SOIL EROSION AND CONSERVATION AS AFFECTED BY LAND USE AND LAND TENURE, EL PITAL WATERSHED, NICARAGUA

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Front Cover: Coffee plantation in the upper portion of the El Pital watershed that is managed using a variety of soil conservation techniques. The coffee trees are shaded by fruit and timber trees. The soil is further protected by maintenance of nitrogen-fixing cover crops.

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INTRODUCTION

Throughout the tropics, water induced soil erosion threatens sustainable agricultural production on steeplands. Nicaragua is the largest country in Central America, with the region's highest annual population growth rate, 3.4%, and its lowest average per-capita annual income level, US $420 (The Economist Intelligence Unit 1999).

Agriculture is the largest sector in the Nicaraguan economy. An estimated 7.7 million hectares in Nicaragua have been degraded by water erosion (IRENA-ECOT-PAF 1994). Farmers with small land holdings make a substantial contribution to the agricultural economy; many of these small farms are located on steeplands with slopes from 10% to 40%. The El Pital watershed is typical of the many steepland regions in Nicaragua where deleterious effects of erosion are increasingly evident.

Overview

This study applied Geographic Information Systems (GIS) tools to a combination of remote-sensed mapping data (1968 and 1987) and interview data (1996) to estimate how estimated annual soil losses from erosion have changed in the El Pital watershed over a 28-year period. Changes in land tenure, and associated changes in land use, were the main factors driving increases in estimated erosion hazard from 1968 to 1996. Some observations concerning patterns of adoption of soil conservation practices in the El Pital watershed were profiled, based on interviews with 135 farmers in 1996.

Evidence from this study supports two over-arching conclusions. First, erosion hazard within the El Pital watershed is increasing at an increasing rate. The primary reason erosion hazard is increasing is that much more of the watershed is being cultivated for annual crop production (e.g., beans, maize) than previously. Second, the portion of a farm devoted to annual crop production is inversely related to farm size.

Farm fragmentation associated with agrarian reform and inheritance customs has contributed to the increase in small farms, hence there has been an associated increase in cultivation of annual crops, leading to an increase in erosion hazard. Soil conservation programs targeted at agrarian reform communities have been successful in promoting the use of conservation practices, thus reducing erosion hazard. Use of geographic information systems (GIS), which enable simultaneous analysis of biophysical and land tenure patterns, can aid in targeting where soil conservation efforts will likely yield the greatest return on investment.

Watershed-scale analysis

Analysis of soil erosion processes over time at a watershed scale takes into account the interrelated biophysical, socioeconomic, and institutional factors which influence natural resource management decisions and outcomes (Thurow and Juo 1995). Traditional analysis of public and private investments in soil conservation emphasizes how erosion adversely affects farmers, through declining crop yields and losses in soil productivity over time.

A watershed approach also takes into account the off-site effects of soil erosion, including drainage disruption, gullying of roads, eutrophication of waterways, siltation of dams and channels, loss of reservoir storage capacity, increased flooding risk, loss of wildlife habitat, damage to public health, and increased water treatment costs (Pimentel et al. 1995).

Since the watershed approach identifies off-site and downstream parties who benefit from reduction or prevention of soil erosion on steeplands, it changes public debate concerning

how much investment in soil conservation practices is appropriate and who should pay for soil conservation. In the aftermath of Hurricane Mitch (October, 1998), these public policy issues are particularly germane because strategic investments in soil conservation might have prevented a share of the losses which occurred both on agricultural lands and downstream.

In Nicaragua more than 3,000 people were killed by the hurricane, and the agricultural sector lost an estimated US $239 million. Smallholders, in particular farmers on steeplands, suffered the most serious losses in proportion to their assets (The Economist Intelligence Unit 1999). The research results reported here have a role to play in guiding the selection among future soil conservation investment options, in order to mitigate against risks associated with extreme climatic events.

Land-use planning using GIS tools

To take action at a watershed scale requires land use planning, the systematic assessment of land and water potential, alternatives for land use, and socioeconomic conditions, in order to identify land use options. The aim of land use planning is to select land use patterns to best meet the needs of people today while also safeguarding natural resources for the future.

In considering complex land-use options, Geographic Information System (GIS) tools are powerful in (1) generating efficient and effective views of databases that describe land records, (2) integrating the land data in ways that foster understanding of relationships, and (3) handling transactional updating of land data to maintain current information (Dangermond 1989). Furthermore, maps generated using GIS tools allow for comparison and analysis of spatial and temporal patterns (Selman 1991; Brown et al. 1994). The ability to consider several data sets simultaneously, and to display numerous complex relationships on a single map, makes GIS analysis a powerful aid for policy discussions.

CHARACTERISTICS OF THE EL PITAL WATERSHED

The El Pital watershed is located in the Pacific region of Nicaragua between 11°42'48" and 11°54'47"N; 85°55'12" and 86°09'12"W in the southern part of the Department of Masaya, 100 kilometers southeast of Managua (Figure 1). The El Pital watershed borders the northwestern shore of Lake Nicaragua. The 165 km^2 watershed is comprised of two sub-basins, Mombacho and Diriomo.

Figure 1. Location of the El Pital watershed

The discharge area for the Mombacho sub-basin is 77 km^2. Its drainage pattern is sub-dendritric with four ephemeral streams; the water in these streams usually infiltrates into the pyroclastic depositions of Mombacho volcano. The Mombacho sub-basin experiences runoff only during extreme flood events. The Diriomo sub-basin is 88 km^2 and its drainage involves seven ephemeral streams (MARENA 1993). Seventeen percent of the watershed has slopes greater than 10%, and five percent has slopes greater than 20%.

The 1994 population of the El Pital watershed was 58,505; its population density was 148 people per km^2. Approximately 62% of El Pital residents live in small communities, the remaining 38% live on their farms in rural areas.

The four municipalities in the Masaya Department are Catarina, Niquinohomo, San Juan de Oriente, and San Jose de Masatepe. The four municipalities in the Granada Department are Diriomo, Diria, Granada, and Nandaime.

Climate

As characterized by the Koeppen Climatic Classification, the watershed has a humid and dry tropical climate (MARENA 1993). Annual precipitation averages approximately 1,500 mm. The rainy season occurs from May to October. The altitude varies from 160 to 1,100 meters.

Elevation has a great influence over mean daily temperature which varies in the watershed from 13°C in December to 25°C in April at the highest elevation, and from 26°C in December to 32°C in April at the lowest elevation (Lopez and Gonzalez 1994). The rainy season (May to October) is divided into two growing periods, *primera* (May to August) and *postera* (September to November). There is a dry period from mid-July to mid-August, the *canicula*.

Geology and soils

The El Pital watershed is part of the southwest Nicaragua depression flank. The geomorphology of soils in the watershed is diverse, with ten soils series represented from the valley to the mountains. The basin has mainly moderately to well-drained soils. The parental material of the soils includes basaltic rocks, volcanic ashes, alluvial sediment, and limestone. The topsoil depth ranges from deep (>80 cm) in lowlands and on well-vegetated hillsides to shallow (<30 cm) on intensively-used steeplands. The two dominant soil texture types in the watershed are sandy loam and clay loam. The organic matter content ranges from 3% to 9%, indicating stable soil structure (MARENA 1993).

Land tenure

In 1996 private land holdings occupied 79% of the El Pital watershed, the remaining 21% were beneficiaries of agrarian reform (BAR) who lived on 60 farm cooperatives. In 1996 farm cooperatives controlled 6,457 hectares, approximately 33% of the land in agriculture in the El Pital watershed.

Large commercial farms in Latin America which support only a few people devote a relatively small proportion of their land farmed to subsistence annual crops, such as corn and beans. Annual crops do not protect the soil from erosion as well as perennial crops, pasture and forest. Before the Land Reform Law was implemented, most large land holdings in Nicaragua were operated as commercial farms emphasizing perennial crops (e.g., coffee, fruit trees), livestock and timber production. The particularly erosive steeplands were usually managed as pasture or forest.

Agrarian reform within the watershed took place during the Sandanista revolution (1979-1990). Before 1979, the agricultural economy in Nicaragua was dominated by a private, modern sector of relatively few wealthy landowners and a relatively large, poor peasant sector. The Land Reform Law of 1981 formally legalized the process of confiscating farm land that was not being used to its potential (Spoor 1995). The confiscations targeted large private farms owned by the Somoza family (the family who controlled the political system prior to 1979) and their political allies. Confiscated land was redistributed to landless peasants who were organized into farm cooperative units. Cooperative holdings of farm land were nonexistent in 1978, but quickly increased to occupy 23.4% of agricultural land in Nicaragua in 1981, and 39.7% in 1988.

Implementation of the Land Reform Law in the 1980s meant that numerous previously-landless families - some from within El Pital watershed, some from urban areas or other rural regions - were encouraged to establish subsistence-level farm enterprises on plots subdivided from the confiscated large farms. Farm cooperatives were formed and used as the institutional mechanism for orchestrating the resettlement process. Though the families who

joined farm cooperatives were not given secure title to the particular plots they farmed, the redistribution of land into cooperatives is considered a permanent arrangement for cooperative members in good standing. Assignment of plots within the cooperative landholding, however, is sometimes changed from year to year. Accordingly, cooperative members have an incentive to contribute labor to the cooperative's landscape-level conservation projects, whether or not working for the common good yields direct and immediate payoffs on their particular plot.

Cropping systems

To understand the context within which land-tenure and land-use changes have occurred in the El Pital watershed, a characterization is presented of its five distinct categories of cropping systems: grain production on the plains, grain production on the hillsides, production of a diverse array of crops, coffee production, and livestock production.

Lowland grain production

In the plains, grain is produced in three different cropping systems, (1) rotation or intercropping of corn and beans, (2) monoculture of sorghum, and (3) monoculture of rice (*Oryza sativa* L.). Generally, tractors are used for plowing and the crop is planted using oxen to make a furrow for the seed.

For corn and beans production, land is cleared in April. The crops are planted when *primera* rains come in May. Corn rows are spaced 80 cm; within each row, two seeds are planted per hole, spaced 30 cm apart. The rate and timing of fertilizer and pesticide application depends on perceived need and availability of cash. Weed control is done either manually or with herbicides. Corn is harvested during the *canicula*. Corn stalks are either chopped for livestock feed or piled and burned. Corn stalks are removed to reduce the risk of pest infestations in the next crop. The field is cleared and plowed after the harvest. Beans are planted at the onset of the *postera*. The row width for beans is 40 cm; two seeds are planted per hole at a distance of 10 cm. The bean harvest occurs at the end of the *postera*.

For sorghum production, seeds are planted at the onset of the *primera*. Like corn, sorghum is produced for commercial markets; accordingly, farmers use fertilizer, herbicides, and pesticides to manage this crop. Only the follicle is harvested at the end of the *primera*. The stalks are left in the soil and a second grain crop is harvested at the end of the *postera*.

A *secano* (rainfed) system is used in rice production. Tractors are used in land preparation and seeds are planted in continuous rows at the beginning of the *postera*. Fertilizers and pesticides are applied at several intervals during the growing season, herbicides are used for weed control. The rice crop is a cash crop, little is used for family consumption.

Hillside grain production

Oxen are used in land preparation, and vegetation is cleared using manual labor, herbicides, or fire. Crops include rotations or intercropping of corn and beans, corn-beans-cassava (*Manihot esculenta* Crantz), or corn-beans-rice.

The corn-beans rotation is normally corn in *primera* and beans in *postera*. Crops are planted in rows made by an ox-drawn plow or in holes dug manually with a digging stick (*espeque*). In a corn-bean intercropping field, either alternate rows or a randomized scheme are used. In the alternate row system, the distance between rows is 80 cm, the spacing of plants within a row is 30 cm between corn and 20 cm between beans. In the *espeque* system, the distance between holes is one meter.

The cultivation of rice is done using either the row system or the *espeque* system. In general, agrichemicals are not used with *espeque* cultivation, because farmers who use this labor-intensive system are almost always poor. If cash is available, some fertilizer and some pesticides or

herbicides may be applied. Cassava is planted with 80 cm between rows and 50 cm between plantings. Cassava is primarily produced for home consumption, only occasional surplus is sold in local markets.

Diverse crops production

Some farms specialize and produce fruits, medicinal plants, ornamental plants, and/or vegetables for both family consumption and local markets. Fruits produced include lemons (*Citrus limon* (L.) Burm.), sweet oranges (*Citrus sinensis* (L.) Osbeck), tangerines (*Citrus reticulata* Blanco), mangos (*Mangifera indica* L.), avocados (*Persea americana* Mill), guavas (*Psidium guajava* L.), pineapples (*Ananas comosus* (L.) Merr.), papayas (*Carica papaya* L.), granadilla (*Passiflora quadrangularis* L.), passion fruit (*Passiflora edulis* Sims), pithaya (*Cereus sp.*), melon (*Cucumis melo* L.), and various types of bananas or plantains (*Musa spp.*). Vegetables include water squash (*Sechium edule* (Jacq.) Sw.), summer squash (*Cucurbita pepo* L.), tomato (*Lycopersicum esculentum* Mill.), taro root (*Xanthosoma sagittifolium* (L.) Schott), and cassava. Medicinal plants include chamomile (*Anthemis nobilis* L.), lemon grass (*Cymbopogon citratus* L.), aloe (*Aloe vera* (L.) N.L. Burm), and sour orange (*Citrus auratium* L.).

These crops are planted either in monocultures or in home gardens. A home garden is an array of plants grown adjacent to the home of the farmer, usually smaller than one hectare. The primary emphasis is production for home consumption and for cash between harvests of other crops. Organic fertilizer produced on-farm is often used. Monocultures, on the other hand, are market-oriented and require intensive use of purchased fertilizer, herbicides, and pesticides.

Coffee production

Coffee plantations are located on the farms at the highest elevations in the watershed. Two coffee production systems are in use, the traditional shadow system and a more recent shade-free system.

Fruit trees or timber trees are used for shade in traditional shadow coffee production. Shade serves allows the beans to mature slowly, to improve coffee flavor richness. Use of shade also lengthens the time period for bean ripening so that a few laborers are employed over a protracted period. Without shade, coffee growers who operate using a full-season system compete for scarce labor during an intense several-week harvest period. In addition, shade trees generate fuel wood, timber, fruit, and spices. Some shade trees assist in maintenance of soil fertility through nitrogen fixation (Lopez and Gonzalez 1994). Shade cover also dissipates raindrop energy and thereby reduces erosion hazard.

Tree species used in traditional shadow coffee plantations include cedar (*Cedrela odorata* L.), acetuno (*Simarouba glauca* L.), laurel (*Cordia alliodora* L.), guaba (*Inga densiflora*), genizaro (*Pithecellobium saman* (Jacq.), chilamate (*Ficus isophlebia*), guanacaste (*Enterolobium cyclocarpum* (Jacq.) Griseb.), and fruit trees like avocado, lemon, zapote (*Pouteria sapota* (Jacq. H.E. Moore), tamarind (*Tamarindus indica* L.), and various banana species. The dominant trees tend to be tall timber species that also fix nitrogen. The canopy of traditional coffee plantations creates a micro-climate with more stable temperature and humidity than similar unshaded plots. The litter from these trees is maintained as a mulch covering the soil surface. Trees are pruned at the beginning of the *primera*. The pruned leaves and small branches add to the mulch layer.

On coffee plantations using the new production system, fruit trees are prevalent -- in particular banana, plantain, orange, lemon and papaya trees - rather than taller timber trees. Because fruit trees give less dense shade than timber trees, some farmers plant live barriers of trees such as madero negro (*Gliricidia sepium* (Jacq.) Steud)), leucaena (*Leucaena leucocephala* (Lam.) de Wit), and acacia (*Acacia siamea*). These barriers shield the coffee trees from dry winds and direct sunlight, in addition to providing

a barrier to soil erosion and supplying a source of organic fertilizer.

Traditional shadow coffee production techniques are prevalent in the El Mombacho region, where Caturra, Catuai, and Mundo Novo coffee varieties are prevalent. The other *comarcos* with coffee production have almost an equal mix of traditional and newer non-shade plantations, and most often grow Caturra and Bourbon varieties.

Livestock production

Farmers raise livestock for milk and meat. In the El Pital watershed, there are (1) small farms which have ten or fewer cattle for family consumption and occasional sale and (2) large commercial farms with hundreds of cattle.

Grain crops rather than livestock are the primary source of farm income for farmers with small land holdings (five to fifteen *manzanas*, i.e. 3.5 to 10.5 ha). The role of cattle in the small-scale farming system is primarily milk production. Cattle are fed available grass, supplemented by either rental or free access to pasture on neighbors' fallow land.

On large commercial farms (100 to 500 *manzanas*, i.e. 70 to 350 ha), milk and/or meat production is the primary farm income earner. Where cattle are raised for meat, cattle graze on native or introduced grasses in extensively-managed pasture systems. In contrast, a milk production system is more intensive and uses purchased inputs including feed supplements. In both the milk and meat production systems, cattle primarily graze.

On intensive milk production farms, some hay is cut for dry season use and sometimes fresh grass is cut for stable-feeding. The most common grasses used are bermuda grass (*Cynodon dactylon* (L.) Pers), pata de gallo (*Digitaria sanguinalis* (L.) Scop.), and buffel grass (*Cenchrus cilaris* L.). Elephant grass or napier grass (*Pennisetum purpureum* Schumach.) and gamba grass (*Andropogon gayanus* Kunth) are used in cut-and-carry feeding systems. The farmers also use some leguminous forage crops such as tropical kudzu (*Pueraria phaseoloides* (Roxb.) Benth.) and cowpea (*Vigna sinenis* L.). Trees dispersed in the grassland are used for forage, shade, fuelwood, and as posts. These trees were established by natural regeneration or were left when the forest was cleared.

Soil conservation

Traditional farming systems in the El Pital watershed incorporate some soil and water conservation practices. Governmental and non-governmental organizations have also established local technical assistance projects to promote the use of additional agronomic and mechanical conservation practices. Agronomic practices have proven most effective on gentle slopes of less than 12% (Sheng 1989). On steep slopes in the tropics, agronomic practices are most effective used in conjunction with mechanical structures, and neither are as effective if used separately.

Cover crops and green manure

In the El Pital watershed, cover cropping and green manure are a combined practice. Cover crops are either planted after an annual crop has had a chance to become well established or after harvest. Cover crops protect soil from direct raindrop impact. Subsequently, they are plowed into the soil to improve structure and fertility. Leguminous species such as velvet bean (*Mucina pruriens* L.) and tropical kudzu are common cover crops and are effective as organic fertilizers.

Vegetative barriers

Vegetative barriers are usually planted in conjunction with terraces. Live barriers are formed by planting either woody species, grasses, or cash crops. The base of these plants obstructs overland flow and stabilizes the bunds in terraces. Plants most commonly used as vegetative barriers in the El Pital watershed include *madero negro*, leucaena, pigeon pea (*Cajanus cajan* L.), napier grass, or sugar cane.

Plate 1: Many poor peasants depend on the steeplands for their subsistence needs and many Latin American countries rely heavily on steepland production to meet the food security needs of their urban populations (e.g., USAID (1980) estimated that 75% of the basic grains – maize, beans, sorghum – produced in Honduras are on steeplands).

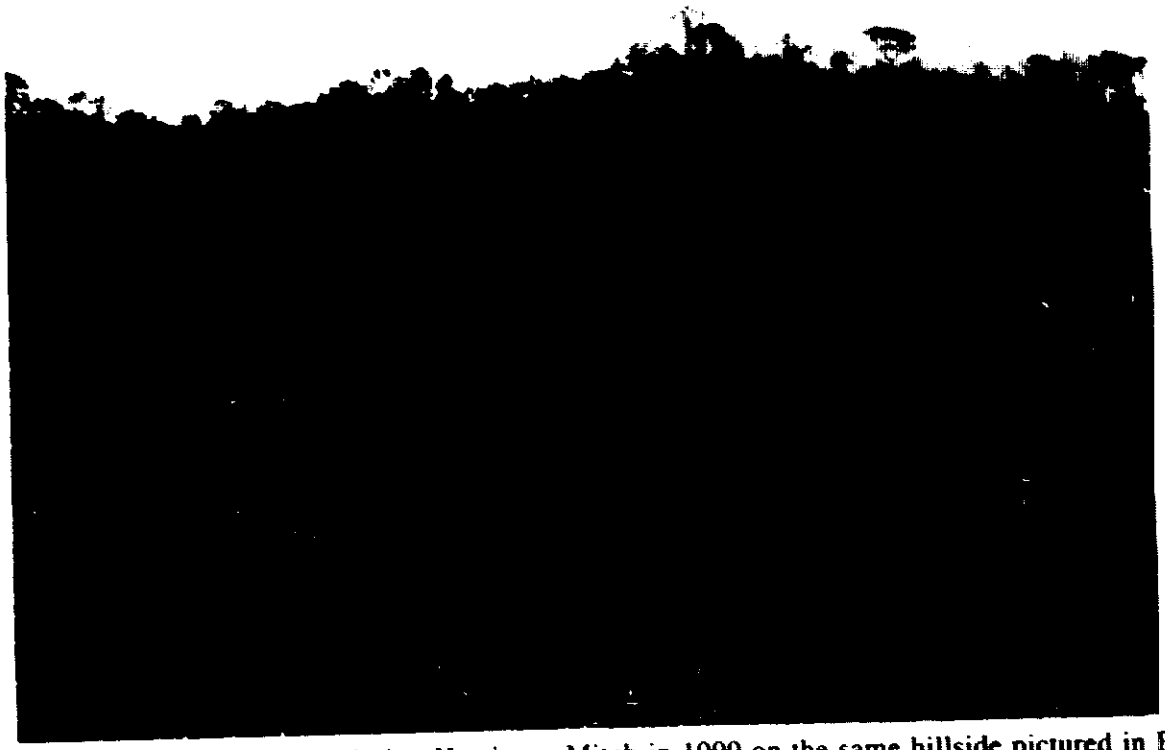

Plate 2: Landslides that occurred during Hurricane Mitch in 1999 on the same hillside pictured in Plate 1. Since customs and policies directly or indirectly result in deforestation for the sake of meeting the regions food production needs there is a corresponding need for the government to foster adoption of soil and water conservation practices that will aid sustainable use of these lands. The Soil Management CRSP is documenting the biophysical and economic viability of various steepland soil and water conservation options (e.f., Thurow and Smith 1998, Toness et al. 1998).

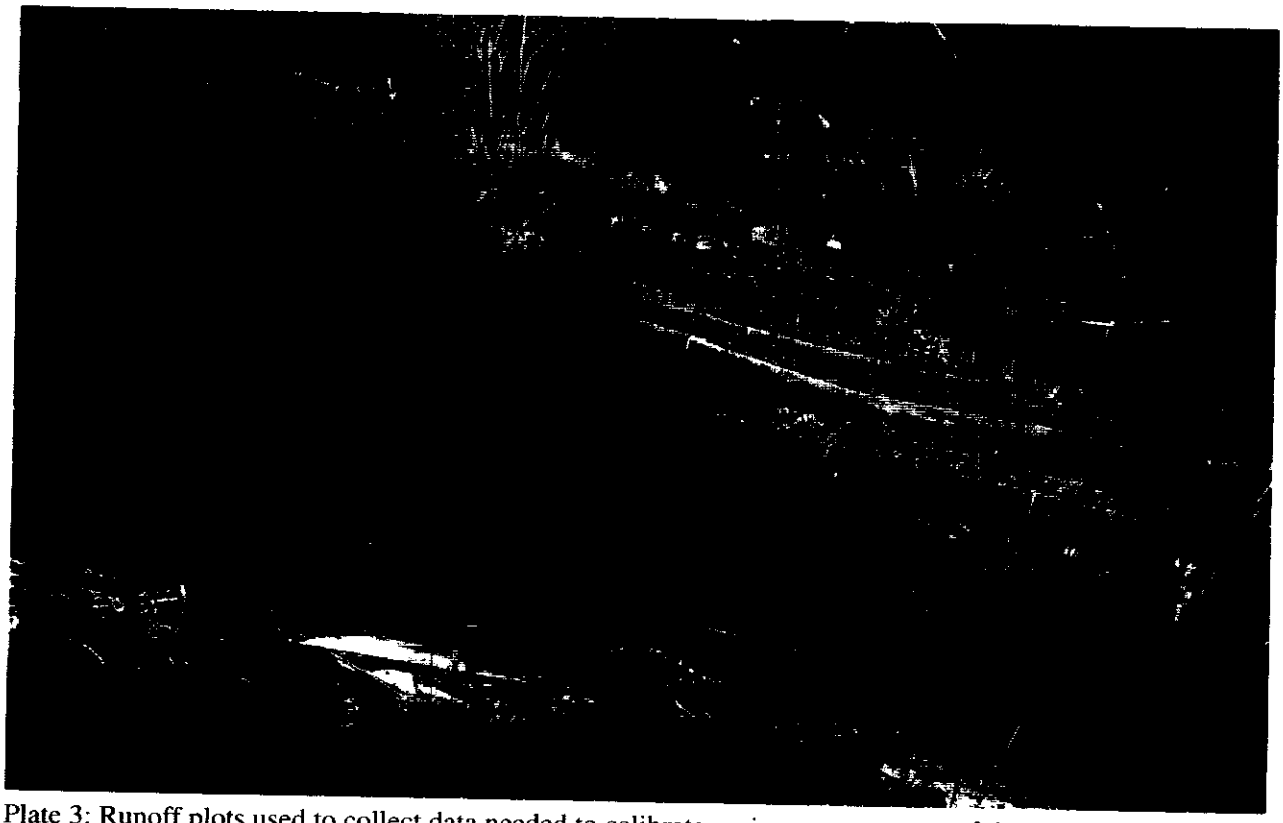

Plate 3: Runoff plots used to collect data needed to calibrate various components of the Universal Soil Loss Equation for the El Pital region.

Plate 4: Much of the land in the region is plowed using teams of oxen prior to the planting maize. In the background is one of the flumes being used to relate runoff plot data (plate 3) to field scale runoff, soil and nutrient loss data. Traditional farming practices are being evaluated against various soil and water conservation treatments to help determine the return on investment associated with installing and maintaining conservation treatments.

Surface mulching

Surface mulching practices are used to dissipate the erosive energy of raindrop impact and overland flow. Some farmers leave crop residues after harvest. Others use pruned material from live barriers or live fences as cover. In traditional farming systems, crop residues were cut, piled, and burned to kill pests and weed seeds. Mulch was a conservation practice introduced relatively recently by outside organizations working in the El Pital watershed.

Multiple cropping

Multiple cropping is a traditional practice. It can be as simple as planting corn and beans together or it can be a complex, heterogenous mix of species used in a home garden. Crop associations can be spatial or temporal. Intercropping involves strips of different crops being alternated. Mixed cropping involves rows with two or more crops planted together. Relay cropping is when one crop is planted first, and the other is planted after the first crop flowers. The most common annual crop associations are corn-beans, corn-beans-cassava, beans-plantain-cassava. Multiple cropping protects soil by increasing crop cover and enhanced amount and diversity of production.

Contour tillage

Contour tillage is more difficult than up-and-down slope tillage when oxen are used for plowing furrows for seed rows. When farmers are contracting for an oxen team to plow their land, the extra time and effort associated with plowing on contour translates into an extra expense of about $US 5 acre, a significant consideration for a near-substance farmer. Cultivation of crops following the contour of the land minimizes rill formation which would otherwise occur from runoff, particularly on steep fields.

Contour tillage is most effective in conjunction with agronomic conservation practices (e.g. mulching, use of cover crops). On steepland sites, contour tillage alone does not significantly reduce soil loss and runoff (Sheng 1989).

Conservation tillage

There are three variants of conservation tillage practiced in the El Pital watershed. One is a traditional farming method (the *espeque* method), two others were introduced relatively recently (minimum tillage and no-till). The *espeque* method involves slashing weeds with a machete and leaving these plant residues on the field. To plant seeds, a stick is used to make a hole in the ground, and through the residues. In contrast, in traditional farming systems, farmers not using the espeque method burned weeds before or after cutting them. Burning left the soil susceptible to erosion from intense rains at the beginning of the *primera* (Smith 1997).

Minimum tillage involves using the minimum possible passes of a plow to plant a crop, in contrast with conventional plowing practices where multiple passes are used. No-till planting involves slashing weeds or applying herbicides, leaving the plant residue from killed weeds on the soil, and using special seeding equipment to plant a crop. Normally, this seeding equipment must be pulled by a tractor, but recently a seeder was introduced which can be pushed without mechanical traction. No-till planting requires frequent application of herbicides.

The *espeque* method is most commonly used by subsistence farmers on steeplands. No-till planting with tractor-pulled equipment is only used on communes or on large farms located on gentle slopes.

Contour terraces

Contour terraces are bunds of soil, often used in combinations with live barriers. The terraces can be built using either oxen or tractor power. The terraces are laid out on a level grade and are raised by excavating soil from the uphill side. They are low bunds which progressively

enlarge with sediment accumulation behind live barriers. Soil accumulation is aided by the practice of placing branches and plant residues on the uphill side of the live barriers. Terracing was introduced in the Pacific region of Nicaragua in the 1960s when numerous farmers planted cotton and invested in the technology package required to support successful cotton production.

Individual basins

Individual basins are mechanical practices primarily used on traditional coffee plantations in the El Pital watershed. They are catchments which help to retain runoff, thereby improving soil moisture content and nutrient retention. Usually cover cropping, mulching, and/or composting is used in conjunction with individual basins.

ESTIMATING ANNUAL SOIL LOSS

The Universal Soil Loss Equation (USLE), an empirically-based model developed for prediction of erosion hazard in the United States (Wischmeier and Smith 1978), was applied to compare estimated annual soil losses over time in the El Pital watershed. Worldwide, the USLE has become the most commonly used soil assessment tool (Renard et al. 1996).

Two caveats apply to interpretation of USLE-derived soil loss estimates for tropical steeplands. First, its soil loss estimates are considered long-term annual averages, the maintained assumption of the USLE model being that over- and under-estimates of soil loss from individual storms will balance out over the long run (Wischmeier 1976). Due to high-energy rainfall conditions in Latin America, combined with attributes of soils common to the tropics, however, this maintained assumption is violated and, accordingly, the USLE model tends to over-predict erosion on cultivated tropical steeplands (Smith 1997). Second, the slope factor in the USLE was developed for modeling soil loss on cropland with slopes less than 16%, because the empirical observations which comprise its database were collected from plots on gentle to rolling slopes, mainly in the midwestern United States (Hudson 1995).

In sum, USLE soil loss estimates for tropical steepland sites are most appropriately interpreted not as absolute values but rather as a basis for comparing the relative effects of land use, cropping systems and soil conservation practices within a particular study area.

Empirical measurements or observations of six factors are used to estimate the average soil loss from a field (A), usually in tons per acre per year, using the USLE equation: rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover crops and management (C), and farming and conservation practices (P). The first four factors (R, K, L and S) are physical characteristics intrinsic to particular sites which do not change over time, the last two factors (C and P) are affected by farmers' land use decisions. Data on physical characteristics and on farmers' behavior are discussed in turn.

Physical factors which affect erosion

In applying the USLE to estimate erosion hazard in the El Pital watershed, the same measurements of the intrinsic physical site characteristics were used to compare 1968, 1987, and 1996 conditions.

Rainfall erosivity factor (R)

Annual rainfall erosivity (R) is the average annual sum of individual erosion index values (EI_{30}) for a particular location. The E component is the total kinetic energy for an individual storm event and I_{30} is the maximum 30-minute intensity of the storm event (Wischmeier and Smith 1978). Simply put, the R factor for a particular site represents the amount, intensity and duration of rainstorms for a particular site (Batie 1984).

To calculate the R factor for sites in the El Pital watershed, regional observations that correlate mean annual precipitation (mm) were applied to values of rainfall erosivity delineated

on aerial photographs from 1968 (1:30,000) and from 1987 (1:25,000) by applying GIS tools using an SI-metric unit (Mj-mm/ha/hr/yr). The annual precipitation isoheyts of the watershed were used to delimit rain erosivity by site (MARENA 1993, Smith 1996).

Soil erodibility factor (K)

The soil erodibility factor (K) indicates susceptibility to erosion of the soil types comprising the watershed. To estimate the soil's resistance to being moved by erosive forces, K is expressed as the rate of erosion per unit of the rainfall erosion index (EI) for a plot 72.6 feet in length with a 9% slope, tilled up and down in continuous fallow (Wischmeier and Smith 1978).

To assign soil types to sites in the El Pital watershed, a soil inventory at the comarca level was used (MARENA 1993). All sites in the El Pital watershed are either from the Niquinhomo series or from the Diriomo series. Mendoza and Rivas (1996) calculated the K factor for three years on three runoff plots located within the El Pital watershed; the Niquinhomo soil series (silty sand) had a K factor of 0.032 (SI-metric unit system) and the Diriomo soil series (silty clay) had a K factor of 0.016 (SI-metric unit system).

Soil length and steepness factors (L and S)

The slope length factor (L) accounts for the phenomenon that soil loss per unit generally increases as slope length increases. As more water accumulates on a long slope, it has the power to erode and transport more sediment (Batie 1984). The L factor is measured as the distance from the origin of runoff to the point where either the slope gradient decreases enough that deposition begins, or the runoff becomes concentrated in a well-defined channel that may be part of a drainage network or a constructed canal (Wischmeier and Smith 1978).

The slope steepness factor (S) is the ratio of the field's soil loss to that of a 9% slope under the same conditions. Increases in slope correspond with increased soil loss unless crop cover offsets the slope effect. Soil loss increases more rapidly as S increases than as L increases (Renard et al. 1996).

For the El Pital watershed, the LS factors were calculated using a slope map, assuming a standard length of 100 m when applying the USLE-LS formula (Wischmeier and Smith 1978). Topographic maps (1:50,000) were used in characterizing slope.

Farmers' choices which affect erosion

To estimate how erosion hazard has changed over time in the watershed, data on changes in farmers' decisions about cover crops and management, and conservation behavior, were collected from maps (1968 and 1987) and from interviews with farmers (1996).

Cover and management factor (C)

The crop cover and management factor (C) is a ratio of the soil loss from a field of certain cropping management practices compared with an identical area clean-tilled in continuous fallow. The C value is 1 when the soil has no cover and is clean tilled and continuous fallow (bare land). The C factor accounts for cropping sequence, the temporal changes in canopy cover, presence of crop residue or mulch, and surface roughness due to tillage and residual effects of the former vegetation (Batie 1984). The timing of rains with the seasonal harvests also affects the C factor.

In the El Pital watershed, a C factor was assigned for each of nine land use categories (forest, mixed range, bush range, grass range, perennial crops, mixed crops, annual crops, urban areas, streams and lagoons, fallow areas), following guidelines for tropical sites (Nill et al. 1996) and closely paralleling estimates for the El Pital watershed by Mendoza and Rivas (1996). For 1968 and 1987, land uses on particular sites were identified using aerial photographs. For 1996, land use cover was estimated based on interviews with 135 farmers. Farmers interviewed were chosen to represent five different cropping systems (basic grains on the plains, basic grains

on the hillsides, diverse crops, coffee and livestock). Fifteen private farmers and fifteen beneficiaries of agrarian reform were interviewed from each of the first four categories. Fifteen private livestock farmers were interviewed, but no beneficiaries of agrarian reform were engaged primarily in livestock husbandry.

Land management practices (P)

The P factor estimates the ratio of soil loss on a field with certain tillage practices to soil loss on a field under straight row plowing up-and-down the slope (Batie 1984). In this analysis of the El Pital watershed, P factors were not used due to a lack of sufficient site-specific data regarding the effectiveness of the soil conservation practices being used. Furthermore, use of some conservation practices would have been difficult to discern from aerial photographs.

CHANGES IN SOIL LOSS IN EL PITAL WATERSHED OVER TIME

Geologic erosion is the soil loss that would be expected to occur without the influence of human land use, maintained in natural vegetation (Figure 2).

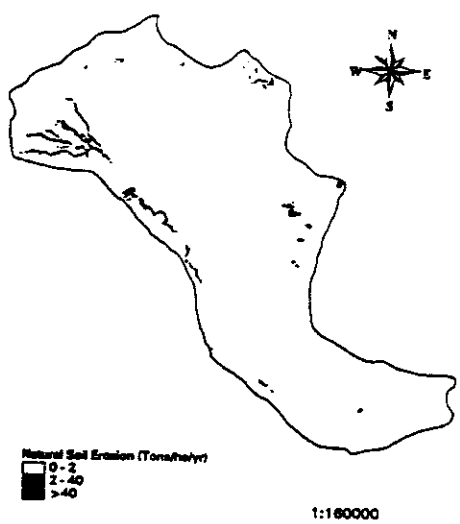

Figure 2. Estimated geologic erosion, El Pital watershed, Nicaragua

Only two of 17 comarcas in the El Pital watershed had geologic erosion of 10 tons/ha/year, the other 15 comarcas had erosion below 10 tons/ha/year. For the watershed as a whole, under natural vegetation only an estimated 220 ha would experience expected annual soil loss above 40 tons/ha/year. Figure 3 shows the average percentage slopes found on cropland in the El Pital watershed.

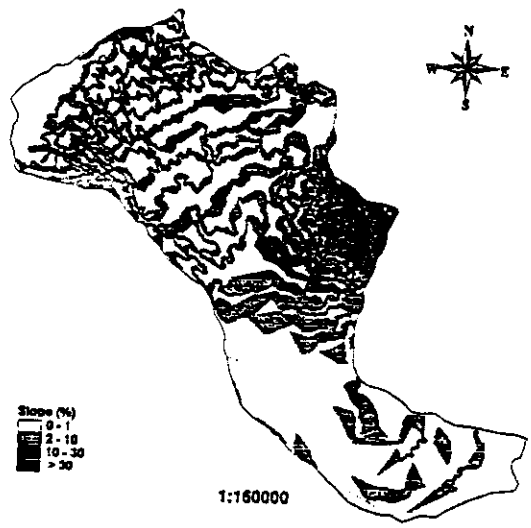

Figure 3. Average percentage slopes on cropland in the El Pital watershed

A comparison of Figures 2 and 3 suggests that without human activity, severe erosion would be occurring in the El Pital watershed on less than 1% of the watershed, only on naturally unstable sites where slopes are steepest.

Only one of the five USLE factors used to estimate annual soil loss in the El Pital watershed varied; for 1968, 1987, and 1996 the R, K, L, and S factors (estimates describing intrinsic physical factors) were unchanged over time. Only the C factor, crop cover and management, changed.

In sum, it is human activity which has been the major factor in the transformation of the El Pital watershed into a region with significant and increasing erosion hazard. Figure 4 depicts how estimated annual soil loss has changed from 1968, to 1987, to 1996. Comarca boundaries are traced in the three maps comprising Figure 4.

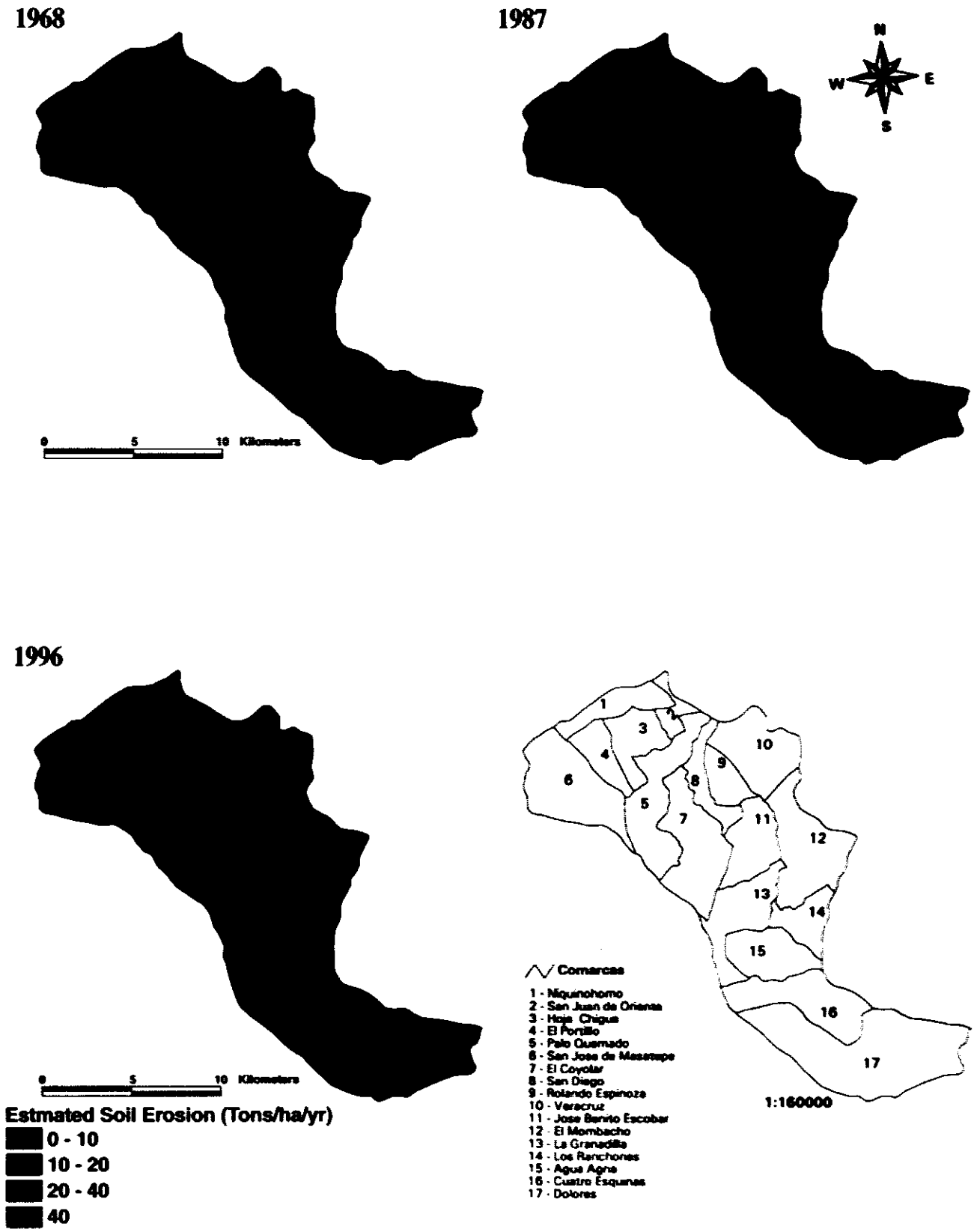

Figure 4. Estimated annual soil loss (tons/hectare/year) within the comarcas of the El Pital watershed, in 1968, 1987, and 1996.

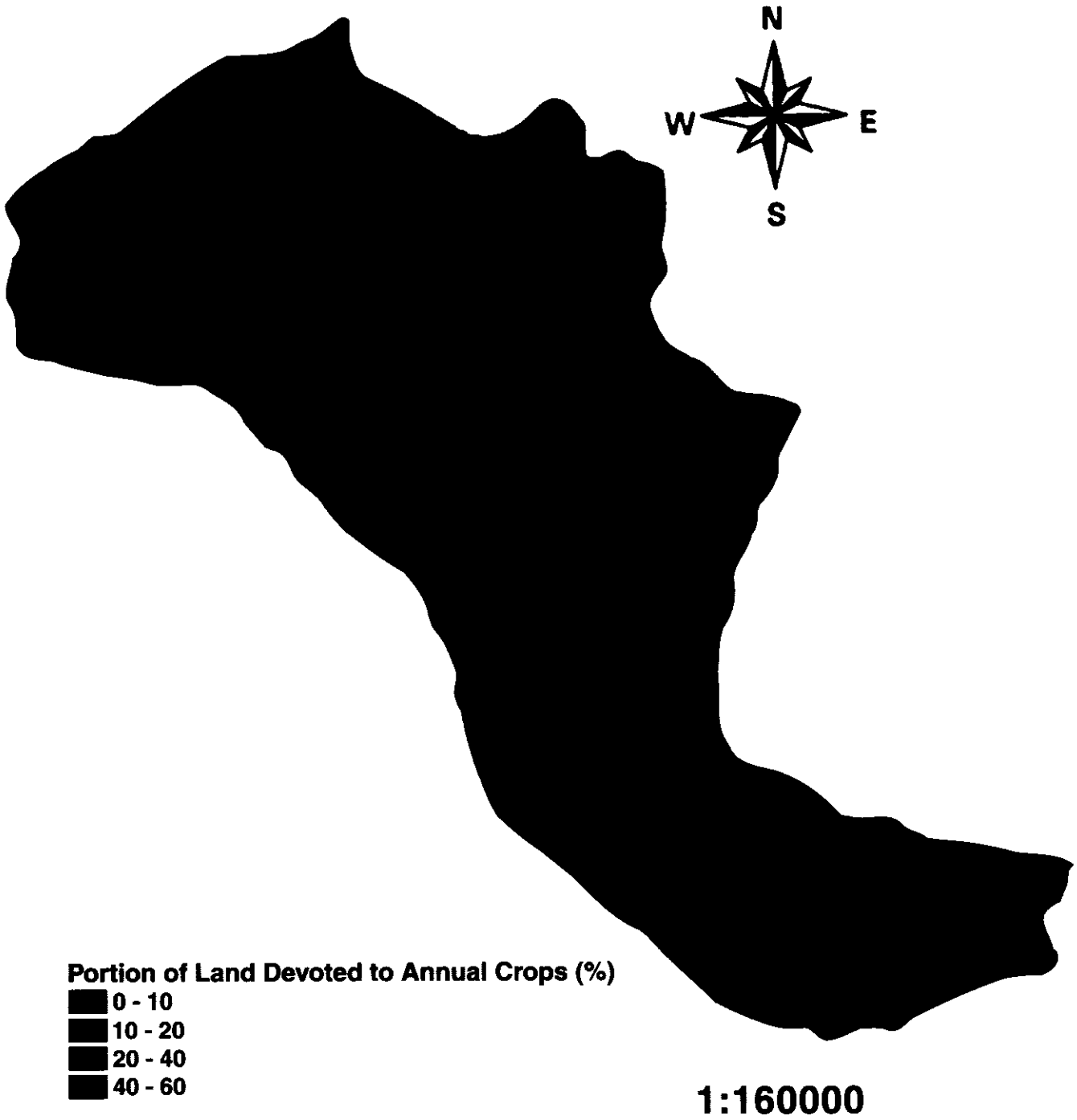

Figure 5. Percentage of cropland planted to annual crops, by comarca, in the El Pital watershed

Table 1 presents the changes in estimated annual soil loss in the El Pital watershed by comarca.

Table 1. Average annual soil loss in the El Pital watershed, Nicaragua (assuming no use of soil conservation practices)

	Estimated annual soil loss (tons/ha/year)			
Comarca	1996	1987	1996	geologic
Dolores	8	8	8	2
Cuartro Esquinas	21	3	3	1
Los Ranchones	29	30	15	4
El Mombacho	37	31	28	6
La Granadilla	37	28	30	4
Niquinohomo	39	18	14	5
San J. de Masatepe	42	21	16	10
Agua Agria	43	16	15	0
San Jn de Oriente	50	36	28	2
El Portillo	51	27	22	5
Veracruz	52	22	16	9
Rolando Espinoza	64	22	20	0
El Coyolar	80	40	36	8
Hoja Chigue	90	33	27	4
Jose B. Escobar	101	56	35	0
Palo Quemado	108	38	36	10
San Diego	132	50	43	2

In 1996, eleven of the 17 comarcas in the El Pital watershed had estimated erosion hazard above 40 tons per acre per year. By comparison, in 1968 only one of the 17 comarcas had erosion hazard above 40 tons per acre per year.

More cultivation of annual crops

Land use in the El Pital watershed changed dramatically from 1968 to 1996. From 1968 to 1987, the forested, mixed crops, and mixed range/pasture areas in the El Pital watershed were reduced by 51%, 62%, and 67%, respectively, based on analysis of aerial photographs combined with use of GIS tools. Concurrently, from 1968 to 1987, the proportion of the El Pital watershed in annual crops increased by 29% and the proportion in perennial crops increased by 14%. Grass dominated rangeland (usually an ecological successionary state on cut/burned and grazed forest land or fallow cultivated land) increased by 49% from 1968 to 1987.

By 1996, an estimated 40% to 60% of the land area was planted to annual crops in over half the comarcas comprising the El Pital watershed (Figure 5). A comparison of the 1987 and 1996 maps from Figure 4 with Figure 5 suggests that estimated erosion hazard increased most rapidly from 1987 to 1996 in comarcas where there was rapid change from extensive land uses and perennial crops to predominantly annual crops, even on steeplands. As land use shifts to annual crops from forest, rangeland, and perennial crops, erosion hazard increases dramatically; these increases are most dramatic on cropland with steep slopes (Figure 6).

Increasing numbers of smaller farms

Population in the El Pital watershed was estimated by regional government officials to be increasing at least as fast as the 3.4% per year estimated population growth rate for Nicaragua. One factor that contributed to the rapid population increase the El Pital watershed was that it was the destination for several relocation efforts associated with agrarian reform in the 1980s. The combination of population pressure, inheritance customs, and agrarian reform, has meant an increasing number of small, subsistence farms in El Pital watershed, as elsewhere in Nicaragua.

This demographic trend has important implications for the shift from extensively-managed land to greater reliance on annual crops and the associated increase in erosion hazard (Figure 7). When planning land uses for a farm of any size, a family provides for its subsistence needs first and then produces commercial crops

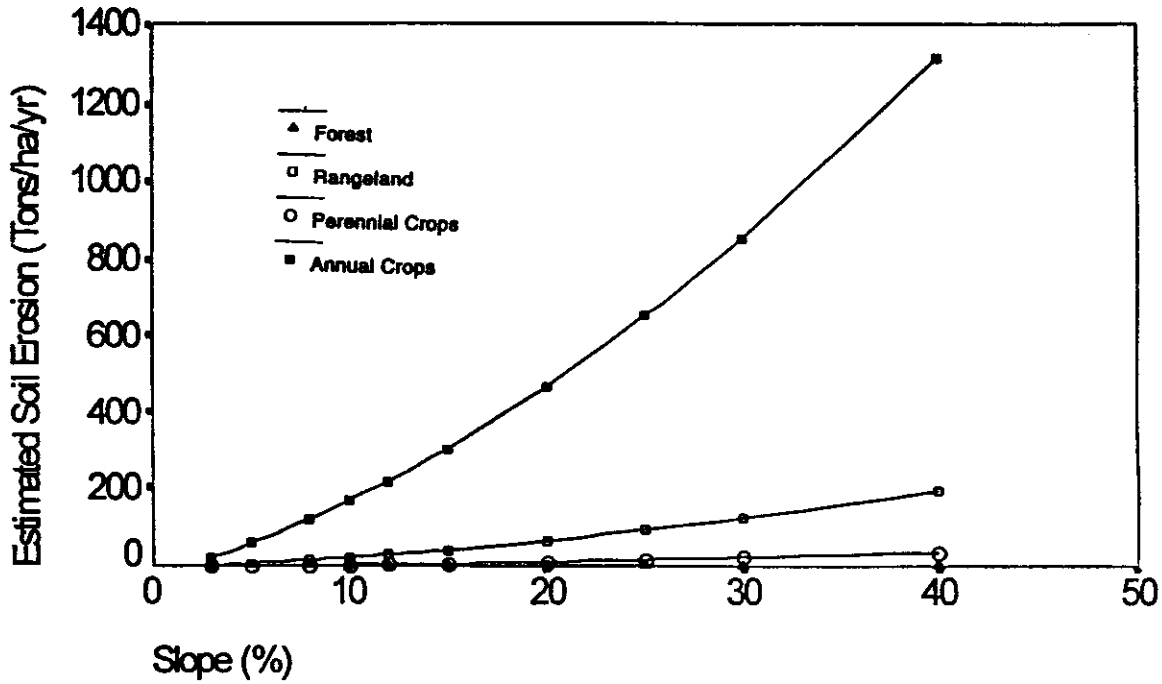

Figure 6. Estimated annual soil loss associated with differences in slopes and cropping systems, El Pital watershed, Nicaragua

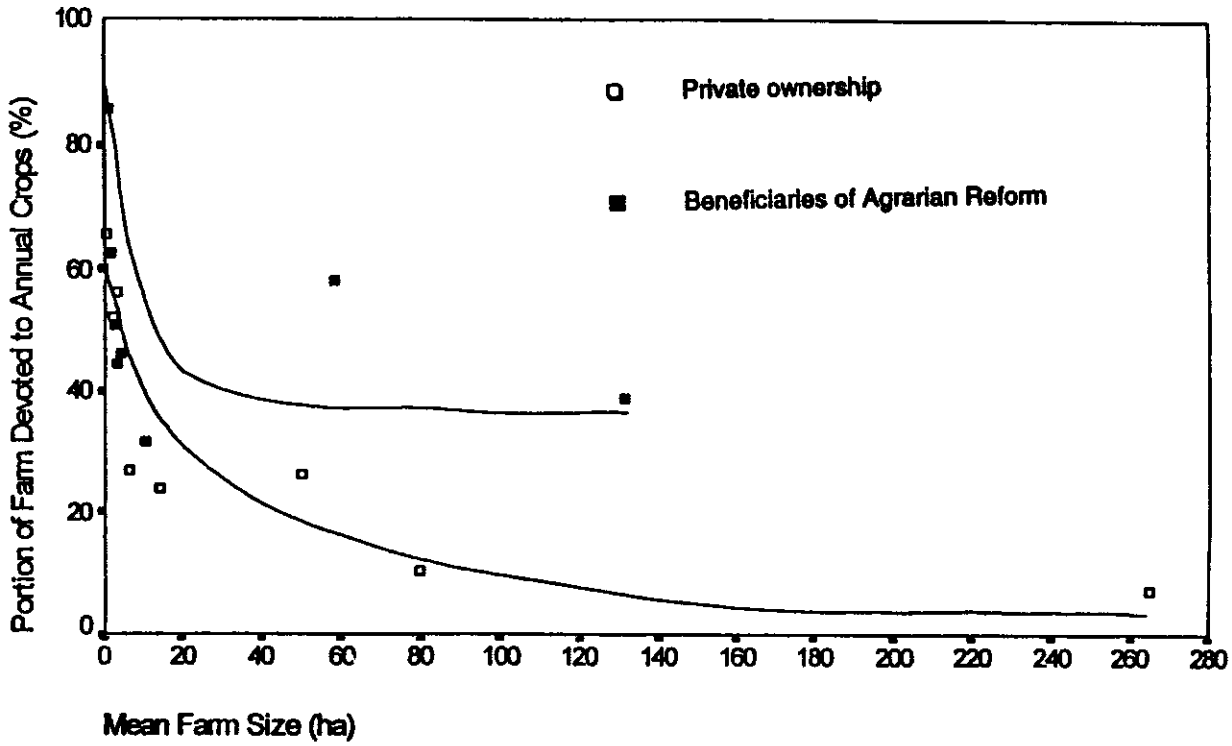

Figure 7. Relationship between mean farm size and the proportion of the farm planted to annual crops, El Pital watershed, Nicaragua

and other output for market. Therefore, the smaller the farm the greater the proportion of land likely to be devoted to annual crops.

Figure 7 shows that those operating small farms plant a significantly larger proportion of their farm to annual crops than do those with large farms. The data points plotted in Figure 7 are from the 135 farmers interviewed in 1996. These data show how, as a group, beneficiaries of agrarian reform are more subsistence-oriented (and thus farm a greater proportion of annual crops) than do private landowners.

Since the late 1980s, the government of Nicaragua has recognized that these demographics of BAR make their farms more prone to erosion, and thus increase their need for technical assistance with soil conservation. Non-governmental organizations have also targeted several conservation projects to BAR. Due to the committee structures associated with farm cooperatives, organizing conservation initiatives for BAR is more streamlined, institutionally and organizationally, than is outreach to private land owners.

Conservation effort has been greater by BAR than by private landowners (Figure 8).

Beneficiaries of agrarian reform

Beneficiaries of agrarian reform (BAR) are more likely than private landowners to have small farms focused on subsistence; accordingly, they are likely to cultivate a larger proportion of their farms to annual crops, even steepland sites, than do private landowners. The focus of conservation programming on BAR is illustrated by the contrast between their level of satisfaction with technical assistance they received, compared with that of private landowners (Figure 9).

Forty percent of private landowners have received no technical assistance with soil conservation at all, whereas 40% of BAR considered the technical assistance which they received to be excellent. The percentage of farmers using each of eight (of nine) conservation practices (all except live fences) was higher for BAR than for private landowners (Figure 10).

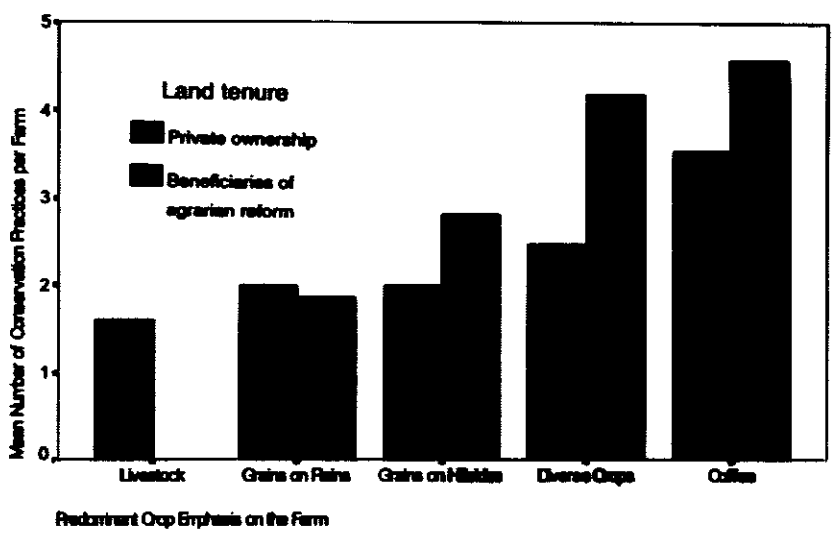

Figure 8. Mean number of conservation practices applied per farm, comparing private landowners with beneficiaries of agrarian reform, El Pital watershed, Nicaragua

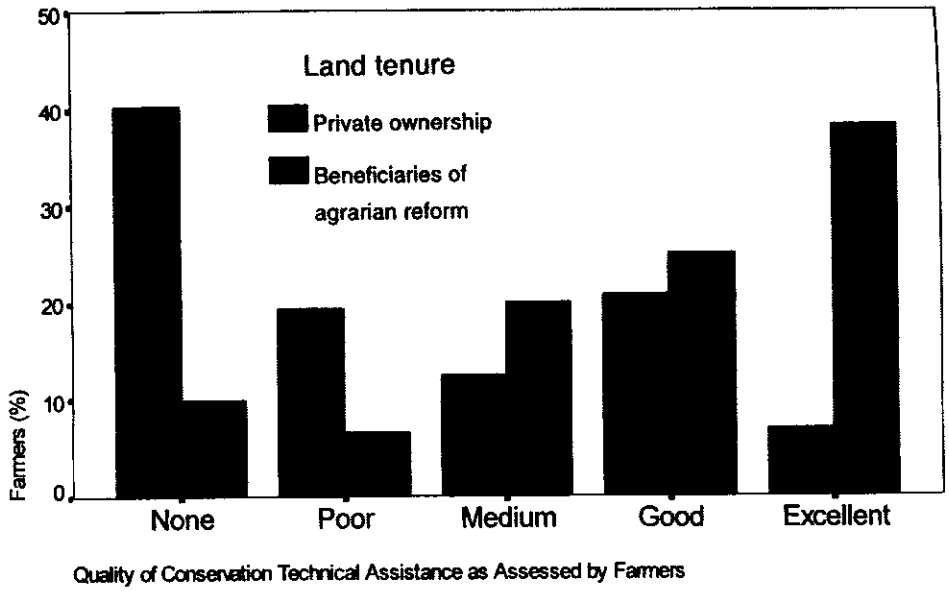

Figure 9. Level of satisfaction with technical assistance with soil and water conservation, comparing private landowners with beneficiaries of agrarian reform, El Pital watershed, Nicaragua

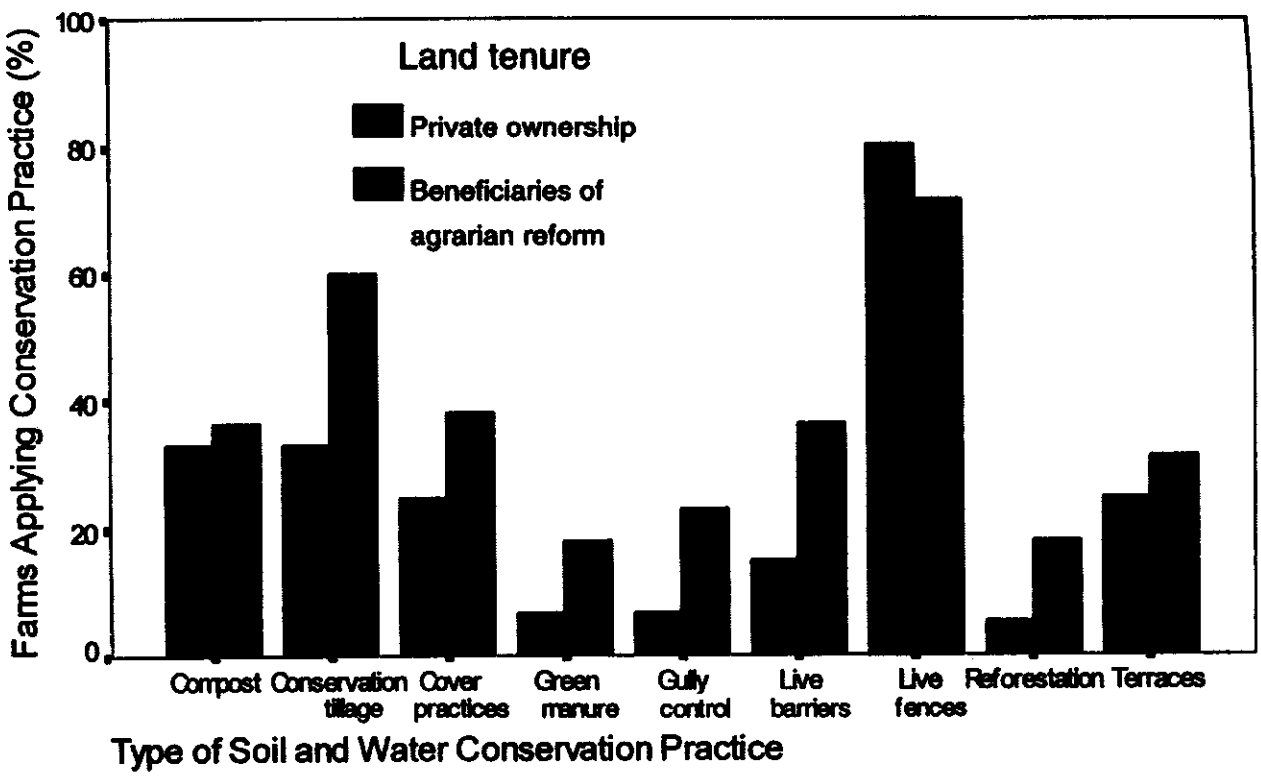

Figure 10. Types of soil and water conservation practices used in El Pital watershed, Nicaragua, comparing private landowners with beneficiaries of agrarian reform

Interviews with farmers in 1996 suggest that both private landowners and BAR have a high level of awareness of the erosion hazard associated with intensive rotations of annual crops. Both BAR and private landowners understand how planting perennial crops can reduce erosion, particularly on steeplands.

When asked about their long-term hopes, many farmers discussed plans to plant more fruit trees. Private landowners and BAR perceived several obstacles to their personal investments in soil conservation and in their shift to a greater emphasis on perennial crops: lack of secure title, lack of access to credit, and fear of land distribution. For BAR in particular, concern that the government would intervene to depress crop prices if production were to increase was considered the most significant barrier to making modifications in cropping patterns and to long-term conservation investment.

POLICY IMPLICATIONS

Significant land use change occurred in the El Pital watershed, Nicaragua, from 1968 to 1996. Agrarian reform, inheritance customs, and population growth have been instrumental in promoting an increase in the number of small farms. Farm families tend to meet their subsistence food needs before producing crops for commercial markets. Accordingly, from 1968 to 1996, the predominant land use in the El Pital watershed became annual crops. More small farms means more subsistence-oriented cropping systems. Increased cultivation of annual crops is the main factor driving increasing erosion hazard, particularly on steeplands.

Soil conservation programs targeted at agrarian reform communities have been successful in reducing erosion hazard. As demonstrated by the results of this study, geographic information systems (GIS), which enable simultaneous analysis of biophysical and land tenure patterns, can aid in land use planning to target where soil conservation efforts are likely to yield the highest return on investment, public and private.

Strategic investment in soil conservation requires dialogue and cooperation between public policy makers, beneficiaries of agrarian reform, and private landowners. These maps describing changes in estimated annual soil losses associated with changing land use patterns provide a starting place for their dialogue and their consideration of investment and policy options.

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