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Front cover Vetiver grass strips planted on contour through one of the field catchments monitored in this study Both the flume and rain gauge is visible

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ASSESSMENT OF SOIL AND WATER CONSERVATION METHODS APPLIED TO THE CULTIVATED STEEPLANDS OF SOUTHERN HONDURAS

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
CHARACTERISTICS OF THE NAMASIGUE WATERSHED	2
Climate	3
Soil	3
Land Use	6
Field Preparation	7
Planting	7
Weeding and Harvesting	7
Soil and Water Conservation	8
RUNOFF, SOIL AND NUTRIENT LOSSES ASSOCIATED WITH SELECTED SOIL AND WATER CONSERVATION TREATMENTS	9
Runoff	10
Soil Loss	12
Nutrient Loss	16
MANAGEMENT IMPLICATIONS SUMMARY	19
LITERATURE CITED	20

ASSESSMENT OF SOIL AND WATER CONSERVATION METHODS APPLIED TO THE CULTIVATED STEEPLANDS OF SOUTHERN HONDURAS

INTRODUCTION

Rapid population growth and shortage of arable land have resulted in expanded cultivation of steeplands (slopes exceeding 20%) in many areas of the world Tropical steeplands occupy almost 1 billion ha and constitute a significant portion of many regions For example, steeplands occupy more than 25% of the total land area in Latin America and the Caribbean More than 80% of the total land area is occupied by steeplands in Honduras Similar statistics are available for some regions of southeast Asia and Africa (Arsyad et al 1992) Especially where human population pressures are severe, steeplands are now being rapidly converted from forests to agricultural use (Pimental et al 1995) Once under conventional cultivation, steeplands are susceptible to high erosion rates (e g , 221 tons/ha/yr in Nigeria, 400 tons/ha/yr in Jamaica) which result in progressive declines in crop productivity (Lal and Stewart 1990)

Research on tropical steeplands has been neglected by the agricultural community, in part because cultivation was deemed an undesirable use of lands so susceptible to degradation Ideally, the use of tropical steeplands would be limited to activities that protect native forests and thereby stabilize upland watersheds However, the reality for the foreseeable future in many developing countries is that the rapid expansion of agricultural activities on tropical steeplands is likely to continue due to subsistence necessities and socio-political pressures (FAO 1982, 1990, Aldhous 1993) Current activities and projected trends for steepland cultivation are of particular concern because of the rapid and self-perpetuating deterioration associated with abused steeplands (Hudson 1981) Moreover, steeplands play a pivotal role in environmental and economic systems in tropical countries, thus degradation of steeplands can cause adverse ramifications which are distant in time and space from the eroding steep slopes (Thurow and Juo 1995) Historically-rooted cultural and political obstacles have hampered research on tropical steeplands The peasants normally do not have the socioeconomic clout required to catalyze research and policy initiatives supporting an action agenda focusing on the soil conservation of cultivated steeplands

In densely populated tropical regions, the people cultivating steeplands often have no other alterative resource for producing food (Tracy 1988) Many poor peasants depend on steeplands for their subsistence needs and many countries rely heavily on steepland to meet the food security needs of their urban populations For example, USAID (1980) documented that steepland farms produce 75% of the basic grains in Honduras

Cultivation of steeplands presents some severe sustainability challenges to the residents of the entire watershed The steep slopes, combined with intense rains during the growing seasons, make cleared fields very susceptible to erosion To make up for gradually diminishing production associated with soil loss, peasants clear more forest or shorten the fallow cycle to expand the area under cultivation Though these decisions are rational and even necessary in accord with their short-run subsistence goals, there are adverse long-run consequences such as flooding, siltation of hydroelectric facilities and degradation of coastal aquatic ecosystems Thus, although the sustainable use of steeplands depends on sound soil management, the factors which affect national planners and peasant farmers' decisions regarding use of steepland involve a variety of environmental, economic, social and cultural considerations

The current downward spiral of steepland soil and landscape degradation is self-

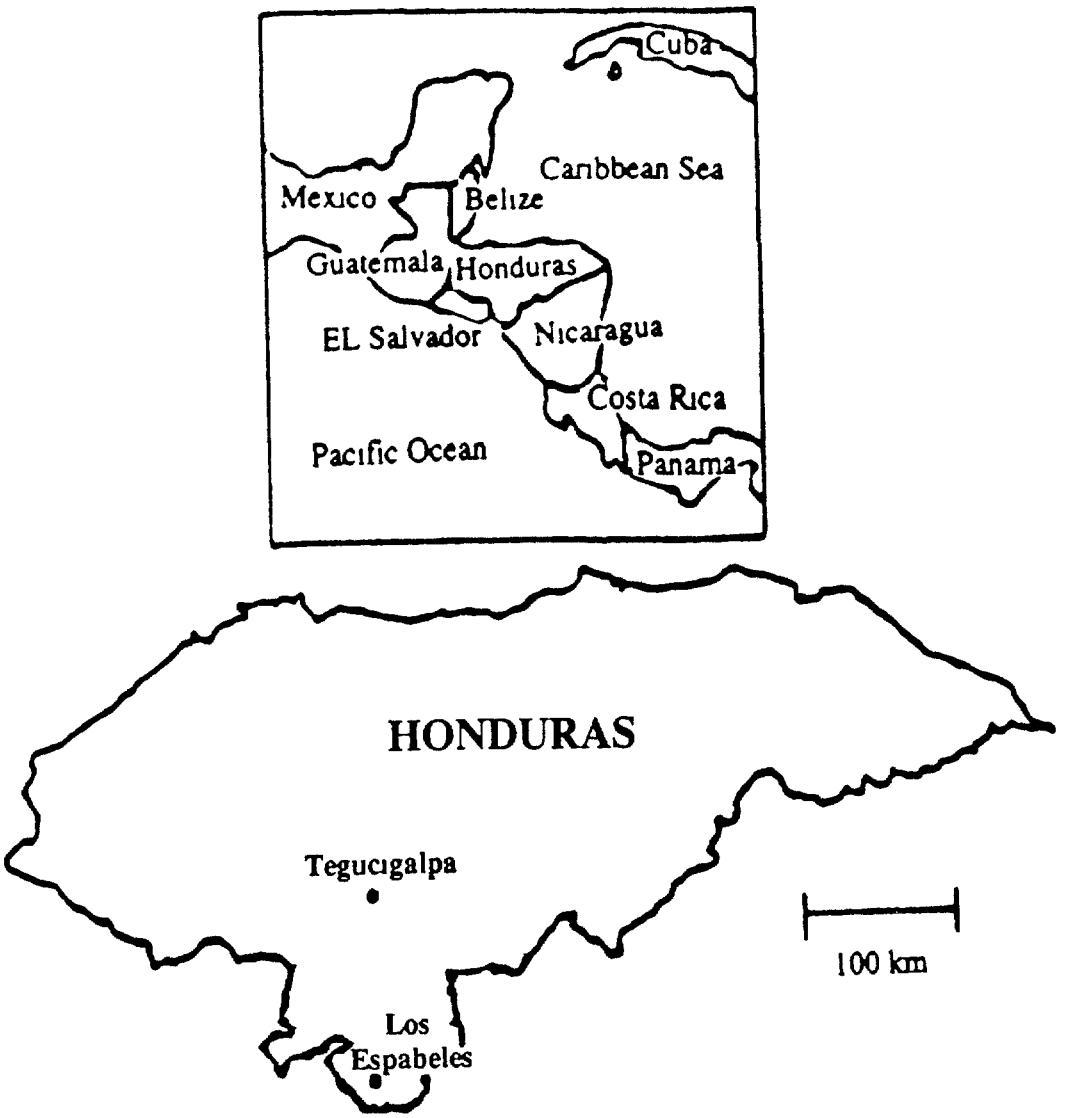

Figure 1 Location of the Los Espabeles, Honduras study area

perpetuating, thus external impetus for change -- both technological and institutional -- is urgently needed Creative approaches are required to develop, refine and facilitate the adoption of practical soil conservation technologies and systems-orient problem solving strategies that will reduce the substantial negative consequences from conventional agriculture practices used on tropical steepland The Honduran Ministry of Natural Resources/USAID Land Use Productivity Enhancement project (LUPE) is working toward addressing these challenges in southern Honduras This publication assesses the effectiveness of some of the soil and water conservation technologies being extended by that program

CHARACTERISTICS OF THE NAMASIGUE WATERSHED

The study area lies within the Namasigüe watershed near the small community of Los Espabeles (13°14'N, 87°05'W), approximately 15 km southeast of Choluteca, Honduras (Figure 1) The 1983 census of this 17,320 ha watershed reported a population density of 0 8 people/ha^2 (NRMP 1984) Fifty percent of the watershed has a gently rolling to flat topography which is located along the Gulf of Fonseca coast at less than 100 m above sea level These lands are primarily held by a few large landowners and

are used as cattle ranches or are cultivated for cash crops such as sugar cane or cantaloupe The area along the estuary is developed for commercial shrimp production The 50% of the watershed that is located between 100 m and the peak of the watershed at approximately 800 m has steep topography About 60% of the upland area has a slope of greater than 30%, 34% of the area has a slope greater than 50% (NRMP 1984) These steeplands tend to be occupied by farms of less than 5 ha in size Typical field size is 0 1 to 0 3 ha The production emphasis of these farms is basic grain crops (maize, sorghum, beans), primarily grown to meet the subsistence needs of the farmers

Climate

The average monthly temperature near Choluteca ranges from about 28°C in September to 30°C in April (NRMP 1984) The average annual potential evapotranspiration near this area is 2453 mm, with average monthly values from 147 mm in October to 273 mm in March (Mayorga 1989)

Rainfall is distributed in a bimodal pattern The first half of the rainy season, the *primera*, begins in late April or early May and ends in early July The second half of the rainy season, the *postrera*, begins in late July or early August and ends in early November The rainy season is interrupted by a short dry period during July, the *canicula* Essentially no rain falls from November through April

Rainfall amount, duration and intensity were determined for each storm event over a five-year period (1993-1997) A dual-traverse rain gauge equipped with a battery operated strip-chart drive using 24-hour rainfall charts (Brakensiek et al 1979) was used to make the measurements Annual rainfall for the 5-year study period clearly illustrates the bimodal rainfall pattern and the variability in monthly and annual precipitation (Figure 2) Most of the rain events occurred as brief, intense showers in the mid-afternoon from clouds that were formed as a result of upwelling of warm humid air The other type of storm occurred when a low pressure system associated with a tropical storm/hurricane passed over the area This type of tropical storm produced a steady rain that often lasted for several days

A precipitation measurement that is an important determinant of erosion hazard is the amount of rain that occurs as erosive rainfall events Wischmeier and Smith (1978) defined an erosive rain event as a storm that results in more than 12 5 mm or a rainfall intensity during a storm that exceeds 6 4 mm during a fifteen minute period Using this rationale, approximately 95% of the rainfall during the study period was considered erosive rain This is in great contrast to temperate regions where most of the rain is classified in the non-erosive category The annual erosivity indices (rainfall energy) for the study was 14,553, 8,986, 18,128, 18,523, 6,838 MJ/mm/ha/hour for the period from 1993 to 1997, respectively Approximately 50% of all the rainfall that occurred over the 5 year study had 30-minute intensities greater than 10 mm/hr, 31% had 60-minute intensities greater than 10 mm/hr Approximately 17% of all the rainfall had 30 minute intensities greater than 25 mm/hr, 9% had 60 minute intensities greater than 25 mm/hr

Soil

The soils at the Los Espabeles study site were derived from sedimentary parent material overlying intrusive volcanic rocks such as dioritic granite (Mayorga 1989) Due in part to the rugged topography of the Namasigüe watershed, there was a large amount of variability in soil pedogenesis

Soil pits were excavated adjacent to the middle of each of the three field catchments monitored by this study The pits were 2 m wide and 2 m deep Five sub-samples from the middle of each horizon were collected and combined into a composite sample for analysis Since most of the soil loss from the fields consisted of topsoil, each field catchment was divided into 9 areas of roughly equal size, and

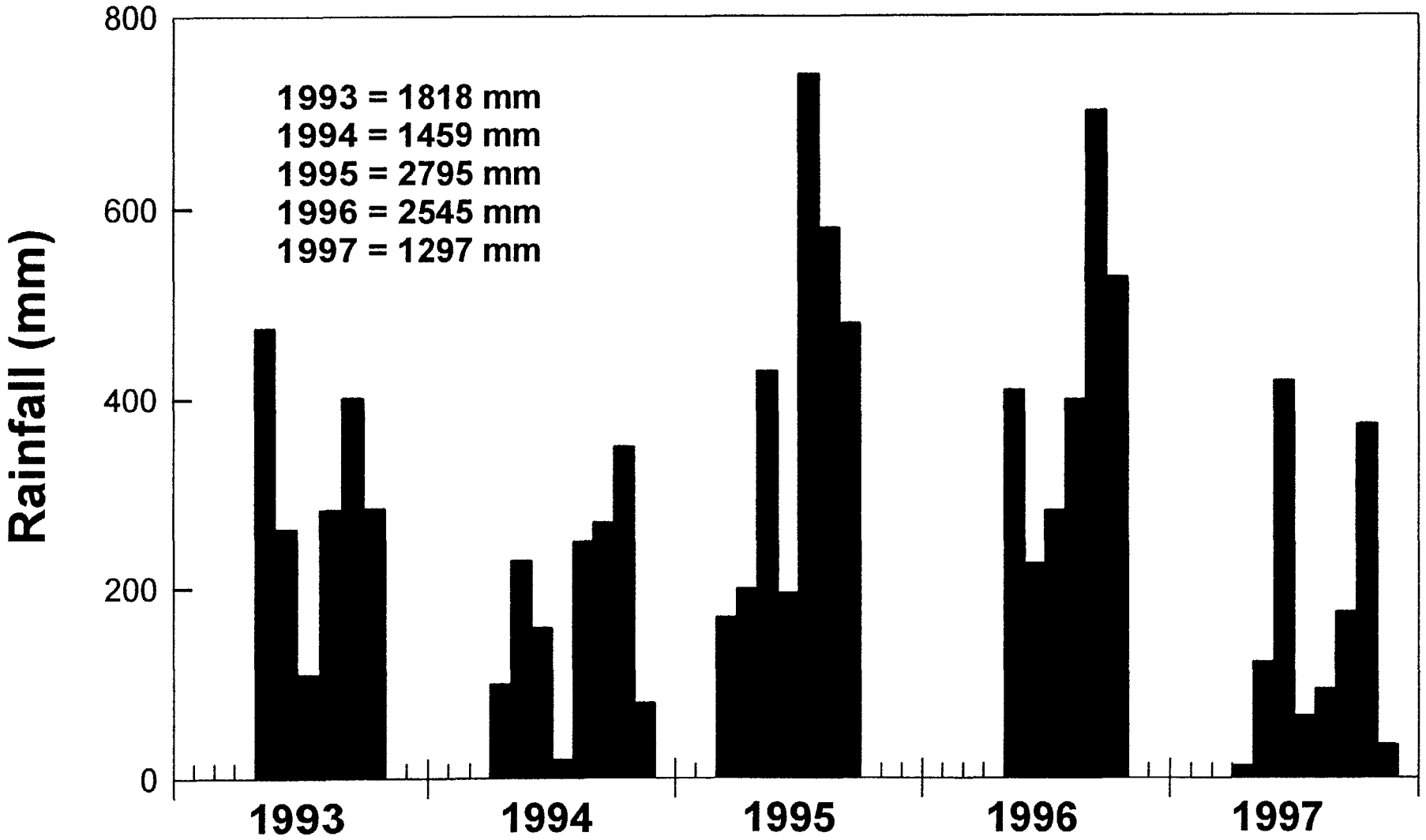

Figure 2 Monthly rainfall from 1993 through 1997, Los Espabeles, Honduras.

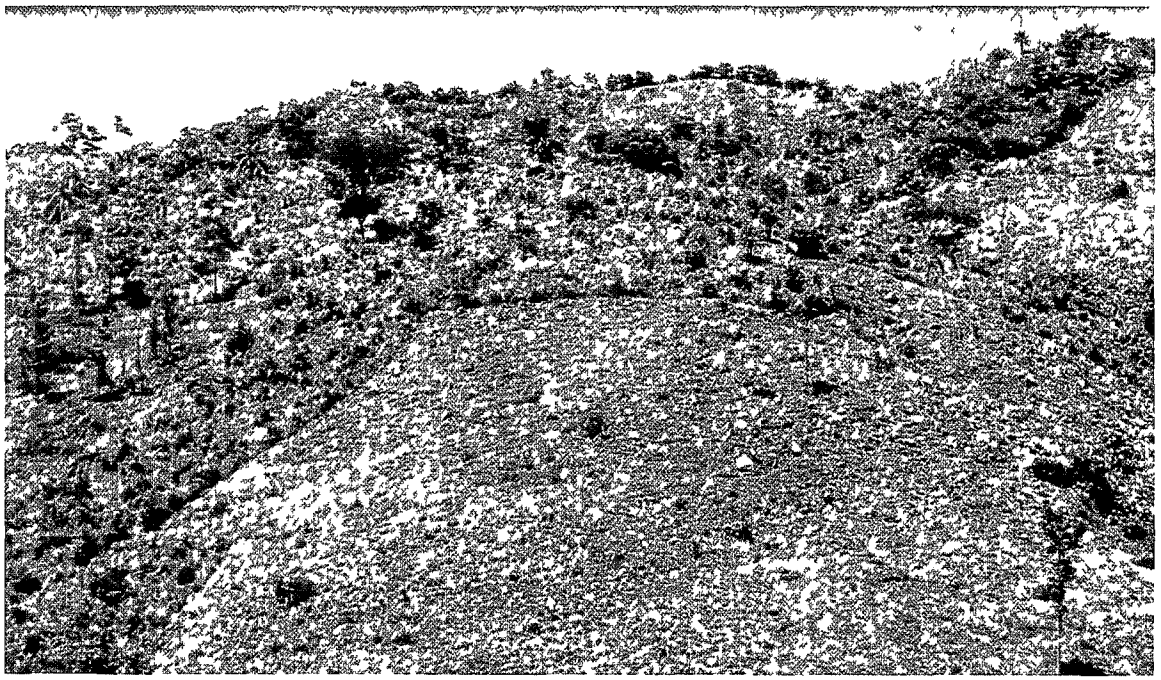

Plate 1 Typical mosaic of active fields and fallow on the steeplands of southern Honduras Note the rocks emerging from the eroded subsoil Statements indicating that rocks "grow out of the hillside" and that "soil erosion is not a primary concern associated with maintaining crop production" are indicative of the fact that many of the farmers do not fully perceive the extent of degradation caused by the gradual erosion of the topsoil

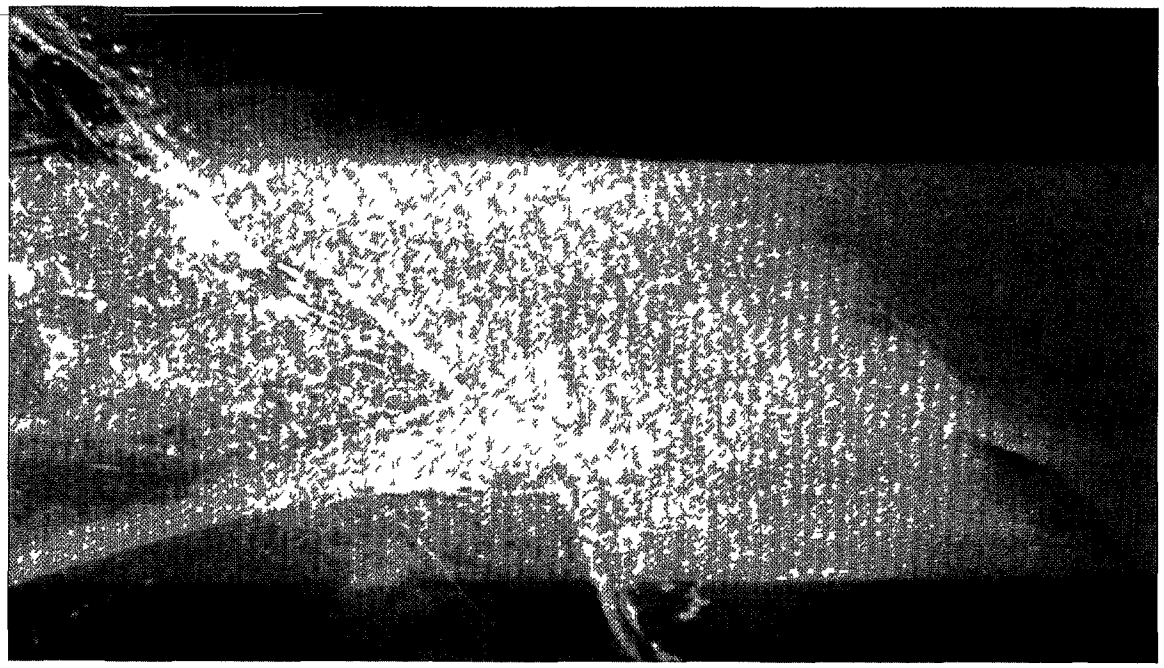

Plate 2 Erosion on the steeplands not only degrades the upland fields, it also poses substantial sedimentation costs downstream In southern Honduras, the sediment generated from steepland farming practices imposes substantial costs to downstream interests such as shrimp production, irrigated agriculture, domestic water quality, port facilities and hydroelectric sites

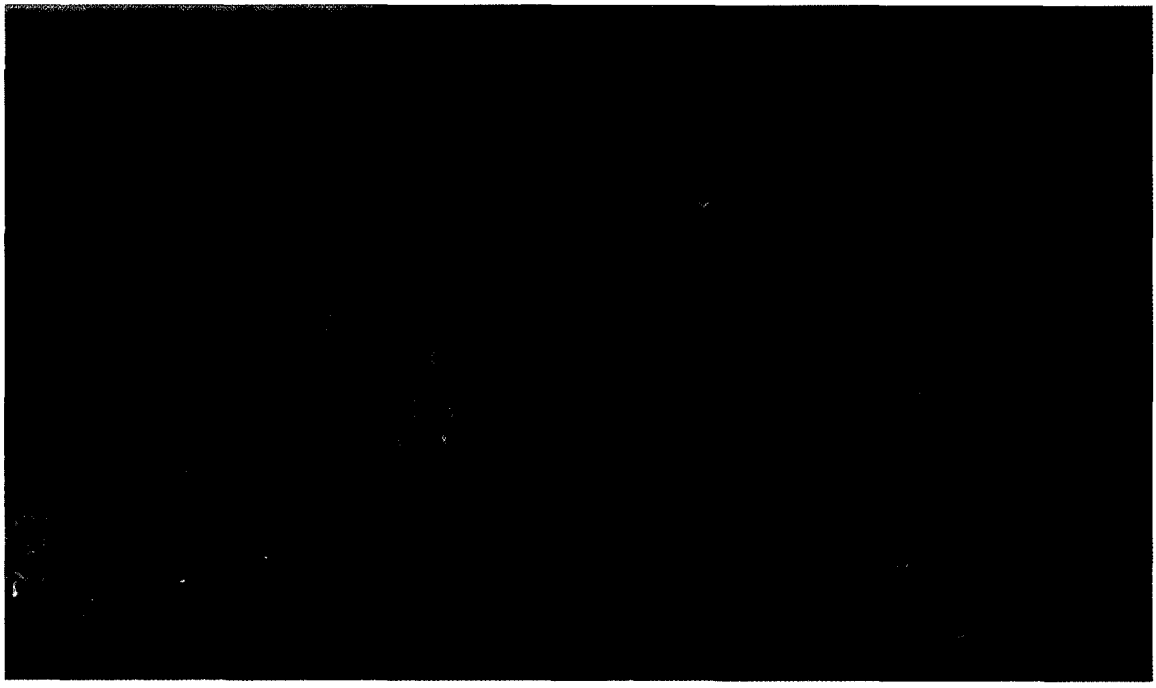

Plate 3 Two of the three field-scale catchments monitored throughout the study Note the vetiver grass contour strips established in one of the catchments Also note near the center of the picture the 2 m x 22 m runoff plots -- a size that is more typical of erosion research done in the tropics The results of this study illustrate that field-scale catchments are necessary to reflect the processes that are important determinants of erosion in a tropical steepland environment

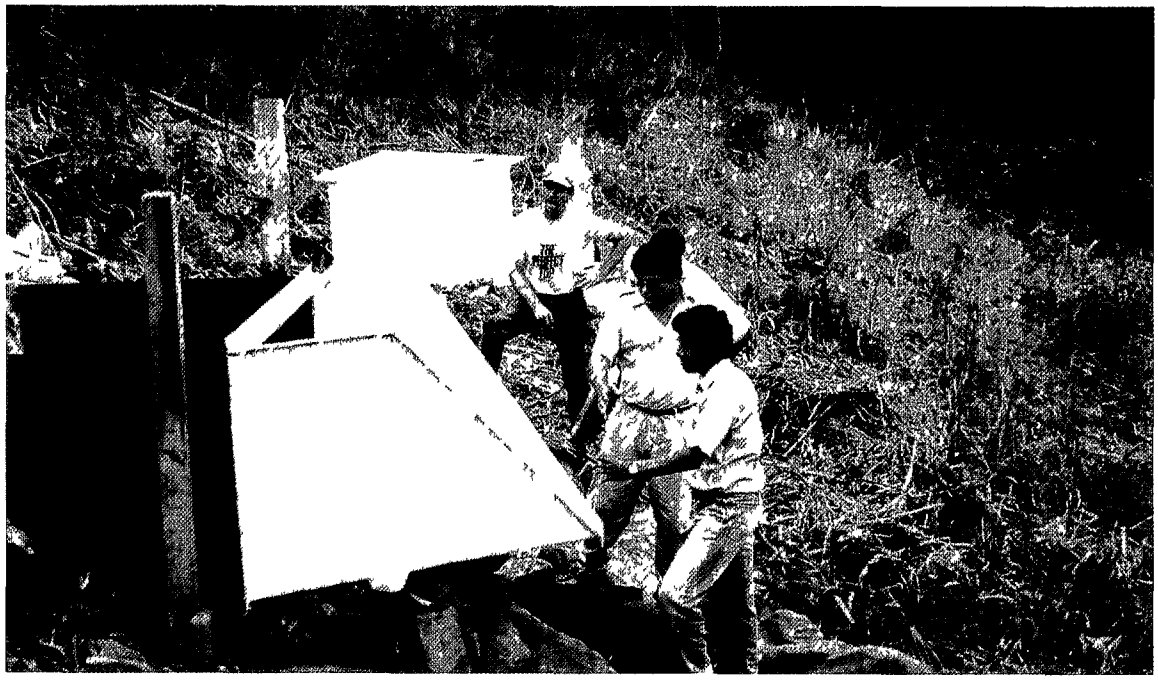

Plate 4 Flume through which runoff from the catchment passed Instrumentation at the flume recorded the volume and collected water samples for runoff and nutrient analysis

composite samples were collected from the 9 areas within each field catchment to better characterize the surface horizon Each composite sample consisted of 5 sub-samples from the middle of the surface horizon

The soils on the cultivated steepland fields were classified as fine-loam, mixed isohyperthermic Typic Ustropepts (Inceptisol) with high degrees of base saturation (>80%) The pipette method (Kilmer and Alexander 1949) was used to determine that average USDA soil texture classes of the three soil profiles consisted of loam over clay to silty loam A change in color from the A to Bw horizons of the soils at the study site was apparent, but all other changes between horizons were gradual The soils had an ochric epipedon over a cambic endopedon There was some evidence of clay illuviation in the Bw horizons, but not enough illuvial clay to form an argillic sub-surface horizon Due to the steepness of the field catchments, the soils did not exhibit advanced pedogenesis However, flatter areas near the region such as road cuts illustrated strong argillic sub-surface horizons along with some albic sub-surface horizons Those soils were classified as Typic Haplustalfs

The catchment soils had an ustic moisture regime and an ishyperthermic temperature regime Ustic soils have a moisture control section that is dry in some or all parts for 90 or more cumulative days in the year in six or more out of ten years Isohyperthermic soils have a mean annual soil temperature that is 22°C or higher with men summer mean winter temperatures that differ by less than 5°C at a depth of 50 cm (Soil Survey Staff 1993)

Topsoil depths ranged from 7 cm at the top of the field catchments to 31 cm near the base of the catchments with means for each field catchment ranging from 14 to 17 cm Mean topsoil bulk densities were determined using the core method (Black 1965) and ranged from 1 13 to 1 15 g/cm^3 Analysis of soil profile core samples indicated that bulk densities for both the Bw and C sub-surface horizons for all three catchments averaged 1 32 g/cm^3 The surface horizons had moderate very fine granular structure, and the Bw horizons had weak fine granular structure The good structure and low bulk densities contributed to rapid infiltration and permeability of the soils, with saturated conductivity rates as high as 263 mm/hour (Thompson 1992) These inherent soil characteristics mean an exceptionally intense and protracted rainy period is required to cause overland flow and rill erosion Thus, these very steep fields have been able to be cultivated for decades and still have some topsoil left

Chemical analysis of the topsoil indicated that the mean organic carbon for the three field catchments ranged from 1 97 to 2 34% (determined by dry combustion in a medium-temperature resistance furnace -- Nelson and Sommers 1982) These levels of organic carbon are relatively high for tropical soils and are comparable to temperate soils Soil organic carbon markedly decreased with profile depth

All soil samples were slightly acidic with mean water pH values ranging from 6 3 to 6 6 (determined, in duplicate, using both 1 1 soil-to-water and 1 1 soil-to-1N KCl mixtures (Soil Survey Staff 1993)) Throughout each profile, the soils had high cation exchange capacities (determined using 1N NaOAc (pH 8 2) following a modified procedure of USDA Handbook 60 (U S Salinity Laboratory Staff 1969)) and high base saturations (determined in 1N ammonium acetate leachate (pH 7 0) following procedure 5B5 of the National Soil Survey Laboratory (SCS 1984)) Mean CEC values for the topsoil of each catchment varied from 23 8 to 30 2 cmol$_c$/kg while mean base saturations range from 79-81% Exchangeable sodium was less than 1% for the topsoil and profile samples Mean extractable iron values for the topsoil of each catchment varied from 1 6 to 2 0%, as determined by the ammonium oxalte method (Soil Survey Staff 1993) In general, the soils were low in plant available phosphorus with mean topsoil values for the catchments ranging from 1 09 to 1 74 mg/kg (determined by the Bray No 1 Method -- Bray and Kurtz 1945) Since soils with Bray-I phosphorus levels less than 16 mg/kg are generally considered phosphorus deficient this could have been a major factor limiting crop growth and yields More detail on soil nutrient concentrations from an adjacent study site is provided by Toness et al (1998)

Land Use

According to long-time residents, the steeplands of this watershed were covered by a broad-leafed forest prior to the 1940's The primary woody species were Aguacatillo (*Nectandra sinuata*), Caoba (*Swietenia humilis*) Carreto (*Samanea saman*) Cedro Espino (*Bombacopsis quinata*) Cedro Real (*Cedrela odorata*), Ceiba (*Ceiba pentandra*) Guapinol (*Hymenaea courbaril*), Guanacaste Negro (*Enterolobium ciclocarpum*) Jobo (*Spondia luthea*) Laurel (*Cordia alliodora*) and Madriado (*Gliricidia sepium*) The valuable timber species were harvested in some instances, but most of the area was cleared by slash-and-burn methods associated with subsistence agriculture These activities were in some cases encouraged by large landowners who saw this as a way to open up the forests so that their cattle could graze the fields when they were fallowed

About 50% of the uplands are currently under cultivation, with most of the rest of the area characterized as a mosaic of fallow fields of varying ages that is vegetated with secondary succession grasses, shrubs and trees Patches of the original forest remain in the upper portions of the watershed, but this area is shrinking each year due to encroachment by farmers who are either landless or do not have access enough productive land to feed their family

Forest clearing, heavy grazing and traditional "slash and burn" practices on the steeplands have resulted in severe land degradation in the region Increased land use pressure has resulted in a shortened fallow cycle and has increased the percentage of land under cultivation Data on land use for the region show that the amount of land considered "eroded" increased from 397,800 ha in 1972 to 760,000 in 1983, an increase of 91% (USAID 1989) A general consensus among natural resource managers in the region is that this trend has continued to the present

Some rights to occupy the steeplands were obtained by many of the current residents when the National Agriculture Institute, under the 1974 Agrarian Reform Program, divided the large hacienda that encompassed the region Title to land is not yet obtained by most residents, but the protracted process of obtaining full ownership rights is underway and most residents expect that they will eventually obtain title to the land they are using

In response to a bimodal rainfall pattern punctuated by a dry period of erratic duration, farmers have developed a cropping system of maize (*Zea mays* L) intercropped with drought tolerant sorghum (*Sorghum bicolor* (L) Moench) (Arias and Gallaher 1987) Small patches of beans (*Phaseolus* spp) and cowpeas (*Vigna* spp) are also occasionally grown Cattle are allowed to graze on the fields during the dry season and during the early stages of fallow succession Basic grains provide 64% of the protein and 75% of the energy for households in southern Honduras It has been estimated that two-thirds of the children in southern Honduras receive inadequate nutrition at some point during their first five years (DeWalt and DeWalt 1987) The concern for maintaining adequate production levels is reflected in farmers' objectives toward production A survey of farmers conducted by Lopez-Pereira (1990) showed that 55% of rural farmers regarded maintaining a minimum level of grain production required for family consumption as their first order of importance Only 12% regarded maximizing income as top priority

In addition to the basic grains which are the focus of most of farmers production efforts, most families also maintain a small flock of chickens and several pigs A few own some cattle Home gardens are maintained near the house and contain a variety of fruit crops such as mango (*Mangifera indica*), mamon (*Melicoccus bijugatus*), papaya (*Carica papaya*), guava (*Psidium guajava*), orange (*Citrus sinensis*), lime (*Citrus aurantifolia*), jocote (*Spondia mombin*), avacado (*Persea americana*), achiote (*Bixa orellana*), sugar apple (*Annona squamosa*), tamarind (*Tamarindus indica*), cashew (*Anacardium occidentale*) carambola (*Averrhoa carambola*) and banana (*Musa sapiemtum*) The home garden provides a small but relatively stable portion of the farmer's income and provides a diversity of vitamins to the household diet that would not be available from the sorghum and maize

Field Preparation

The traditional production system of hillside farmers in southern Honduras is shifting cultivation The practice consists of cutting and piling trees and shrubs in the dry season (March and April) and burning all of the woody material before the onset of the rainy season (May) Steepland fields were usually cultivated for 3 to 4 years until productivity begins to decrease, a point at which the farmers say "the land is tired and needs to rest" In order to restore soil productivity, the fields are fallowed for several years, during which time native trees and shrubs are allowed to naturally recolonize the area Increasing land pressure due to population increases have caused the fallow periods on many farms to have been reduced or totally eliminated (Dewalt and DeWalt 1982, Stonich 1989) In places where available land is scarce, fertilizer of varying amounts (usually not anywhere close to the amount recommended for optimal production) is added to the degree that cash is available

Many of the local farmers near Los Espabeles had not burned the crop residue since the late 1980's when extension programs such as the Land Use and Productivity Enhancement (LUPE) project was able to educate and convince farmers about the benefits of leaving the crop residues on the fields as a mulch to reduce erosion, add organic matter and nutrients to the soil, conserve moisture, and regulate soil temperature Preparing the land for planting using the slash and mulch method requires 12 man-days per hectare versus 6 man-days per hectare for the traditional slash and burn method Despite this difference in labor investment, most farmers of the region have voluntarily decided to no longer burn their fields

Planting

Small-scale farms in southern Honduras are often characterized by low crop productivity and limited land resources Intercropping provides these farmers with a possible means of increasing total productivity per unit land area and reducing the risk of being dependent on a monocrop The dominant cropping system in the area is composed of early maturing local maize cultivars (46 days to tasseling and 80 days to harvest) intercropped with land race sorghums called "*maicillos criollos*" These tropical sorghums are three to four meters tall, drought tolerant, and sensitive to photoperiod Planting time begins with the onset of the rainy season, which starts about the second weed of May

Different maize and sorghum arrangements are used by the farmer depending on the date of planting or the position of maize and sorghum seed (Sierra 1996) The most common cropping systems used by the farmer are married, alternate row, and alternate hills The married system refers to the practice of planting both maize and sorghum in the same hole simultaneously In the alternate row system, alternate rows of maize or sorghum are planted either simultaneously or else the sorghum is planted two weeks after maize emergence In the alternate hill system, maize is planted in alternate hills with sorghum either simultaneously or two weeks after sorghum emergence Peasants use a planting stick (*barreta*) to make the holes to deposit seed, with each hole about 0 9 m away from the others The number of maize seeds used is three to four per hole and about 7-10 sorghum seeds per hole Planting one hectare requires 6 man-days

Insect damage is a serious constraint for sorghum and maize production A complex of lepidopterous defoliators including *Spodoptera frugiperda* (fall armyworm), *Sprodoptera eridania* (southern armyworm), *Metaponpneumata roghenhoferi*, and *Mocis latipes* may cause severe damage during the first stages of sorghum and maize growth (Pitre 1988) Most farmers will treat the seed with an insecticide to protect against nematode damage, but few invest in application of foliar insecticides due to a shortage of cash and the low market price for grain

Weeding and Harvest

Weeding is manually done with the aid of a curved machete to cut or uproot the undesirable plants close to the ground Weeds are removed from the fields two times during

the rainy season at about 30 and 105 days after planting The first weeding needs to be done carefully since the sorghum is still small (5-8 cm) and maize plants are about 20 cm tall After the second week of August, maize has reached physiological maturity and the stalks are bent to prevent seed damage from rain and birds Once the cobs are dry they are hand picked and stored in a dry place Maize is sometimes planted as a pure stand in August at the onset of the postrera and harvested in early December Maize harvested in August usually has a high moisture content and is difficult to store This grain must be consumed within a few months or sold locally Many of farmers in Namasigue plant maize in both the primera and postrera seasons to secure enough grain supply The second weeding takes place soon after the maize is harvested in August to help release the sorghum crop from competition Approximately 15 to 20 man-days are required to weed a hectare of steepland Sorghum is allowed to grow until late December and is typically harvested in early January

Since most of the grain is consumed on the farm, steepland farmers do not realize much of a monetary profit from their harvest The average hillside farmer produces less that the minimum necessary to support himself and his family A portion of the grain produced on the farm may be sold to generate cash flow to purchase other necessities Family members work off the farm for part of the year to earn enough to at least allow the family to survive

Soil and Water Conservation Activities

In 1980 the U S Agency for International Development (USAID) and the Honduran Ministry of Natural Resources began the Natural Resource Management Project (NRMP) for the purpose of combating degradation that was occurring on cultivated steeplands A primary focus of the NRMP was to work with farmers to establish rock wall terraces on steeplands Rock walls are valued by farmers because the terraced land is perceived as being more productive than adjacent unterraced parcels (Thompson 1992, Sierra 1996) Rapid depletion of soil moisture and low fertility were the reasons farmers cited as the main constraints to crop growth on the unterraced sites (Toness et al 1998) A testament to the perceived value of rock walls is that farmers voluntarily maintain them without further subsidies However, the cost associated with the initial construction of rock walls is beyond the means of most small farmers, consequently very few farmers built rock walls without subsidization

The apparent need to subsidize the initial construction of rock walls is an obvious problem when funds are not available Therefore, when the NRMP ended in 1990, the follow-up project (Land Use and Productivity Enhancement Project (LUPE)) shifted emphasis to establishing cheaper soil and water conservation practices such as convincing farmers not to burn their fields prior to planting season, establishing live barriers such as vetiver grass contour strips and encouraging adoption of improved fallow systems such as planting nitrogen-fixing trees as part of the fallow

The Soil Management CRSP at Texas A&M University has been working from 1992 to present (1998) with LUPE to address soil and water conservation problems which originate in the upland portions of the watershed The amount of water, soil and nutrient loss associated with traditional slash and burn systems, and the degree to which each of these factors is by practical soil and water conservation technologies is being evaluated The insight gained through this research feeds back into improved technology that is than disseminated by the LUPE extension effort

RUNOFF, SOIL AND NUTRIENT LOSSES ASSOCIATED WITH SELECTED SOIL AND WATER CONSERVATION TREATMENTS

Three adjacent fields were selected to determine the effectiveness of various soil and water conservation treatments The criteria for selection was that they have as similar of area, slope, soils, and management history as was practical to find All three field catchments were located on the same hill complex and drained into the same stream Each of the catchments were bounded on the top of the field by a ridge and all had well defined drainages Total area for each catchment was surveyed to range between 0 12 and 0 27 ha The length of each field catchment ranged from 60 to 70 m The slope from the base to the top of each catchment, with the slope ranging from 55 to 63%

A 0 3 m H-flume was installed at the base of each catchment to measure runoff volume and rate Each flume was fastened to a pre-fabricated 1 2 m long metal approach section with a 0 3 m drop spillway to reduce runoff energy and disperse flow through the flume evenly Each H-flumes was equipped with a portable liquid level recorder (5-FW-1 Series) which had a battery operated strip-chart drive using 24-hour runoff charts (Brakensiek et al 1979) Runoff events from the strip-charts were digitized and summed in mm by month and year

Attached to each H-flume were two 19-litter chemically inert sample tanks that collected a composite water sample made up of water contributed throughout a runoff event A 1-liter subsample from this composite of the storm runoff was analyzed for sediment content by filtering it through a pre-weighed #1 Whatman filter After the soil and filters were oven-dried, the sediment content per liter was determined and expressed as soil loss in tons/ha

In addition, a sub-sample from the composite of each storm's runoff was kept frozen in Honduras and were brought back to Texas A&M University for analysis The unfiltered water samples were analyzed for total Kjeldahl nitrogen and total phosphorus using a Technicon Auto Analyzer II Total Kjeldahl nitrogen, which includes organic and ammonium nitrogen, was measured using the ammonia/salicylate complex method after digestion with a salt/acid catalyst mixture (APHA 1976) Total phosphorus was digested using the persulfate digestion method, and concentrations were determined by the ascorbic acid reduction method (APHA 1976)

Treatment effects for the soil and water conservation practices were evaluated using a paired catchment study design (Clausen et al 1993) The basic approach requires two periods of study (a calibration period and a treatment period) and requires that a control catchment be maintained throughout the study period for comparison with the treatment catchments This design makes it possible to minimize the effects of year-to-year or seasonal climate variations

During the calibration period, land use on all three catchments the same -- all were managed to maintain a mulch cover (i e , no burning), all were managed using hand labor (i e , cleared with a machete, planted using a planting stick and weeded using a machete), the seeds were treated with insecticide prior to planting but no herbicides, pesticides or fertilizer was added to the fields, maize and sorghum were intercropped using the traditional method of planting corn and sorghum in alternate rows spaced at 0 45 m intervals (see p 7 for a more description of site preparation and planting practices) During the calibration period, the observation values do not have to be the same for the catchments as long as a relationship between paired observations can be established (Clausen et al 1993) Since the paired observations are typically different, the paired catchment approach works well because the technique does not assume that the catchments are exactly the same

Sixty-three runoff events occurred during the calibration year of the study (1993) The relationship of runoff, soil and nutrient loss from these events formed the basis for understanding the natural differences expected to occur between the three catchments Catchment #1 was the catchment with intermediate values for

runoff, erosion and nutrient loss, therefore it chosen as the control for future years Serving as a control, Catchment #1 was managed the same as during the calibration year throughout the entire study period for the purpose of providing a reference point against which other catchments with newly imposed different management practices could be compared Catchment #2 naturally had substantially more runoff, erosion and nutrient loss than Catchment #1, while Catchment #3 naturally had less runoff, erosion and nutrient loss than Catchment #1

In 1994, different soil and water management practices were implemented on Catchments #2 and #3, but all aspects of crop management remained the same as during the calibration year The difference in the expected relationship (established during the calibration year) between Catchments #1 and #2 and between Catchments #1 and #3 and the new relationship (caused by the change in soil and water management practice) is considered to be the response attributable to the management change

In 1994, Catchment #2 was planted with strips of vetiver grass (*Vetiveria zizanioides*) in addition to maintaining the mulch cover Vetiver grass is a preferred contour strip species because

- it has rigid leaves to slow overland flow and trap sediment,
- it has strong roots which grow deep into the soil but have limited horizontal root growth, which reduces competition with crops,
- it is relatively easy and inexpensive to establish,
- it is resistant to damage from disease and insects,
- it is durable and hardy, capable of thriving in many climates and soil types (BOSTID 1993)

The strips of vetiver grass were spaced at 5 m intervals along the contour of the catchment Within each strip, slips composed of 2 or 3 tillers each were planted at a 0 1 m spacing within the row Approximately 317 m of vetiver grass were planted along twelve linear barriers on the 0 16 ha field catchment The vetiver grass was managed by cutting it back to a height of about 0 5 m twice during each rainy season This practice helped to promote tillering and thereby form a more solid barrier of grass within the contour strip The cuttings were placed on the upside portion of the hedgerows to help increase the effectiveness of the barriers This treatment was maintained from 1994-1997

In 1994, the management of Catchment #3 was changed to reflect the traditional practice of burning the crop residue remaining from the previous year and the weeds that had grown to cover the field since harvest The fields were burned in early May of both 1994 and 1995, prior to the onset of the planting period All other aspects of crop management were the same during the calibration period

After the second weeding of the 1995 crop, *Gliricidia sepium* seeds were planted under the crop These tree seedlings were able to establish in a relatively weed-free environment, giving the seedlings an improved competitive advantage during 1996 and 1997 when the field was left fallow By helping gliricidia establish, this practice is considered an improved fallow since this species fixes atmospheric nitrogen, which should help the nutrient status of the topsoil recover more quickly Another advantage of this practice is that gliricidia produces marketable poles within a 3-4 year period, thus the farmer can actually make some money during the process of rehabilitating the field

Runoff

The amount of runoff from the three catchments is shown in Figure 3 The runoff characteristics established during the calibration year (1993) when all were managed as a mulch only treatment indicated that the runoff from Catchment #2 was naturally greater than the Catchment #1 When the vetiver contour strips were planted, the Catchment #2 yielded substantially less runoff than would have been expected if mulch was present without the vetiver contour strips The rigid leaves of the vetiver obstructed overland flow This resulted in concentrated rills of water flow being spread

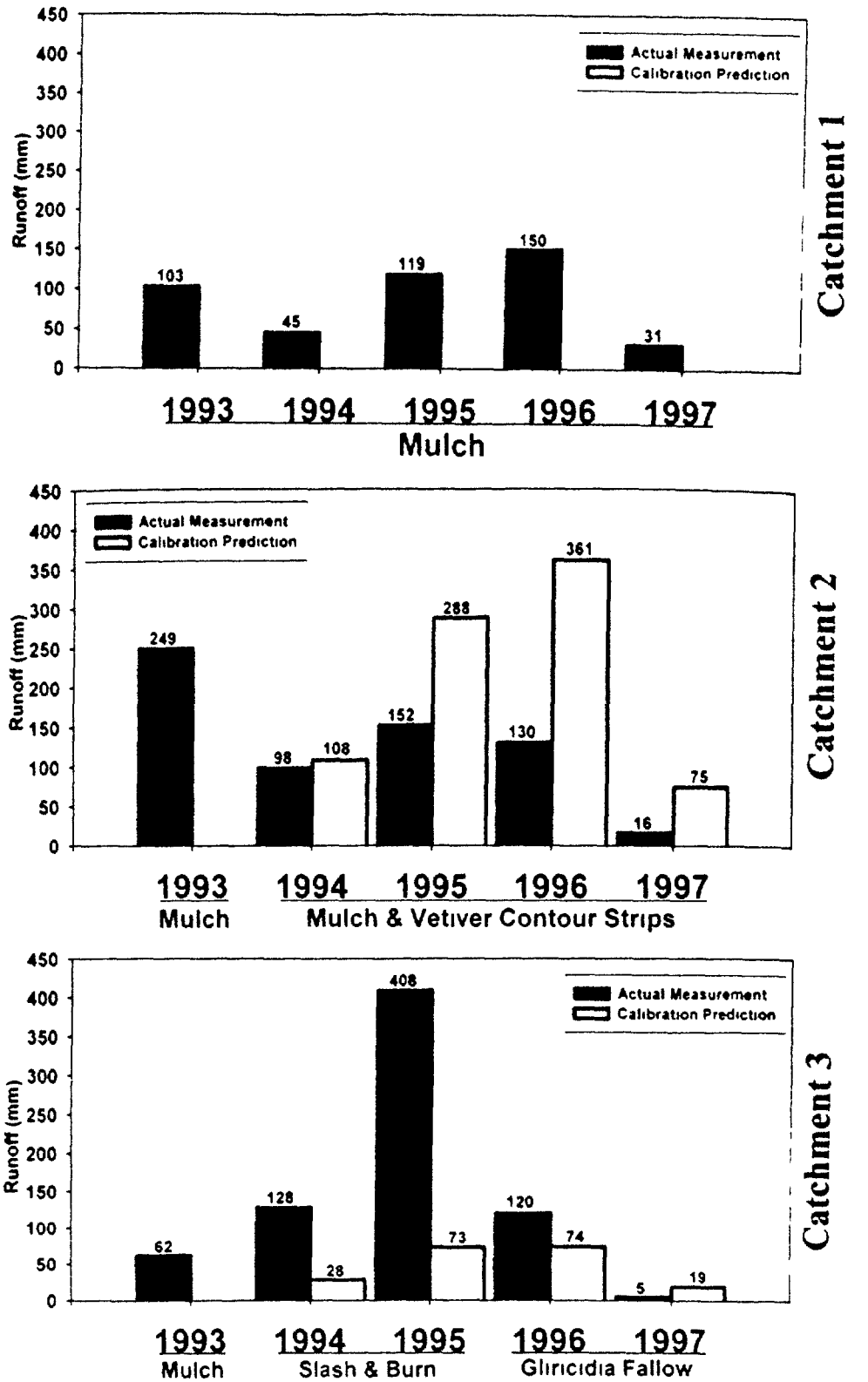

Figure 3 Runoff patterns from the monitored field-size catchments, Los Espabeles, Honduras

along the vetiver strip, dispersing the water over a broader area as it seeped through the porous barrier of vetiver Rills that were in the field had generally filled in by the third year after the vetiver strips were planted

The burned field of Catchment #3 yielded substantially more runoff than would have been expected based on the calibration of 1993 The extra runoff was associated with the removal of cover by fire which resulted in direct raindrop impact on the exposed soil This caused the soil surface to partially seal during heavy rains as the raindrop energy disaggregated the structure at the soil surface Also, with less litter, there was little obstruction to slow overland flow, giving water less time to soak into the ground Runoff was especially great at the beginning of the growing season when the crops had not yet grown enough to provide much cover for the soil

As soon as the fallow was established the difference narrowed between the actual and predicted runoff The primary reason why runoff remained greater than predicted was that some landslides occurred in the catchment during intense rains of 1996 This exposed soil of part of the catchment resulting in an overland pathway for more rapid runoff This exposed soil was naturally revegetated by 1997 and for the first time on this catchment the actual runoff was less than predicted

Figure 4 shows the percentage of annual precipitation that left the field as runoff Due to the steepness of the fields, the land area received less rain than recorded at the rain gauge It was necessary to use a correction factor was used to adjust rainfall depth on the slopes of each field catchment when calculating the percent of precipitation that ran off the fields The correction factor was based on the following trigonometric relationship

$CF = (L \cos \Theta)/L$, where,
CF = correction factor
L = slope length of field catchment
Θ = slope angle (degree) of field catchment

The patterns shown in Figure 4 are similar to Figure 3 The timing and intensity of the storms accounts for some of the differences between the two figures For example, a greater percentage of precipitation left the site as runoff in 1993 than 1995, even though 1995 received much more rain This is because 1993 received much more rain in May when the crops provide less cover and have a lower transpiration demand The dramatic increase in runoff from the burned catchment illustrates the downstream flooding hazard that could occur as a result of burning the upland fields In contrast, much of the water that fell on the fallow or terraced fields entered the soil This alleviates downstream flooding concerns associated with peak storm flow The water that entered the soil would be available for crop production, the portion of water that percolates beyond the plant roots would eventually recharge aquifers or contribute to springflow in streams This illustrates the apparent water yield paradox associated with clearing forests -- there is greater total water yield (mainly as peak flow during rain events) but springs stop flowing during the dry season (because little water has percolated through the soil to contribute to dry season baseflow or aquifer recharge)

Soil Loss

Due to the high intensities of tropical rainfall, unprotected soil aggregates can easily be broken down by the energy of rain and the detached soil particles removed via runoff (rill erosion) or via raindrop splash (interrill erosion) Therefore, it is important to provide some form of cover for tropical steeplands Cultivated fields have the least amount of cover protection during crop establishment, especially if the fields are burned prior to planting Combining the lack of cover with intense storms at the onset of the rainy season often leads to severe erosion and runoff on burned steepland at the beginning of the rainy season Leaving the mulch on the fields provides good soil cover and thereby dissipates the erosive energy of raindrop impact and overland flow

Another important aspect of the erosion process in humid steepland regions is associated with landslides Landslides occur during rainy

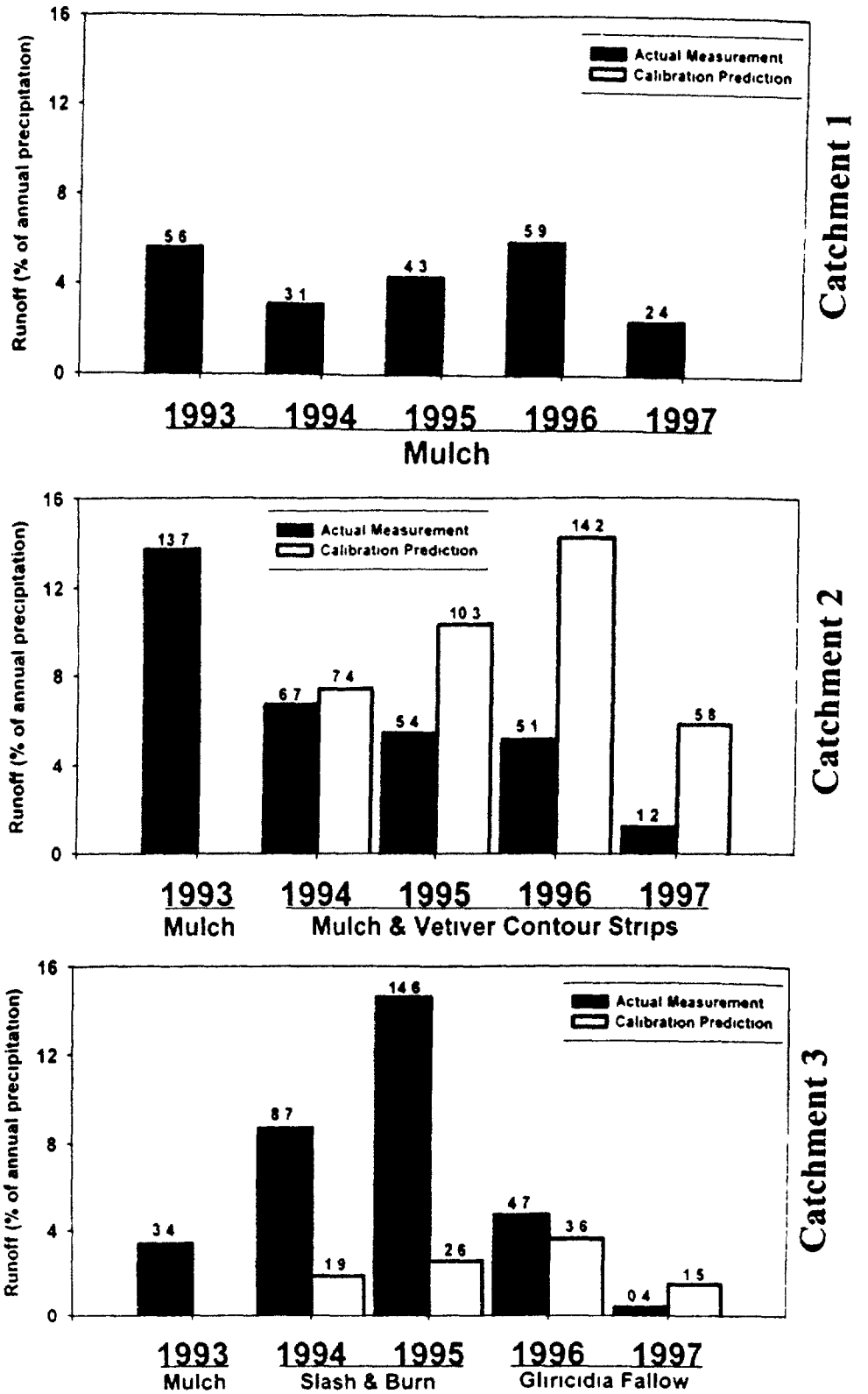

Figure 4 Percentage of annual precipitation that flowed off the monitored field-size catchments, Los Espabeles, Honduras

periods when the upper layers of the soil become saturated The weight of the water in the soil combined with the susceptibility to gravitational pull on steepland soils causes a portion of the hillside to give way and slide downslope Since these soils have a marked increase in bulk density between soil horizons and some locations show a weak argillic horizon, the rate of water percolation would slow as it moves through the soil profile This makes it more likely that the topsoil will approach saturation during a prolonged rainy period and it makes it more likely that the soil will slip at the interface between the saturated topsoil and the more densely packed subsoil

Figure 5 shows that during a normal or below normal rainfall year (1993, 1994, 1997) little soil erosion occurs on catchments with mulch cover This shows that mulch dissipates the raindrop energy and obstructs overland flow so that rill and interrill erosion are insignificant In contrast, when mulch is not present in a normal rainfall year (i e , 1994 in Catchment #3) the erosion rate associated with rill and interrill erosion is great No evidence of landslides occurred during 1994 in Catchment #3, however, there was much evidence of rills forming in the field The soil loss from Catchment #3 in 1994 was all due to rill and interrill erosion The difference in erosion between the mulched Catchment #1 and the burned Catchment #3 in 1994, dramatically illustrates the value of maintaining cover and, conversely, the increased erosion hazard associated with the traditional use of fire to clear the fields

In 1995 and 1996 the mulch cover on Catchment #1 was not sufficient to prevent substantial erosion associated with landslides Landslides also occurred on Catchment #3 in 1995 and 1996 These landslides occurred during prolonged rainy periods In strong contrast, landslides did not occur in Catchment #2 that had mulch plus vetiver contour strips The roots of the vetiver grass apparently tied the soil to the hillside so that landslides did not occur On adjacent fields with rock terraces or on fallow sites with trees, landslides did not occur either In contrast, almost every cropped field in the region that did not have either rock walls or vetiver grass had landslides In addition to losing the topsoil, some of these landslides caused the entire crop of maize and sorghum planted in the field to be lost In several instances, houses and roads downslope of the landslides were ruined

There was still moderate soil loss in Catchment #3 under the first year of fallow This erosion was associated with a landslide that occurred during particularly heavy rains (230 mm in 2 days) Apparently the roots from the newly established fallow vegetation had not developed to the point necessary to tie the soil to the slope Nevertheless, the reduction in soil loss between the two heavy rainfall years of 1995 (2795 mm of rain) and 1996 (2545 mm of rain) was dramatic

Table 1 further illustrates the value of mulch The 0 004 ha plot (2 m x 22 m) with mulch had very little soil loss whereas the 0 004 ha plot that was kept bare throughout the rainy season had an extremely great erosion rate This bare plot shows the maximum extent of soil erodibility uninfluenced by cover The results from this bare plot were used to calculate the soil erodibility "K" factor of the Universal Soil Loss Equation for this soil type This result shows that mulch cover is very effective at reducing raindrop energy and thereby reducing erosion caused by raindrop splash and runoff This table also illustrates the importance of plot size in measuring erosion processes The 0 004 ha plot was too small for landslide processes to occur, therefore this important erosion process was not detected On the field scale catchment with mulch landslides did occur, thereby causing a field scale estimate of erosion associated with mulch to be much greater than the plot scale estimate

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al 1996) are two of the most commonly applied erosion prediction tools throughout the world Both models were primarily developed using data from the temperate croplands in the United States Applying these models to a region with much

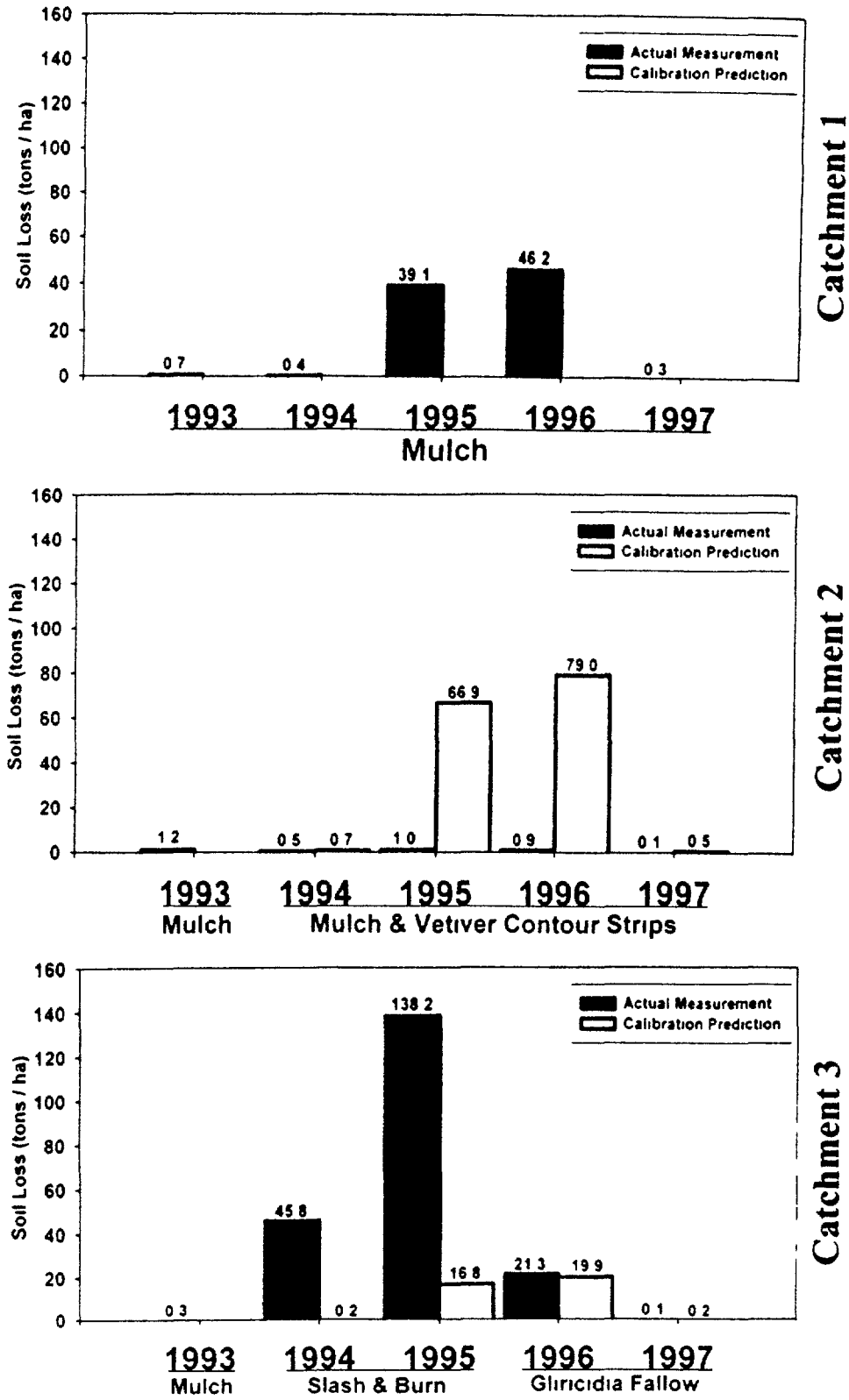

Figure 5 Soil loss from the monitored field-sized catchments, Los Espabeles, Honduras.

Table 1 Estimates of soil loss during the 1995 wet season as affected by catchment size and management practice, Los Espabeles, Honduras

Catchment Characteristics			Management Practice	Soil Loss (tons/ha)		
Area (ha)	Length (m)	Slope (%)		Actual	USLE	RUSLE
0 272 field	70	63	Mulch	19 7	671 6	74 4
0 004 plot	22	55	Mulch	0 5	293 9	34 3
0 122 field	60	57	Slash and Burn	92 0	1019 1	111 6
0 159 field	60	55	Vetiver Contour Strips & Mulch	0 7	447 1	52 1
0 004 plot	22	55	Continuous Bare Soil Fallow	760 6	1896 0	927 4

greater rainfall intensities, much greater slopes, and much different soil types than was used in model development is bound to have significant short-comings Indeed, there was a large disparity between what the two models predicted for erosion rates and what actually occurred These results illustrate the need for incorporating environmental conditions representative of the tropics into model development for creation of predictive tools useful for conditions such as found in the region

Nutrient Loss

Figures 6 and 7 illustrate the nitrogen and phosphorous losses from the catchments via runoff The patterns of nutrient loss roughly parallel the patterns of soil loss The relatively low amount of nutrient loss reflects the low nutrient status of the fields, a limiting factor to crop production in the region All farmers in the region understand the substantial increase in crop yields that could be obtained by adding fertilizer However, few farmers add fertilizer to their grain fields because of a shortage of cash and the low price of grain Farmers are understandably reluctant to take a loan to buy fertilizer because the variable rainfall may lead to crop failure which would make a difficult situation much worse if the farmer had to repay a loan in addition to struggling to survive in the aftermath of a poor crop Farmers in the area explain that since the price for grain is low, the upside benefits from investments in fertilizer are more than off-set by the downside risks of losing the investment as a result of unforeseen drought

Plate 5 Soil profile at the study site The average topsoil depths was 15 cm, the soil was classified as an Inceptisol

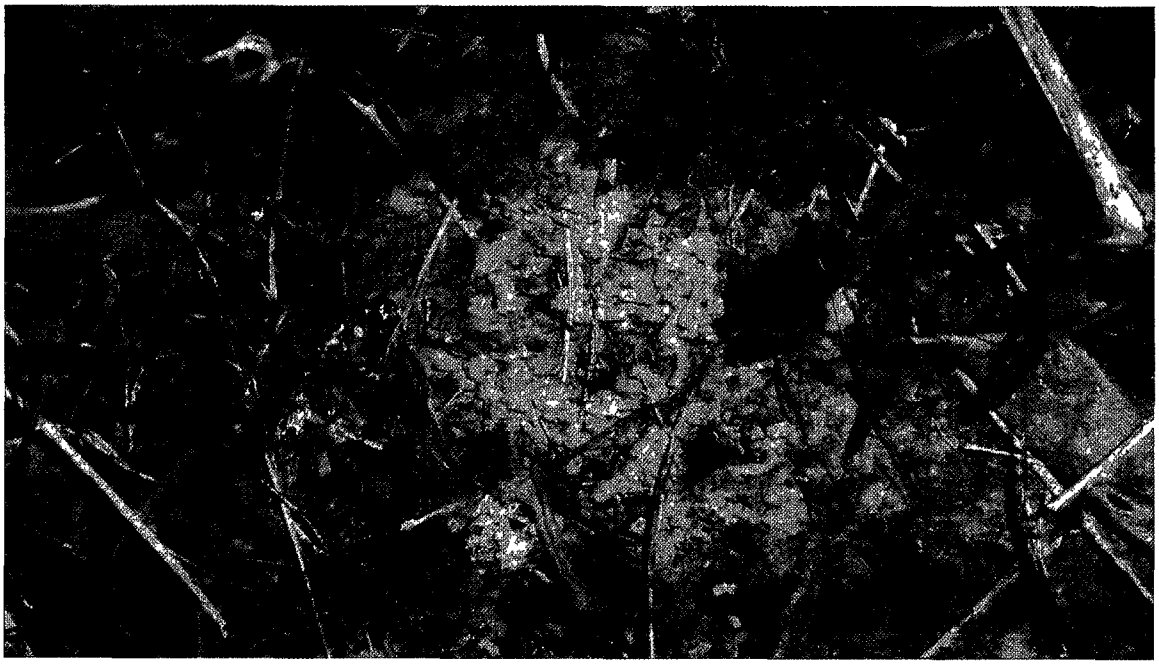

Plate 6 The topsoil had a good soil structure and very rapid permeability (saturated conductivity rates as high as 263 mm/hour), in part because of the relatively high organic matter content (organic carbon averaged about 2%) and high level of microorganism activity This picture is of a soil surface in the second year of being fallowed (1997) The runoff and erosion rate was virtually nil The erosion rate when this site was under traditional slash-and-burn management (1994 & 1995) averaged 92 tons/ha/yr

Plate 7 Field where crop residue is maintained as a mulch During average or low rainfall years the mulch provides adequate protection of the soil During high rainfall years these steeplands are prone to landslides To minimize the likelihood of landslides, deep rooted plants or rock terraces need to be incorporated into the management of the field to tie the soil into the slope (note the white flume at the bottom of the catchment for a perspective of the 63% slope of this field which is typical of the region)

Plate 8 The rigid leaves of vetiver grass contour strips helps to hold the soil on the field and did not experience landslides in wet years The vetiver grass continues to grow as soil accumulates behind the strip Four years after they were established, a terrace of sediment about 30 cm deep has formed behind each strip

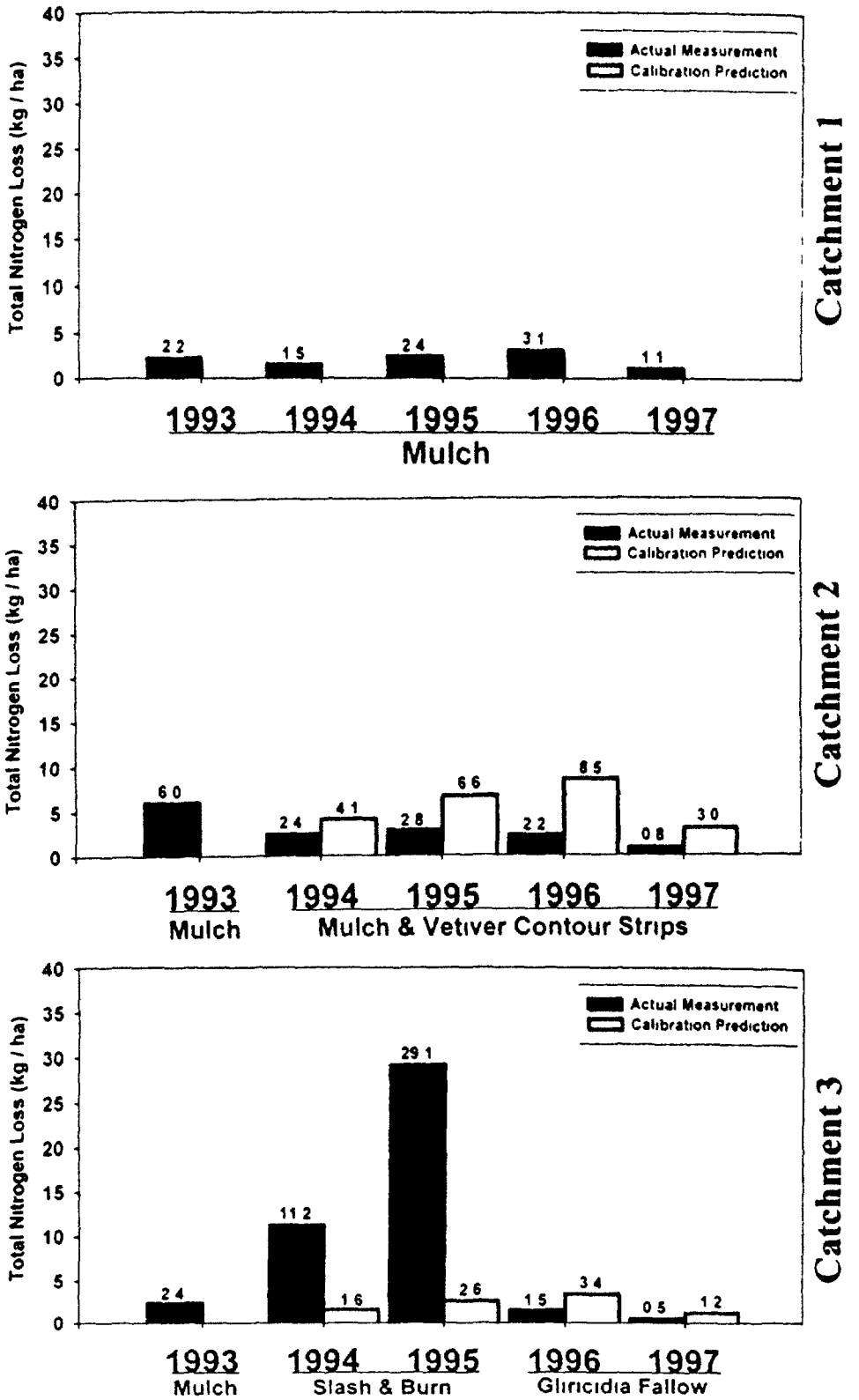

Figure 6 Total nitrogen loss from the monitored field-sized catchments, Los Espabeles, Honduras

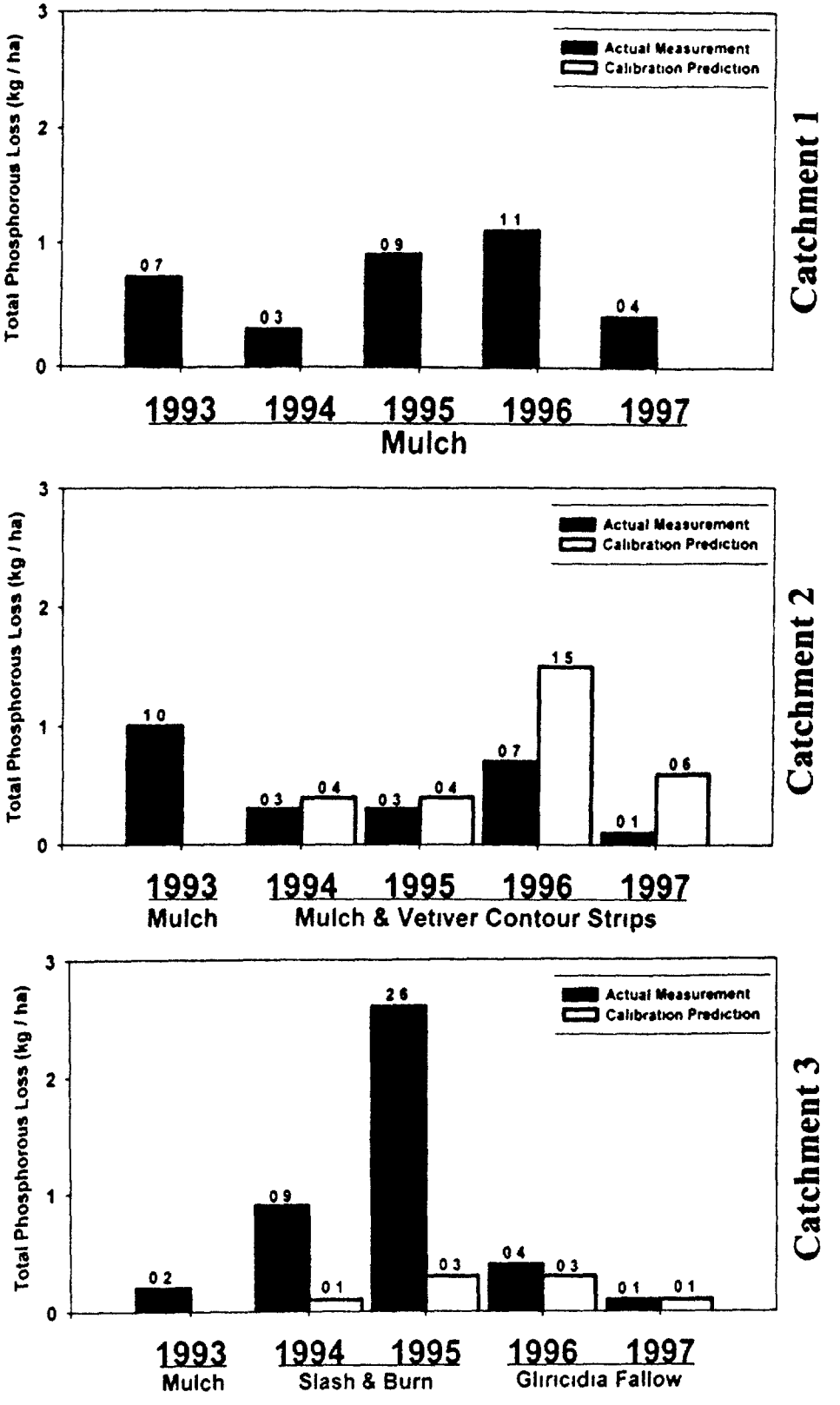

Figure 7 Total phosphorous loss from the monitored field-sized catchments, Los Espabeles, Honduras

MANAGEMENT IMPLICATIONS SUMMARY

This research illustrates that the traditional practice of burning the fields prior to planting creates extreme runoff and erosion hazard Suppression of fire, allowing the crop residue to be retained as a mulch on the fields, is an very effective soil and water conservation tool during years with average and below average precipitation This is because the cover provided by the mulch dissipates the raindrop energy and obstructs overland flow In above-average rainfall years protecting the surface soil with mulch cover is not the only issue determining soil erosion There is a high susceptibility of the steepland fields to landslides when the topsoil is saturated during prolonged rainy periods To prevent landslides, it is necessary to combine with mulch cover with some added practice that will tie the soil onto the hillside Vetiver grass contour strips and fallowed land with several year old trees did not experience landslides because the plant roots held the soil on the slope Likewise, rock walls on adjacent fields were effective at holding the soil on the slope during years with above average precipitation

Very few studies have been conducted in the tropics at a field scale of resolution Data from this study shows that the size of the plot is a very important determining factor in erosion prediction Small plots (2 m x 22 m), reflective of most of the research done in the tropics, were of insufficient size to reflect the landslide processes which accounted for most of the erosion on the fields Data from the field catchments provide more realistic information on the magnitude of runoff, erosion and nutrient loss likely to be occurring on cultivated steepland fields

Gathering the type of information presented in this publication is necessary as a *first step* in the assessment of soil and water conservation options relative to traditional slash and burn land preparation Future publications in this series will use these data, combined with Geographic Information System mapping techniques, to estimate the benefits and costs of soil conservation to the farmer and to downstream interests In this way a more complete assessment of the value of various soil and water conservation options will be possible

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