Table 6, cultivated area as a proportion of total farm land increased only slightly between 1984 and 1990. A sharp reported decrease in area in pasture was

compensated by an equally dramatic increase in fallow area, with the total of fallow and pasture remaining virtually unchanged. The surveys in the different years used different definitions and methods for classifying land as fallow, pasture, or cultivated. It would appear that the changes in fallow and pasture were largely definitional. We are not persuaded by Clay (1993) that the reported decrease in pasture reflected a major conversion of pasture land to cultivation resulting from increased land scarcity.

The interpretation of the statistics on cropped areas presented in Table 6 is critically important for calculations of changes in crop yields. If cropped area actually increased between 1984 and 1990 by 10-13% as reported, the 5% reported decrease in total production would imply a 15-20% decrease in average yields (MINAGRI, 1992). The most obvious explanation for decreasing reported yields is decreasing soil fertility (Loveridge, 1988; Schnepf, 1991). However, a simpler explanation, which can account for both the increase in reported cropped area and the decrease in reported average yields, is an increase in intercropping. Rwandan farmers intercrop many of their fields, which complicates the calculation of cropped areas and yields, especially when comparing surveys which use different methodologies. A large and growing proportion of parcels are intercropped with more than one crop (roughly half in 1989) (MINAGRI, 1991).

The Ministry of Agriculture has attempted to standardize cropped areas by multiplying the total amount of area planted in each crop by the fraction of the land area planted in that crop relative to the density expected on a pure stand (MINAGRI, 1991; Kangasniemi and Reardon, 1994). The major problem is that the 1984 survey did not record information on crop densities and also only recorded the presence of a maximum of two crops per field. Attempts to "retrofit" the 1984 data to conform to the 1989 and 1990 survey methodology are unverifiable. Also, on intercropped plots, production of each individual crop is lower than on pure stands, even though total production is usually higher (Jones and Egli, 1984). Thus, even if the reanalysis of the 1984 data was perfectly conformable to the 1989 and 1990 survey methods, an increase in intercropping would result in a decrease in average reported yields.

Various other explanations may also account for much of the decreases in reported average yields, assuming that the increases in cropped areas are real and not artifactual. One possible explanation is the extension of cultivation to marginal lands with inherently lower yields (Bart, 1993; Charlery, 1993b). This is especially true for bananas and beans, both of whose yields decrease sharply at altitudes over 2000 meters. It is also suggested by the Ministry of Agriculture that decreasing yields for coffee and bananas reflect the lag time before new plants produce acceptable yields (MINAGRI, 1992). The decreasing yields for root crops (sweet potatoes, potatoes, cassava) are said to partly reflect a growing tendency for Rwandan farmers to harvest tubers before full maturity, in part because of periodic food shortages and in part out of fear of theft of unharvested tubers (MINAGRI, 1992).

It may also be argued that the string of bad harvests from 1987 to 1990 constitute too short a period to define a trend rather than resulting from presumably normal fluctuation (Robert Ford and Jaakko Kangasniemi, personal communications). Heavy rains in 1987 adversely affected production of several crops, especially beans. In 1988, beans were affected by various pests and infections and potatoes were affected by a lack of seed stock. In 1989, production of all crops except banana and potato were off. Cassava was particularly affected by crop disease (MINAGRI, 1991). Similarly, the 1990 crop year had decreases from the previous crop year in production of bananas, beans, peas, and cassava, owing in part to crop pests affecting cassava and beans and a precocious dry season in the East (MINAGRI, 1992). Although it can be argued that these crop pests as an essentially exogenous and unpredictable series of unfortunate coincidences, their increased incidence may also in large part result from increased vulnerability of crops caused by decreasing soil fertility (Myers, 1992; Verhaegen and Degand, 1993). On the other hand, cassava pests have been spreading throughout Africa, and it is unclear that soil conditions in Rwanda have had much to do with the increased cassava crop losses.

It is widely maintained that increasing population density is causing numbers of cattle in Rwanda to decrease because of decreases in pasture land (Nzisabira, 1989; Rossi, 1991; Bart,

1993; Clay. 1993). However, the available evidence does not clearly support that impression. As noted above, the total area of "pasture" and "fallow" which can be grazed did not decline between 1984 and 1990 (Table 6). While households owning more land tend to own more cattle, one can calculate from 1984 survey data presented by Bart (1993) that the number of cattle per hectare of farm land does not decrease at all as farm size shrinks (Table 7). This indicate that subdivision of land into ever smaller holdings has little or no effect on total number of cattle which the same area of land can support. Also, the density of cattle is highest in three of the most densely settled prefectures. Gitarama. Gikongoro. and Butare (Bart, 1993).

Table 7. Association between cattle ownership and farm size from the 1984 national survey of farm households in Rwanda. expressed in terms of head of cattle per hectare. (Source: Bart, 1993).

Total farm size (ha)	Cattle per hectare
0.25-0.50	0.77
0.51-0.75	0.60
0.76-1.00	0.66
1.01-1.50	0.60
1.51-2.00	0.62

Information on changes over time in livestock numbers also does not provide evidence of any important downward trend (Table 8). The number of cattle in Rwanda according to the 1984 and 1990 national farm household surveys was 837,000 and 813,000 respectively (MINAGRI, 1992). These numbers exceed previous estimates by roughly 200,000 head which is presumably due to a methodological difference. Previous estimates had generally fluctuated within a range of 550,000 to 630,000, except for a brief period during the early 1970s. It has also been reported that the progressive disappearance of natural pasture in Rwanda has resulted in decreasing quality rather than quantity of the national herd (Decuypere et al., 1982).

Table 8. Historical evolution of numbers of cattle in Rwanda. (Sources: Nzisabira, 1989; Bart, 1993; MINAGRI, 1992).

Year	Number of cattle
1949-51	600,000
1964	557,000
1966	600,000
1971	748,000
1982	626,000
1984	837,000 *
1990	813,000 *

* The 1984 and 1990 estimates are derived from national farm household surveys whereas estimates from the previous years were not based on any systematic samples and presumably understated the number of cattle, perhaps by 200,000 in the early 1980s.

Although the total number of cattle has been stable, the proportion of farm families owning cattle and the number of cattle per family have presumably both diminished over time because of increasing population size (Bart, 1993). The implications of decreasing numbers of cattle per capita are unclear. Nutritionally, this would be expected to be a negative factor, except that animal products already account for extremely small fractions of food intakes in rural Rwanda (Vis, 1975). A more important question is the contribution of cattle manure to agricultural production. Some writers assume that any decrease in cattle ownership would be expected to impair soil fertility by reducing the availability of cow manure (Rossi, 1991; Clay, 1993). However, other writers note that this manure is very inefficiently utilized, with relatively little manure collected and deposited on fields (Guichaoua, 1989). As stabling or corralling of animals increases, availability of manure may increase rather than decrease.

The number of small livestock, who are valuable as sources of manure, has been rising since the early 1970s (Nzisabira, 1989). Small livestock are less demanding of space and labor, and are also more efficiently integrated with cultivation. The most commonly owned small livestock are goats, which are kept tied down and hence are not destructive (Bart, 1993). In 1990,

Rwandan farm households were believed to own 1,892,000 goats, 733,000 sheep, and 245,000 pigs (MINAGRI, 1992).

Fuelwood and water scarcity in Rwanda

Rwanda is well-known in international circles as being among the countries with the lowest per capita supplies of renewable fuel and water. There is evidence of some depletion of both of these resources, including resulting from the drainage of wetlands and the degradation of watersheds because of deforestation at high elevations (Sirven et al., 1974). The major source of increased resource scarcity is the increase in the number of consumers. The loss of forest cover in Rwanda has been compensated by tree planting on farms and woodlots, so it is not clear that there has been any reduction in the natural production of wood in Rwanda (Weber, 1987). The key ingredient is the quadrupling of the population between 1948 and 1993, since for a roughly constant supply, per capita availability will have fallen by three quarters.

Scarcity appears to be most critical for fuelwood. Natural growth of fuelwood is believed to account for less than half of demand (Ntezilyayo, 1986; Weber, 1987). Responses include cutting down trees from forests and fallow land, use of crop residues and dung as fuel in place of fertilizer, and reduction in the use of fuel in cooking. It is reported that substantial amounts of animal manure and crop wastes are being diverted as fuel, with negative repercussions on soil fertility (Bart, 1993). Further, it is reported that the average number of meals cooked per day has been falling because of increased scarcity of fuelwood (Cecelski, 1986; Brouwer, 1989).

Water scarcity may soon become a critical limiting natural resource in Rwanda (Falkenmark, 1991; Engelman and LeRoy, 1993). This is not so much in terms of limitation of agricultural production, because Rwandan agriculture is almost entirely rainfed. Water scarcity is a serious constraint to agricultural intensification only in arid or semi-arid areas with short growing seasons (Falkenmark, 1991). More critical in Rwanda is the limited availability of water for personal, domestic, and industrial needs (Bart, 1993). This is especially true in the volcanic

lava zone in the northwest and in some southeastern and eastern savanna areas (Sirven et al., 1974). Based on estimates of the availability of renewable freshwater supplies, Falkenmark calculates that countries experience "water scarcity" when they have less than 1,000 cubic meters available per person per year. According to Engelman and LeRoy (1993) 20 countries experienced water scarcity in 1990, including Kenya, Burundi, and Rwanda.

Environmental degradation in Rwanda

Judgements about the extent and severity of degradation of agricultural land in Rwanda are inherently subjective. Those observers who have characterized Rwanda as being among the most degraded areas of Africa include Cleaver and Schreiber (1993), Falloux and Talbot (1993), and Clay and Reardon (1994). Those who have instead described Rwanda as being among the more stable of African environments include Rossi (1984), Harrison (1987), Dommen (1988), Lewis et al. (1988), Berry et al. (1990), Ford (1990; 1993), Bart (1993), and Hyden et al. (1993). This divergence of views reflects in large part differences in reference points. For example, erosion in Rwanda appears to be markedly less severe than in the highlands of Madagascar (Rossi, 1979; see below) or Ethiopia (Dejene, 1990). It is also reported that soil loss as indicated by sedimentation in streams, has been less in Rwanda and Burundi than in the highlands of Kenya and Tanzania (Berry et al., 1990). Charlery (1993a) notes that a comparison of aerial photographs at the scale of 1/50,000 taken in 1959, 1973, and 1979 show overall stability of land use patterns in northern Rwanda.

The environmental stability in Rwanda observed up to the 1980s can be accounted for by a combination of factors. These include physical characteristics of the environment. The Universal Soil Loss Equation (USLE) involves 6 elements which determine the rate of soil loss: rainfall erosivity, soil erodibility, slope length, slope steepness, crop cover and management, and soil conservation (Wischmeier and Smith, 1978). We discuss cropping systems and cultivation practices in the next section. The major negative factor in Rwanda is the steepness of slopes

which are cultivated. Primarily for this reason, Rwandan farms are sometimes said to be "uncommonly" vulnerable to erosion (Clay and Lewis, 1990). The average slope of fields assessed in 1984 was 23 to 24%, or roughly 13 degrees (Lewis, 1988). However, except on steeply sloped lands at high elevations, this is offset by other factors, as discussed below.

Factors other than steepness of slope tend to reduce the sensitivity to erosion of farm land in the majority of highland Rwanda. As Rossi (1991) has pointed out, the composition of most soils in Rwanda make them less vulnerable to erosion than most soils elsewhere in Africa. In particular, on ferralitic soils, slopes of up to 50% can be stably cultivated. Further, the clay content rarely exceeds 10%, so that the soils are porous and can absorb relatively great quantities of rainwater without causing runoff. Lateritic soils are rare, except in the lowlying, drier eastern parts of the country (Bart, 1993). In parts of northern Rwanda, soils tend to be thin and with a heavily acidic layer underneath the topsoil (Lewis, 1992). Also, the northernmost section of the Zaire-Nile Divide (between Gisenyi and Ruhengeri), at altitudes of 2000 to 2700 meters, is covered with soils with extremely fragile structures (Charlery, 1993b). Elsewhere, the same author reports that soil types tend to be quite stable. It is noted by English (1993) that Rwanda and Burundi benefit from a good climate and soils, similar to highland Kenya.

Soil erosion is a function not of total rainfall but of kinetic energy, which is a function of amount of rain falling within a short period of time (Moeyersons, 1989). According to a number of experts, for a given amount of rainfall, rains in Rwanda are usually relatively moderate and evenly spaced, so that the degree of aggressivity is relatively low compared to other areas in Africa and Madagascar (Bidou, 1989; Rossi, 1991; König, 1993). Models which assume that rainfall erosivity in Rwanda is comparable to elsewhere (e.g., Lewis, 1988) may overstate the problem. Because of variations in soil type and rainfall aggressivity, it is reported that soil erosion is observed greater from a slope of only 1-3% in Burkina Faso or northern Nigeria than from a much steeper slope of 20-30% in Rwanda (Roose, 1988).

To some extent, the appearance of environmental stability in Rwanda may be deceiving. Catastrophic erosion, in the form of large gullies, ravines, and landslides, is relatively rare in most of Rwanda despite the steep slopes which are often cultivated. The major exception is the northern part of the Zaire-Nile Divide, where massive soil erosion appears to be worse than elsewhere in the country (Byers, 1988; Ford, 1990; Charlery, 1993b). Soil erosion in Rwanda generally takes the less visible form of diffuse erosion rather than gullying, thus deceiving the observer into thinking that erosion is not a problem in most of Rwanda (Moeyersons, 1989). This is especially likely to be the case for observers who are familiar with the semi-arid Sudano-Sahelian region of West Africa, where such obvious forms of erosion are much more apparent than in Rwanda (Roose, 1988; Clay and Lewis, 1990).

Also, even if Rwanda may be less severely impacted by obvious environmental degradation than many other African countries, degradation is still an increasingly serious problem within Rwanda, especially in the northwest (Weber, 1987). The consensus of experts on Rwandan geography is that the relative stability observable at the beginning of the 1980s (Rossi, 1984; Cambrezy, 1984) began to unravel during the course of the following decade (Wassmer and Michel, 1986; Weber, 1987; Rossi, 1991; Uwizeyimana, 1991; Charlery, 1992; 1993a; 1993b; Bart, 1993). Behind an appearance of "precarious" and "tenuous" stability (Ford, 1993) increasingly frequent and serious signs of rupture and latent crisis began to appear: landslides, pockets of famine, etc. (Charlery, 1992).

Since 1980, there has been a spectacular increase in runoff erosion in part of northwestern Rwanda, aggravated by the inability of the now cultivated wetlands to absorb the runoff. Thus the delta of the Mugonero river at Lake Kivu increased by only 0.4-0.6 m/year between 1973 and 1981, but in the mid-1980s was expanding by 30-40 m/year (Wassmer and Michel, 1986). However, this process is not yet generalized throughout the country. Some basins have become seriously degraded, while others remain relatively stable.

In recent years there has also been a dramatic increase in landslides in northwestern Rwanda, especially in years with torrential downpours, including 1986 and 1988 (Byers, 1988). In both Rwanda and Burundi, landslides are found chiefly where roads have been cut into steep hillsides (Weber, 1987; Byers, 1988; Moeyersons, 1991; Rossi, 1991; Sibomana, 1992; Delor-Vandueren and Degand, 1992). While Rwandan roads have had a generally good reputation, it would seem that precautions were rarely taken by the public works department to avoid runoff causing landslides on the surrounding land. Hence, with the recent extension of the road network, the number of landslides has greatly increased (Rossi, 1991).

Despite the accumulating evidence of increasing environmental problems in Rwanda, it can be misleading to make generalizations about soil erosion in Rwanda from localized case studies (Ford, 1993). Charlery (1993b) distinguishes 4 ecological zones within his study area in northwestern Rwanda. The northernmost section of the Zaire-Nile Divide (between Gisenyi and Ruhengeri), at altitudes of 2000 to 2700 meters, is covered with soils with extremely fragile structures. Also, perennial crops such as banana and coffee cannot be cultivated on most fields at this altitude, only seasonal crops. Soil erosion is very marked in this zone, including ravines and gullies. On the other hand, the 3 other zones, including the Buberuka highlands, the lower elevation hills between 1600 and 2000 m altitude, and the steep slopes of the transition zone between 1750 and 2500 m altitude, all are reported to have continued to display apparent stability despite rapid population growth and increasing land scarcity.

Perhaps an even more important challenge facing Rwanda than soil erosion is the less visible yet insidious threat of loss of soil fertility resulting from depletion of soil nutrients (Rossi, 1991; Olson, 1992). Abandonment of fallowing without substantial animal or green manuring has resulted in widespread leaching of the top layer of soil and a reduction in the recomposition of organic matter. Also, lack of vegetative cover can reduce soil fertility independently of soil erosion through increased aeration and soil temperature, which result in accelerated decomposition of organic matter, reduced soil exchange, and leaching of nutrients (König, 1993).

A number of surveys have reported evidence of decreasing soil fertility based on farmers' perceptions. In the 1991 Survey of Agroforestry in Rwanda, roughly 40% of parcels are reported by farmers to have had declines in productivity (Clay, 1993). The 1984 National Agriculture Survey revealed that in Ruhengeri prefecture over 50% of farmers thought that crop productivity was declining (Weber, 1987). Later surveys, conducted during 1986 and 1990 in various parts of Ruhengeri prefecture, found that 72 to 96% of farmers perceived declining soil fertility to be a problem on at least some fields (Weber, 1987; Charlery, 1992; Ndiaye and Sofranko, 1994).

The major perceived cause of decreasing soil fertility in Rwanda is depletion of soil nutrients by cultivation rather than erosion. Even in Ruhengeri, where erosion is the most severe, farmers mention soil exhaustion as a problem much more often than erosion (Weber, 1987; Ndiaye and Sofranko, 1994). In a 1992 survey in Gikongoro prefecture, 67 to 85% of farmers reported decreased soil fertility (Olson, 1992). Most attributed the decrease to the lack of fertilizer, and erosion was not reported to be a major problem.

Changes in vegetation and ground cover

Perhaps the most important factor contributing to the lack of severe erosion in Rwanda is the protective effect of cropping systems. Traditional mid-elevation Rwandan cultivation systems have been relatively protective of soils because of vegetative cover (Rossi, 1984; Ford, 1993). The most important protective element is the widespread reliance on perennial crops, chiefly bananas and coffee. Bananas are often intercropped with crops such as beans and sorghum, with the bananas providing crucial soil cover during the early part of the growing season. Another key aspect has been the small, dispersed parcels. Since neighboring parcels are rarely on the same cropping cycle, no extensive areas of clear soil exist at any time which would favor mass erosion (Rossi, 1984; Lewis and Berry, 1988; Ford, 1993). In addition, dense intercropping of seasonal crops is reported to greatly improve vegetative cover and thus to reduce the risk of erosion (Kangasniemi and Reardon, 1994).

Lewis (1988) has calculated crop cover values (C values) for each crop based on 100 sample erosion sites. A lower value indicates less risk of soil erosion. As already noted, two of the most important crops in Rwanda are calculated to contribute less to erosion than uncultivated fields (0.10), namely coffee (0.02) and bananas (0.04). The low erosion from these two crops reflects predominant cultivation practices in Rwanda, with virtually all coffee parcels regularly mulched, and banana plots also protected by ground cover and fertilized with wastes. The worst offenders are tobacco (0.45), sorghum (0.40), and maize (0.35). Potatoes (0.22), sweet potatoes (0.23), and cassava (0.26) are intermediate. Thus, while root crops such as cassava may deplete soil nutrients (Rossi, 1991), they provide better ground cover than cereals. Beans also provide better cover (C = 0.19) than cereals, especially during the early part of growing season, when protection against rainfall is most critical (Lewis, 1988).

Banana cultivation is considered to be one of the most important factors helping to maintain environmental stability in Rwanda (Cambrezy, 1984; Lewis, Clay, and Dejaegher, 1988; Rishirumhuirwa, 1992). It has sometimes been argued that bananas, which in Rwanda are grown chiefly for producing home-made banana beer (cider), represent a waste of resources which could be devoted to food (Gotanègre, 1983). However, since bananas can be consumed if need be and represent an important source of cash income, they constitute an important reserve for food security (Scott Loveridge, personal communication). The weak attempts by the Rwandan government to discourage cultivation of beer bananas in order to protect the state beer monopoly has been ineffectual (Ford, 1990). Further, it could be argued that the beer monopoly has in effect promoted the production of banana beer by artificially depressing demand for bottled beer (Jaakko Kangasniemi, personal communication).

The importance of cropping systems for environmental stability in Rwanda is illustrated by altitudinal variation. Above a transition zone of 1800 to 2000 meters, cropping systems change dramatically (Delepierre, 1982; Jones and Egli, 1984; Bart, 1993). Bananas, coffee, and the usual varieties of beans provide very low yields and tend not to be cultivated to any great extent,

although bananas are increasingly cultivated at up to 2200 m. Instead, at higher elevations farmers rely chiefly on seasonal crops, notably grains (wheat and maize) and potatoes, as well as tea in some places (Bart, 1993). As a result, ground cover during rains tends to be quite poor, and the risk of soil erosion quite high (Charlery, 1993a; Kangasniemi and Reardon, 1994). Within Ruhengeri prefecture, those sectors located at above 2000 m elevation were found to display serious surface soil erosion on a large fraction of fields (roughly 40%), while other sectors suffered from little visible erosion (Charlery, 1993a).

The protective effect of cultivation practices in Rwanda should not be overstated. It appears that mechanical erosion of soil in Rwanda caused by cultivation methods (e.g., hoeing downwards) is as important as water erosion or even worse (Nyamulinda, 1988; Nyamulinda and Ngiruwonsanga, 1992). Furthermore, early estimates of soil erosion from cultivated parcels in Rwanda (Lewis, 1988; Lewis et al., 1988) appear to have greatly understated the amount of erosion typically experienced (Jan Moeyersons, personal communication). Moeyersons (1990) reports, based on 10 years of observations on cultivated fields on a hill near Butare, an average soil loss of 120 t/ha/yr. An erosion rate of 12 t/ha/yr is considered the maximum tolerable rate (Roose et al., 1992). Studies on experimental plots have reported that soil erosion can average 300 to 550 t/ha/yr on unprotected plots and 50 to 150 t/ha/yr on plots of cassava or sweet potatoes using traditional hoe cultivation. In Burundi, cultivation with maize and beans was similarly found to result in erosion of 150 t/ha/yr from a field with a 49% slope (Roose, 1988).

The protective effect of bananas depends on the method of cultivation employed. Roose et al. (1992) report that erosion from banana groves in Rwanda is 20 to 60 t/ha/yr with no mulching and 1 to 5 t/ha/yr with complete mulching. This is in comparison with the 0 to 1 t/ha/yr of soil loss under mulched coffee plantings, natural forest, or old-growth fallows. Experimental plots in Burundi in which bananas were cultivated under traditional methods without mulching yielded average soil loss rates of 15 t/ha/yr under mature banana groves planted in the traditionally high density, compared to 30 t/ha/yr following recommended densities (Rishirumhuirwa, 1992).

However, soil loss was calculated to be even higher, 55 t/ha/yr in banana groves with lower densities, characteristic of young groves or groves intercropped with other crops.

Another potentially important form of vegetative cover comes from tree planting. Deliberate forms of agroforestry are considered in the following section. Here we consider the spontaneous planting or protection by farmers of useful species of trees or woody plants on farms as well as the directed planting of exotic species of trees on private or communal woodlots and along the sides of roads. An aggressive tree planting program, accelerated during the 1980s on the basis of umuganda corvée labor, planted an average of 14,000 ha per year in communal woodlots, mostly in eucalyptus (Ford, 1990). Rwandan farmers on their own seem to show good sense in selecting fruit trees, most commonly papaya, and other species for various purposes such as shade and poles for supporting banana plants (Balasubramanian and Egli, 1986).

The potential advantages of officially-sponsored tree planting efforts in Rwanda have been gravely compromised by the single-minded promotion of planting with eucalyptus trees rather than indigenous species (Weber, 1987; Ford, 1990). While these trees grow quickly and are a good source for building poles, they are of little or no benefit for protecting the environment. In particular, eucalyptus trees in Rwanda appear to inhibit ground cover, to deplete soil nutrients, and to dry out the soil (Jones and Egli, 1984; Wassmer, 1984; König, 1993). High rates of runoff erosion have been found under eucalyptus trees, which almost totally lack ground cover because of toxic substances produced by the trees (Moeyersons, 1989; 1990). Often the tree roots become exposed in the eroded soil in eucalyptus plantations.

Measures to minimize erosion in Rwanda

The Rwandan government installed after the 1973 coup reinstituted coercive colonial-era soil conservation policies (Jones and Egli, 1984; Brondeau, 1991; Bart, 1993). Farmers were obliged to plant trees, construct anti-erosive measures, and engage in unpaid public works projects under the umuganda system of unpaid corvée labor. These efforts have been fairly effective in

inducing farmers to go along with the prescribed practices, even though contacts by Rwandan farmers with agricultural extension agents are limited (Ndiaye and Sofranko, 1994). The persuasive powers of the local authorities may have been partly responsible for the adoption of recommended practices.

Survey data on soil conservation and agroforestry practices in Rwanda indicate that soil conservation methods, chiefly simple terraces with ditches and/or grass strips, are widespread. The 1984 agricultural survey in Rwanda showed that erosion control technologies, most notably infiltration ditches and contoured bunds, were found on 32% of all plots (Lewis and Berry, 1988). The 1991 Survey of Agroforestry revealed that the proportion of households with various conservation practices is as follows: radical terraces 1%, hedgerows 37%, anti-erosion ditches 55%, and grass strips 76% (Clay and Reardon, 1994). It should be noted that since farms have multiple parcels, the proportion of farms with a given practice is much higher than the proportion of parcels with the same practice.

The adoption of anti-erosive measures is generally much greater on steeper slopes. For example, a 1990 survey in communes in Ruhengeri prefecture found that 83% report having constructed "terraces" on steep fields (many of which had washed away), 81% planted tall grasses to control erosion, and 88% had constructed and used compost pits to maintain soil fertility (Ndiaye and Sofranko, 1994). Clay and Lewis (1990) note that the construction of hedgerows or terraces, found on 29% of all fields surveyed in Rwanda during 1984, is found chiefly on fields with slopes of 15 degrees or more (which comprised roughly 40% of parcels examined). Very little soil erosion is reported on relatively flat parcels, while 38% of parcels on slopes of over 21 degrees are reported to suffer from erosion.

The anti-erosive measures aggressively promoted in Rwanda and Burundi during the 1980s are widely regarded by soil conservation experts as ineffective in preventing erosion as well as uneconomical (Roose, 1988; König, 1993; Ndayizigiye, 1993; Jones and Egli, 1984; Clay and

Lewis, 1990; Brondeau, 1991). Also, these soil conservation measures have not been found to have any effect on improving crop yields (Barel, 1989; Uwizeyimana, 1991; Roose et al., 1992; Ndayizigiye, 1993). Grass strips are frequently cut for use as fodder and mulch, and within 3-5 years growth rate of the grasses is so low that the primary purpose of erosion control is defeated (Balasubramanian and Egli, 1986). Poorly maintained anti-erosion ditches by unmotivated farmers often increased the risk of gullying (Bidou, 1989; Bart, 1993; Ndayizigiye, 1993). The bench terraces associated with anti-erosion ditches on steeper slopes in Rwanda have commonly resulted in decreased soil fertility and increased soil acidity in fragile highland areas (Lewis, 1992). Soil erosion is aggravated by the common practice of cutting back terrace berms to counter soil acidity. Lewis points out that any technical solution which does not factor in the human dimension is doomed to be ineffective.

Biological methods of soil conservation have advantages over mechanical means such as terracing, but these have not been actively promoted. The planting of leguminous bushes (Calliandra and Leucaena) on micro-terraces has been found to reduce topsoil loss by 95%, and as an added benefit the biomass generated by pruning these bushes can be used as mulch or forage (Ndayizigiye, 1993; König, 1993). Roose et al. (1992) calculate the annual rate of soil erosion to be 3 to 10 t/ha/yr when crops are combined with both trees and living hedges, and only 1 to 4 t/ha/yr when combined with trees, hedges, and covered ridges. Low rates of erosion are reported on fields with radical terraces with stone walls, but these terraces are costly to build and no Rwandan farmers have seen it worthwhile to pay to construct them (Roose et al., 1992; König, 1993; Jan Moeyersons, personal communication).

Biological methods of soil conservation generally fall under the category of agroforestry, which involves the integration of trees or woody shrubs and bushes with cultivation for the purposes of maintaining soil fertility. Agroforestry is at a rudimentary stage in Rwanda and biological soil conservation practices are less advanced than in a number of similar regions (Clay, 1993). For example, only 14.6% of plots are reported to have hedgerows planted on them (Clay,

1993). A survey in Ruhengeri prefecture found that only 11% of farmers reported any awareness of agroforestry, and this was only in a locality where a special agroforestry project had already been operating (Weber, 1987).

Indigenous soil conservation or fertility-maintaining practices include manuring, composting, mulching, micro-terraces, and multi-storeyed cropping. Each by itself is of limited efficacy, but together they can make a major difference in soil erosion (Brondeau, 1991). Also, under certain of these techniques, yields seem to be improved (Nyamulinda and Ngiruwonsanga, 1992). Many critics have accused the extension services implementing techniques inherited from the Belgians in a rigid, inflexible, top-down manner (Weber, 1987; Derenne, 1989; Brondeau, 1991). In the late 1980s, the government increasingly emphasized voluntary participation and utilization of farmers' knowledge (Brondeau, 1991).

Rwandan farmers typically use manure and crop residues or other plant material to fertilize and mulch parcels in close proximity to homesteads planted in coffee or bananas. However, these practices do not generally extend to the plots used to grow food crops. Also, green manuring is extremely unpopular, because of the amount of labor involved and the need to take land out of cultivation to plant shrubs (Jones and Egli, 1984; Ndiaye and Sofranko, 1994). The 1991 Survey of Agroforestry in Rwanda revealed that only 1% of parcels have green manure applied (Clay, 1993).

Structure of landholdings and on-farm investments

Population pressure has been reported to be beginning to lead toward polarization and proletarianization in high-density areas of rural Rwanda and Burundi (Uwizeyimana, 1991; Verhaegen and Degand, 1993). A field study in a high-density area of northern Burundi, near the Rwandan border, reports that land sales have increased in recent years, with most purchasers having relatively high incomes (Verhaegen and Degand, 1993). Customarily, permanent emigrants leaving their farm should cede the land to family members, but active land markets

have developed given the reality of severe land scarcity. On the other hand, most land transfers still occur outside the market mechanism, so that polarization of landholdings is still quite low. The Gini coefficient of land distribution was found to be 0.26, which indicates an egalitarian distribution, and the primary determinant of land area is life cycle stage, not social class. Similarly, the distribution of consumption expenditures in rural Rwanda is reported to be equivalently egalitarian (Gascon, 1992).

In Rwanda, population pressure has also led to the traditional right of extended families to block land transfers being effectively converted into individual freehold (Bart, 1993). The proportion of permanently held parcels which can be transferred to non-family members without approval is reported to range from 77.8% in Ruhengeri prefecture to 34.5% in Butare prefecture, and was 67.0% in a third prefecture, Gitarama (Migot-Adholla et al., 1991). In most of Rwanda, land sales to non-family members are still quite limited. However, in certain areas, especially near urban areas, economic and demographic pressures have resulted in much land being alienated under economic necessity (Bart, 1988; Charlery, 1992; 1993). It is generally agreed by experts than any change in the land tenure system towards individualization of land tenure, with registration of titles, is likely to lead to increased concentration of land ownership (Barel, 1989).

Land scarcity in Rwanda has resulted in intense rivalry and conflict among neighbors, with frequent fights and lawsuits over disputed land and frequent thefts from fields (Bart, 1993). Disputes over land are reported to have been a major motivation for Rwandans to denounce neighbors during the ethnic conflicts of 1994. In some areas, farmers are said to deliberately undermine the terraces of upslope neighbors in order to take advantage of the topsoil from the collapsed terraces (Lewis, 1992).

It has been argued that increased insecurity of tenure associated with changes in the structure of landholdings may be an important mediating factor in the association between population growth and environmental degradation (Clay, 1993; Clay, Guizlo, and Wallace, 1994).

The empirical importance of this mechanism in the current Rwandan context is uncertain, although it is likely to become increasingly important in the future (Barel, 1989). In Rwanda, average farm holdings shrank by 12% in the 5 years from 1984 to 1989, and the proportion of plots rented in rose to 18.7% (Clay, 1993). It is suggested that since cultivators are much less likely to make costly investments in protecting soil fertility on land they do not own, this change in land structure has negative long-term implications. Data from the 1991 Survey of Agroforestry confirm that farmers are much more likely to plant trees or use manure or compost on land they own, and are also somewhat more likely to install anti-erosion technologies on their own land. On the other hand, owner-operated parcels tend to be on steeper slopes and to be more degraded than parcels which are rented in (Clay, 1993).

A survey conducted in 3 prefectures under World Bank sponsorship during 1988 yielded similar empirical results (Barel, 1989; Migot-Adholla et al., 1991; Place and Hazell, 1993). As in the later survey mentioned above, it was found that land improvements almost never were made on land rented in but only on parcels with bequest rights. Interestingly, investments were not more likely to be made on parcels with long-term use rights than on those with short-term use rights, which does not support a distinction commonly made (Barel, 1989). Official land tenure and the right to sell, with or without approval of others, was found to be unrelated to improvements, given the right of bequest. Also, it was found that productivity was higher on parcels rented in than on owned parcels. These results have been interpreted as indicating at most a relatively minor importance of land tenure for agricultural performance in Rwanda and the other two African countries studied (Migot-Adholla et al., 1991; Place and Hazell, 1993). Further, they find no evidence that variations in land use rights have as yet had any impact on soil fertility, including in Rwanda.

A statistical analysis of on-farm investments indicates that Rwandan farmers behave in a rational manner. It is reported by Clay and Reardon (1994) that average regional agricultural productivity is strongly positively related to investment, while the average nonagricultural wage is

less strongly negatively related. That is, investments in agriculture are positively related to the expected return on the investment and negatively related to the opportunity cost. Investments are also found to be inversely related to the steepness of slopes, presumably because these areas are harder to protect and have poorer soils anyway. Farm households with less land area are more likely to make conservation investments than are those with more land (which runs counter to the myth that poorer households have a shorter time horizon).

Clay and Reardon (1994) attempt to explain why Rwandan farmers are not aggressively adopting soil conservation measures. Explanations offered include poorly functioning credit markets, lack of liquidity because of limited off-farm income sources, and uncertainty over risk from price or climatic variability. A more obvious explanation, which is defended above, is that most of the standard soil conservation measures are either of limited efficacy or are too costly to be economically attractive. Another perspective is that since the adoption of such measures may largely reflect the pressures brought to bear by government officials, it is of uncertain validity to explain the adoption by reference to household or physical characteristics (Jennifer Olson, personal communication). Uwizeyimana (1991) has found that such characteristics are at best weakly related to the adoption of anti-erosive measures.

Historical evolution of land use patterns in Rwanda and Machakos District (Kenya)

In some respects, the evolution of land use patterns in Rwanda since the 1930s bears some similarities to the experience of Machakos District in Kenya, as alluded to in the introduction. Tiffen et al. (1994) have demonstrated, using a colonial report from 1937 with photographs for comparison, that land use has improved and degradation decreased since that period. No comparable study has been carried out for Rwanda. However, the existence of a published report on famine in Rwanda by Scaetta (1932) offers a tantalizing parallel. This volume includes more than a dozen photographs depicting denuded, eroded hillsides throughout central Rwanda. It would be interesting to try to identify the exact locations and take comparison photographs as the

Kenyan team did. A casual comparison of Scaetta's photographs with more recent photographs from the Central Plateau of Rwanda suggests that vegetative cover has greatly increased and that visible erosion has decreased.

Regarding the densely peopled central massif of Rwanda between 1400 and 1900 m altitude, degradation produced by erosion is said by Scaetta (1932) to have been clearly evident. Vast ravines and gullies were said to occur everywhere, from valley bottoms to mountain tops. Whole valleys had become uncultivable, deserted by their inhabitants. For example, the valley of "Muhembe" between Kabaya and Kanoko is said to have been uninhabited for 12 years, leaving only a degraded prairie. All vestiges of forest in the central region had disappeared, even at 2200-2300 m altitude. It is argued that valleys were being taken over by transhumant pastoralists, who burned the grass 2, 3, or 5 times per year. It is argued that this transhumant pastoralism with burning was aggravating the degradation of soils.

Similar to the case of highland Machakos in Kenya (Tiffen et al., 1994; English et al., 1994), gullying in central Rwanda appears to have been more common and severe in the 1920s and 1930s (Scaetta, 1932) than at present. In both of these cases, the reduction of gullying appears to be related to the replacement on steep slopes of eroded pasture by cultivation using shrubs and various forms of contoured terracing to reduce runoff erosion.

At least five major changes in land use patterns in Rwanda in subsequent decades are consistent with the hypothesis of reduced environmental degradation within parts of the Central Plateau. First, the elimination of burning of pastures and the generalized replacement of pastures by cultivation has acted to increase vegetative cover. Second, as the population has multiplied, the extension of banana groves has increased in parallel. As discussed above, mature banana groves provide substantial protection against soil erosion. Third, the extension of coffee cultivation has improved vegetative cover. Fourth, tree cover has greatly increased as a result of the

planting of trees in woodlots, alongside roads and other public spaces, and on farms. Fourth, anti-erosion measures such as infiltration ditches have become widespread.

The evolution of tree cover in Rwanda involves some ambiguity. During the 1920s and early 1930s, massive deforestation of the Zaire-Nile Divide occurred, followed by some inhibition by colonial restrictions (Gatera, 1980). Between 1958 and 1982, the remaining forest area in Rwanda was reduced by a further 43% (Ford, 1990). The tremendous destruction of natural forest on the Zaire-Nile Divide and elsewhere has caused substantial environmental degradation in those areas and in certain watersheds. On the other hand, tree planting efforts have greatly increased tree cover on already cultivated land. This is confirmed by old photographs and by the memories of people who have worked in Rwanda for several decades (Weber, 1987; Claude Heimo, personal communication). As Maquet (1961: 9) observes,

> The present-day typical Ruanda landscape, eucalyptus-covered hills and roads bordered by three or four lines of trees is new. Fifty years ago the country had an even more denuded appearance than it has today. The result of the scarcity of trees in a country of steep hills has been erosion. Torrential rainfall has washed off the more fertile top soil. The deterioration of the ground has been a long process which has not yet been reversed.

It is reported by Lewis (1988) that soil erosion in central Rwanda is less than in the central highlands of Kenya, which would include the western part of Machakos District. This is in spite of the fact that terracing and other mechanical anti-erosion measures are much more advanced in Kenya than in most of Rwanda. The explanation is that ground cover is generally better in Rwanda. This is said to be due to the dense banana groves and the intense multicropping of fields, in contrast to the monocrop maize fields which predominate in Kenya.

Comparisons of Rwanda with Kivu (Zaire) and Madagascar

Interesting contrasts to the Rwandan situation can also be found in other African highland environments. This includes the ecologically similar Masisi district of North Kivu province in neighboring Zaire. This district in 1980 had a population of 434,096, with a density of 92

inhabitants per km^2 (Hangi, 1989). The majority of the population consist of the descendants of Rwandan immigrants who were brought in on an organized basis during the colonial era in order to alleviate population pressure in Rwanda. Estimates of the number of Rwandan migrants in northern Kivu at the end of the colonial era were 200,000 to 300,000, most of whom were official colonists and the majority of whom were located in Masisi district (Leurqin, 1963; Guichaoua, 1989).

The land tenure system in northern Kivu remains communal in nature, except that large tracts have been alienated by customary chiefs to form commercial farms and ranches (Hangi, 1989). Some land continues to be converted from customary land tenure to private ranches which raise cattle for sale to urban residents, thereby aggravating land scarcity. Traditional pastoralism remains intact and is said to result in serious erosion because of overgrazing and brush fires. The communal land system removes any incentive for peasant cultivators to invest in protection of lands, since they have no rights or security of tenure. Also, young people resent the customary authority and prefer to migrate to cities. An almost total lack of roads and public services makes any hope of agricultural modernization in the district impossible.

One of the most interesting bases of comparison for Rwanda is Madagascar, which shares with Rwanda the reputation as being a mountainous country with a biological diversity of global significance under threat of human overpopulation. By all indications, Madagascar has experienced much worse environmental degradation and agricultural stagnation than has Rwanda. Madagascar is much larger and much less densely populated than Rwanda. On a land mass of 587,000 km^2, which is more than 20 times that of Rwanda, Madagascar has a population of 12 million, only half again as large. Thus, the population density in Madagascar is only about 21 per km^2, one fifteenth that of Rwanda.

The physical characteristics of highland environments in Madagascar appear to be less favorable for maintaining environmental stability than in Rwanda. Rossi (1979) asserts that the

potential risk of erosion is very high in Madagascar because of the steep slopes and especially because of the high intensity of rainfall, characterized by frequent torrential downpours. In addition to high sensitivity to erosion, the montane forests of Madagascar appear to be characterized by unusually low resilience. Almost everywhere in Madagascar, when forests are cut, they are quickly succeeded by savanna, not secondary forest. It is suggested that the forests are relics from a more humid past and that rainfall is not adequate for them to be spontaneously reconstituted.

Subsistence strategies in Madagascar, with the exception of rice grown on terraces, also appear to put much more stress on the environment than those which are common in Rwanda. In particular, the slash-and-burn 'tavy' and grazing systems result in serious degradation (Brinkerhoff and Yeager, 1993). Mottet (1988) describes cultivation practices employed on steep lands at elevations above 1,250 m. These include planting crops such as maize and potatoes in single crop stands on steep slopes without any kind of terracing. Indeed, potatoes cultivated on ridge running up and down slopes result in dramatic soil erosion, and the loss of soil fertility after 2-3 years of cultivation results in abandonment to cultivation (fallow). Further, extensive pastoralism remains common in highland Madagascar. Widespread brush fires set to create pasture impoverish the soil and destroy woodland.

It is unclear to what extent the destructive practices observed in Madagascar reflect rational responses to what are still objectively low population densities or a form of sociocultural blockage, a failure to properly adapt to changing circumstances. Rossi (1979) suggests the latter. He notes with some astonishment that the Malagasy prefer to cut down forest in order to plant rainfed rice crops, with the land quickly wearing out after 2-3 years on these granitic soils and abandoned, rather than to intensively cultivate already cleared lowlands using simple irrigation. The other major source of deforestation is brush fires to create pastures for cattle herds. Once again, it is argued that it is cultural norms which leads to the destruction of forest, despite the availability of other lands.

The political economy of Madagascar during the last 20 years has also been highly unfavorable to sustainable development (Brinkerhoff and Yeager, 1993). Droy (1991) notes that until 1970, Madagascar was self-sufficient in rice, but since then has had to rely increasingly on imports. Since 1960, per capita production of rice has fallen by 15%. Between 1960 and 1970, production increased from 1.2 to 1.9 million tons, and average yields rose from 1.5 to 2.5 t/ha. This was associated with very supportive government policies. After 1970, production rose only slowly, to 2.15 million tons in 1983, and average yields fell. State monopoly on purchases and a collapse of agricultural credit were partly responsible. Producer prices stagnated in order to keep consumer prices low and because of inefficiencies in marketing. After 1983, economic liberalization resulted in a freeing of producer prices, but there was also a drastic increase in the price of fertilizer.

The extent of soil erosion in Madagascar depends primarily upon deforestation, which is reported to be worst in the western and northern portions of the island (Rossi, 1979). Deforestation has had catastrophic effects on soil erosion and hydrology. In 1968, Herveu calculated that the rate of soil erosion in western Madagascar was 2.9 mm/yr, almost 6 times the average for Africa reported by Fournier in 1962 (Rossi, 1979). From the 1950s onwards, visible soil erosion has been seen as a major problem in Madagascar. This includes the famous 'lavaka' lands as well as extensive areas of barren land on the plateaux.

The case of Ifasy in the Extreme-North is considered edifying by Rossi (1979), although a relatively extreme case. Here land scarcity in the valley bottom has led to the clearing and cultivation of slopes since the 1950s. This movement accelerated after independence because of slackened control. The slopes, up to 30-40 degrees, are covered with thin, poor soils based on silica and poorly cemented conglomerates. After 3-4 years of cultivation, the soils disappear. These clearings accelerated after 1972 with the collapse of local administration. Some 30 years ago the river of Ifasy flowed year-round, but now it is dry during July-August. Flash floods have also become common and severe. Flooding has seriously hurt crops on the lowlying lands.

Discussion

The major environmental challenge facing Rwanda over the last decade has been one of agricultural stagnation or involution rather than imminent ecological collapse. Rwandan farmers through hard work and creativity have managed to maintain the cohesion of their farming system against all odds and despite the dire predictions of outsiders (Charlery, 1989). While existing cultivation methods may for the most part be reasonably well-adapted in terms of maintaining environmental stability, problems of depletion of soil nutrients have been mounting. Most critically, given the lack of additional land, existing methods have not allowed production to increase in line with the needs of a growing population. Thus, the limits of Rwandan farmers' existing adaptations appear to have been reached, although this does not rule out the possibility that with a different policy environment new adaptations could be developed. By the late 1980s, Rwandan agriculture appears to have been characterized by "implosion, paralysis, and inertia" (Charlery, 1989).

The physical features of the Rwandan environment have had mixed effects on environmental stability but have generally been conducive to agricultural intensification based on year-round cultivation of fields. The major negative factor is the steep slopes which are often cultivated. This risk factor is offset in the majority of ecological zones in Rwanda by relatively moderate rainfall and favorable soil quality. More importantly, the physical features and climate of Rwanda have lent themselves to widespread cultivation of bush and shrub crops, chiefly banana and coffee, with important positive effects on the maintenance of soil fertility. The widespread cultivation of banana reflects the result of socially-influenced choices, and a different set of choices might have had much more negative consequences for the integrity of the environment.

The most restrictive aspect of Rwanda's environment is its geographic isolation, which is as much political in origin as it is physical. This isolation has been caused by narrowly-drawn boundaries (which largely coincided with precolonial frontiers), a location distant from dynamic

economies, and poor transportation infrastructure in surrounding countries. The high cost of imports and the few exports which could pay the high transportation costs and still be competitive on world markets have severely constrained Rwanda's economic options (Jones and Egli, 1984). Efforts to promote new export crops to complement coffee have largely been failures. Cinchona and pyrethrum could not effectively compete with synthetic alternatives. Tea prices are so low that smallholder tea cultivators earn less than they would from food crops (Laure, 1986). One of the few sources of dynamism in Rwanda in the late 1980s is reported to have been the unofficial exportation (or reexportation) of goods and services to border regions of Zaire and Uganda (Loveridge, 1988).

Residents of similarly high-density regions within larger African countries have benefited from membership in a larger political entity by being able to specialize in production for markets and nonagricultural employment (see Turner et al., 1993; Tiffen et al., 1994). These options were less available to Rwanda's rural population because of the small numbers of urban consumers and urban jobs. The lack of integration of Rwandan cultivators into markets may also be a major factor inhibiting the adoption of methods for improving crop yields (Charlery, 1992). Bart (1988) argued that the lack of monetary investment in agriculture in Rwanda was a result of the lack of agricultural credit and the poor development of internal markets. Also, purchased inputs such as fertilizer are unavailable or unaffordable for most uses.

Rwanda enjoyed political stability from 1973 until 1990, which had mixed benefits (Ford, 1993). In particular, this resulted in large investments in rural development financed by foreign aid. On the other hand, the rather extreme authoritarian character of the government contributed to major rigidities. No space was left for voluntary organizations to articulate interests and mobilize support behind local initiatives in the realm of environmental protection. Rwanda's economic policies often muffled price signals. For example, the government protected and promoted domestic industries which were uneconomic producers. The government sometimes dictated to farmers which crops to grow and how to grow them, even though this may have

worked to the disadvantage of farmers (Jones and Egli, 1984; Laure, 1986). As yet one more example, economic incentives to plant trees were reduced by restrictions on sales of fuelwood or charcoal by farmers.

As discussed above, Rwanda's agricultural extension service has been characterized by a top-down approach in which recommended practices were often ineffective or poorly adapted to local circumstances and farmers' resources (Brondeau, 1991). Incorporation and modification of indigenous practices in soil conservation, cropping systems, and agroforestry could have provided a much more fruitful alternative approach. Rwandan farmers (especially women) have proven themselves to be adept at selecting seeds on-farm and in evaluating recommended seed varieties (Voss, 1992). It is noted that ome of the varieties recommended by agricultural researchers, including the famed "climbing bean," do not always pass muster with these careful observers.

The structure of landholdings in Rwanda is essentially individualized, which is probably an important factor in the dramatic and mostly successful agricultural intensification occurring in Rwanda during the last several decades. The abolition of customary control over pasture land in the early 1960s unleashed a major wave of land investment and colonization (Prioul, 1981; Nzisabira, 1989; Bart, 1993). On the other hand, land scarcity is increasing the amount of land which is rented in, which reduces the amount of on-farm investment compared to if the land was individually owned (Clay and Reardon, 1994). However, this has as yet not had any demonstrable effects.

The family system of Rwanda may have been less of a negative factor for agricultural intensification compared to some other African societies. Unlike the archetypal African family system, the Rwandan family is at present generally nuclear and monogamous. This may be conducive to a greater degree of cooperation between husbands and wives. According to the 1991 census, only 1 in 20 men who were married or in a union were polygamous (MINIPLAN, 1993). Roughly 3 to 5% of both men and women in their 30s and 40s were reported to be divorced,

separated, or widowed, which may be underestimated. Household surveys give estimates of the fraction of female-headed households in the range of 15 to 20% (Bucyedusenge et al., 1990), which includes women living in polygamous unions where the husband resides with another wife. The fraction of female-headed households is much lower than in other countries in the region in which large numbers of men are absent from rural areas as migrants.

Sex-role specificity in agriculture remains common in Rwanda, with women largely responsible for food crops. Overall, women in male-headed farm households are reported to spend 1.7 times as much time in cultivation as do men. On the other hand, men spend much more time taking care of livestock, and men and women are both reported to spend 35-37% of their time in agricultural and livestock activities (Bucyedusenge et al., 1990). Thus, the popular image of rural African women spending far more time in primary production than their husbands (Boserup, 1970) does not seem to apply in Rwanda. Further, the division of labor appears to be less rigid than in some other African societies. For example, roughly two thirds of labor on bananas is done jointly by husbands and wives (Ford, 1993). Men and women typically share tasks in cultivation of sorghum, bananas and coffee, and to a lesser extent with regard to peas, potatoes, and cassava (Bucyedusenge et al., 1990).

In conclusion, Rwanda displays a mix of factors which have influenced environmental stability and agricultural intensification in complex ways. Many writers emphasize the manifestations of increased environmental instability in Rwanda. The existence of these phenomena is undeniable but they do not seem to be major contributors to the recent subsistence crises in Rwanda. The impasse which Rwanda has experienced in the past decade is chiefly due, in our opinion, to economic isolation caused by being landlocked in a remote area surrounded by economies with poor transportation infrastructures, although the extent of such isolation may be overstated (Loveridge, 1988).

Rwandan farmers have displayed a remarkable capacity for adaptation. They have tremendously expanded agricultural production over the last half century with minimal outside inputs. The strategies followed were ultimately not sustainable in either economic or environmental terms. However, if the constraints regarding access to markets and resources could have been relaxed, we are confident that Rwandan farmers could have coped as successfully as have rural residents of a number of other high-density regions.

Policy implications of demographic trends

Given the current drastic reduction in the population of Rwanda caused by the death or flight of close to 40% of the country's people, it seems pointless to make any predictions or prognoses about the future. However, we can still say that a reduction of fertility, if it had occurred much sooner, might have helped postpone or avert the demographic impasse which had already been reached (May, 1993). Important strides were made in Rwanda in recent years, with an impressive 30% reduction in fertility rates achieved in less than 10 years (ONAPO, 1994). The reduction in birth rates in Rwanda, though, was too little, too late.

The dilemma of population policy is that an extremely long planning horizon is required. In order to prevent demographic momentum from continuing to drive population growth long after a country decides that its population is already sufficiently large, it is necessary to begin reducing birth rates far in advance of the time at which population-resource imbalance can be predicted to occur. The difficulty is that there is no consensus for predicting when, or even if, an impasse will be reached. Also, it may be hard to convince people of the importance of population stabilization until resource constraints and scarcities become clearly visible. Analyses which conclude that a country is currently coping satisfactorily with population growth may contribute to an attitude of complacency by opinion leaders and thereby make it more difficult to mobilize support for an active population policy.

Projections of a population-resource imbalance in Rwanda have in the past been contentious. A number of researchers have argued that the simple, mechanistic models of population growth and agriculture generally used to make these predictions are deficient in terms of both theory and empirical realism. Such models yield negative, pessimistic predictions regardless of context. On the other hand, with the benefit of hindsight we can say that studies such as Wils et al. (1986) did a valuable service in calling attention to real problems in Rwanda well in advance of the occurrence of these problems. In addition, observers familiar with the land-extensive nature of Rwandan agriculture growth could and did predict, without the benefit of a simulation model, that per capita food production would begin to decline in the 1980s because of the inevitable saturation of cultivable land (Nyrop et al., 1969). It was realized that in the absence of major economic diversification, Rwanda would face an economic crisis after the agricultural frontier was closed (Sirven, Gotanegre, and Prioul, 1974).

The fact that demographic momentum ensures continued population growth long after fertility rates begin to fall also brings out the need to complement an active population policy with an equally strong push to increase both food production and food security through nonagricultural employment generation. It is unrealistic for international development agencies to focus their resources and attention on reducing the population growth rate to the exclusion of planning for the needs of those persons who have already been born. Over the next two decades, population planning efforts will probably have relatively little impact on averting or alleviating subsistence crises. Countries such as Rwanda which are facing population-food imbalances need to receive increased and better focused assistance in agricultural research which is adapted to the variety of local contexts found in African countries. Unfortunately, international funding for such areas is being drastically slashed, which may have serious negative ramifications for the future ability of these countries to feed their growing populations (Budiansky, 1994). Even more important for achieving food security in countries such as Rwanda is the employment which can be generated through increased opportunities for exports of nonagricultural goods.

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