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POPULATION PRESSURE AND THE MICROECONOMY OF LAND MANAGEMENT IN HILLS AND MOUNTAINS OF DEVELOPING COUNTRIES

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ABSTRACT

Concerns about harmful environmental impacts are frequently raised in research and policy debates about population growth in the hills and mountains of developing countries. Although establishing wildlife corridors and biosphere reserves is important for preserving selected biodiverse habitats, for the vast majority of hilly-mountainous lands, the major ecological concerns are for the sustainability of local production systems and for watershed integrity. What matters for sustained use of those lands not only is the number of producers but also what, where and how they produce. Indeed, comprehensive evidence from empirical research indicates that population growth in hills and mountains can lead to land enhancement, degradation, or aspects of both.

The evidence can be explained by extending induced innovation theory to address environmental impacts of intensification. Increases in the labor-land endowment ratios of households and in local land demand and labor supply make the opportunity cost of land relative to labor increase. As a result, people use hilly-mountainous land resources more intensively for production and consumption, thus tending to deplete resources and significantly alter habitats. But, at the same time, capital- and labor-intensive methods of replenishing or improving soil productivity may become economically more attractive, especially where specific property rights develop.

Users will choose production systems that enhance the land if the expected discounted returns are greater than those of systems that degrade the land. In addition to population change, other factors—market conditions, local institutions and organizations, information and technology about resource management, and local ecological conditions—determine the returns from various production systems. Theoretical arguments and empirical evidence about these other determinants of land-improving investment and management are examined. The challenge to researchers and policymakers is to help to configure microeconomic incentives for production that enhance both the land and the welfare of people in these areas.

CONTENTS

POPULATION PRESSURE AND THE MICROECONOMY OF LAND MANAGEMENT IN HILLS AND MOUNTAINS OF DEVELOPING COUNTRIES[*]

Scott R. Templeton[**] and Sara J. Scherr[***]

1. INTRODUCTION

Human populations are growing in many hilly-mountainous areas in developing countries. This growth is expected to continue for at least the next few decades. There is considerable historical evidence to suggest that intensification of farming systems is likely to occur with population growth, sufficient to ensure stable or increasing agricultural production (if not always per capita income) particularly in areas of “higher-potential” where densities are not yet already very high (for example, Ruthenberg 1980; Turner, Hyden, and Kates 1993). This proposition, however, hinges on the assumption that land degradation does not constrain the process, and it is evident that in hilly and mountainous areas, intensification poses greater potential ecological risks both for local production and for the broader environmental services provided by upper watersheds.

Indeed, many researchers, policymakers, environmentalists, and other members of society argue that greater production in these areas due to population pressure degrades forests, farms, and grazing lands and creates significant, negative off-site environmental impacts (FAO 1994; Harrison 1992; Lele and Stone 1989; Repetto 1986; Southgate 1988; World Bank 1992).

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A number of microeconomic arguments underlie this pessimistic assessment. As population density increases, the supply of people who clear trees increases (Kang and Wilson 1987; Southgate 1988; World Bank 1992) and the demand for products from forests or forest land grows too. As a result, a larger area is deforested and biodiversity diminishes. In addition to these forest changes, both the number of producers who use degrading agricultural or grazing practices (for example, Repetto 1986) and the demand for crops and livestock produced with degrading practices increase (Brown and Wolf 1984). To increase production and because the marginal product of labor decreases, farmers move onto and cultivate lower quality land (FAO 1994; Gillis, Perkins, Roemer, and Snodgrass 1987; UNFPA 1991). Lower quality land, by definition, tends to degrade more and faster. Finally, people become poorer as population grows. As such, they are less able (UNFPA 1991) and willing (World Bank 1992) to conserve soil and make other resource-enhancing investments.

A contrasting view—more optimistic, but also grounded in microeconomic theory—is that population growth may lead to land enhancement (for example, Simon 1981). This view suggests that people plant larger areas with trees or plant more trees in a given area as the demand for products from trees and the number of tree farmers increase. Similarly, farmers use land-enhancing agricultural or grazing practices either more frequently in a given area or on larger areas as the demand for agricultural and livestock products increases and as the number of producers increase. People change their production methods to overcome declines in the marginal product of labor, change property institutions to better protect land, and make landscape investments (Boserup 1965; Hyden, Kates, and Turner 1993; Ruttan and Hayami 1991; Kates and Turner 1993). The poorer are people who rely on land for their sustenance and have no better alternative, the greater the incentive they have to protect the source of their sustenance (Pagiola 1994).

Other scholars argue that rural depopulation or labor shortages threaten land degradation. For example, throughout rural Africa, local population decline or diminished growth due to greater access of people to non-local economies will make many existing resource management systems unsustainable due to labor shortages (Goldman 1995). Migration of youngsters from Mt. Kilimanjaro to urban areas and the consequent decrease in local labor supply and loss of farming knowledge and experience could threaten the viability of the complex multistoried homegardens of the Chagga (Fernandes, Oktingati, and Maghembe 1984). In Nepal, the major shift in the population from the middle hills to the lowlands, or *terai*, could lead to a substantial reduction of labor inputs into the intensive farming and land-management systems of these hills and, thereby, could be ecologically devastating (Blaikie and Brookfield 1987).

These divergent assessments of the effects of population growth and decline on land and other natural resources suggest different answers to important policy questions: How can policymakers promote land enhancement in hilly-mountainous areas? Under what conditions should policymakers encourage out-migration and depopulation? Under what conditions should policymakers accept or even encourage population growth by promoting infrastructural development and private property rights for local land users? In this paper, we argue that neither the pessimistic nor optimistic assessments can adequately answer these questions. What is needed is a comprehensive framework to understand not only the ecological potential of specific areas to sustain intensive or extensive production systems but also the microeconomic factors that increase the likelihood that people will develop or adopt production systems that can be ecologically sustained under hilly-mountainous conditions.

This paper has two related purposes. The first is to examine and critique existing empirical evidence about how population change affects land quality in hilly-mountainous areas. In section 2, we review literature linking demographic change with changes in forestry, agriculture, and livestock production and in land quality.[1]

The second purpose is to develop a microeconomic conceptual framework to understand changes in land management in these areas. In section 3, the empirical results of section 2 are put into perspective with an analysis of the microeconomic basis for choices about production systems. Emphasis is given to how population growth, institutional-organizational factors, information and technology for resource management, market forces,

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[1]The issue of how per capita incomes or other measures of economic welfare change with population growth is also critical to the policy debate, but not addressed directly in this review. In this paper we maintain a focus on key relationships between population growth, production and productivity, and environmental conditions.

and intrinsic ecological conditions can create microeconomic incentives for resource-conserving investments, products, inputs, and technologies. The implications of the evidence and analysis for research and policy are explored in the final section.

The evidence analyzed in this paper comes from our review of English-language literature from economics, sociology and geography that pertains primarily, but not exclusively, to the hilly-mountainous areas of the Himalayas, Andes, Southeast Asia, East Africa, and Central America. Sources of literature include key-word searches on computer indices, direct contacts with social and soil science experts, and our own bibliographies. The type of evidence (data sources and analyses)—for example, aerial photographs over time, researcher assessment or statistical correlation of variables from case studies, or estimated coefficients of multivariate econometric models—is presented in various tables and discussed in the text.

2. POPULATION CHANGE AND LAND QUALITY IN HILLS AND MOUNTAINS

Intensification of land use and management in the hills and mountains of developing countries could potentially have three types of negative effect on land quality. The degradation of soil, water and vegetation resources can reduce the long-term productive potential of the land, leading to declining production and impoverishment of producers. Expansion of land area under agricultural production into new regions, or into niches of existing farm landscapes that were previously uncultivated, threatens habitats needed to support unique or valued biodiversity. (Indeed, mountain areas in the tropics and sub-tropics contain some of the world's richest biodiversity reserves.) Finally, increased populations and intensification could affect populations and economic activity downstream from hill and mountain settlements, by interfering with critical watershed functions. Possible threats include water pollution, water supply reductions, flooding due to inadequate water absorption or vegetative cover to slow water movement during storms, and sedimentation clogging water channels or building up behind dams.

The most critical land management factors affecting environmental outcomes are land use, vegetative cover, landscape modifications and management practices. This section looks, in turn, at empirical evidence relating population growth with forest, agricultural and pastoral land management and quality.

POPULATION CHANGE AND FOREST COVER

Deforestation

A number of statistical analyses document an inverse relation between population and forest cover. For example, according to multivariate statistical analysis of FAO data for 98 low- and middle-income countries, a one percent increase in population during 1975-1980 led to small and statistically weak reductions in forest cover of 0.12 percent during 1980-1985 (Deacon 1994). An estimation of Spearman's rank correlation coefficient (r_s) between change in forest and woodland area and population growth rates for 99 more and less developed countries between 1975 and 1981 was -0.683 (Mather 1987). The correlation coefficient (r^2) between population density and forest cover was -0.8 for Latin America and moist Africa, and -0.96 for Asia (Palo and Mery, *18th IUFRO Congress Report*; Ljubljana 1986 as cited by Harrison 1992). Population density at the *municipio* (district) level of Guatemala between 1950 and 1981 was strongly inversely correlated with the percent of the *municipio*'s land area in forests (Mendez 1988 as cited by Bilsborrow and DeLargy 1991).

Some cross-sectional data imply a positive correlation between deforestation and population pressure. For example, Cameroon and Tanzania have more arable land per capita and smaller percentages of total forest area being deforested than Malawi, Nigeria, Senegal, and Kenya have (Lele and Stone 1989). Case studies for Meru district, Kenya (Bernard 1993), an eastern hill area of Nepal (Kumar and Hotchkiss 1988), and the middle hills of Nepal (Blaikie and Brookfield 1987) indicate that population growth leads to a reduction in forest cover. One longitudinal case study of a village near Ranomafana, Madagascar (Harrison 1992) illustrates this population growth-deforestation process well:

> The land in what is now the village of Ambodiaviavy was dense forest at the start of the 1940s. Then, in 1947, eight families, 32 people in all, came to the area after French colonials burned down their old village. These families

> farmed only the valley bottoms, which were easily irrigated by the stream running down from the hilltops. Each family took as much land as they were capable of working; no land shortage existed. The valley bottom lands had filled up completely by the 1950s. New couples started to clear forest on the sloping valley sides. They moved gradually uphill. As a result of natural growth and immigration from an overcrowded area nearby, the village population had increased tenfold, to 320, and the number of families had grown to 36 by 1990. By that time the people had cleared forest two thirds of the way to the hilltops.

Evidence that population growth induces a decrease in forest cover is presented in Table 1.

However, caution is required in interpreting findings of a positive correlation between forest cover (or change in forest area) and population density (or population growth rate). Such findings are consistent *both* with the argument attributing deforestation to population increase, *and* the argument that increases in population density *followed* initial deforestation due other factors, such as logging or ranching More case histories, such as that of Ambodiaviavy, Madagascar, or time-series data are needed to determine whether population growth preceded deforestation. Moreover, negative correlation between population density and forest cover at a national or regional level can, as we will illustrate below, mask positive correlation between population density and planted tree density in specific areas or in exceptional national or regional cases.

In many cases, plantation agriculture, logging, and ranching are clearly more proximate causes of reductions in forest cover than is local population growth. For example, the rainforest on the lower slopes of Malaysia was cleared for rubber and palm oil plantations (Gupta 1988). In particular, conversion of rainforests for plantation crops was responsible for 89 percent of total deforestation from 1976 to 1981 in peninsular Malaysia, according to the FAO (Gillis, Perkins, Roemer, and Snodgrass 1987).

Table 1 Evidence of negative relationship between population growth and forest cover

Source	Hilly-mountainous area	Type of evidence	Type of negative relationship
Deacon (1994, 427-428)	98 low- and middle-income countries (not all hilly)	Multivariate statistical analysis of FAO and other secondary country-level data	1% population growth rate during 1975-80 led to 0.12% deforestation rate during 1980-85; weak statistical significance of effect (p-value ≈ .11 for one-sided test)
Mather (1987, 5)	99 developed and developing countries (not all hilly)	Univariate statistical (simple correlational) analysis of FAO country-level data	Population growth rates negatively correlated with percentage changes in forest or woodland areas for 1975-1981
Palo and Mery (1986), cited by Harrison (1992)	Countries in Latin America, moist Africa, and Asia (not all hilly)	Univariate statistical analysis of country-level data	More population growth correlated with less forest cover
Mendez (1988), cited by Bilsborrow and DeLargy (1991)	Guatemalan *municipio*s (districts) (not all hilly)	Univariate statistical analysis of *municipio*-level census data for 1950 and 1981, field visits to 40 *municipio*s	Higher population density correlated with smaller percentages of forest area
Lele and Stone (1989, 19)	Malawi, Nigeria, Senegal, Kenya, Cameroon, and Tanzania (not all hilly)	Non-statistical correlation in table, country-level government estimates and FAO forest assessments	Greater arable land per capita weakly associated with smaller percentages of total forest area being deforested
Bernard (1993, 92, 99)	Meru district, Kenya	Previous research based on unspecified primary data	Loss of forest accompanied population growth
Kumar and Hotchkiss (1988, 9, 13) and Blaikie and Brookfield (1987, 39, 44, 46)	Areas in eastern and middle hills of Nepal	Government survey of forest cover and FAO estimate of subsequent decrease, citation of previous research, researcher observation	Loss of forest accompanied population growth
Harrison (1992, 78-80)	Ambodiaviavy, Ranomafana, Madagascar	Case history from village informants	Loss of hilly forest after bottom land filled with people

Excessive commercial logging of various hardwood species has caused a substantial portion of forest disturbance in the Philippines (Cruz, Meyer, Repetto, and Woodward 1992). After commercial loggers convert the primary forest into degraded secondary forest, small-scale agriculturalists convert the degraded secondary forest into farmland (Cruz, Meyer, Repetto, and Woodward 1992; Kummer 1992). Available evidence does not indicate whether this conversion of degraded secondary forest into farmland generally represents enhancement or degradation. Nor does available evidence indicate the extent to which natural or migration-induced increases in hillside population represent increases in the number of small-scale agriculturalists who are converting 'immature, degraded, or commercially insignificant' forest stands instead of primary forest. Thus, hillside population pressure in the Philippines has not been the chief cause of primary forest degradation and its role in the conversion of secondary forest into farmland, to the extent that degradation has occurred, is debatable.

In Central America, cattle ranching is the major factor in forest destruction (Myers 1981). Even after the elimination of subsidized public credit and fiscal incentives for livestock, deforestation continues (at a lower pace) due to attempts to claim public lands, public road construction, colonization programs and the market characteristics of cattle—not to population increase. In Costa Rica, although the demand for pasture land has historically been the principal cause of deforestation, timber extraction and the expansion of banana and other plantations have now become the leading causes of deforestation (Cruz, Meyer, Repetto, and Woodward 1992; Kaimowitz 1995).

To summarize, most of the empirical evidence suggests that population growth is indeed associated with deforestation of natural forests, which would frequently have negative effects on natural forest biodiversity.

Planted Tree Density

However, other empirical research indicates that increases in population density may be associated with increases in planted-tree density. For example, in two districts near Lake Victoria, Kenya managed-tree cover in agricultural areas was significantly greater in the late 1980s than earlier in this century, when population densities were lower (Scherr 1993). Machakos, Kenya became more densely covered, by larger trees, as the number of people increased fivefold between 1930 and 1990 (Tiffen, Mortimore, and Gichuki 1994a). In Ruhengeri, Rwanda, although the population growth rate between 1978 and the mid-1980s was 2.9 percent and the average population density was 367 persons/km^2 in 1984, the total area reforested nearly doubled from 5,487 hectares in 1980 to 10,354 hectares in 1985, out of a total of 168,470 hectares (Ford 1993). In Algeria, where most people live in or near the Atlas mountains, population growth was very high—32 percent—and the percent increase in forest and woodland area was one of the largest of 127 countries during the 1970s (Heilig 1994).

Average population density on Java is 760 persons per square kilometer (Fujisaka 1989b). On this densely populated island, the area devoted to intensive multistory home gardens increased with population density, occupying anywhere from 15 to 75 percent of the cultivated land, producing more than 20 percent of household income and 40 percent of household caloric requirements, and providing one of the highest returns to labor of all available employment opportunities (Stoler 1978).

In four village *panchayat*s in two central hill districts of densely populated Nepal, the number of trees per hectare grew two- to three-fold on rain-fed terraced farms during the period 1964-1988 and substantial increases in tree densities also occurred on non-cultivated segments of farm land. Similar increases in tree cover on rain-fed terraces were detected over most areas of these two districts and in several other hill. The population in these hills probably almost doubled during 1960-1990 (Carter and Gilmour 1989).[2]

The chief reason for this positive correlation is that people tend to consciously allocate parts of their farms for tree growing or preserve existing trees on their farms at all population densities beyond the levels associated with forest or bush fallow. For example, at the time they entered into pulpwood growing contracts with the Paper Industries Corporation of the Philippines (PICOP), farmers were engaged in low-density extensive agriculture; the average land holdings were 11 hectares per farm household (Arnold 1987, 177). Woodlots have been common in western Kenya for more than 50 years and today cover about 60,000 hectares of

[2]Forest area has not significantly changed since at least 1900 in a densely peopled area at Thokarpa, east of Kathmandu, despite large population increases (Mahat 1985 as cited in Blaikie and Brookfield 1987).

the landscape, some of which is the most densely populated in the area (Spears 1987, 55 and 59).[3] In many locations on Cebu, one of the most densely populated and hilly islands in the Philippines, farmers have sustainably cultivated and harvested fuelwood and produced charcoal for decades (Bensel and Remedio 1993; Kummer, Concepcion, and Canizares, forthcoming, 16). Finally, farmers in about 50 percent of the area of Nepal deliberately retain or plant strips of trees and shrubs across and along the perimeter of steep—40 percent-70 percent slope—fields and in terraces on more gently sloping fields to control soil erosion and to have as sources of fodder, firewood, and fence posts (Fonzen and Oberholzer 1984).

Similarly, case studies indicate that as population density increases, people in some instances transform native forests, swidden land, or recently logged areas into agroforests that are more economically beneficial but nonetheless ecologically viable. For example, on the southern and eastern slopes of Mt. Kilimanjaro, one of the most densely populated areas in Tanzania, the Chagga people gradually replaced the natural forest with home gardens (Fernandes, Oktingati, and Maghembe 1984). This multistoried agroforestry system involves integration of several multipurpose trees and shrubs with food and cash crops and livestock simultaneously on the same unit of land. With an average size of 0.68 ha, homegardens are labor-intensive and human capital-intensive, that is, require intimate knowledge of various trees, crops, and plants and their ecological requirements (Fernandes, Oktingati, and Maghembe 1984). In another instance, as a result of increases in relatively low population densities on the islands of Roti and Savu in eastern Indonesia, people replaced shifting cultivation with a more sedentary production system based on nearly total exploitation of the multipurpose lontar palm, which had dominated their degraded fallows. This tree-based economy is both economically and ecologically superior to the degraded swidden systems on nearby islands (Fox 1977). Table 2 summarizes the evidence relating population growth with increases in tree density.

The watershed effects of replacing natural forest with planted trees depends upon their configuration (in relation to annual crops or other land uses), associated ground cover, water

[3]The increase in the area of small woodlots accounts for 83 percent of the total increase in tree cover during 1980-1985 in Ruhengeri, Rwanda (Ford 1993).

Table 2 Evidence of positive relationship between population growth and tree cover

Source	Hilly-mountainous area	Type of evidence	Type of positive relationship
Scherr (1993)	Lake Victoria, Kenya	Aerial photographs over time, farm surveys, archives, previous research	Higher managed-tree densities
Tiffen, Mortimore, Gichuki (1994a, 5-12, 218-224)	Machakos, Kenya	Photographs in 1937, 1948, 1960-61, 1978, and 1991, farmer surveys, and previous research	Higher planted-tree densities and bigger trees on farms
Ford (1993, 155-156, 163-164)	Ruhengeri, Rwanda	Non-statistical correlation, official prefectural data on reforested area and population density	89% larger reforested area for 1980-1985 and 225% higher population density for 1948-1984
Heilig (1994, 847)	Algeria (not entirely hilly)	FAO country-level data on forests and woodlands, unclear source of data on national population growth	32% population growth rate in 1970s and almost 1% percent increase in forest or woodland area between 61/63-89/91
Fernandes, Oktingati, and Maghembe (1984, 73, 76)	Mt. Kilimanjaro, Tanzania	Photographs, other data probably from farm surveys or informants	Conversion of native forest to multistory agroforest
Carter and Gilmour (1989, 381-382, 386-390)	Central hills, Nepal	Aerial photographs in 1964 and ground survey in 1988 of 60 plots, anecdotal information	Two- to three-fold increase in tree densities on these plots and other areas
Fonzen and Oberholzer (1984)	Nepal	Photographs and a previous case study of unspecified primary data	Retention and planting of strips of trees and shrubs
Stoler (1978)	Java, Indonesia	Cited by Raintree and Warner (1984, 50), unclear primary data	Area of multi-story home gardens increases with population density
Fox (1977)	Roti and Savu, Indonesia	Cited by Raintree and Warner (1984, 50), unclear primary data	Conversion of degraded swidden land to tree-based economy
Fujisaka and Wollenberg (1991)	Two villages in central Luzon, Philippines	Researcher observation, surveys of 81 farm families, biophysical analysis of 15 plots	Conversion of degraded forest into agroforests

management practices, and geographic features. According to recent evidence from the tropics and sub-tropics, most watershed functions can, in principle, be provided in many farming landscapes by these features (Jackson and Scherr 1996).

POPULATION CHANGE AND AGRICULTURAL LAND QUALITY

Fallow Length

Evidence from around the world indicates that length of fallow and population density are negatively correlated (Kumar 1973; Turner, Hanham, and Portararo 1977). Similarly, a table of frequencies between population density and cropping frequency in 52 cases in sub-Saharan Africa implies that cropping frequency and population density are positively correlated (Pingali, Bigot, and Binswanger 1987). Case histories and quantitative data from specific developing countries or areas around the world also indicate that increases in population density lead to decreases in fallow periods or increases in cropping frequency (Blaikie and Brookfield 1987; Cruz, Meyer, Repetto, and Woodward 1992; Harrison 1992; Hyden, Kates, and Turner 1993; Nwafor 1979; Perkins 1969 as cited by Bilsborrow 1987). (See Table 3.) As the length of fallow decreases, *ceteris paribus*, soil productivity decreases in most cases (Boserup 1990; Brady 1990; Fujisaka and Sajise 1986; Kang and Wilson 1987).[4]

Land Expansion

Expansion of agricultural land is a special case of an increase in cropping frequency. According to Harrison (1992), population growth was allegedly responsible for 72 percent of arable land expansion in developing countries between 1961 and 1985. However, he assumes that the only three factors responsible for changes in arable land are changes in population, agricultural production per capita, and farm area per unit of production (the inverse of yield). Multiplied together these factors are identical to the expansion in agricultural land. So an increase in any of these factors will 'cause' expansion, even if the

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[4] *Ceteris paribus* means 'everything else remaining the same.' In this context the phrase means that all the other factors that could influence soil productivity, such as fertilizer use, are held constant so that they do not influence this outcome.

Table 3 Evidence of positive relationship between population growth and cropping frequency

Source	Hilly-mountainous area	Type of evidence	Type of relationship
Turner, Hanham, and Portararo (1977)	Areas of Brazil, Indonesia, Mali, New Guinea, Nicaragua, Nigeria, Panama, Peru, Sarawak, Solomon Islands, Tonga, Uganda, Ukara Islands, Venezuela, and Zambia	Multivariate statistical analysis of secondary data on 29 groups of tropical subsistence cultivators	Increases in population density led to increases in agricultural intensity
Kumar (1973), cited by Bilsborrow (1987, 192-195) and Boserup (1981, 18-20)	56 countries around 1960, 5 regions in 1950 and 1960, and 7 Asian countries and Egypt in 1960 and in various years between 1910 and 1960 (not all hilly)	Non-statistical correlation in tables, cross-sectional and longitudinal country-level and regional time series data	Ratio of fallow land to arable land declined and cropping frequency rose with population density
Pingali, Bigot, and Binswanger (1987, 51-52)	52 areas in Botswana, Burkina Faso, Cameroon, Cote D'Ivoire, Ethiopia, Guinea, Kenya, Nigeria, Tanzania, and Zambia (not all hilly)	Non-statistical correlation in tables, field visits to 48 locations and data from previous case studies	Agricultural intensity ® value) grew with population density
Blaikie and Brookfield (1987, 39-47)	Nepal	Researcher observation, citation of Mahat (1985) and others, whose primary data are unclear	Both arable land area and population grew
Cruz, Meyer, Repetto, and Woodward (1992, 18-24)	Philippine uplands, those lands with slopes of 18% or greater	Non-statistical correlation, country-level census and agricultural data and, for 1987, satellite surveys of the World Bank	Cropped upland area grew 2.5 % annually during 1960-1987 and upland population grew 3.0 % annually during 1960-1985
Harrison (1992, 80-81)	Ambodiaviavy, Ranomafana, Madagascar	Case history from village informants	Both arable land area and population grew
Hyden, Kates, and Turner (1993, 401-409)	Meru and Kisii, Kenya; Jos Plateau and Awka-Nnewi, Nigeria; Ruhengeri, Rwanda; Usambara Mountains, Tanzania; Bushenyi, Uganda	Previous research and household-, village-, or regional-level data	Cropping frequencies and population grew
Bilsborrow (1987)	China from 1400-1957 (not entirely hilly)	Non-statistical correlation in table of data from Perkins (1969), whose sources are not clear	Cultivated area and population grew

factor has not created an incentive for the change. Moreover, Harrison interprets this increase in farm land as evidence of environmental degradation. But, if expansion of farm land occurs in previously degraded forests, shrub land, *Imperata* grassland, or pastures, that expansion should not necessarily be considered evidence of degradation.[5]

Soil Quality

Econometric analysis of the effects of population pressure on agricultural land quality are rare. An effort to use existing secondary data for the Ethiopian highlands found that as the ratio of the population-supporting capacity to the actual rural population of *awrajas* (districts) decreases below one, the likelihood that these indigenous land areas are classified into more severe categories of soil erosion increased significantly and substantially (Grepperud 1996).[6]

Longitudinal case studies indicate that increases in population densities have led to greater soil erosion, declining soil fertility, or slope failures in several areas: the volcanic slopes of Meru District, Kenya (Bernard 1993), the formerly fertile highlands of Ethiopia (Hurni 1990 as cited in UNFPA 1991, 93), Rwanda's fertile northwestern region (Nyamulinda 1988 as cited in Clay, Byringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995), the Awka-Nnewi Region, Nigeria (Okafor 1993), a watershed in West Java (Repetto 1986), and the hills of eastern Zambia (Robinson 1978). Expansion of agricultural production in the highlands of Kenya, Tanzania, Rwanda, and Burundi has led to increases in soil loss and sediment load in streams (Berry, Lewis, and Williams 1990). The extent of soil erosion worsened as population densities increased in communal land areas of Zimbabwe (Tagwira 1992). (See Table 4.)

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[5]With some notable exceptions (Geertz 1963) and (Soerjani, Eussen, and Titrosudirdjo 1983), most observers consider the conversion of forest into *Imperata cylindrica* grassland an example of land degradation. However, farmers in South Kalimantan tend to be more divided about the desirability of this grassland (Blaikie and Brookfield 1987, 164-176).

[6]*Awrajas* range in size from 3,400 to 16,000 sq. km. (Grepperud 1996).

Table 4 Evidence of positive relationship between population growth and soil erosion, slope failure, or soil fertility decline on agricultural land

Source	Hilly-mountainous area	Type of evidence	Type of relationship
Grepperud (1996, 21-28)	47 *awraja*s in the Ethiopian Highlands	Ordered logit statistical analysis of regional (*awraja*) data from various primary sources	Higher ratio of rural population to the population-supporting capacity implies higher rank of soil erosion severity
Bernard (1993, 102-103)	Meru District, Kenya	Survey of 161 farm households in 1986, population census in 1979	Soil erosion, soil-fertility decline, and use of rocky or excessively steep land on farms in high-population density areas
Hurni (1990)	Ethiopian Highlands	Cited by UNFPA (1991, 93), unclear primary data	Estimate of annual soil loss in area and statistic on increase in national population from 1950 to 1970
Nyamulinda (1988)	Northwestern Rwanda	Cited by Clay *et al*. (1995, 68), unclear primary data	Slumps and landslides occurred after population-growth induced expansion of agriculture onto marginal lands
Okafor (1993, 328-330, 341)	Awka-Nnewi, Nigeria (not entirely hilly)	Extrapolation of population census data, unclear data on soil erosion	Soil erosion dominates heavily-populated landscape in this region
Repetto (1986, 14)	Watershed in West Java	Sediment loss data for watershed from USAID, population data for entire province from World Bank	Sediment losses of 1 mm/yr in 1911, 2 mm/yr in 1935 and 6 mm/yr in 1980s while population grew 1.9% per year during 1930-1980
Robinson (1978, 32)	Eastern hilly Zambia	Cited by Blaikie and Brookfield (1987, 107), unclear primary data	High population densities induced by land reservation led to erosion
Berry, Lewis, and Williams (1990, 537-541)	Highlands of Kenya, Tanzania, and Rwanda	Highland population densities based on census data, unclear data on soil loss and sediment load	Moderate soil loss in Rwanda, high sediment loads in rivers and moderate-high soil loss in Kenya and Tanzania
Tagwira (1992, 372)	Communal land areas of Zimbabwe (not necessarily hilly)	Non-statistical correlation in table of data from Whitlow (1988), whose sources are unclear	Percentage of communal land that is moderately to very severely eroded increases with population density

Land Improvements

Thus, while we generally accept the empirical evidence of a positive correlation between population density and expansion of agricultural land or other forms of increases in cropping frequency, the evidence that these changes in land use inexorably lead to degradation is still debatable. Increases in population density eventually lead to decreases in soil fertility and increases in soil erosion as a result of increases in cropping frequency if the cropping pattern and all other methods of agricultural production do not change. In many instances, however, land users not only increase cropping frequency but also substitute other means of replenishing soil fertility for fallowing and make land improvements that conserve soil, water, and fertilizer and that enable a more productive soil-air-water relationship (Boserup 1965; Boserup 1990). These landscape investments and changes in crops and technologies improve land quality or, at least, help to maintain land capabilities for future use (see Table 5).

Numerous historical cases from the Americas and Africa support this more optimistic view of the environmental impacts of population growth (Binswanger and Pingali 1988). Archeological research indicates that ancient terraces, walled fields, and intensive agricultural techniques were in use in southern Mesoamerica during the peak period of population density, toward the end of the first millennium A.D. (Boserup 1981). The Mayas instituted terracing of sloping fields to make continuous cropping possible during the Classic period (A.D. 300-800), a period of relatively high population density (Boserup 1990; Rice 1991).

Before the colonial period, farmers in the densely populated Jos plateau in Nigeria, the Mandara mountains in Cameroon, the Kikuyu highlands in Kenya, and the steep highlands of Rwanda used ridging, tie-ridging, silt traps, and elaborate systems of stone-walled terraces (Pingali, Bigot, and Binswanger 1987). As early as the nineteenth century on Ukara Island, a small island in Lake Victoria where population density had increased since the fifteenth century and land ownership had become individualized, the Wakara people's agricultural practices included manuring, production of fodder crops, erosion control measures, such as terraces, and irrigated rice farming of the lowlands and lakeshore regions (Pingali, Bigot, and Binswanger 1987). In those highlands of sub-Saharan Africa that served as refuges from slavery and warfare, or where groups were unable to expand their domain into neighboring

Table 5 Evidence of positive relationships between increases in population or in cropping frequency and either agricultural land investments or greater use of non-land inputs

Source	Hilly-mountainous area	Type of evidence	Investment or agricultural practice
Boserup (1981, 23)	81 countries (not all hilly)	Tabular correlation of UNRISD data	Greater fertilizer use in countries with higher population densities
Pingali and Binswanger (1987)	57 locations in Asia, Africa, and Latin America (not necessarily hilly)	Tabular correlation of data from case studies	Land improvements and fertilizer use increase with farming intensity
Boserup (1981, 54-55; 1990, 29)	Southern Mesoamerica	Previous archeological research	Terraces, walled and elevated fields
Hyden, Kates, and Turner (1993, 402-409)	Jos Plateau and Awka-Nnewi, Nigeria; Usambara Mountains, Tanzania; Ruhengeri, Rwanda; Meru and Kisii, Kenya; Bushenyi, Uganda	Household-, village-, or regional-level data and previous research	Ridging, terracing, and use of new cultigens, fertilizers, and pesticides associated with high and increasing population densities
Pingali, Bigot, and Binswanger (1987, 36, 42fn)	Mandara mountains, Cameroon; Jos plateau, Nigeria; Kikuyu highlands, Kenya; and Rwanda	Unclear primary data	Ridging, tie-ridging, using silt traps, and stone terracing in these densely populated, pre-colonial refuges
Pingali, Bigot, and Binswanger (1987, 42fn, 43, and 45, 49)	Ukara Island, Lake Victoria in 1800s and Kainam, Great Rift valley before 1890	Ludwig (1968) and Iliffe (1979), whose primary data are unclear	Fodder cropping, manuring, and terracing in concentrated settlements
Pingali, Bigot, and Binswanger (1987, 46, 70)	Kigezi District, Uganda	Purseglove (1946), whose primary data are unclear	Intercropping and terracing in area with 144 people/km^2 in 1944
Tiffen, Mortimore, and Gichuki (1994a, 3-12, 67-76, 194-200, 239-244)	Machakos, Kenya	Photographs in 1937, 1948, 1960-61, 1978, and 1991, farmer surveys, previous research	More terracing, manuring, and composting as population grew five-fold during 1930-1990
Blaikie and Brookfield (1987, 37, 44-45, 47)	Middle hills of Nepal	Researcher observation, Mahat (1985) and other researchers, whose primary data are unclear	Terracing, no tillage, relay cropping, and intercropping in area with 1500 people/km^2
Magrath and Arens (1989, 24) and Fujisaka (1989b, 144-145)	Dryland areas, Ciamis area, and Diang highlands of Java	Roche (1987, 1988), whose primary data are unclear, official statistics, farmer interviews, researcher observation	Increased use of inorganic fertilizers and manures, and bench terracing

areas controlled by more powerful tribes, people frequently cultivated small plots of land with extremely high inputs of labor for investments such as terracing and for maintaining soil fertility (Pingali, Bigot, and Binswanger 1987).

More contemporary evidence also indicates that increases in population density lead not only to increases in cropping frequency but also to increases in the incidence of land improvements and the use of soil fertility enhancers. A frequency table of farming intensity and technologies used in 57 specific locations of Asia, Africa, and Latin America indicates that more land investments are made when farmers crop land multiple times in a year than when farmers cultivate only once a year; no land improvements are made when farmers engage in forest, bush or grass fallow (Pingali and Binswanger 1987). Since increases in population density are positively correlated with higher intensities of land use, and these are in turn positively correlated with more land improvements, increases in population density are implicitly correlated with more land improvements.

Numerous individual case studies of contemporary agricultural change in Africa also indicate an implicit positive correlation between population density and both land improvements and higher use of fertilizer and other inputs (Hyden, Kates, and Turner 1993). For example, in Machakos District, Kenya, as population density increased over time (1930-1990) and space, not only did the percentage of cultivated land increase but the percentage of terraced cultivated land increased too and manuring became widespread. In general, less soil erosion occurred and agricultural land quality had improved by the end of the sixty-year period (Tiffen, Mortimore, and Gichuki 1994a). Pingali and Binswanger (1987) illustrate the argument with this case:

> The population density of the Kigezi district was about 144 people per square kilometer in 1944 and 280 in the early 1980s. As population density increased, cultivation proceeded upward from the middle altitudes of the Birunga mountain range, toward the summits of the hills, and then toward the valley. By 1946 almost all the summits were being cultivated and cultivation of the bottomland had begun. In this area of very steep slopes farmers rely exclusively on labor for power and intercrop field and root crops on small terraced plots.

No sign of serious landscape deterioration in Kigezi is evident (Tiffin 1995).

Case studies from Asia also indicate that increases in population density induce not only changes to production systems in which more labor is used, but also adoption and adaptation of agricultural methods that protect hilly landscapes. For example, although Nepal is often cited as a place where population pressure causes land degradation (Eckholm 1976), larger population densities have actually induced farmers to upgrade land. In the main agricultural areas of the middle hills, almost all arable land is terraced. Moreover, recent population growth in this area has also led farmers to use relay-cropping, intercropping, zero-tillage cultivation, and some quick-maturing crop varieties (Blaikie and Brookfield 1987).

Concerns about overpopulation in Java have been voiced for more than 175 years. Governmental concerns about soil erosion and efforts to promote bench terracing began as early as the second half of the nineteenth century and continue today (Belsky 1994). As population density has increased, hillside production systems have evolved from forest fallow to bush fallow to short fallow to annual cultivation to multiple cropping (Boserup 1965). Despite erosion of soil in dryland areas (*tegal*), yields of major dryland crops have consistently risen over the last 15 years because of increased fertilizer use and intensification of other farming practices (Magrath and Arens 1989). In addition to practicing agroforestry, farmers terrace and use other methods to enhance soil productivity where they experience land degradation as a problem. For example, farmers have completely terraced large hillside expanses and grow vegetables using large amounts of manure and inorganic fertilizers in the Diang Highlands and have adopted bench terracing for cassava production in the Ciamis area in central Java (Fujisaka 1989b).

Impact of Population Decline

Historical case studies also indicate that the obverse of this process has occurred. That is, decreases in population density have led not only to decreases in cropping frequency but also to neglect or abandonment of terraced landscapes (see Table 6). For example, depopulation in what is modern-day Israel began after the Moslem conquest in 640 A.D., continued for more than 1300 years throughout the Arab, the Crusader, and the Mameluke rule, and reached the lowest point during the end of the 19th century under Turkish rule. As

Table 6 Evidence of relationship between hillside depopulation or decreases in population density and decreases in cropping frequency and landscape degradation

Source	Hilly-mountainous area	Type of evidence	Type of relationship
Naveh and Dan (1973, 375, 385, 387)	Israel and Palestine	Lowdermilk (1944), Reifenberg (1955), and Taylor (1946), whose primary data are unclear	Terrace destruction and abandonment, decay of irrigation ditches, soil erosion, siltation, and land desiccation after Muslim conquest
Pingali, Bigot, and Binswanger (1987, 45)	Migration from Ukara Island to southeastern Lake Victoria	Ludwig (1968), whose primary data are unclear	Wakara quit intensive crop husbandry and began shifting cultivation when domination by tribal enemies ended
Pingali, Bigot, and Binswanger (1987, 49)	Kainan, Great Rift Valley	Iliffe (1979), whose primary data are unclear	Iraqw spread out and quit intensive agricultural methods in 1890 as Masai domination subsided
Garcia-Barrios and Garcia-Barrios (1990, 1578) and Boserup (1981, 54-55, 85-86)	La Alta Mixteca, Mexico and other parts of southern Mesoamerica	Pastor (1980) and Wolf (1959), whose primary data are unclear	People abandoned elevated fields and terraced land, returned to long fallow, and chose low labor-demanding products after Spanish conquest
Netting, Stone, and Stone (1993, 242)	Jos Plateau, Nigeria	Unclear primary data, probably researcher observation	Visible scars on steep hills, unrepaired terrace walls, and more soil erosion associated with serious depopulation
Speece and Wilkinson (1982, 6-7), Vogel (1987)	Yemen and Oman	Steffen (1979) and environmental profiles prepared for UNESCO's Man and the Biosphere Programme (MAB), unclear primary data	Washed out or clogged diversion systems, terrace deterioration, severe soil erosion, and loss of hillside productivity associated with migration out of rural areas and abandonment of terraced mountain land

demographic decline occurred, terraced hill land was abandoned, irrigation ditches decayed, terrace walls became destroyed, the landscape became desiccated, and catastrophic soil erosion and siltation occurred (Naveh and Dan 1973).

Whenever East African societies of refugees from tribal warfare and slavery spread out of their concentrated settlements, they invariably abandoned terracing and other labor-intensive practices and reverted to shifting cultivation. For example, after European colonial powers succeeded in controlling East Africa, many of the Wakara migrated from Ukara Island to the regions bordering the southeastern part of Lake Victoria. There they abandoned the advanced methods of crop husbandry and resumed shifting cultivation. In another instance, the Iraqw people expanded northward and settled below the Rift wall during the early 1890s as Masai domination subsided. They quickly increased their herds and abandoned the sophisticated agriculture of Kainam (Pingali, Bigot, and Binswanger 1987).

A similar process of disintensification and landscape disinvestment occurred in the distant and recent past in parts of the Americas. The reduction of the Indian population in the urbanized societies of Latin America after the arrival of the Spanish and imported African slaves brought on ruralization and a return to extensive subsistence systems. In particular, the Mayas in southern Mesoamerica, abandoned their elevated fields and terraced land and returned to long-fallow techniques (Boserup 1981). As people in La Alta Mixteca of Oaxaca, Mexico abandoned the pre-Hispanic terrace systems and various agricultural environments, land and water were rapidly degraded, and severe erosion extended over the region (Garcia-Barrios and Garcia-Barrios 1990).

More recently, a reduction in rural population density and the concomitant increase in the amount of land managed per household between 1955 and 1985 also led to a reduction in the time that farmers from San Andres Lagunas, Oaxaca, Mexico spent on maintenance of terraces and land containers (Garcia-Barrios and Garcia-Barrios 1990). This conscious neglect of old terraces and furrows has caused accelerated erosion of hilly lands and siltation of reservoirs used to irrigate once fertile land in the valley (de Janvry and Garcia 1988).

Recent decreases in population densities in hillsides in parts of the Mediterranean, Arabian peninsula, and Africa have been associated with similar negative results. For example, serious depopulation of the hills around the Jos plateau, Nigeria in recent times has led to visible scars on the landscape; unrepaired terrace walls are probably causing more soil erosion (Netting, Stone, and Stone 1993). Migration from and abandonment of terraced fields in Malta and neighboring Gozo have led to neglect of fertile slopes, soil erosion, and soil impoverishment (Busutti 1981). Previously terraced land in Yemen and Oman continues to be abandoned due to massive migration out of rural areas. As a result, soil erosion on and below these abandoned terraces is severe. Eventually entire hillsides are stripped of any productive capacity (Dregne 1992; Speece and Wilkinson 1982; Vogel 1987).

POPULATION CHANGE AND PASTORAL LAND QUALITY

Livestock Population Densities and Grazing Areas

Relationships between human and animal population growth, production methods, and land quality are complex (see Table 7). In developing countries between 1961 and 1985, the annual population growth rates of humans and livestock were 2.3 and 1.3 percent, respectively (Harrison 1992). These growth rates indicate that as human population grows in developing countries as a whole, animal population grows but generally at a slower rate. Moreover, these growth rates probably reflect a more specific trend. Namely, as human populations grow from low to medium-high (>75-100/km^2) densities, animal populations grow and animal densities on ranges and pastures increase too.

But this trend is reversed over time and space with more population growth. That is, as human population densities increase beyond medium-high densities, grazing areas become smaller and, eventually, animal population densities decline too. Thus, increases and decreases in animal populations and densities can occur in contiguous areas where the land frontier is open in some parts but closed in others. For example, total human and animal populations both increased between the 1950s and the 1980s for Machakos, Kenya as a whole. However, the livestock population decreased in two of the five agro-ecological zones of this District—the highlands—as the corresponding human population and persons per square kilometer grew during this period. As of 1990, these zones had the highest number of people per square kilometer but the lowest livestock density among all zones in the District (Tiffen, Mortimore, and Ackello-Ogutu 1993).

Table 7 Relationship between human populations, animal populations, and quality of grazing areas

Source	Hilly-mountainous area	Type of evidence	Type of relationship
Harrison (1992)	All developing countries	FAO country-level data for 1961-85	2.3% and 1.3% annual population growth rates of humans and livestock
Bernard (1993), Okoth-Ogendo and Oucho (1993) Feierman (1993), and Ford (1993)	Meru and Kisii, Kenya, West Usambara mountains, and Ruhengeri, Rwanda	Previous research and household data (Meru), government statistics and researcher observation (Kisii), unclear primary data (Usambara), and district statistics (Ruhengri)	Traditional grazing areas decrease and livestock more confined as human populations increase beyond medium-high levels
Tiffen, Mortimore, and Ackello-Ogutu (1993)	Machakos, Kenya	Aerial photographs in 1948, 1961, and 1978 of land uses, official archives, farmer informants	Grazing areas decrease as population density increases, both degradation and rehabilitation of grazing areas occur
Blaikie and Brookfield (1987)	Middle hills of Nepal	Researcher observation, Mahat (1985) and other researchers, whose primary data are unclear	High numbers of livestock per human inhabitant associated with loss of forest cover due to tree lopping for fodder
Ehui, Williams, and Swallow (1995)	Highlands in Ethiopia	Previous research on densities, unclear primary data on overgrazing	High human and animal densities, uncontrolled grazing, and soil loss
Zimmerer (1993)	Calicanto watershed, Bolivia	Official census data, farm household surveys, researcher observation	Low-moderate population growth rates, increase in livestock densities, overgrazing, and soil erosion
Naveh and Dan (1973)	Israel and Palestine from 640 until late 1800s	Lowdermilk (1944), Reifenberg (1955), and Taylor (1946), whose primary data are unclear	Depopulation, pastoral nomadism, increase in animal population, and land degradation after Muslim conquest
Pingali, Bigot, and Binswanger (1987)	Kainan, Great Rift Valley	Iliffe (1979), whose primary data are unclear	Iraqw population density decreased and herd sizes increased
Garcia-Barrios and Garcia-Barrios (1990)	La Alta Mixteca, Oaxaca, Mexico	Pastor (1980), whose primary data are unclear	Larger grazing areas, larger goat herds, and overgrazing as population declines
Netting, Stone, and Stone (1993)	Hills around Jos Plateau, Nigeria	Unclear primary data, probably researcher observation	Larger grazing areas, bigger herds, and land degradation as population declines

Similarly, according to local land-use statistics, farmer informants, and researcher observation, traditional grazing areas decreased as the number of humans in the area increased after the land frontier was closed in Meru District, Kenya (Bernard 1993), West Usambara mountains (Feierman 1993), Ruhengeri, Rwanda (Ford 1993), and Kisii District, Kenya (Okoth-Ogendo and Oucho 1993).

At densities beyond medium-high levels, people do one or more of the following: substitute crop residues for pasture, gather forest fodder, cultivate fodder grasses on separate plots or on erosion-control bunds, eventually restrict livestock to stalls, and switch to smaller animals. Livestock production in the middle hills of Nepal (Blaikie and Brookfield 1987), Ruhengri, Rwanda (Ford 1993) and Machakos (Tiffen, Mortimore, and Ackello-Ogutu 1993) illustrate this evolution of feeding methods and animal sizes.

Some historical and contemporary case studies suggest the reverse: as population decreases from high or medium levels, grazing areas and thus livestock densities increase. For example, one consequence of the 'serious' depopulation of the once densely-populated hills around the Jos plateau, Nigeria, is an increase in the amount of land used for grazing. Some men take advantage of the increased natural grazing possibilities by keeping larger herds of cattle; livestock densities increase, by implication, in these cases (Netting, Stone, and Stone 1993). The authors do not indicate, however, whether these larger herds and the increase in grazing area have contributed to the concurrent land degradation in the area.

Evidence from all the case studies reviewed is broadly consistent with this conclusion (McIntire, Bourzat, and Pingali 1992): similar livestock population densities are possible at a wide range of human population densities in all agro-ecological zones. But, the feeding methods are land-intensive at low levels and labor-intensive at high ones.

Pastoral Land Degradation

Some case study and anecdotal evidence do suggest a link between population growth in hills and mountains and actual degradation of these areas due to livestock production. For example, in the Ethiopian highlands, uncontrolled grazing is a major cause of soil degradation, along with encroachment of cropping into forested areas and continuous cropping (Ehui, Williams, and Swallow 1995). The human population densities and growth rates in this area are moderate relative to densities and growth rates in other East African highland areas.[7] As the Akamba population in the Machakos 'Reserve' in Kenya grew in the late 1920s and during the 1930s, areas of bare grazing land spread and soil erosion increased on those areas deprived of vegetation (Tiffen, Mortimore, and Ackello-Ogutu 1993). Low to moderate population growth rates during 1953-1991—for example, 0.21 percent per year between 1950-1975—accompanied an increase in livestock per unit area of grazing land in the Calicanto watershed, Bolivia; overgrazing contributed to soil erosion in this area (Zimmerer 1993).

Increasing human and livestock pressure since 1948 has caused loss of vegetative cover and soil erosion in various parts of Israel-Palestine (Naveh and Dan 1973). Degradation of rangeland vegetation, in terms of composition and the extent of cover, is considered a serious problem in the Indian state of Himachal Pradesh, the trans-Himalayas, and west Asia (Scherr and Yadav 1996). Over the last few decades, population in most Himalayan regions has grown more than 2.5 percent per year, which implies a doubling of human numbers in less than 28 years (Denniston 1995).

In densely populated Nepal, livestock is a very important element in farming systems. The number of livestock per human inhabitant is among the highest in the developing world (Blaikie and Brookfield 1987). For example, in the middle hills east of Kathmandu there is one 'livestock unit' per head of population. In this area and others, farmers lop trees to provide leaf-fodder for livestock (Blaikie and Brookfield 1987 and Bajracharya 1983 cited in Blaikie and Brookfield 1987). Increases in this tree lopping, which results from more people demanding fodder, has been one of four main reasons for the clearance of mixed forests and the tree *Rhodedendron arboreum* in the middle hills of Nepal (Blaikie and Brookfield 1987).

Two case studies indicate that increases in livestock densities induced by population decline can lead to land degradation. With the Moslem conquest in 640 A.D. of Israel-

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[7]The population growth rate between 1950 and 1990 was 2.3 percent for Ethiopia, 2.0 percent for Burundi, and 3.0 percent for Rwanda (United Nations 1993). The highland population density (people per square kilometer) in 1994 was 98 in Ethiopia, 164 in Kenya, 230 in Burundi, and 311 in Rwanda (Hoekstra and Corbett 1994).

Palestine, nomadic Arab tribes began to replace settled, Mediterranean agriculture with pastoral nomadism. As depopulation occurred from the time of this conquest until the end of the 1800s, pastoral land use became more and more dominant and, by implication, the amount of land used for grazing increased (Naveh and Dan 1973). Allowing livestock to graze on land previously used for agricultural production is one likely reason for the land degradation that occurred during this period of prolonged depopulation.

Similarly, the people who survived the epidemics and social disruptions of Spanish colonizers in La Alta Mixteca, Mexico began to raise goats and allowed them to graze on the abandoned hilly land with terraces. This implied increase in goat density and their grazing on abandoned terraced land created additional soil erosion and ecological disruption (Garcia-Barrios and Garcia-Barrios 1990).

Case evidence also suggests that if population growth induces degradation of hilly rangelands, then this degradation most likely occurs when population densities are at relatively low or moderate levels but not at high levels. For example, the rangelands that are currently being degraded in the greater Himalayan region generally have low to moderate population densities for this region (Scherr and Yadav 1995).

Pasture Land Improvement

Population growth can also induce improvements in land used for livestock production. For example, the same population growth in the 1930s that induced degradation of some grazing lands in Machakos, Kenya also sparked public and private efforts to rehabilitate some of the degraded grazing lands in the area.[8] Although these efforts continued and gradually spread as population grew between 1940 and 1990, most of the improvements in land used for grazing occurred in the 1980s, when population growth became more rapid (Tiffen, Mortimore, and Ackello-Ogutu 1993).

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[8]People rehabilitated some of the degraded land for grazing and converted other portions into terraced arable fields with fodder grasses planted besides terrace walls, along drainage ways, and in gullies (Tiffen, Mortimore, and Ackello-Ogutu 1993).

GENERALIZATIONS FROM EMPIRICAL EVIDENCE

The empirical evidence reviewed provides a basis for the following generalizations about the relationship between population growth, production systems, and land qualities in the hills and mountains of developing countries:

1) Changes in farming systems associated with population growth can lead to either land degradation or land enhancement, or aspects of both.

2) As population grows, people use land more frequently to increase production. That is, as their numbers increase, people tend to convert 'unused' forests or grasslands into crop land, grazing land, or planted tree land, to utilize 'unused' spaces for these purposes, to 'harvest' products from forests or tree farms sooner, to reduce the length of fallow, to cultivate annuals for a second or third time within a year, to graze a pasture more frequently, or to increase the stocking rate on a given piece of land. If land investments or changes in products or methods of production do not occur, these increases in production frequency deplete various biological and physical resources or degrade biophysical characteristics of hills and mountains.

3) However, as population grows, people tend to produce more labor-intensive crops and substitute labor-intensive and capital-intensive inputs and production techniques for land-intensive ones. Some of these products, inputs, and production techniques also enhance certain aspects of the land, for example, vegetative cover or soil nutrient levels. Moreover, population growth commonly induces people to make landscape investments, such as trees, terraces, vegetative barriers, and fodder banks, which improve the land's capacity for intensive and sustainable use, for example, tree cover, soil water-holding capacity, or fodder availability.[9]

4) Because people can and sometimes do invest and change crops, inputs, and techniques, production systems that enhance landscapes, minimize degradation, or mimic many of the ecological functions of 'original' vegetation in watersheds exist at all levels of population density.

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[9]Because people change crops, use different methods of replenishing soil nutrients and make land improvements, the Ricardian assumption of fixed land quality, or soil productivity, does not hold.

5) However, population growth from low levels of population density often leads to decreases in the abundance and diversity of certain natural resources in the hills and mountains. In particular, this often leads to conversion of 'natural' grazing land into agricultural land or of 'natural' forests into grazing land or farms, or the fragmentation of such areas. Some of these conversions can cause irreversible damage to certain aspects of hilly-mountainous ecosystems, such as loss of unique habitats and biodiversity.

6) Population decline from medium or high levels of population density often leads to disintensification of production systems and land degradation. As their numbers decrease, people tend to neglect or cease maintenance of hilly-mountainous landscapes previously transformed by abundant human labor, to overgraze livestock, to not produce other land-intensive crops that protect the landscape, and to not make traditional labor-saving investments, such as tree planting, that also enhance the local environment. On the other hand, depopulation which leads to large-scale land abandonment or reversion to natural vegetation may have positive environmental effects; this pattern is found mainly where population densities were initially low or in peri-urban areas with high non-farm employment opportunities.

7) Although examples exist in which people make landscape investments at all levels of population density, the type of investment changes as population density increases. For example, people may protect naturally-growing trees or maintain dry season grazing reserves in low population density systems, while construction of contour-hedgerow terraces or intensively-managed fodder banks would usually be found in systems with high population densities. More labor- or capital- intensive land improvements often represent the end of transitional phases from relatively degrading to relatively enhancing land use systems, following earlier adaptations in technologies, variable input use or management practices.

3. MICROECONOMY OF HILLY-MOUNTAINOUS LAND MANAGEMENT

We conclude from the above that population growth in hilly-mountainous areas of developing countries can lead either to land degradation or land enhancement. To predict which outcome is more likely requires an understanding of how population growth affects microeconomic incentives for land management. In general, most of the environmental impacts of production increases in these areas depend on whether sufficient microeconomic incentives exist for people to choose production systems—products, inputs, land use intensities, technologies, and landscape investments—that enhance land characteristics or, at least, retard their degradation.

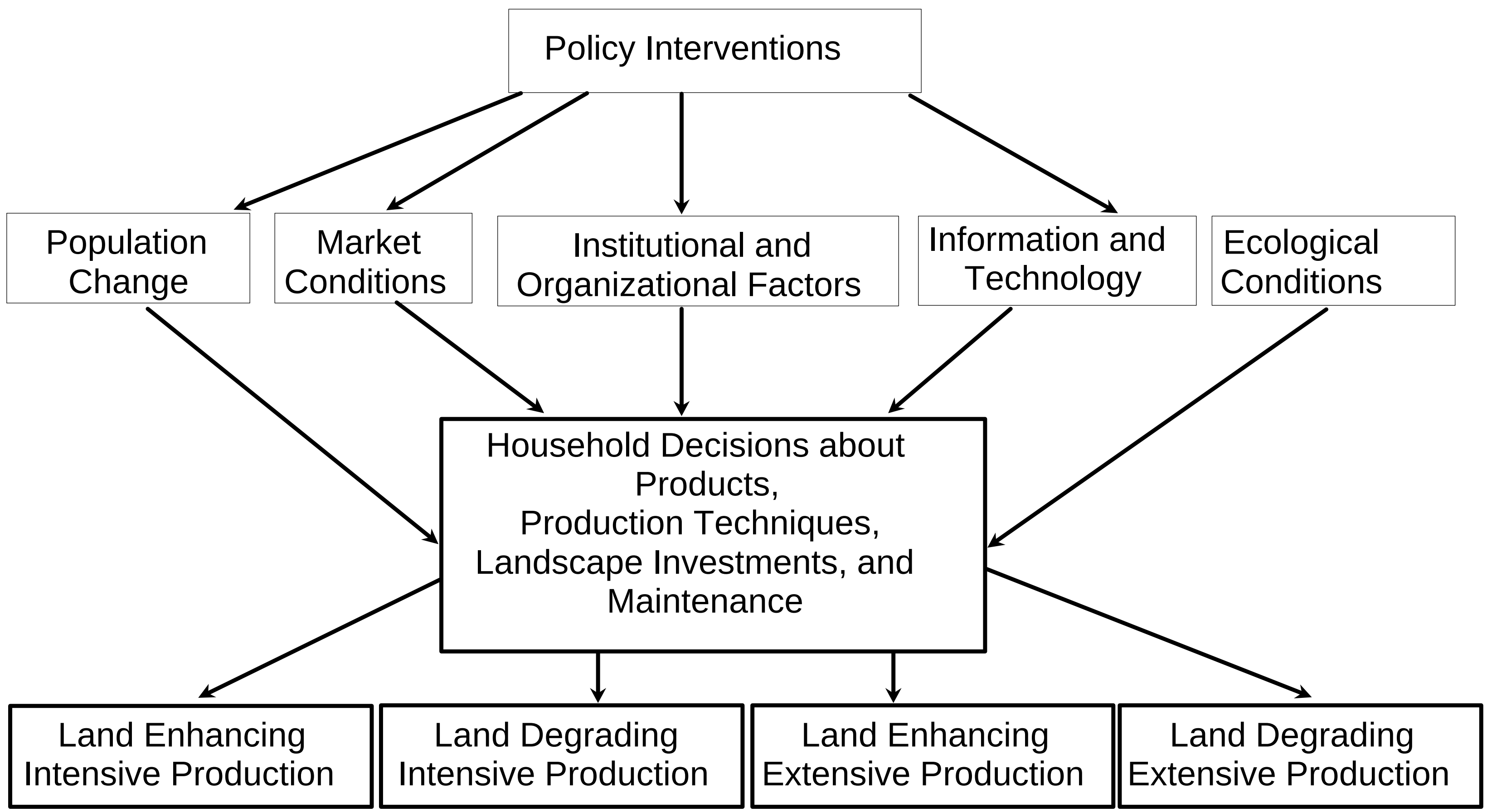
Figure 1 summarizes our microeconomic conceptual framework. Producers in hilly-mountainous areas, just as in other areas, make production and investment choices according to their own individual, but not necessarily selfish, interests. These interests include earning profit from production and reducing consumption variability. Their choices depend on certain features of the microeconomy: 1) local supply of labor, local demand for land, and household land-labor endowments as affected by demographic change; 2) institutional and organizational factors, such as property rights and organizations that collectively manage land; 3) information and technology for resource management; 4) market conditions, such as transport costs, crop prices, fertilizer costs, and non-farm income opportunities; and 5) intrinsic ecological conditions, such as rainfall and topography.

This section examines findings from the empirical literature which link these features to land management practices in hilly-mountainous farming systems.

POPULATION GROWTH

Population growth affects the calculus of land management in two major ways: by affecting general factor markets, and individual household resource endowments. Both processes induce technical change in farming systems, as a direct response to shifting relative prices, and by creating incentives for local invention and active borrowing of technologies better suited to the new economic environment.

Figure 1. Microeconomic Conceptual Framework for Hilly Land Management



Increases in Labor Supply and Land Demand

An increase in the number of local people who work, due to immigration or natural increase, implies an increase in the supply of labor. This increase, in turn, puts downward pressure on agricultural wages. As labor costs fall, labor-intensive products and production methods become more profitable relative to others.

Meanwhile, the demand for land increases, due to the increased number of local producers and increased local demand for land-using products; these raise the opportunity cost of not using land for production. An increase in the number of homesteads, paths, etc., also makes land for production more scarce. As land costs rise, land-intensive products and production methods become relatively less profitable.

A case study from a hilly area of Sumatra, Indonesia illustrates the importance of the relative cost of land and labor on the type of production system that prevails. In this area, where lands are still abundant and not degraded, farmers strongly prefer cinnamon-based relay agroforestry systems over bench terracing because cinnamon requires little labor once seedlings are established and can remain in the ground until the market offers a high price (Belsky 1994).

In particular, decreases in the opportunity cost of labor relative to land induce producers to increase cropping frequency.[10] For the same reason, producers tend to substitute labor-intensive means of providing nutrients to crops, such as weeding or collecting and applying manure, for land-intensive means, such as fallowing.

People also tend to substitute labor for land to provide nutrients to livestock by improving grazing land, as the opportunity cost of fodder from ‘natural’ grazing land increases relative to the opportunity cost of fodder from labor-enhanced pastures. For example, some methods of range improvement—such as hedging, fencing, bush and indigenous tree management, scratch ploughing, and reseeding or replanting—became more attractive in Machakos, Kenya as the number of people increased from the low population density levels of the 1930s (Tiffen, Mortimore, and Gichuki 1994b).

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[10]Low off-season real wages are an important incentive for more frequent cropping by cultivators who rely on hired farm workers or produce for the market (Boserup 1965; Boserup 1990).

As land becomes still scarcer relative to labor, people substitute even more labor-intensive means of providing nutrients to livestock—such as planting, cutting, and carrying fodder to animals in stalls—for the land-intensive means of open grazing on improved pastures. For example, cattle are stall-fed much of the time in west-central Nepal and the manure, together with leaf material from animal bedding, is then applied to fields (Blaikie and Brookfield 1987).

Increases in the cost of labor relative to land induce opposite changes in crop choice and livestock production. Higher labor costs due to demographic decline explain why Muslim conquerors of Israel-Palestine engaged in pastoral rather than intensive agricultural production and why people in La Alta Mixteca, Mexico at the start of the colonial period began not only to raise goats but also to cultivate wheat, two low-labor demanding products (Garcia and Garcia 1990).

As agricultural wages decrease due to increases in labor supply, labor-intensive improvements to agricultural land also become more profitable (Pingali and Binswanger 1987). For example, in Mindanao, Cebu, Batangas, and Bicol—areas that represent a wide variety of soils and rainfall patterns in the Philippines—the probability that farmers construct and maintain grass strips, tree-grass strips, contour hedgerows, and rockwalls increases as real agricultural wages decline (Templeton 1994b). In Rwanda, by contrast, farmers maintain longer grass strips, anti-erosion ditches, hedgerows, and radical terraces as the agricultural wage increases (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). This result might mean that higher farm wages enable farmers who were net suppliers of labor to self-finance these investments.

The same changes in the supply of labor and demand for land also induce changes in the credit market. As the supply of labor increases, the demand for credit to finance wages rises. Moreover, as the demand for land increases, the collateral value of land increases and, as a result, the supply of credit increases as well (Binswanger, McIntire, and Udry 1989). Consequently, land improvements, particularly those with high start-up costs, become more economically feasible as population grows. For example, people tend not to terrace agricultural land until population densities are high because these investments tend to be not only labor-intensive but also cash-intensive initially. In contrast, the improvements in grazing land that people began to make at the early stages of population growth in Machakos were attractive because farmers could make them with their own household labor and, thus, did not need cash to pay hired laborers (Tiffen, Mortimore, and Gichuki 1994b). (See Table 8.)

Larger Families, Fewer Land Holdings, and Smaller Farms

If labor, land, credit, and insurance markets were perfectively competitive and farmers shared the same technology and goals, then farm sizes and total labor allocated to production on farms would not vary with the land-labor endowments of households (Kevane 1996). But, since market imperfections are widespread in hilly-mountainous areas, production systems are typically a function of the land-labor endowments of farm households.

Higher population densities can imply larger household size. As the number of non-working family members increases, working family members may increase cropping frequency and work harder in other ways to produce enough food (Boserup 1990). As the number of working family members increases, a farmer is more able to do one of more of the following: expand the area under annual cultivation (Boserup 1990), make land improvements (Boserup 1965), cultivate labor-demanding crops, or use labor-intensive production methods. Farmers can do these things because they can 'borrow' the labor of other family members and because household labor is less costly than hired labor (Binswanger, McIntire, and Udry 1989).

Holding family size constant, higher population densities imply more families and lower average land holdings (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995; Pingali and Binswanger 1987). Because family labor is cheaper than hired labor and because the incremental collateral and insurance value of land increases as land holdings decrease, smaller land-labor endowments imply smaller farms. As farm size decreases, the amount harvested per cropping decreases, merely as a result of a reduction in cultivable space. To prevent a decline in output per year and to meet subsistence needs over the course of a year, farmers reduce the length of fallow or the share of land under fallow (Boserup 1990; Boserup 1965; Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). But farmers also are more likely to make land improvements or undertake more of these investments as farm size decreases to enable these desired increases in cropping frequency (Boserup 1990) and to prevent decreases in yields per cropping that otherwise

Table 8 Effects of scarcity of land relative to labor, farm wages, and farm size on production and land investments

Source	Hilly-mountainous area	Specific factor	Evidence	Effects
Tiffen, Mortimore, and Gichuki (1994b, 20); Tiffen, Mortimore, and Ackello-Ogutu (1993, 19, 22-24)	Machakos, Kenya	Scarcer land	Archival records, farmer interviews	Range-land improvements
Blaikie and Brookfield (1987, 46)	Middle hills, Nepal	Scarcer land	Case history	Stall feeding of cattle
Zimmerer (1993, 1664, 1666)	Calicanto, Bolivia	Scarcer labor	Case history	More livestock per hectare
Bedoya (1987, 300, 302-304)	Upper Huallaga, Peru	Smaller farms and larger families	Table of farm-level statistics	Higher land-use intensity
Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya (1995, 87, 94)	Rwanda	Less cultivable land per adult equivalent	Figure based on farm-level data	Share of land under cultivation increases
Cruz, Meyer, Repetto, and Woodward (1992, 51, 53)	Costa Rica	Smaller farms	Table of national census data	Larger shares of annual and perennial crops
Templeton (1994a, 158-160; 1994b, 19, 37-41)	Various hilly areas in Mindanao, Cebu, Alba Batangas, Albay, Philippines	Lower farm wage and smaller farms	Logit statistical analysis of village- and farm-level data	More likely to terrace
Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya (1995, 97)	Rwanda	Higher farm wages	Econometric	More terracing
Feder, Onchan, Chalamwong, and Hongladarom (1988, 103-108, 111)	Four districts, Thailand (flat and hilly)	Smaller initial land holdings	Econometric	More likely to bund or destump
de la Brière (1996)	Dominican Republic	Less total land used	Econometric	More likely to adopt soil conservation practices
Scherr (1995, 797)	Siaya and South Nyanza, Kenya	Smaller farms	Statistical table	More trees per hectare
Arnold (1987, 179)	Kakamega District, Kenya	Small farms (0.6 ha.)	Case study	Wood growing
Tiffen, Mortimore, and Gichuki (1994a, 220-221)	Mbiuni, Machakos, Kenya	Smaller farms	Statistical table	More fruit trees per hectare
Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya (1995, 88, 94)	Rwanda	smaller farms	farm-level statistics	more trees per hectare
Arnold (1987, 177-179)	Mindanao, Philippines	Large farms (11 ha.)	Case study	Woodlots
Tiffen, Mortimore, and Gichuki (1993, 26-27)	Mwala, Machakos, Kenya	Smaller farms	Statistical table	More livestock per hectare

occur as cropping frequency increases (Boserup 1990; Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995).

National land use data for Costa Rica indicate that, as farm size decreases, the shares of farm land in annual and perennial crop production become larger and the shares of farm land as forest and pasture become smaller (Cruz, Meyer, Repetto, and Woodward 1992). Similarly, according to national survey data of households and parcels in Rwanda, the share of land under cultivation increases as the amount of cultivable land per adult equivalent decreases (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). In the upper Huallaga Valley of Peru, where average farm sizes range from 18-52 hectares, the shares of land in perennial crop production become larger and shares of fallow land and forests become smaller as farm size decreases (Bedoya 1987).

Econometric evidence from Rwanda, selected areas of Thailand, the Philippines, and the Dominican Republic indicates that decreases in farm size induce agricultural land investments, such as bunds, grass strips, hedgerows, and rock walls (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995; de la Brière 1996; Feder, Onchan, Chalamwong, and Hongladarom 1988; Segura-de los Angeles 1986; Templeton 1994a).

Case study evidence suggests that tree densities initially decrease but, in some cases, eventually increase as farm sizes increase. Among participants in the Agroforestry Extension Project (AEP) in Siaya and South Nyanza Districts in Kenya, tree density decreases as farm size increases from less than 0.7 ha. to 7.3 ha. (Scherr 1995).[11] In land-scarce Rwanda, small farmers grow more trees per hectare (Kangasniemi and Reardon 1994 as cited by Clay, Byiringiro, Kangasniemei, Reardon, Sibomana, and Uwamariya 1995) and the percent of cultivated land with 'many' trees increases as cultivable land per adult equivalent decreases (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). But in an area

[11]In an area of the Kakamega district of Kenya, households that have very small farms (0.6 ha. on average) and that need to devote a substantial part of their labor to non-farm employment grow trees (Arnold 1987). In Mbiuni, an area of Machakos, Kenya with both sub-humid and semi-arid rainfall, the number of fruit trees per hectare increases as farm size decreases (Tiffen, Mortimore, and Gichuki 1994a).

of the Philippines farmers manage woodlots because their land-holdings considerably exceed the area on which they can cultivate food and other crops with family labor (Arnold 1987).

One case study suggests a similar negative correlation between livestock density and farm size. In Mwala, a semi-arid area of Machakos, the number of livestock per hectare of an individual farm increases as farm size decreases because people with smaller farms are more likely to plant fodder and practice stall-feeding and use more cash to purchase non-farm inputs, such as feed (Tiffen, Mortimore, and Ackello-Ogutu 1993). (See Table 8 for summary.)

INSTITUTIONAL AND ORGANIZATIONAL FACTORS

Property Rights

Governments regulate or claim *de jure* ownership of much larger portions of hills and mountains than flat areas in developing countries, typically for watershed or forest protection, or for public parks or reserves. Although occasionally successful, government land-use regulations and natural resource policies have generally failed to control deforestation (Repetto 1988; Scherr, Jackson, and Templeton) and have interfered with indigenous resource management. For example, commercial loggers, ranchers, and their agents have deforested areas in the Philippines, Costa Rica, and Sabah because short-term timber leases, lack of titles for uncleared or underutilized land, and titles for land cleared of trees did not create secure, long-term interests in forests (Cruz, Meyer, Repetto, and Woodward 1992; Repetto 1988). In most countries in Central America and the Caribbean, harvesting laws and regulations created to protect forests have been a major disincentive to farm tree-planting activities (Current and Scherr 1995).

As population densities increase over time or space, *de facto* land tenure systems become less general and more specific, less communal and more individualized (Binswanger, McIntire, and Udry 1989; Boserup 1965). For example, population growth induced people to convert open-access grazing land into private property and to devise a technique, namely thorn hedging, to effectively enclose and restrict access to their exclusive grazing land. After creating private property, people began to rehabilitate the land. But thorn hedging also put more pressure on and, thereby, created more degradation of the remaining open-access land

(Tiffen, Mortimore, and Ackello-Ogutu 1993). As this case study suggests, although the population-induced evolution of *de facto* property rights engenders land improvements, this endogenous privatization also creates incentives for greater degradation of the non-privatized land.[12]

Population growth induces this evolution of property rights because the demand for land and the supply of labor increase and land-labor endowments decrease. Greater scarcity of land increases the benefits of creating and rigorously enforcing rules that better define rights and obligations among people on the use of this more valuable resource and rules that settle possible conflicts (Hayami and Kikuchi 1981). Stronger competition for land also increases the benefits of using existing tenure rules to claim specific portions of open-access property as private land and of developing methods to effectively restrict the access of others to these exclusive areas (Tiffen, Mortimore, and Gichuki 1994b). Less land per capita and lower labor costs make effective monitoring of property and enforcement of rights less costly.

Secure, long-term rights of access to land, particularly in the form of locally-recognized use rights, create an incentive for people to make landscape-improving investments. For example, terracing or other investments in soil erosion control are generally associated with secure, long-term rights to land in West Java, Nigeria, Tanzania, and colonial Kenya (Pingali 1989). The right to at least bequeath, if not sell, parcels increases the likelihood that a farmer makes at least one long-term improvement on a parcel of land in Butare and Gitarama, Rwanda; in Kianjogu, Kenya; and in Wassa and Anloga, Ghana (Place and Hazell 1993).

In areas that lack informal credit, farmers who can offer their land as collateral to formal lenders are more likely to be able to finance land improvements with high start-up costs. Hence, in a Thai province with abundant informal credit, possession of a title does not

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[12]Exogenous privatization can have negative impacts too. For example, land reform in a semi-arid area of western Rajasthan in 1953-1954 abolished but failed to replace old mechanisms that restricted access to common property grazing land and led former tenants to convert other common property grazing land into annual crop land . Those portions of common property grazing land that became *de facto* open-access pasture have much lower productivity and degradation of the common property pasture that became private annual crop land is obvious (Jodha 1987).

affect the likelihood that farmers bund and has a smaller impact on the likelihood that they clear stumps from land than in two other provinces with negligible informal credit (Feder and Onchan 1987).

Insecure or short-term rights of access usually have the opposite effect. For example, female cultivators resisted building permanent erosion-control ridges on rent-free land used for subsistence cropping in the West Usambara mountains in Tanzania during the 1950s because they expected to be evicted by male owners once improvements were made (Feierman 1993).

'Insecure' property rights can also mean that owners are uncertain about their ability to restrict access. Thus, in certain areas of the Philippines owners forbid tenants to plant perennials for fear of losing their ownership claim (Sajise 1987 as cited in Fujisaka 1994). For the same reason, however, non-owners or settlers plant trees, create fences, or terrace to gain more secure rights in various countries (Place and Hazell 1993; Sellers 1988; Fujisaka and Wollenberg 1991). Hence, land improvements can also create more secure property rights.

More importantly, cultivators do not necessarily need to have titles or even be private owners to have secure, long-term access rights to land.[13] For example, lack of title has not prevented farmers, most of whom are private owners, from improving land in Kitui-Machakos, Kenya (Pagiola 1993) or in the Tatumbla area of Honduras (Lutz, Pagiola, and Reiche 1994).[14] Non-ownership of land by cultivators has no discernible effect on the likelihood that they cooperatively build check dams in small watersheds in Haiti (White and Runge 1994).[15] (See Table 9 for a summary.)

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[13]Nor do titles, tax returns, and other claims of private ownership guarantee secure tenure in areas where local government either can not enforce these claims or actually helps outsiders to usurp them.

[14]Ability to transfer parcels of land does not increase the likelihood that a farmer makes long-term improvements in Ruhengeri, Rwanda; in Ejura, Ghana; or in Madzu, Kenya (Place and Hazell 1993).

[15]Since population growth induces greater precision in the definition and allocation of property rights (Ruttan and Hayami 1991), cultivators who are non-owners, communal owners, or owners without title in hilly-mountainous areas are more likely to have secure, long-term rights of access to land and be able to sell or bequeath their usufruct rights in areas with high population densities.

Table 9 Effects of property rights on tree planting, terracing, and other land investments

Source	Hilly-mountainous area	Property right	Type of evidence	Effect
Cruz, Meyer, Repetto, and Woodward (1992, 28-29, 51-54) Repetto (1988, 13)	Philippines, Costa Rica, Sabah, Malaysia	Short-term leases to timber concessionaires, lack of titles for forests or ‘underutilized’ land, titles for cleared land	Case studies	Deforestation
Current and Scherr (1995, 99)	Most countries in Central America and Caribbean	Harvesting laws and regulations created to protect forests	Case studies of 21 agroforestry projects	Major disincentive to tree-planting activities
Tiffen, Mortimore, and Ackello-Ogutu (1993, 16-18)	Machakos, Kenya	Conversion of open-access to private grazing land	Case history	Rehabilitation of private but more pressure on open-access areas
Pingali (1989, 12-13)	West Java, Nigeria, Tanzania, and colonial Kenya	Secure, long-term rights to land	Case studies	More terracing or other soil erosion control
Place and Hazell (1993, 14-16)	Butare and Gitarama, Rwanda; Kianjogu, Kenya; Wassa and Anloga, Ghana	Right to at least bequeath, if not sell, parcels	Econometric	Greater likelihood of long-term land improvement
Feder and Onchan (1987, 313, 317-318)	District of Thailand with abundant informal credit	Possession of title	Econometric	No effect on bunding, smaller effect on destumping than in two other areas with scarce informal credit
Feierman (1993, 137-139)	West Usambara mountains, Tanzania	Rent-free borrowing	Case study	Female cultivators resisted building permanent erosion-control ridges
Sajise (1987)	Philippines	Non-ownership	Case study	Forbidden to plant perennials
Fujisaka and Wollenberg (1991, 117)	Two areas of central Luzon, Philippines	Settling open-access land	Farmer interviews	Plant trees to claim rights
Sellers (1988, 75-78)	Tucurrique, Costa Rica	Squatting and rent-free borrowing from kin	Table of plot-level statistics	Plant perennial crops to claim rights
Pagiola (1993 127)	Kitui-Machakos, Kenya	Lack of title	Researcher observation	No effect on terracing
Lutz, Pagiola, and Reiche (1994, 13)	Tatumbla, Honduras	Lack of title	Researcher observation	No effect on building diversion ditches
Place and Hazell (1993, 14-16)	Ruhengeri, Rwanda; Ejura, Ghana; Madzu, Kenya	Inability to sell or bequeath parcels	Econometric	No effect on making long-term land improvements
White and Runge (1994, 16-17, 20-25)	Various small watersheds in Maissade, Haiti	Non-ownership	Econometric	No effect on cooperation in building check dams

Local Collective Action

In the past and present, labor exchange groups and other local mutual self-help organizations have enabled farmers to, among other activities, terrace and make other land improvements. For example, women's labor-exchange groups, called *mwethya*, have helped poorer farmers to construct indigenous bench terraces, or *fanya juu*, in Machakos (Tiffen, Mortimer, and Gichuki 1994a). People who already belong to peasants groups that engage in collective social and economic activities, called *groupman*, are six times more likely to join a cooperative effort to build check dams in Maissade, Haiti (White and Runge 1994). Similarly, small, work-sharing groups and their promotion by credible extension agents effectively promoted non-paddy terracing in the Philippines (Fujisaka 1989b); Queblatin 1985; Templeton 1994a).[16]

Obversely, a key reason for current degradation of hilly landscapes in a rural community in Mexico is the breakdown of local institutions that mobilized familial and collective labor for steep slope management and erosion control (Garcia-Barrios and Garcia-Barrios 1990). Similarly, a breakdown in cooperation among women, who do much of the agricultural work, is a secondary reason why they have abandoned many terraces and poorly maintain the remaining ones on Rusinga Island, Kenya (Conelly 1994). Finally, a reduction in the number of workers participating in reciprocal labor exchange between 1953-1991 contributed to reduced use of soil conservation techniques by peasant households, particularly labor-scarce households of 'poor peasants', in the Calicanto watershed, Bolivia (Zimmerer 1993).[17] (See Table 10 for summary.)

Population pressure, non-farm income opportunities, and other factors that affect the opportunity costs of labor and land play important roles in the emergence and breakdown of these community organizations. As the demand for land increases, the benefits of organizing and participating in collective action to manage externalities associated with uses of the land

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[16]Credible extension agents frequently visit local farmers, are willing to labor with them in their fields, and are familiar with local practices.

[17]Some rural development projects in Latin America have also been effective in restoring or creating labor-sharing groups and other local resource-management institutions (de Janvry and Garcia 1988).

Table 10 Effects of local collective action on landscape investments and maintenance

Source	Hilly area	Institutional factor	Type of evidence	Effects
Tiffen, Mortimore, and Gichuki (1994a, 135, 192, 194-197, 201)	Machakos, Kenya	Membership in labor sharing groups, *mwethya*	Farmer interviews	More terracing
White and Runge (1994, 20)	Maissade, Haiti	Membership in collective action groups, *groupman*	Econometric	More likely to cooperatively build check dams
Garcia-Barrios and Garcia-Barrios (1990, 1570-1571)	San Andrés Lagunas, Mexico	Breakdown of familial and collective work	Case study	Lack of steep slope management and erosion control
Conelly (1994, 152-155)	Rusinga Island, Kenya	Breakdown of female labor sharing	Case study	Abandonment or neglect of rockwalls
Zimmerer (1993, 1664-1665)	Bolivia	Reduced participation in labor sharing groups	Case study	Reduced use of soil conservation practices

increase. The costs of time spent organizing and participating in collective action decrease if wages fall or a given number of people live closer together. Moreover, if people cannot clearly specify individual rules of access and exclusion and if the costs of enforcing individualized rules are prohibitively high, then creating and participating in these non-market institutions becomes more attractive than private property (Hayami and Kikuchi 1981). If adoption of better technologies has certain fixed costs which can be met through group labor inputs (for example, establishment of some types of irrigation systems), then increased population could facilitate the organization of such groups.

INFORMATION AND TECHNOLOGY

Another critical factor affecting local people's ability to adapt farming systems to new demographic and economic conditions is the quality of local information about potential land management innovations. Innovation may derive from three sources: independent *invention* or adaptation through local experimentation, organized introduction by *extension* programs, and *diffusion* from other areas through rural information systems (Scherr and Yadav 1996).

Local Technical Knowledge and Invention

The importance of local invention and adaptation has been widely reported in recent literature. Long-established farming communities in higher-density hillside regions have often developed plant varieties, landscape improvements and management systems of potentially broad relevance for farmers who are currently making the transition to more intensive production in those environments (Rhoades 1982; Richards 1985; Turner, Hyden, and Kates 1993).[18] Some extension programs working in hilly-mountainous areas have attempted to improve and accelerate this process by strengthening local capacity for innovation (attitudes, institutions, skills in experimentation), rather than focus on technology introduction (Bunch and Lopez 1995).

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[18] By contrast, there is widespread evidence of degradation associated with new settlement in hilly areas by farmers from the lowlands who were unfamiliar with appropriate management systems.

Technical Extension Programs

Technical assistance programs have been widely used in hilly and mountain areas to promote resource conservation. But some forms of extension are more effective than others. For example, local people as paratechnicians successfully promoted agroforestry in nine out of eleven projects in Central America and the Caribbean and small, in-kind, material inputs generally provided by these and other extension agents effectively persuaded farmers in these areas to try related practices (Current, Lutz, and Scherr 1995). Farmer-instructors and other credible extension agents who provide free or below-cost plant materials that are locally appropriate are more effective than one-shot classes, demonstration farms, radio messages, or a lack of extension in inducing farmers in the Philippines to invest in contour hedgerows and rockwalls in the Philippines (Fujisaka 1989a; Templeton 1994a). Similarly, the ‘community-based’ approach of CARE International's Agroforestry Extension Project (AEP) in Siaya and South Nyanza Districts, Kenya was more appropriate for local conditions than ‘commodity-based,’ ‘training-and-visit,’ ‘farming systems,’ or ‘media-based’ extension (Scherr 1992).

Extension programs do not always provide effective incentives. In some cases, the subsidized crop, technique, or investment is economically or ecologically inferior to non-subsidized ones (Belsky 1994; Fujisaka 1994). Moreover, farmers who have rock walls, trees, or hedgerows installed for free by others or who receive food or cash in exchange for this work are not likely on their own, unpaid initiative to make new landscape improvements, to maintain the existing investments, or to inspire non-beneficiaries to follow suit (Belsky 1994; Current and Scherr; Fujisaka 1989b; Hudson 1991; Lutz, Pagiola, and Reiche 1994). (See Table 11.)

Diffusion of Innovations

Widespread diffusion of land-improving innovations, either from indigenous or introduced sources, is essential to sustainable management of hillsides and mountains. The quality and penetration of local information systems can influence the transaction costs of information exchange, and hence the degree of diffusion of appropriate practices in a particular hillside region (Röling 1988). The degree of access by local people to external

Table 11 Effects of extension programs on tree planting and agricultural land investments

Source	Hilly area	Type of extension	Type of evidence	Effects
Fujisaka (1989b, 152), Queblatin (1985, 73), Templeton (1994a, 111, 121-122, 155-156, 169, 224-229)	Cebu and other provinces, Philippines	Farmer-instructors and other credible extension agents	Case studies and econometric results	More terraces and other forms of soil and water conservation
Current, Lutz, and Scherr (1995, 161, 170-172)	Central America and the Caribbean	Local people as paratechnicians	Case studies	More trees per hectare
Scherr (1992)	Siaya and South Nyanza Districts, Kenya	Promotion of nurseries and tree planting through women's groups and primary schools	Case study	More trees per hectare
Belsky (1994, 433-436)	Two villages in Kerinci, Sumatra, Indonesia	Government payments for bench terracing, planting a specified grass on terrace risers, and cultivating soybeans and peanuts but not cassava	Case study	Beneficiaries do not maintain bench terraces after subsidy period; most nonbeneficiaries do not construct bench terraces or follow other practices
Fujisaka (1994, 411-416 and 1989b, 145, 151)	Java, Indonesia; South Cotabato, Philippines; and Laos	Government payments for bench terraces; government planting of *Leucaena leucocephala* strips; food payments for constructing contour ditches	Case studies	Lack of maintenance of subsidized land investments, no expansion without subsidies or spontaneous imitation

sources of information, through extension programs, participation in associations, government contacts, informal networks (ethnic groups, family, employment), mass media, etc., can also affect the cost and availability of relevant information for land management. Finally, diffusion is strongly affected by the economic attractiveness of the market conditions described in the section below.

MARKET CONDITIONS

In closed, subsistence-oriented economies, the processes described above are largely responsible for changes in land management systems. In open economies, however—which characterize most hilly-mountainous regions—broader market factors will influence farmers' incentives in significant ways, particularly affecting transport, input and labor costs.

Transport Costs

Population growth enables lower transport costs (Boserup 1990) and improvements in transport infrastructure encourage immigration (Pingali and Binswanger 1987). Transport costs are one measure of the degree of access that producers in hilly-mountainous areas have to buyers in markets in other areas or countries. Declines in costs of transporting to and from hilly-mountainous areas make production more profitable due to higher product prices and lower prices of fertilizers and other purchased factors of production at the farmgate.

Product Prices

Increases in the price of a product induce an intensification of production of that good similar to what occurs with local population growth. That is, as the price of a farm product increases, people use land more frequently to produce the good and allocate more land, labor, and purchased inputs to its production. But, because some inputs, such as manure, enhance land and because payoffs from land-improving investments increase too, the effects of these reallocations on land quality is indeterminate.

Price Changes for Annual Crops. As a rule, annual crops provide less vegetative cover than perennial crops or trees for timber. Moreover, the soil is exposed to rainfall from harvest until new crops grow to provide some vegetative cover. Thus, the greater the area that a farmer devotes to production of annual crops at the expense of perennial crops or timber, the less likely her production system enhances land quality. For the same reason, increases in the frequency of annual cropping without any change in production methods or amounts of land-enhancing inputs usually cause soil degradation.

Case studies from Indonesia (Belsky 1994) and from Eastern Nigeria, West Africa, Kenya, Tanzania, and Uganda (Pingali 1989) indicate that cropping frequency and the evolution from shifting cultivation to sedentary cultivation to multiple croppings per year is determined in part by increases in farmgate prices and better access to markets. But farmers are more likely to terrace or make other land improvements in response to larger wholesale markets in the Philippines (Templeton 1994b), to better access to vegetables markets in Java (Fujisaka 1989b), and to greater profitability of agricultural production in Rwanda (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). Moreover, increases in annual crop prices can induce greater use of inputs that replenish soil productivity. Hence, the net effect on land quality of increases in annual crop prices is indeterminate. Results of theoretical analyses of a permanent increase in annual crop prices echo this indeterminacy (Ardila 1991; Barbier 1990; LaFrance 1992; Pagiola 1993). (See Table 12.)

Price Changes for Perennial Crops. Products that are harvested from trees, shrubs, and other perennial plants that stay rooted generally provide the best protection against rainfall erosion on sloping lands, because these plants provide some vegetative cover of the soil at all times.[19] As a result, increases in perennial crop production in hilly-mountainous areas tend to reduce erosion from rainfall and, thereby, improve soil quality. However, the full effect on soil quality and other natural resources of any price increase for perennial products also depends on the extent to which, if any, the price increase encourages people to convert nearby open-access forests or natural grazing land to perennial crops and the extent to which this conversion creates transitional degradation or represents loss of habitat of important species.

[19] These products include perennial field crops (for example, bananas), shrub crops (for example, coffee or tea), and tree crops (for example, rubber or oil palm) (Ruthenberg 1976).

Table 12 Effects of market access and prices for crops and fertilizer on perennial cover, cropping frequency, and agricultural land investments

Source	Hilly area	Market factor	Type of evidence	Effect
Fujisaka (1994, 415 and 1989b, 145)	Central-East Java	Strong markets for perennial crops	Case study	Planted less food crops and more coffee, cloves, apples, grapes, and other perennials
Eder (1981)	Palawan, Philippines	Proximity to good market for fruits	Case study	Conversion of swidden plots to fruit orchards
Spears (1987, 54-55, 59, 61)	Kenya and Philippines	Higher wood prices	Case studies	More trees planted
Harrison (1992, 112)	Rwanda	Emergence of wood markets	Case study	More woodlots on small farms
Carter and Gilmour (1989, 389)	Several hill districts of Nepal	'Short' supply of forest products	Case study	Higher tree densities on private land
Mortimore (1993, 374-375)	Kano, Nigeria (flat)	Greater fuelwood demand	Case study	More trees planted on private land, trees cut down from open-access areas
Belsky (1994, 432-433) and Pingali (1989, 3)	Sumatra, New Guinea, Eastern Nigeria, West Africa, Kenya, Tanzania, and Uganda	Better market access	Case studies	More frequent cropping
Fujisaka (1989b, 144-145, 150)	Diang Highlands, Java	Better access to vegetable markets	Case study	Widespread terracing and use of manure and inorganic fertilizer
Templeton (1994b, 9, 20, 37, 41)	Philippines	More populous wholesale markets	Econometric	More likely to terrace
Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya (1995, 82, 89, 97)	Rwanda	Higher profits	Econometric	More terracing
Templeton (1994b, 11-12, 19-20)	Philippines	Higher fertilizer costs	Econometric	More likely to terrace

Hence, an increase in the price of perennial crops will probably have the strongest positive impact on soil quality in high population density areas where open-access resources no longer exist.

Some case studies examine farmer responses to perennial price increases. For example, farmers in the middle volcanic slopes of Central-East Java created widespread change from annual crops to cash perennials, planted coffee, cloves, apples, grapes, and other perennial crops because the markets for these crops were strong (Fujisaka 1994; Fujisaka 1989b). Farmers on the Philippine island of Palawan, where the population density is $200/km^2$, converted swidden plots into fruit orchards in part because of their proximity to a 'good' market (Eder 1981 as cited by Raintree and Warner 1986). Low coffee prices almost induced Chagga farmers on Mt. Kilimanjaro to remove coffee bushes from their homegardens (Fernandes, Oktingati, and Maghembe 1984). Subsidies for rice—an alternative land use—and declining market demand for damar threatened ecologically protective damar agroforest systems in Sumatra (Mary and Michon 1987). (See Table 12.)

Meanwhile, if non-timber forest products increase in value, this may induce farmers to reduce forest-clearing. However, this result is dependent on a complex of other factors, in particular tree tenure, the potential for domestication of the valued products, and market access (Dewees and Scherr 1996).

Price Changes for Timber Products. The effects of timber price changes depend on whether the changes are expected. In response to an unexpected but permanent increase in timber prices, farmers harvest more wood from a given area of privately-managed, mixed-age stand of trees in the short-term because the opportunity costs of not harvesting the more valuable trees and of not utilizing the land to plant new ones increase unexpectedly. But, since trees are not allowed to grow as long, farmers harvest less wood (that is, smaller trees with smaller canopies) and replant at shorter intervals in the long-term (Clark 1976). Since timber harvests typically expose the soil for a significant period and timber transport may cause further damage, unexpected price increases probably harm land quality. However, expected future price increases, similar to unexpected current price decreases, enhance land quality because they induce people decrease current harvest rates on private lands (Clark 1976) and, thus, to increase tree biomass densities in the form of older trees with larger canopies, higher tree densities in younger-age stands, or new tree plantings.

Empirical evidence is consistent with the argument about the effects of anticipated price increases on timber management. For example, farmers manage woodlots and small-scale forest farms because of rising farmgate prices for wood products, as is the case in Kenya (Dewees and Saxena 1995; Scherr 1995), or expectations of favorable prices in the future, as was the case with contract tree growers in the Philippines (Spears 1987). Although photographs from the 1930s show a Rwandan landscape almost bare of trees, by 1989 every small farm had its own woodlot, because of the scarcity of wood and the emergence of wood markets (Harrison 1992). Increases in tree densities in Nepal have been greatest in those areas where forest products are in short supply and, thus, where the opportunity cost of not using land for economic trees is high (Carter and Gilmour 1989). Dewees and Saxena (1995) and Scherr (1995) show similar findings for Central and Western Kenya.

The effects of price increases on tree management are stronger the more that property rights enable residents to (expect to) capture future benefits of new trees. For example, population-induced increases in demand for fuelwood between 1952 and 1983 not only led large-scale entrepreneurs to extend the open-access fuelwood hinterland of metropolitan Kano City, Nigeria by cutting and transporting wood from greater distances from the metropolitan area, but also led farmers in the close-settled zone of the metropolitan area to increase the tree density on their private farms (Mortimore 1993).[20] (See Table 12.)

Fertilizer Prices

Since land in general becomes scarcer as population density in hilly-mountainous areas increases, the opportunity cost of nutrients for plant growth increases. Fertilizer and other nutrient supplements become cheaper relative to fallowing. But whether decreases in fertilizer prices make landscape-improving investments and practices more attractive depends on whether those investments are intended for, or dependent on, nutrient conservation.

[20]This area is not hilly. But the case study result is important and relevant to hilly areas.

Increasing amounts of fertilizer may be needed to substitute for the erosion-induced loss of soil nutrients; terraces may be constructed to protect the investment in fertilizers. On the other hand, fertilizer price declines may deter farmers from investing in longer-term soil improvements (which improve organic matter content or texture), such as composting systems or green manures.

Empirical investigations of the effect of fertilizer prices on landscape investments or the choice of production techniques are rare. Farmers in well-settled hillsides of the Philippines are less likely to use grass strips, contour hedgerows, and rock wall terraces as the farmgate price of fertilizer decreases (Templeton 1994b). Farmers in Ambodiaviavy, Madagascar do not use fertilizer on hillsides because fallowing and opening new hill forest for production are still possible, no local fertilizer market exists, and production credit is not available (Harrison 1992). Purchased fertilizers will not usually be used in non-marketed crops, due to cash constraints, hence price changes will have little impact on such systems.

Non-Farm Labor Demand

In open economies, farm wages do not necessarily decrease as population density increases, because the demand for non-farm labor might increase. As a result, farmers may not make labor-intensive investments in land or maintain labor-intensive production systems as population grows. For example, in spite of increases in population density on Rusinga Island, Kenya since the 1930s, farmers, who are usually women, have abandoned most agricultural stone terraces and poorly maintain the remainders on steep hillsides of the island because a growing number of people, particularly young ones, allocate their labor away from farming into more remunerative commercial fishing or migrant employment (Conelly 1994). Similarly, in spite of increases in population density in a Bolivian watershed between 1953-1991, farm households in these areas have ceased using various soil conservation techniques and reduced their participation in reciprocal labor exchange because members of these households allocate their labor time to more lucrative commercial (that is, off-farm) activities or migrant employment (Zimmerer 1993).

Numerous other case studies indicate a similar phenomenon. The better are off-farm income opportunities relative to on-farm ones, the less time that people devote to farm production and the less soil conservation that they practice in Latin America (de Janvry and Garcia 1988) and in specific hilly-mountainous areas of Mexico (Garcia and Garcia 1990), Ecuador (Southgate 1988), and the Dominican Republic (Murray 1992). In one area of the Philippines, farmers with off-farm and non-farm work opportunities were less likely to establish and maintain contour hedgerows and grassy strips (Fujisaka 1993). Similarly, better job opportunities in the oil, tourist, maritime freight handling, and other non-agricultural industries in urban areas were the primary reason for abandonment or neglect of terraced hilly land and consequent soil erosion in Yemen (Vogel 1987), Oman, Malta and Gozo (Busutti 1981), Israel and Palestine (Bunyard 1980), and the Canary Islands (Bunyard 1980). (See Table 13.)

However, increases in the opportunity cost of farm labor induced by better off-farm income opportunities do not automatically induce land users to make more environmentally destructive production choices. For example, rising agricultural wages in Gujarat and other states in India have encouraged farmers to have woodlots because growing trees is less labor-intensive than production of many other agricultural crops and spreads labor requirements over the year (Noronha 1982; Swaminathan 1987). Similarly, the steady outmigration of much of the active work-force from two hill districts of central Nepal and the higher labor costs implied by this out migration were one of the main reasons why residents of these areas planted more trees on their farms. As a result, people spent less time, effort, and money collecting fuelwood and fodder from their farms than from more distant communally-owned forests (Carter and Gilmour 1989). Dewees (1995) reports a similar result for woodlots in central Kenya.

Better nonfarm income opportunities can also enable a household to self-finance land investments, particularly those with high start-up costs. For example, in Machakos farmers sometimes use off-farm earnings and livestock sales to pay laborers to terrace (Tiffen, Mortimore, and Gichuki 1994). In Rwanda farmers maintained more soil conservation infrastructure as nonfarm income and the value of livestock holdings increased (Clay,

Table 13 Effects of non-farm wages and income opportunities on perennial cover, cropping frequency, and agricultural land enhancement

Source	Hilly-mountainous area	Market factor	Type of evidence	Effects
Conelly (1994, 145-147, 151-155, 165)	Rusinga Island, Kenya	Better fishing opportunities or migrant employment	Case study based on key informants	Abandonment or neglect of terraces
Zimmerer (1993, 1660, 1665-1666); (Garcia and Garcia, 1990, 1569-1570); Southgate (1992); Murray (1992)	Calicanto, Bolivia; San Andrés Lagunas, Mexico; Ecuador; Dominican Republic	Better off-farm income opportunities or migrant employment	Case studies	Less time in agricultural production and soil conservation
Fujisaka (1993, 102-103)	Claveria, Philippines	Off-farm and non-farm work opportunities	Case study	Less likely to adopt hedgerows
Vogel (1987, 18); Busutti (1981, 14); Bunyard (1980)	Yemen; Oman, Malta and Gozo; Israel, Palestine, and Canary Islands	Better jobs in oil, tourism, maritime freight handling and other non-agricultural industries in urban areas	Case studies	Depopulation, abandonment and neglect of terraced land, soil erosion
Noronha (1982) and Swaminathan (1987, 33)	Gujarat and other states in India (not necessarily hilly)	Rising agricultural wages	Case study	More tree growing
Carter and Gilmour (1989, 388)	Two hill districts of central Nepal	Out migration of workers and higher associated labor costs	Case study	More trees planted on nearby farms and less fuelwood and fodder collected from more distant communally-owned forests
Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya (1995, 85, 90, 92, 97)	Rwanda	Increases in non-farm income and value of livestock holdings	Econometric	More investing in soil conservation
Tiffen, Mortimore, and Gichuki (1994a, 201)	Machakos, Kenya	Off-farm income and livestock sales	Case study	Farmers hire laborers to terrace

Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). (See Table 13 for summary.)

ECOLOGICAL CONDITIONS

The ecological conditions in hillsides and mountains themselves condition the relative costs and benefits of different land management practices, investments and strategies. It is sometimes misleading to assume their "marginality," relative to flatter areas, will constrain patterns of land use intensification or land quality improvement. As argued by Kates, Hyden and Turner (1993), "the quality of an agricultural environment is as much as product of its use, including landscape transformations, as of raw nature."

Hills and mountains in developing countries generally have greater variation in rainfall, sunlight, elevation, topography, soil, and other ecological characteristics than flat areas, not only in aggregate, but also among and within fields. Thus, cropping patterns and production techniques exhibit greater variety in hilly-mountainous areas than in flat areas. For ecological reasons (and not simply reasons related to risk aversion, labor-spreading or unreliable food markets) production of monocultures is not likely to be as economically attractive in these sloping areas as elsewhere. This greater ecological diversity implies that production is more human-capital intensive, that is, requires more farmer knowledge and research information, and intra-regional trade is more likely to occur in hilly-mountainous areas than in flat areas with less natural diversity.

Climate and Rainfall Effects on Land Use

Differences in ecological conditions affect both the benefits and the costs of producing various goods and, thereby, affect the types of production. Climate broadly constrains the amount and types of plants and animals that either grow naturally or humans produce. For example, lower slopes and depressions are the only lands cultivated in arid regions because only these places have sufficient water-holding capacity to allow any cropping at all (Pingali, Bigot, and Binswanger 1987). Thus, hilly-mountainous land in arid regions is typically used for grazing animals since the low rainfall and water-holding capacity of soil are enough for growth of perennial grasses but usually make production of annual or tree crops either ecologically or economically unviable.

On the opposite end of the rainfall spectrum, humid and sub-humid areas with soils that are relatively susceptible to leaching and acidification are more ecologically conducive to perennial cropping than to annual cropping (Pingali, Bigot, and Binswanger 1987; Ruthenberg 1976).[21] For example, coffee, tea, rubber, other perennial crops, natural forests, degraded forests, and homesteads with perennial crops dominate the hilly landscape in many upland humid zones, for example, Ratnapura district, Sri Lanka (van der Bliek 1991) and the east African highlands (Hoekstra and Corbett 1994). Cereal and tomato cropping were neither profitable nor sustainable in two humid and once densely-forested areas in the southern Sierra Madre mountains of the Philippines but production of multistory perennial crops intercropped with roots crops was both (Fujisaka and Wollenberg 1991).

Rainfall Effects on Land Use Intensity

Evidence from sub-Saharan Africa (Pingali, Bigot, and Binswanger 1987) suggests that as rainfall increases from arid to semiarid to sub-humid levels, cropping frequency increases; the effect of a longer production period dominates any possible detrimental effects of leaching or acidification on soil. But as rainfall increases from sub-humid to humid levels, cropping frequency usually decreases because leaching and greater acidity become severe enough to offset the benefit of longer growing seasons.

Increases in rainfall might have a similar effect on the intensity of livestock production. In general, as rainfall increases from arid towards sub-humid conditions, the amount of household-produced and purchased inputs used for livestock increases because fodder grows better with more rainfall. But excessive heat and humidity can hurt livestock growth by upsetting animal physiology and making conservation of fodder for the dry season very difficult (MacArthur 1976).

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[21] 'Tropical' and 'temperate' areas differ according to temperature. 'Humid,' 'subhumid,' 'semiarid,' and 'arid' areas differ according to rainfall.

In addition to affecting product choice, annual cropping frequency, and the intensity of livestock production, rainfall also affects the profitability of soil conservation.[22] Case studies from Machakos, Kenya (Tiffen, Mortimore, and Gichuki 1994a), Burkina Faso (World Bank 1992), and Haiti (White and Jickling 1994) indicate that bench terraces, rockwalls, and other soil conservation structures have a larger positive impact on crop yields in dry years or dry areas. Econometric evidence is equivocal: farmers are more likely to terrace as rainfall decreases from humid to sub-humid levels in hilly-mountainous areas of the Philippines (Templeton 1994a) but they maintain longer conservation structures per hectare as rainfall increases in Rwanda (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995).

Effects of Topography on Land Use and Management

Location on hills and mountains also affects the economic attractiveness of production and landscape investments. As farmers move down a hill or mountain, they trade off higher yields with higher labor requirements for land preparation, for lower risk of drought (Pingali and Binswanger 1987). As a result of these tradeoffs, people tend to produce annual crops on mid slopes at low population densities (Pingali and Binswanger 1987). The inherent risk of drought does not change as population grows but tillage of heavier soils on the lower slopes becomes cheaper as the opportunity cost of labor decreases. Thus, cultivation in the upper slopes is usually the least desirable option at high population densities because yields from annual cropping are usually lowest and drought risk greatest in these areas (Pingali and Binswanger 1987). Various case studies illustrate the relative disadvantage of production of annual crops in these areas: people use upper slopes in Gambia, Tanzania, Zambia, and Botswana (Pingali and Binswanger 1987) and ridgetops in Nepal (Blaikie and Brookfield 1987) primarily for forestry or grazing.

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[22]The greater the rainfall, the greater the potential erosion of soil nutrients, rooting depth, and commercial fertilizer. Thus, the benefits of controlling erosion of soil nutrients, rooting depth, and commercial fertilizer with landscape structures increase as rainfall increases. On the other hand, the benefits of conserving water and soil moisture with these land improvements decrease as rainfall increases.

In addition to location on a hill or mountain, the steepness of that location also matters for choices of production activity and technique. In Rwanda, the steepest areas were traditionally reserved for pasture, woodlots, and perennial crops; frequent fallows were common practice. Yet as a result of population growth in recent decades, some farmers now cultivate slopes once thought to be too steep and fragile for annual cropping (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995). In densely populated Burundi and the Kigezi district of Uganda, people also cultivate very steep fields by hand (Pingali, Bigot, and Binswanger 1987). In Nepal, the steepest slopes and the ridgetops are unterraced and used primarily for pasture and occasionally for annual crop cultivation (Blaikie and Brookfield 1987).

These case studies suggest that, except in cases of extreme land scarcity, people use the steepest portions of land for grazing or wood production because the susceptibility to erosion and costs of annual crop production are highest on these portions and, if water-holding capacity and soil depth vary inversely with slope, the yields are lowest there as well. However, if population growth and wage levels make hand hoeing sufficiently cheap relative to land, annual crop production replaces livestock or perennial crop production even on the steepest areas.

Steepness of fields, or slope, also affects the benefits and costs of terraces and other landscape investments. Econometric evidence from Rwanda and the Philippines indicates that the net benefits of terraces and other soil conservation structures are highest on fields of medium steepness (Clay, Byiringiro, Kangasniemi, Reardon, Sibomana, and Uwamariya 1995; Templeton 1994a). This evidence suggests that as slope increases from low to medium levels, the benefits of conserving soil, water, and fertilizer with terraces or other terrace-creating landscape structures increase faster than the costs of these investments. But net benefits, while positive, decrease as slope increases from medium to high levels, since the costs of these investments—particularly the space and maintenance required for the structures, the difficulty of maneuvering draft animals, and the likelihood of terrace walls collapsing—grow faster than the benefits.

Effects of Soil Characteristics on Land Management

As alluded to earlier, relatively permanent soil characteristics affect crop choice, cropping frequency, and use of other inputs. For example, in humid and sub-humid areas, volcanic soils, alluvial soils, and vertisols can strongly resist the leaching of nutrients and, thereby, sustain intensive production of field crops with low levels of soil degradation (Pingali, Bigot, and Binswanger 1987; Ruthenberg 1976). Thus, fertile, volcanic soils enable permanent upland (dry field) farming on much of Java (Ruthenberg 1976), on Mt. Kilimanjaro (Fernandes, Oktingati, and Maghembe 1984), and in portions of Batangas that surround Mt. Taal (Librero 1985). Case studies of the Ada district in Ethiopia, Nyanza province in Kenya, and the southern province of Zambia indicate that better soil fertility attracts immigrants, leading to higher population densities and, as a result, greater intensity of annual cultivation (Pingali and Binswanger 1987). In the volcanic zones of East Java, where soils are fertile and deep, farmers are willing to invest in soil conservation measures because of the high productivity of the land, while in the shallow limestone areas of East Java farmers do not invest time and money in conservation and rehabilitation measures because the land productivity is low (van den Hoek 1991).

But returns also depend on the purposes that the investments serve. Returns on investments that enable a production activity or technique that would otherwise be difficult or impossible are higher the more naturally productive is the land. Thus, for example, farmers in three out of four sample areas of Thailand bunded with greater probability on black rather non-black soil, flat rather than non-flat land, and when some kind of irrigation is available rather than none (Feder, Onchan, Chalamwong, and Hongladarom 1988), since bunds enable production of paddy rice and other crops and yields are higher under these ‘favorable’ conditions. On the other hand, the returns on investments that augment a certain quality of land are higher, the more the land lacks the particular quality. Thus, for example, farmers in California are more likely to use drip or sprinkler irrigation techniques on lighter soils, since these techniques help soils with less clay to hold and distribute water (Caswell and Zilberman 1985).

4. CONCLUSIONS AND IMPLICATIONS FOR POLICY AND RESEARCH

The microeconomy of land management depends on local population growth, property rights and resource management institutions, systems for information access and technological innovation, market integration, and local ecological conditions. Local population growth leads to increases in the supply of labor and demand for land, larger families, fewer land holdings, more individualized and specific property rights, and other microeconomic changes. Institutions and organizations function to help determine which individuals have access to land and other resources, the degree to which groups of individuals cooperate to manage these resources, and how they transfer rights and responsibilities for management of these resources to others.

Access to information and technology for natural resource management, and local processes of technical innovation, influence the costs and returns to intensification through land-improving investment and management, and the pace of local adaptation to population growth and market expansion. Market factors—buyers and sellers outside of these areas and the degree of access that local producers have to these other market participants—critically affect the local prices of outputs and inputs. Given available technologies, intrinsic ecological conditions determine the range of viable production and investment choices, the growth response of plant and animal products to factors of production and to landscape investments, and the environmental impacts of various products, production methods, and landscape investments.

How can population growth lead to land degradation or enhancement? An increase in the demand for local goods leads to an increase in their production. But larger families, smaller farms, and an increase in the local supply of labor create incentives for farmers not only to use land more frequently for production but also to switch to crops and production techniques that use more labor and other 'cheaper' inputs per production cycle and to make labor-intensive and cash-intensive land improvements. The expected returns on land improvements increase as local property rights become more individualized and specific. The net benefit of collective management of hard to privatize resources can improve with population growth too. These changes in goods, inputs, production methods, investments, and resource-management institutions can be beneficial or harmful to land quality.

Insights from the empirical evidence and theory suggest that population growth is more likely to induce land-enhancing changes in institutions, investments, technologies, inputs, and products in areas where the following characteristics exist: 1) growth is slow, 2) growth is local and not a result of immigration of people who lack technical knowledge appropriate for local ecological conditions, 3) the land frontier is closed because open-access areas do not exist, 4) indigenous forms of private property exist, 5) land managers have continual and cheap access to new technical ideas and institutional innovations, crops, and markets; 6) product prices are not kept artificially low; 7) soils do not deteriorate rapidly if cultivated or otherwise disturbed; and 8) soil productivity responds strongly to complementary inputs such as water or fertilizer.

Weaknesses in methodologies and data presentations in the existing empirical literature make more exact hypothesizing about the microeconomic configurations that lead to land degradation or enhancement difficult. Researchers often failed to document adequately the topography, rainfall and other ecological conditions that exist in their sample areas. Indicators of land quality were often vague. For example, the literature, including our own research, often did not distinguish whether terracing actually improved certain soil properties or merely retarded their depletion. More explicit indicators--for example, soil depth, vegetative cover, soil nutrient levels, downhill runoff, or habitat size--are needed to establish links between land quality, production, and land investments. Furthermore, researchers often failed to adequately describe the data; basic assumptions, sample size, and selection criteria were often not specified.

Evidence of longitudinal or spatial changes in land quality and related factors was most commonly drawn from photographs, comparative description of multiple sites (with tabular summaries), and local histories. Few studies analyzed such evidence in a quantitatively rigorous way. Multivariate statistical analyses generally used only cross-sectional data, often without accounting for variation in ecological conditions.

Perhaps the most problematic aspect of the review as a whole is the indeterminacy, both empirically and theoretically, of many key factors, such as population and prices, in predicting resource quality outcomes. Most studies did not compare evidence across sites, time, and space and, thus, did not disentangle the relative importance of site, household, community, market, and other institutional and policy factors.

Still, the evidence reviewed and our microeconomic interpretation of it do provide a basis for identifying eight substantive research and policy challenges about the environmental impacts of production systems in hilly-mountainous areas and the microeconomic configurations that give rise to them.

First, 'land degradation' needs to be better defined. The term can refer to depletion in renewable components of hilly-mountainous land (for example, vegetative cover or nitrogen content), to depletion of non-renewable resources (for example, soil depth), to reductions in land productivity that result from depletion, or to possible extinction of plants or animals and other irreversible changes. Future research and policy need to define different types of land degradation so as to distinguish private and social costs and benefits, and clarify the objective and value of policy intervention. For example, a policy objective to protect certain habitats might require creating biodiversity reserves, while the objective of protecting tree biomass (for watershed protection or long-term forest production) might only require creating secure property rights or expectations of favorable timber prices.

Second, 'carrying capacity' is not a useful absolute concept for analysis of the environmental impact of human population and production over time or space. In any instance or place, carrying capacity for humans depends on the extent of landscape transformations and the nature of production systems (Kates, Hyden, and Turner 1993). Since changes in market conditions, institutions, and local population induce changes in products, input use, technologies, land-transforming investments, and institutions, carrying capacity is endogenous. Moreover, as evidence about depopulation and some deforestation experience suggest, certain landscape transformations are irreversible. Hence, carrying capacity is also path dependent.

Third, high rural population levels are not directly associated with degradation. However, the slower the *rate* of demographic growth or decline, the more time that people have to innovate and adopt products, technologies, individual property rules, and local collective management.[23] Researchers should identify and policy-makers promote specific incentives to slow the rate of demographic change and to speed up innovation of technologies and institutions that address not only growth but also decline in local populations. For the same reason, the environmental benefits of ambitious programs to title land are probably highest in areas undergoing rapid demographic change or conflicts over claims to land.

Fourth, large-scale migration out of hilly-mountainous areas, as a result of better non-local income opportunities or settlement policies, is likely to lead to landscape degradation if these areas have already been substantially transformed and are maintained and protected with relatively large amounts of labor. Policymakers might need to provide technical assistance to farmers who continue to cultivate in these areas to make the transition to less labor-intensive systems without degradation. Of course, where depopulation leads to the conversion of land from agriculture to natural vegetation with full ground cover, there may be positive effects on watershed conditions.

Fifth, better non-farm income opportunities associated with economic growth can both encourage and discourage landscape investments. The research challenge is to identify the conditions under which these opportunities encourage improvements. Better non-farm income activities are likely to discourage land improvements if policies and programs have made the profitability of production in the hills and mountains artificially low. Better non-farm income sources are more likely to encourage investments if a household member can earn the income at home or during slack periods of production or does not provide most of the labor for production.

Sixth, the microeconomic basis for the empirical relationships between farm size and production frequency, tree density, agricultural investments, and livestock density needs to be more thoroughly investigated. That is, the research challenge is to identify specific market failures that form the basis of these relationships and examine their effects on land quality through their impacts on choices of products, inputs, technologies, and investments. For example, labor heterogeneity and credit market imperfections might account for the effect of

[23]Pingali and Binswanger (1987) and Paarlberg (1994) make similar arguments about rapid population growth.

farm size on agricultural land investments. As farm size decreases, people are more able to improve agricultural land without borrowing money or labor. Moreover, as farm size decreases, these improvements become more profitable because the share of hired labor decreases more rapidly with agricultural production on the improved land than with production on unimproved land because the former system is more labor-intensive.

Seventh, the environmental effects of product price increases or input price decreases depend on local bio-physical conditions. The policy challenge is to avoid creating incentives for productive activities that are not otherwise 'well-suited' for local ecological conditions.

Eighth, the environmental impacts of greater profitability of production in hilly-mountainous areas also depend critically on property rights. The research challenge is to identify which *de facto* property rights discourage land investments and to assess whether these rights are likely to evolve into well-defined communal or private property rights. This research requires an investigation of the effects of government titling programs and other *de jure* land-use policies on *de facto* property rights and on the expected returns of various production systems. It is worth exploring alternative mechanisms to grant property rights to rural communities in low density areas, who might be able more effectively to control local immigration.

In conclusion, most humid and sub-humid hill and mountain areas, and many semi-arid areas, could ecologically sustain production at higher population levels. Areas clearly need to be set aside for habitat preservation; but it should be recognized that the evidence of government capacity to protect large areas from settlement, under conditions of rapid population growth, is disappointing. In the vast land areas outside these protected reserves, the technological challenge is to enhance old and create new farming systems, technologies and management systems that protect watersheds, enhance the economic welfare of people, and create niches for greater biodiversity. The policy challenge is to help in configuring local microeconomies and institutions to support these objectives.

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