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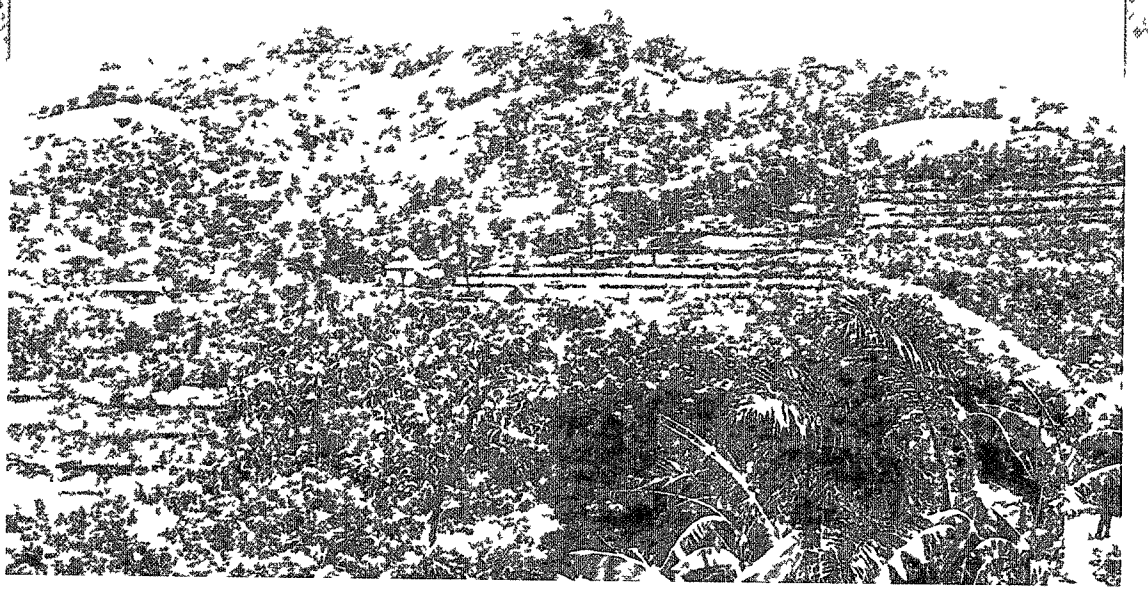

Front Cover Rock wall terraces on hillside farms, Los Espabeles, southern Honduras

SUSTAINABLE MANAGEMENT OF TROPICAL STEEPLANDS: AN ASSESSMENT OF TERRACES AS A SOIL AND WATER CONSERVATION TECHNOLOGY

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This publication is intended to summarize the diffuse literature available on use of terraces in steepland farming systems and present information on the research conducted in southern Honduras on this subject This work was, in part, made possible through the support provided by the Global Bureau, United States Agency for International Development, under the terms of Grant No LAG-G-00-97-00002-00 The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U S Agency for International Development Over the years the soil and water conservation research in southern Honduras has benefited from the expertise and friendship extended by numerous colleagues with shared interests The Land Use Productivity and Enhancement (LUPE) project has been very supportive In particular we thank Olman Rivera, Miguel Sanchez, Mario Pinto, Jose Santos and Wilfredo Arrazola of LUPE, former LUPE employees Javier Mayorga and Jorge Quinonez and former LUPE consultant David Leonard Another colleague and friend who has provided much technical, administrative and logistic support throughout the study is Mr Peter Hearne of USAID in Tegucigalpa, Honduras We especially thank Los Espabeles farmers Cupertino Galindo, Miguel Gomez, Martin Guido and Simeon for their help and friendship throughout our work in the region Dr Francisco Gomez, Chito Moran and Juan Rosas of the INTSORMIL-CRSP program at the Escuela Agricola Panamericana provided help with the data collection logistics We thank Dr Tony Juo of the Soil and Crop Science Department, TAMU for his support and advice throughout the project

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SUSTAINABLE MANAGEMENT OF TROPICAL STEEPLANDS: AN ASSESSMENT OF TERRACES AS A SOIL AND WATER CONSERVATION TECHNOLOGY

INTRODUCTION

Steeplands are typically characterized as hillsides with slopes greater than 20% (Lal 1988) In tropical regions, land area with slopes greater than 30% occupy slightly more than 1 billion ha, approximately 16% of the total land area (Purnell 1986) (Table 1) In Latin America and the Caribbean, approximately 400 million ha are classified as steeplands (Purnell 1986, Arsyad 1992) Many tropical steeplands are marginally suited for agriculture since they are often characterized by low nutrient availability, low levels of organic matter and shallow top soils These characteristics, combined with high intensity monsoon rains, make them very susceptible to erosion The consequences of using steeplands for agricultural production are cause for concern on a local, regional and global scale since unsustainable practices on steeplands also pose a series of problems for downstream portions of the watershed (Thurow and Juo 1995) Terracing steeplands is a common practice used to aid soil and water conservation (Sheng 1986) This publication addresses five topics concerning steepland management

1) Factors influencing current patterns of steepland use
2) Tradeoffs associated with different terracing practices affected by topographic characteristics (slope), soil characteristics, precipitation patterns, socioeconomic influences (labor dynamics) and traditional agricultural practices
3) Tradeoffs of terracing as a soil conservation practice for small farmers on tropical steeplands relative to other conservation or traditional no-conservation practices
4) Information gaps that must be addressed to evaluate the effectiveness of different terracing practices
5) Long-term impact of steepland management improvements on the watershed

Challenges Associated with Steepland Agriculture

Soil erosion is the most significant ecological restriction to sustainable agricultural production on steeplands Measured rates of soil losses between 100-200 tons/ha/yr have been reported on many steepland areas (Pimentel et al 1995) Soil losses of 500 tons/ha/yr have been estimated using models, such as the Universal Soil Loss Equation (USLE), although these models were developed using data from temperate systems and are therefore of questionable value for direct application in the tropics (Cook 1988) An erosion rate of 100 tons/ha/yr is approximately equivalent to losing two cm of soil

Steepland erosion rates are influenced by precipitation patterns, inherent soil properties, topography, land uses and management practices High intensity monsoon rains combined with the runoff energy that can be generated on steep slopes contribute to high erosivity conditions Shallow soils, rapid decomposition of litter which covers the soil and poor soil structure characteristic of many tropical steeplands contribute to high erodibiltiy conditions

Approximately 51% of tropical sites are comprised of highly weathered, leached soil such as Oxisols, Ultisols, and Alfisols (Sanchez 1976, Lal 1990) One third of steeplands have high levels of aluminum toxicity (Cook 1988) Almost 17% of the sites are composed of dry sands and shallow soils containing psamments and lithic groups (Sanchez 1976) Some steepland soils, especially some of volcanic origin, have high infiltration rates, which reduces the potential for runoff and erosion and are therefore more compatible with agricultural use than others (Lal 1990) However, these soils may also have layers of subsoil that restrict percolation resulting in rapid interflow and an increased risk of landslides when

Table 1 Area of steeplands in tropical regions of the world (Purnell 1986)

Slope (%)	Land Area (%) Africa	Southwest Asia	South America	Central America	Southeast Asia	Total Area 10^6 ha	(%)
0-8	58	45	52	35	40	3,340	51
8-30	34	31	30	40	31	2,107	33
>30	8	24	18	25	29	1,048	16

the surface soils become saturated This sloughing hazard greatly increases when trees are cut and their roots, which help to stabilize the slopes, decompose

The main causes of steepland deterioration are overgrazing and deforestation, which are often associated with expanding cultivation of annual crops Steepland erosion poses serious socioeconomic and ecological concerns for the entire watershed because the actions on the uplands may result in siltation and large flow changes in rivers downstream (increased flooding risk during the rainy season and decreased base flow during the dry season) Forests, which originally provided cover, thereby dissipating raindrop energy, tying the soil to the slope and helping to moderate seasonal flow rates, are the most secure way to maintain stable watershed conditions (Thurow and Juo 1995) Given the problems associated with cultivating steeplands, why are forests being cut down, people settling in these areas and expanding agriculture to these marginal hillsides? In particular, why is it important to study steepland agricultural systems when it is clearly better that these lands be managed as forests?

Cultivated area of the earth has increased 5 7 fold since 1700 and has approximately tripled since 1850 (Pimentel et al 1995) Fertile lands conducive to farming have been settled long ago As population grows, the poorer segments of the farming community increasingly develop marginal sites, such as steep and less fertile lands The world population is expected to double by the year 2050, with most of this increase (86 million out of 90 million/yr) in ecologically sensitive regions of the tropics where arable land is already scarce (Lal and Stewart 1995) In many of these ecologically sensitive regions population growth already exceeds it's rate of increase for agricultural output Projected population increases will double food requirements in developing countries and necessitate further expansion to land unsuitable or marginally suitable for agriculture (Lal and Stewart 1995)

The result of agricultural expansion has been fragmentation of small holdings and an increased number of rural landless population (Cook 1988) It is predicted that by the year 2000 population pressures will cause such severe fragmentation of land that per capita arable area will be 0 15 ha in the Far East, 0 35 ha in Asia and 0 45 in Latin America (Lal and Stewart 1995) Land holdings are already considerably reduced For example, the average farm size is only about 1 ha of land per family in El Salvador (Annis et al 1992) and 50 5% of the rural population is landless or owns less than 0 7 ha (SIECA 1989 in Utting 1993) Population pressure and increasing land fragmentation are driving changes in cropping patterns and deforestation

The traditional pattern of tropical steepland use is largely based on a rotation system that requires large tracts of land necessary to accommodate a long fallow period Native vegetation is cut and burned prior to planting annual crops After the grain is harvested these fields are often intensely grazed during the dry season (Thurow and Juo 1995, Nye and Greenland 1960, Sanchez 1976) Once under cultivation, steep slopes are susceptible to high erosion rates which results in progressive declines in crop productivity (Pimentel et al 1995) For example, after forests were cut and

replaced with cassava or groundnuts in the Ivory Coast, erosion increased from 0 05 tons/ha/yr to 750 tons/ha/yr (Roose 1988) The traditional shifting cultivation system can be a relatively sustainable practice (Cook 1988), but increasing human population has intensified pressure on existing agricultural lands and resulted in a reduction or elimination of fallow rotation (Pimentel et al 1995, Pla Sentis 1992), threatening the sustainablity of traditional cropping systems

Subsistence farmers face a dilemma between the need for producing food and harvesting wood to meet their daily needs and sustainably managing the soil resource to ensure long-term productivity of the site Almost all small farmers worldwide rely on fuelwood for energy purposes, compounding agricultural land degradation with deforestation (FAO 1983, Goodman 1987) When land is cleared for farming, the wood products are used first for building and construction and the remaining trees and shrubs are cut for fuelwood (Cook 1988)

When woody material no longer meets the fuel needs of the locale, crop residues and animal wastes are burned as a substitute for fuelwood, further degrading the soil by depriving them of inputs of organic matter and protection through cover For example, appoximately 60% of crop residues in China and 90% in Bangladesh are removed and burned for fuel each year (Wen Daznog 1993 in Pimentel 1993) More than 70% of El Salvador's population relies on fuelwood, which accounts for 95% of the national consumption of wood products (Heckadon 1989 in Utting 1993) Studies conducted by CATIE indicate that nearly three quarters of all Central American households (72%) use fuelwood, with a daily per capita consumption rate of approximately 2 5 kg (Martinez 1986 and Heckadon 1990 in Utting 1993) This is not uncommon for many regions of the world (Utting 1993, Durning 1993)

Often, forest products produced on the uplands are not valuable enough to offset the effort to control wood harvesting and settlement by squatters In fact, governments often view disbursement of upland titles as a mechanism to placate the land needs of the rural poor without antagonizing the wealthy and politically powerful land owners with land reform Many developing countries have policies and laws which directly or indirectly foster deforestation and steepland settlement

Land tenure exacerbates population pressures The most common situation among small land holdings in tropical areas is land occupation for short periods of time without any legal right of settlement (Pla Sentis 1992) Unstable land tenure is often the root of a subsistence farmer's inability/unwillingness to risk investment for a long-term benefit (Thurow and Juo 1995) It is often subsistence farmers in the lowest economic and social strata, those with the least tolerance for risk, who clear and use steeplands for agricultural purposes The combination of reduced land availability and insecure tenure results in farmers using unsustainable farming practices while trying to provide for their families immediate needs

The lack of available land coupled with increasing demands to provide the necessities of life are causing a shift in the role of women on the farm Women are increasingly becoming the head of food production activities because the men often participate in seasonal, migrant labor patterns to earn cash necessary to provide for some of the families needs such as medicine and education Shortage of these necessities results in declining family health (particularly seen in high infant mortality rates), lower nutritional status and increased poverty This trend is partially responsible for the rapid growth of cities and urban "slums", as farmers leave unproductive land and migrate to cities to seek employment

Erosion not only damages the immediate agricultural area where it occurs, it negatively impacts the surrounding area within the watershed Eroded soil moves into rivers and reservoirs and causes accelerated siltation which shortens the life of hydroelectric plants and increases costs for dredging As rivers silt up and runoff increases, flooding becomes more of a problem and can result in heavy financial losses Other off-site effects include

eutrophication of waterways, siltation of harbors and channels, loss of reservoir storage, loss of wildlife habitat, disruption of stream ecology, flooding, damage to public health and increased water treatment costs (Pimentel et al 1995, Gray and Leiser 1989, Thurow and Juo 1995, Pla Sentis 1992) Downstream residents are therefore directly impacted by decisions made by upland farmers and ranchers

In order to address soil conservation adequately, it is important to understand the linkages within a watershed and how conservation farming in upland systems affects the system as a whole and the tradeoffs and decision-making process of upland farmers and downstream residents Most research on soil erosion and erosion control has been done on flat or rolling land with a maximum slope of less than 20% (Lal 1988) Research on steepland has been neglected in part because these lands are marginal for agricultural production and are therefore not targeted for study Unfortunately, this lack of research does not mean that this land is not being used or cultivated (Lal 1988, Purnell 1986)

The likelihood of expansion of agricultural activities on tropical steeplands makes research a pressing need, specifically focusing on steeplands as an integral part within the watershed and studying steeplands within the context of the landscape in which they exist (FAO 1990, Aldhous 1993, Lal and Stewart 1995, Thurow and Juo 1995) In fact, steepland destabilization has been demonstrated to have a cascading effect, making their management a keystone factor in ecosystem and watershed integrity Using watersheds as a planning unit can internalize the costs of upland soil and water conservation activities with the benefits of such programs to downstream users (Thurow and Juo 1995) It is useful to summarize research that has been conducted on steeplands because it indicates gaps in past research and highlights implications for the effectiveness of terracing to aid steepland soil conservation Future publications in this series will highlight other viable conservation practices

Processes Resulting in Land Degradation on Steeplands

Deforestation, cultivation and over-grazing of steep slopes have often led to accelerated degradation and erosion of tropical steepland and the associated watershed system The interrelated problems resulting from these practices are

- **deteriorated soil structure**
- **reduced hydrologic condition**
- **accelerated erosion and runoff**
- **reduced fertility**

Deteriorated Soil Structure

Loss of soil structure occurs most rapidly where there is a lack of ground cover Cover aids maintenance of aggregate structure by intercepting and dissipating the kinetic energy of raindrops Raindrops have high erosive energy, often representing a greater erosion threat than overland flow Rain drops striking exposed soil act as tiny bombs, breaking up soil aggregates and launching particles into the air, dispersing them up to 1 m or more (Pimentel et al 1995, Satterlund and Adams 1992) On slopes, splash erosion displaces the soil downhill, resulting in a net soil loss Thus, significant soil erosion may be occurring even though there are not rills or gullies present The traditional practice of burning residues exposes the soil and reduces organic matter, which is an important component in the formation of water stable aggregates The aggregates creating the soil structure must maintain their structural integrity when wet if infiltration through those pores is to occur Soils loosened by tillage and weeding are more easily detached Annual crops do not develop extensive root systems necessary to stabilize the slope and reduce the risk of sloughing The loss of the physical soil structure degrades the soil's potential for sustainable cultivation

Reduced Hydrologic Condition

Vegetation cover and soil structure are the greatest factors affecting the infiltration rate of soils that can be influenced by management Cover intercepts raindrops and dissipates their kinetic energy before they strike the soil, thus protecting the pore integrity of the surface structure and making it less likely that pores will be clogged by disaggregated soil particles which may result in a "wash in" crusted layer that can reduce infiltration rate by as much as 90% (Boyle et al 1989) Moderately eroded soils absorb form 10 to 300 mm/yr less water than uneroded soils, or between 7 to 44% of total rainfall (Lal 1976)

As topsoil is lost so is water storage capacity A decrease in water storage capacity may result in crops running out of available water sooner in a dry spell This may result in farmers asserting that droughts are becoming more frequent and severe, when in reality the loss of soil moisture storage capacity has shortened the time to when crops manifest the signs of drought stress Soil organic matter from decaying vegetative cover is also important because it binds, lightens, and expands the soil and enhances formation of water-stable aggregates In addition, decaying organic matter provides channels for water movement into the soil, thus increasing soil porosity For these reasons, not burning or grazing the crop residues can help maintain soil structure and hydrologic condition

Runoff and Accelerated Soil Erosion

The loss of soil structure combined with lower infiltration rates results in accelerated soil loss and runoff as greater amounts of water flow overland rather than percolate through the soil Flooding hazard increases as the peak flow in waterways associated with individual storm runoff events increase Conversely, because less water enters the soil, there is less interflow through the soil and therefore a decline in waterway baseflow during the dry season Siltation of downstream waterways occur as eroded soil particles are broken up and carried away by the force of water flowing overland, a process which is exacerbated on steep slopes In addition, accelerated runoff and erosion carry away nutrients bound to soil aggregates in the fertile topsoil, further reducing nutrient reserves in the soil

Natural or geologic erosion results from climatic and topographic conditions and is independent of human activities Accelerated erosion is defined as an increase in soil erosion associated with human activities related to changes in vegetation cover and/or the physical properties of the soil The erosion rate must be equal or less than the rate of soil formation if sustained, long-term productivity is to be maintained

Soils form slowly It takes between 200 and 1000 years or more to form 2 5 cm of topsoil (Pimentel et al 1995) Erosion represents a threat to the long-term sustainability of the system when soil is lost more quickly than it is formed Erosion is a function of the erosivity of the detachment factor (energy of water and wind acting on the soil) and erodibility of the soil (physical characteristics, topography, type of land use and type of vegetation) (Smith and Wischmeir 1957) Erosion is intensified on sloping land where more than half of the soil contained in the splashes is carried downhill (Pimentel et al 1995) The four major soil erosion processes are (1) interill erosion, (2) rill transport, (3) gully erosion, and (4) stream bank erosion (Mutchler et al 1994)

1 Interill erosion results from the detachment of soil as a result of raindrop splashes combined with thin surface flow of water This thin flow of water is highly turbulent and has a high erosive capacity Extreme interill erosion is evident when, for example, soil pedestals are formed by erosion around an area covered by a resistant material, such as rock The fact that the surrounding soil is eroded without undercutting the soil under the resistant cap illustrates that raindrop splash is the major transport mechanism, rather than surface

2 flow Therefore, although no running water is observed, water erosion may still be taking place
3 Rill erosion begins as the diffuse water movement causing interill erosion concentrates into discrete flow paths
4 Gully erosion is defined to be occurring when a crevice greater than about 30 cm has formed
5 Stream bank erosion results when water flowing through streams or rivers cuts into the banks

Nutrient Deficiency

Nutrient deficiency and drought stress are common and often interdependent factors limiting agronomic production on steeplands Soil loss reduces both water holding and nutrient holding capacity Compounding the problem is the inherent vulnerability of many tropical steepland soils due to their poor chemical composition When nutrient reserves are depleted by erosion, plant growth is stunted and crop yields decline (Pimentel et al 1995) About 95% of the nitrogen and 25-50% of the phosphorous is contained in the soil's organic matter (Pimentel et al 1995), which is scarce in continually cultivated fields especially if they are annually burned and/or heavily grazed after the grain is harvested Crop yields in severely eroded soils are lower than those on protected soils because soil erosion reduces soil fertility and water availability For example, corn yields on severely eroded slopes in Kentucky have been reduced by 12-21% and up to 24% in Illinois Erosion at a site in the Philippines was documented to cause corn productivity to decline by 80% in 15 years (Pimentel et al 1995)

USE OF TERRACES AS SOIL CONSERVATION STRUCTURES

Soil conservation practices fall into two general categories 1) agronomic or crop and vegetative management, such as crop rotation, strip cropping, cover crops, multiple cropping, green manuring, mulching, agroforestry, grazing and forestry management, and 2) structural or mechanical methods, generally used to control the movement of water over the soil surface including contouring, contour bunds, waterways (diversion ditches, terrace channels, and grass waterways), stabilization structures (dams, wattles), windbreaks, and terraces (diversion, retention, and bench) (Morgan 1986, Bennett 1970)

Terraces are embankments constructed on contour across the slope and are used to reduce the steepness and length of slope and to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity (Morgan 1986) Planting grasses, shrubs, or trees along terrace edges stabilizes the terrace structure, and can provide other benefits, such as fuelwood, nitrogen fixation and forage Combining physical structures with multi-use vegetation planted to stabilize the terrace edges is a common conservation practice (Thurow and Juo 1995)

By substantially decreasing soil and nutrient loss, conservation technologies preserve water holding capacity, soil fertility and enable sustainable crop production In many instances, the use of conservation technologies may increase crop yields by 50% (Pimentel et al 1995, Siebert and Belsky 1990) Much research has compared soil loss and runoff rates of soil conservation structures such as terracing with traditional farming methods and/or bare plots to assess the effectiveness of these practices (Table 2) Although most studies do not include cost/benefit comparisons of terraces with other conservation methods or no conservation, they conclude that terraces can be a practical method for reducing erosion and runoff

History of Terraces

Terraces have a long history of use by agricultural cultures around the world, the earliest dating to China, around 2000 BC (Troeh and Thompson 1993) These early civilizations which used terracing methods were generally characterized by needing to farm sloping lands and having an abundant human resource pool for labor In the Yangtse Valley, in twelfth century AD, the Mongols forced Chinese in some regions to retreat to the mountains where they began to farm using terraces to hold the soil on the steep slopes In the Philippines, Java, Sri Lanka and India, farmers have been building terraces for over 2000 years (Bennett 1970) In Yemen, terraces 1 5 to 5 m high have been continuously cultivated for 3000 years (Vogel 1987) These techniques were passed on by the Arabs to Spain in the tenth century when Spain was conquered Terracing and large scale irrigation structures were used before 360 AD in Antioch, Syria, which supported a population of 400,000 at that time (Bennett 1970) Knowledge of terracing and irrigation was introduced into Greece by 600 AD (Bennett 1970) In Africa, a traditional method still used today is *fanya juu* terracing, meaning "throw upwards" in Swahili This is a method whereby a ditch is cut along the contour and the excavated soil is thrown above the ditch, creating a hump that serves as a barrier to overland flow (Thomas 1988)

In Peru, the Incas and their predecessors had developed highly efficient methods of conserving soil on steepland, dating back to 1400 to 1532 AD The pre-Inca culture Chavin, dating from 900-200 BC, already used terracing of mountain slopes, construction of raised fields for intensive cultivation and sophisticated irrigation and drainage systems (Burger 1992) The Incas built large scale, complex terraces which were supported by stone retaining walls built along the contour, varying from 2 5 to 17 m in height and from 1-3 m in thickness Soil was filled in by hand behind the walls, the lower

Table 2 Comparison of past studies using terraces as a soil and water conservation technology in tropical steepland regions
Blank spaces in the table indicate that the particular information was not reported in the publication

Country	Conservation Type	Crop	Slope (%)	Rainfall (mm)	Soil type	Plot size (m)	Soil Loss (tons/ha/yr)	Runoff (mm/ha/yr)	Study length (yrs)	Source
Burundi	bare	bare	40		permeable		440-880		1 5	Durand 1984
	traditional	cassava	49				70-90			Roose 1988
	grass barriers	cassava	49				29-50			
	traditional	maize and beans	49				150			
	bench terraces	maize and beans	49				5 - 11			
Dominican Republic	bare	bare	30	1530	Typic-	10 plots	1254	579	1	Veloz and
	traditional	mixed grains	30		Tropor-	15 x 3 m	187	166		Logan 1988
	no-tillage	mixed grains	30		thent		2	11		
	rock wall typical tillage	mixed grains	30				163	142		
	grass strip/hillside ditch	mixed grains	30				81	111		
El Salvador	traditional	maize and beans	30	1900	loamy to		110		2	Sheng 1979
	traditional		30		clay loam		127			Sheng 1989
	bench terraces	maize and beans	30				33			
	grass barrier	maize and beans	30				71 5			
Ethiopia	traditional	grains	28	1566	Nitosol,	9 plots	123		2	Kejela 1992
	graded bund	grains	28		Regosol,	varying	64			
	fanya juu	grains	28		and	30 x 6 m	56			
	fanya juu 1985	grains	12		Luvisols	15 x 2 m	73			
	fanya juu 1986	grains	12			3 x 1 m	39			
	badlands with grass	grains	16				269			
	badlands with gully	grains	16				322			
	traditional	lentil					42 5	171	1	Keddeman
	grass strip	lentil					3 5	52 6		1992
	graded fanya juu	lentil					14 7	110 3		
	level fanya juu	lentil					2 5	70 2		

Table 2 Comparison of past studies using terraces as a soil and water conservation technology in tropical steepland regions, continued

Country	Conservation Type	Crop	Slope (%)	Rainfall (mm)	Soil type	Plot size (m)	Soil Loss (tons/ha/yr)	Runoff (mm/ha/yr)	Study length (yrs)	Source
Honduras	traditional	maize and sorghum	60	1800-	Entisol,	6 plots	1 54	141	1	Sierra 1996
	rock wall terraces			2900	Alfisols,	2 x 5 m	1 78	53		
	at 6 m intervals	maize and sorghum	60		Mollisols					
	traditional	maize and sorghum	60		Typic	4 plots	87 2		0 5	Thompson
	rock wall terraces	maize and sorghum	60		Haplustalf		38 5			1992
Indonesia	traditional	peanuts and corn	33-38	1945	red-yellow	10 plots	4 0		1	Siebert and
	bench terraces	peanuts and corn	33-38		podzolics	1 5 x 10 m	1 0			Belsky 1990
	grass bunds	peanuts and corn	33-38				0 7			
Jamaica	traditional	yellow yams	30	3300	clay loam		133		4	Sheng 1979
	traditional	yellow yams	30				120 9			
	bench terraces	yellow yams	30				15 5			
	hillside ditches	yellow yams	30				23 6			
	individual mounds	bananas	30				34 5			
	traditional	bananas	30				183		2	Sheng 1989
	bench terraces	bananas	30				15 5			
	hillside ditches	bananas	30				19 1			
Java	traditional	maize, mixed grain		1945			12 6	4263 4	2	Fagi and
	bench terrace	maize, mixed grain					1 5	2164 6		Mackie 1988
	ridge terrace	maize, mixed grain					5 7	4963 5		and
	traditional	maize, mixed grain					211 2	885		El-Swaify
	bench terrace	maize, mixed grain					2 8	795		et al 1985
	ridge terrace	maize, mixed grain					5 8	1305		
	traditional	maize, mixed grain					106 4	390		
	bench terrace	maize, mixed grain					7 5	345		
	ridge terrace	maize, mixed grain					150 0	990		
	individual terraces	maize, mixed grain					9 6	4873 2		
	traditional	potatoes	10				136 1	259 5		
Malaysia	traditional	peppers	60				107			Hatch 1980
	traditional	peppers	58	3048-	red-yellow	3 plots	63			
	bench terraces	peppers	58	5588	podzolic	4 x 10 m	1 4			

Table 2 Comparison of past studies using terraces as a soil and water conservation technology in tropical steepland regions, continued

Country	Conservation Type	Crop	Slope (%)	Rainfall (mm)	Soil type	Plot size (m)	Soil Loss (tons/ha/yr)	Runoff (mm/ha/yr)	Study length (yrs)	Source
Sierra Leone	traditional	rice	31				40 7-54 5		1	Millington
	bench terraces	rice	31				7 53			1982
	stone bunding	rice	31				30			
	contour bunding (soil)	rice	31				18			
	traditional	cassava	31				11 2-55 1			
	stone bunding	cassava	31				4 4			
	contour bunding (soil)	cassava	31				16 82			
Taiwan	reverse slope	tea	32	1472	clay		0 9	107 4	6	Liao and Wu
	level bench	tea	32		loam		3 2	132 5		1987 in
	outward slope	tea	32				17 4	228 16		Lal 1990
	traditional	tea	32				24 6	270 8		
	reverse slope	tea	27	1457			0 4	99	9	
	level bench	tea	27				0 9	129 7		
	outward slope	tea	27				3 5	155 9		
	traditional	tea	27				3 3	174 8		
	reverse slope	banana	28	2349			1 6	880 87	2	
	level bench	banana	28				1 6	239 6		
	outward slope	banana	28				6 8	897 3		
	traditional	banana	28				92 5	1533 9		
	reverse slope	citrus	28	1743			8 1	435 7	3	
	level bench	citrus	28				0	31 4		
	outward slope	citrus	28				6 5	515 9		
	traditional	citrus	28				156 4	1286 3		
	traditional	mixed grains	52	2500	loam		208			Sheng 1989
	traditional	cassava	52	2500	clay loam		128			
Thailand	traditional		20				74			Harper and
	bench terraces		20				26			El-Swaify
	traditional		35				155			1988
	bench terraces		35				34			

levels of the terraces being filled with gravel and stone and the upper portion with 2 to 3 feet of fertile soil The terraces were irrigated by stone aqueducts from water sources that were often located kilometers away It is estimated that about 1 million ha of land was terraced in Peru under the Inca empire, of which about one third is still in cultivation today (Denevan 1985 in Lal 1990) Williams (1987) estimates that these terraces are retained by 3 billion m^3 of rock wall that would have required at least 4 million person-years of labor for the wall construction alone (Lal 1990) This system is clearly a result of careful planning and design as plots of considerable size were developed at the same time, requiring a very sophisticated organizational system of human labor The Inca technique of using rock walls to construct terraces is a method still used throughout Latin America today

Terrace System Design

Since the 1920's, modern agricultural societies have further developed designs, specifications and methodologies for terracing (Bennett 1970) There are many different classifications and designs of terraces Shaxson (1989), defines terraces as cross-slope structures designed to control runoff, with two main forms and many variations (1) where the crop is cultivated on the leveled structures themselves ("benches") and, (2) where the crop is cultivated in the spaces between the structures or benches

Sheng (1977, 1986) gives specifications for different types of terraces (Table 3), illustrated and explained in detail in the following sections When considering what type of steepland soil conservation techniques to apply there are five basic factors to consider (Sheng 1989)

- Runoff Control Conservation techniques should facilitate the slowing, diversion, and safe disposal of overland flow
- Erosion control Conservation techniques should reduce soil loss in the field
- Integrated Land Management Measures should not be isolated in the field Soil conservation is an integrated system of land management that should include efforts to conserve soils in order to improve crop production though enhanced soil and nutrient management
- Cost Effectiveness Costs and effectiveness of conservation structures should be weighed carefully
- Opportunity for Choice Structures should be adapted to meet the needs and choices of individual farmers

Bench Terraces

Sheng (1989) defines bench terraces as a series of level or nearly level strips running across the slope at certain vertical intervals These level strips are used for cultivation and are supported by steep banks or risers made of earth or rocks Reasons for using bench terraces include

- Creating arable lands on hillsides
- Increasing choices and crop diversity when land is flat
- Retaining soil moisture and increasing crop production
- Increasing irrigation and mechanical potential
- Encouraging settled farming and reducing shifting cultivation
- Decreasing erosion

Bench terraces are considered to be among the most effective structural erosion control measures (Sheng 1989) They can reduce erosion by 90-95% or more and have increased crop production by 200-300% in Jamaica, with the proper soil management (Sheng 1989) Their disadvantage is that they are also the most labor intensive conservation technology

Table 3 Design specifications for the primary types of terrace systems (Sheng 1986)

Treatment	Specifications						
	Width of bench (m)	Length[1] (m)	Horizontal gradient[2] (%)	Reverse grade (%)	Riser slope[3]	Slope (%)	VI or Spacing[4]
Bench terraces							
hand made	2 5-5 2	<100	up to 1	5	0 75 1	12-47	$\frac{S \times Wb}{100-S \times 0\ 75}$
machines	3 4-8 2	<100	1	5	1 1	12-36	$\frac{S \times Wb}{100 - S \times 1\ 0}$
Hillside ditches	1 8-2	<100	1	10	0 75 1	<47	$\frac{S+4}{10}$ or $\frac{S+6}{10}$
Individual Basins	1 5-2 1 round	--	--	10	0 75 1	<47	distance of crop
Orchard Terraces	1 8-2 5	<100	1	10	0 75 1	47-58	11-13 m along the slope
Intermittent	2 5-5	<100	1	5	0 75 1	12-47	3 times the bench terrace
Convertible	2 5-5	<100	1	5	0 75 1	12-47	as hillside ditch
Natural terraces	8-20	--	--	--	1 1	<12	1 m VI

Wb = Width of the bench (flat part), VI = Vertical Interval between two succeeding terraces which determines spacing, S = Slope (rise over run) in %

[1] **Length** The length of a terrace is limited by the size and shape of the field and the permeability and erodibility of the soil Longer terraces are more efficient, particularly for mechanized agriculture and reduce the cost of construction but they must be constructed to very tightly controlled specifications to avoid increasing the risk of accelerated runoff and erosion (Sheng 1977)

[2] **Gradient** It is very important to control the grade (slope) of a terrace In low rainfall areas with permeable soils a horizontal grade of less than 0 5% is recommended, while areas with intense rainfall and heavy soils should use a 1% horizontal grade in order to better manage excess runoff A reverse grade of 5% is also recommended to prevent runoff hazard For very narrow terraces, a reverse grade of 10% is needed to avoid hillside slippage (Sheng 1977)

[3] **Riser and Riser Slope** The riser is the zone of elevation increase between the two terraces (Figure 1) The height of the riser is dependent on the width of the terrace A very high riser is more difficult to construct and maintain A height of 1 8 to 2 m, after settling, has been found to be the practical limit The slope of a riser depends upon the texture of the soil and the tools and materials to be used in construction A riser slope of 1 1 (horizontal width vertical height) is recommended for machine built terraces and 0 75 1 for hand made ones provided they are compacted well enough and protected by grass cover or a rock wall The minimum soil depth is obtained by dividing the height of the riser by two

[4] **Vertical Interval (VI)** is the elevation difference between two succeeding terraces It is determined by the slope of the land and the width of the benches, using the above formula, where S is the slope (%), Wb is the width of the bench and U is the slope of riser (ratio or horizontal distance to vertical rise using a value 1 0 for machine built terraces and 0 75 for hand made ones) (Figure 1) (Sheng 1977)

The four main types of bench terraces are (1) level, (2) outward-sloped, (3) runoff conservation, and (4) reverse-sloped (Figure 1) Level bench terraces are completely level and possess no slope on the bench itself Outward-sloped bench terraces are sloping slightly downhill or outward These require less soil to be moved during construction and are thus easier to build than reverse-slope terraces which slope into the hill Reverse-sloped bench terraces are suitable for the following conditions heavy, monsoon rains, steep slopes under cultivation, dense populations with small holdings, and high rural unemployment Conservation terraces are designed to harvest water and direct it to the bench The choice of which terrace structure to use depends primarily on rainfall and soil characteristics and labor availability The two most conventional, more costly terrace designs are (1) irrigation terraces (or rice paddies), used mainly for irrigated crops, and (2) reverse-sloped bench terraces, which are primarily used for rain-fed upland crops and irrigated in the dry season (Figure 2)

Bench terraces can be used on slopes between 12-47%, on relatively deep soils on sites that are not too stony (Sheng 1989) Natural (or gradual) and formally constructed bench terraces can be effective in erosion control on steep slopes up to 58% or more (LUPE 1994) They can be built by manual labor, animals, or machinery Hillside ditches may be combined with bench terraces on slopes up to 47% Hillside ditches help to retain water along the contour and enhance terrace drainage

The width of the bench on a terrace should be 2 5 to 5 m wide, less than 100 m long, have a 5% reverse slope, and the riser to slope ratio should be 0 75 1 or 1 1 (FAO 1977, Sheng 1989) Morgan (1986) delineates broad based types of terraces which occupy a width of 15 m and narrow based types which would occupy a width of 3-4 m The theoretical formula for bench terraces in a steady state conditions on a hillside can be expressed as $Qw = (R - i)\ L \cos \theta$, where Qw is runoff, L is the slope length, R is the rainfall intensity, i is the infiltration capacity and θ is the slope angle Empirical formulae for constructing terraces vary, particularly by country It is recommended that three or more of the empirical formulae be used and the spacing be based on a consensus of the result (Morgan 1986) Table 4 gives examples of empirically based formulae for terrace spacing calculations for different countries An example of recommendations for bench terrace construction are demonstrated by specifications given for 5-25% sloping land in the Loess Plateau, China, illustrated in Table 5a and 5b and Table 6 (Fang et al 1980, FAO 1988)

Studies on the effectiveness of bench terraces in controlling runoff, erosion, and the costs and benefits of doing so have been performed in a number of countries with varying conclusions among different regions (Table 2) In Jamaica, bench terraces reduced soil loss from 121-133 tons/ha/yr under yellow yams and 183 under bananas to 15 5 and 15 5 tons/ha/yr on 30% slopes, respectively (Sheng 1979, 1989) In El Salvador bench terraces reduced soil loss from 110 to 33 tons/ha/yr on 30% slopes under maize and beans (Sheng 1979)

In Thailand, bench terraces reduced soil loss from 674 to 26 tons/ha/yr on 20% slopes and 155 to 34 tons/ha/yr on 35% slopes (Harper and El-Swaify 1988) In Java, Indonesia, a variety of terrace designs were studied with traditional cropping patterns with mixed crops, yielding soil loss of 12 6 tons/ha/yr for traditional plots and 1 5 tons/ha/yr for bench terraces and reduced runoff from 4263 4 to 2164 6 mm/ha/yr (Fagi and Mackie 1988) On a second site, soil loss was reduced from 212 to 2 8 tons/ha/yr while runoff was reduced from 888 to 795 mm/ha/yr (El-Swaify et al 1985) In Taiwan, four years of research was conducted comparing various terrace designs such as reverse slope, level terraces and outward sloping terraces on 17-32% slopes under tea, banana and citrus (Liao and Wu 1987 in Lal 1990) Table 2 shows a summary of these results, which indicate that level and reverse slope benches are more effective in reducing soil loss and runoff than outward sloping terraces In Malaysia, bench terraces were shown to reduce soil loss on 35% slopes under peppers from 63 to 1 4 tons/ha/yr (Hatch 1981, Chisci 1981, Pimentel 1993)

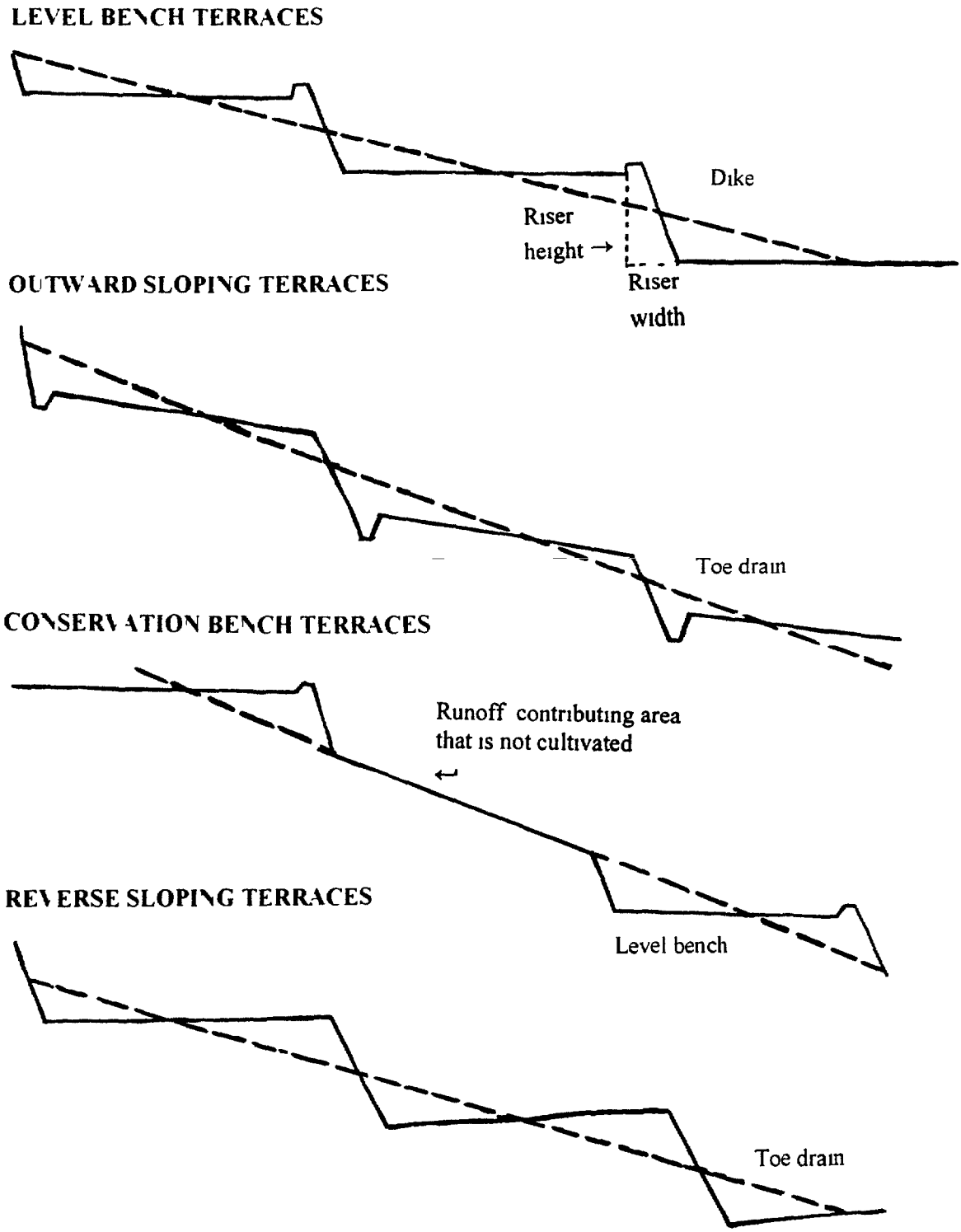


Figure 1 Types of bench terraces The dotted lines represent the original slope of the land surface (Sheng 1977)

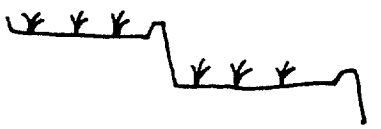
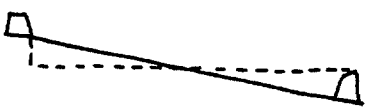
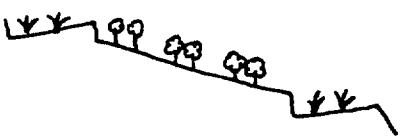
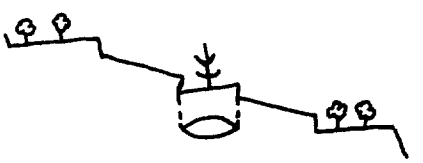
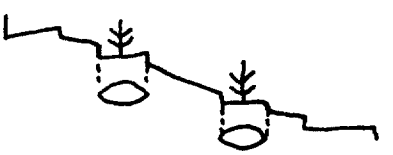
Type	Cross-sectional view	Use
CONVENTIONAL SYSTEMS		
1 Level bench terraces (Irrigation terraces or rice paddies)		Mainly for rice or irrigated crops
2 Reverse-sloped bench terraces		Rain-fed crops and/or irrigated crops in dry season
SIMPLER AND LESS EXPENSIVE SYSTEMS		
1 Natural terraces (stone retention walls, grass barriers, contour bunds, fanya juu)		Upland crops on slopes < 12% Terraces form naturally after several years
2 Intermittent terraces		Upland or irrigated crops on slopes < 36%, inter-spaces can be terraced over several years
3 Convertible terraces		Mixed farming uses or for flexibility in future land use, slopes < 36%, trees planted in individual basins
4 Orchard terraces with benches 1 75 m wide and individual basins		Tree crops or fruit trees on steep slopes > 46%

Figure 2 Cross-sectional views of various terracing designs

Table 4 Empirical formulae used by soil conservation agencies in different countries to determine vertical interval between two succeeding terraces (VI) (Morgan 1986)

United States Soil Conservation Service	VI (ft) = $aS + b$	where a varies from 0 3 in the south to 0 6 in the north and b is 1 or 2 according to the erodibility of the soil
Zimbabwe	VI (ft) = $\frac{S + f}{2}$	where f varies from 3 to 6 according to the erodibility of the soil
South Africa	VI (ft) = $\frac{S}{a} + b$	where a varies from 1 5 for low rainfall areas to 4 for high rainfall areas and b varies from 1 to 3 according to the erodibility of the soil
Algeria	VI (m) = $\frac{S}{10} + 2$	
Kenya	VI (m) = $\frac{0.3\ (S + 2)}{4}$	
Israel	VI (m) = XS + Y	where X varies from 0 25 to 0 3 according to the rainfall and Y is 1 5 or 2 according to erodibility of the soil
Taiwan/Jamaica	VI (m) = $\frac{S \times Wb}{100 - (S \times U)}$	where Wb is the width of the bench (m) and U is the slope of the riser, expressed as a ration of horizontal distance to vertical rise usually 1 0 to 0 75
China	VI (m) = $\frac{Wb}{(\cos S - \cot \beta)}$	where β is the angle of slope of the riser
Taiwan	VI (m) = $\frac{(Wb \times S) + (0.1S - U)}{100 - (S \times U)}$	for inward sloping bench terraces

VI = the vertical interval between two succeeding terraces which determines spacing, S= Slope (%), Wb = Width of bench

In Burundi, on 49% slopes, bench terraces reduced soil loss from 150 tons/ha/yr under traditional maize/beans cropping patterns to 5-11 tons/ha/yr (Fagi and Mackie 1988, Durand 1984 in Roose 1988) Results from a study in Sierra Leone show that soil loss was reduced by bench terracing from 41-55 tons/ha/yr under no conservation with rice on 31% to 7 5 tons/ha/yr (Lal 1990, Millington 1982) However the labor requirements are high In Burundi, approx-imately 800 man days/ha/yr are necessary to construct bench terraces on 49% slopes and in Sierra Leone 708 man days/ha/yr is required for 31% slopes (Durand 1984 in Roose 1988) (Table 7)

Studies also show that bench terraces can increase crop yield (Table 8) In Sumatra, Indonesia, under peanut cultivation, total crop yield at the base of the riser was 4,112 kg/ha/yr, while on mid bench sites peanut yield was 8,160 kg/ha/yr Total biomass increased from 190,736 kg/ha/yr to 16,160 kg/ha/yr and percent Carbon increased from 1 46 at the base to 4 45% Both N and P increased slightly also (from 0 14% to 0 32% for N and from 0 2 to 4 4 ppm for P) (Siebert and Belsky 1990) This indicates yield differences at different locales along the terrace, probably resulting in an accumulation of fertile soil towards the lower slope of the terrace However, cropping area for bench terraces with peanut cultivation was reduced by 32% under

Table 5a Specifications for bench terraces (Fang et al 1980)

Land slope α (°)	Height of riser (m)	Riser slope β (degrees)	Width of bench (m)	Percent land loss (%)
5 (7%)	1	76	11 2	2 2
	2	74	22 3	2 5
10 (18%)	2	74	10 8	5 1
	3	72	16 1	6
15 (27%)	2	74	6 9	7 8
	3	72	10 2	8 6
20 (36%)	2	74	4 9	10 6
	3	72	7 3	11 6
25 (47%)	2 5	73	4 6	14 5
	3 5	71	6 3	15 9

Table 5b Conversion values for percent (%) and degree (FAO 1988)

Degree	%	Degree	%	Degree	%	Degree	%	Degree	%
1	1 8	6	10 5	11	19 4	16	28 7	21	38 4
2	3 5	7	12 3	12	21 3	17	30 6	22	40 4
3	5 2	8	14 1	13	23 1	18	32 5	23	42 4
4	7 0	9	15 8	14	24 9	19	34 4	24	44 5
5	8 6	10	17 6	15	26 8	20	36 4	25	46 6

bench terraces as opposed to a 17% reduction for grass bunds (Siebert and Belsky 1990) Not all studies have concluded that terracing is an effective method of soil conservation Studies in the Uluguru Mountains of Tanzania show that the terrain is not suitable for terracing, primarily because the topsoil is too thin, the construction exposes the infertile soil and accelerates soil loss, the labor input for construction and maintenance required is too high, and enough water to cause landslides during heavy rains is held back (Temple 1972) In this case, Morgan (1986) recommends the use of step or ladder terraces (*fanya juu*) In addition, surveys conducted in the Machakos District of Kenya showed that many steep reverse-sloped terraces were inadequately maintained or poorly constructed The banks were either too low to prevent runoff or there was a need for grass cover on the banks for stabilization, which are both factors that can lead to terrace collapse (Barber et al 1981)

Labor costs for bench terraces as soil conservation methods pose their biggest disadvantage Table 7 summarizes labor costs for different conservation practices by region. Labor costs for terraces range from as low as 100 man days/ha/yr for contour bunds in natural terracing systems in Thailand to 253 for rock walls on 20% slopes in El Salvador to 1,800 for bench terraces on 50% slopes (Sheng 1975, Stocking and Abel 1992) Clearly, the labor needed for construction of terraces can be demanding and costly Bench terraces require more labor than stone or contour bunding (*fanya juu*) terraces Furthermore, there can be economic disadvantages due to the reduction in cropping area in bench terraces A soil conservation project in Sumatra, Indonesia shows that bench terraces reduce cropping area for peanuts by 32% and 13% for corn compared with traditional practices (Siebert and Belsky 1990) Poorly maintained bench terraces increased soil erosion on 4% of farms surveyed The survey revealed that only 63% of

Table 6 Specifications for hand made bench terraces (riser slope = 0 75 1 and reverse slope = 0 05) (FAO 1988)

Width of the bench Wb (m)	Slope		SPECIFICATION										
	%	Grade	VI (m)	RH (m)	Hr (m)	Dc (m)	Wr (m)	Wt (m)	L (m)	A (m)	Pb (%)	C (m^2)	V (m^3)
3 00	42	22 8	1 84	0 15	1 99	0 71	1 49	4 49	2227	6681	67	0 75	1670
	44	23 7	1 97	0 15	2 12	0 73	1 59	4 59	2179	6537	65	0 80	1743
3 50	20	11 3	0 82	0 18	1 00	0 44	0 75	4 25	2353	8236	82	0 44	1035
	24	13 5	1 02	0 18	1 20	0 51	0 90	4 40	2273	7956	80	0 53	1205
	28	15 6	1 24	0 18	1 42	0 58	1 07	4 57	2188	7658	77	0 62	1357
	32	17 7	1 47	0 18	1 65	0 65	1 24	4 74	2110	7385	74	0 72	1519
	36	19 8	1 73	0 18	1 91	0 72	1 43	4 93	2028	7098	71	0 84	1704
	40	21 8	2 00	0 18	2 18	0 79	1 64	5 14	1946	6811	68	0 95	1849
4 00	20	11 3	0 94	0 20	1 14	0 50	0 86	4 86	2058	8232	82	0 57	1173
	24	13 5	1 17	0 20	1 37	0 58	1 03	5 03	1988	7952	80	0 69	1372
	28	15 6	1 42	0 20	1 62	0 66	1 22	5 22	1916	7664	77	0 81	1552
	32	17 7	1 68	0 20	1 88	0 74	1 41	5 41	1848	7392	74	0 94	1737
	36	19 8	1 97	0 20	0 77	0 36	0 58	4 83	2070	8798	88	0 41	849
4 50	20	11 3	1 06	0 23	1 29	0 57	0 97	5 47	1828	8226	82	0 73	1334
	24	13 5	1 32	0 23	1 55	0 66	1 16	5 66	1767	7952	80	0 87	1537
	28	15 6	1 60	0 23	1 83	0 75	1 37	5 87	1704	7668	77	1 03	1755
	32	17 7	1 90	0 23	2 13	0 83	1 60	6 10	1639	7376	74	1 20	1967
5 00	20	11 3	1 18	0 25	1 43	0 62	1 07	6 07	1648	8240	82	0 89	1467
	24	13 5	1 46	0 25	1 71	0 73	1 28	6 28	1592	7960	80	1 07	1703
	28	15 6	1 77	0 25	2 02	0 82	1 52	0 52	1534	7670	77	1 26	1933

VI = Vertical Interval
RH = Reverse Height
Hr = Height of the riser
Dc = Depth of the cut

Wr = Width of the riser
Wt = Width of the terrace
L = Length of the terrace per ha
A = Area of the benches (flat area) per ha

Pb = Percentage of the benches
C = Cross section of the terrace
V= Volume of the cut per ha

Table 7 Comparison of labor costs for terraces Blank spaces in the table indicate that the particular information was not reported in the publication

Country	Conservation type and conditions	Slope (%)	Labor (man days/ ha/yr)	Labor (man hrs/ 100 m)	Source
Burundi	bench terraces, maize and beans	49	800		Durand 1984
China	bench terraces		900		McLaughlin 1993
El Salvador	bench terrace	44	500		Sheng 1979
	hillside ditches	55	100		
	intermittent terraces	44	167		
	orchard terraces	44 60	112		
	individual basins	44 60*	12	16*	* = 200 basins/ha
	natural terraces, contour bunds	15	100		
El Salvador	hillside ditches with vegetation				Wiggins 1981
	protected main drains	20	84		
		30	114		
		40	143		
	stone wall barriers with drains				
		20	253		
		30	279		
		40	310		
	bench terracing				
		20	238		
		30	266		
		40	283		
	live barriers				
		20	40		
		40	43		
Honduras	biological conservation (labor over maize monocrop)				Rodriguez 1980
	Maize/cassava/beans intercrop		148		
	Maize/cassava with terrace		207		
India (NE)	establishment of terrace cultivation		696		Mishra and Ramakrishnan 1981
Indonesia (Java)	bench terraces on slopes up to 50%		750 -1800		Barbier 1988
Jamaica	bench terraces for 0 8 acre farm				Sheng 1986
	Construction	13	496		
	Maintenance	13	42		
Kenya	fanya juu terrace	5	150		Barrett 1985
	fanya juu terrace	20	250		Wenner 1980
Kenya	fanya juu terrace	35	281		
Peru	terraces with grass side slopes		336		Alfaro Moreno 1988
	contour furrows		110		
	infiltration ditch		205		
	terraces		1181		
	contour furrows		328		
	infiltration ditch		57		
Sierra Leone	contour bunding	31		19	Millington 1982
	bench terrace	31		708	
	stone bunding	31		31	
	no method	31		15	
Vietnam	full integrated agroforestry		1500		Stocking and Abel 1992
	annual maintenance		55		
West Africa Sahel	contour stone bunds for terraces		180		Reij 1994

Table 8 Comparison between terracing on soil nutrients, crop yield, and infiltration rates Blank spaces in the table indicate that the particular information was not reported in the publication See Table 2 for site characteristics

Country	Land-use Practice	Slope (%)	Total Biomass (kg/ha/yr)	Grain Yield (kg/ha/yr)	OM (%)	N (kg/ha)	P (kg/ha)	Infiltration rate (cm)	Source
Ethiopia	traditional	28				60 56	31 5	0 2	Kejela 1992
	graded bund	28				16 7	12 2		
	level fanya juu	28				26 3	13 2	5 5	
	traditional	12				84 5	15 5	2 6	
	graded bund	12				76 3	10 9		
	level fanya juu	12				27 7	3 6	8 1	
	grass strips	12				68 9	9 9		
	badlands with grass	16				128 4	50 9	3 2	
	badlands with gully	16				138 5	64 8	0 1	
	traditional, lentils		8,450	2,580					Keddeman 1992
	grass strip, lentils		8,950	2640					
	graded fanya juu, lentils		11,330	3,220					
	level fanya juu, lentils		13,370	4,850					
Indonesia	base of terrace riser, peanuts		10,736	4,112	1 46 (%C)	0 14%	6 (0 3 ppm)		Siebert and
	mid-bench sites, peanuts		16,160	8,160	4 45 (%C)	0 32%	8 (4 4 ppm)		Belsky 1990
Honduras	traditional, maize and sorghum	60	5,170	1,179	5 6	4 1	35 2		Sierra 1996
	rock wall terraces maize and sorghum	60	7,167	1,996	6 5	93 9	30 2		
	traditional, maize and sorghum	60	2144	798	5 98	0 28%	5 3		Thompson 1992
	rock wall terraces maize and sorghum	60	3369	1161	7 96	0 28%	6 7		

subsidized users (which accounted for 24% of those who had constructed bench terraces, of which 20% did so because they were promised payments) and 47% of un-subsidized users maintained their terraces (Siebert and Belsky 1990) Terraces were not maintained because they conflicted with existing agroforestry techniques that are less labor demanding Farmers believed that tree crops provide sufficient protection against erosion and reported that the use of terraces typically resulted in topsoil loss and an initial reduction in crop yield, competition between crops and grasses on the risers, and a 25-35% loss of cropping area (Siebert and Belsky 1990) A study in Jamaica showed similar results related to terrace maintenance In a survey of 99 plots of land with bench terraces, 40% were poorly maintained, 50% were adequately maintained, and only 10% were very well maintained The major reason for non-maintenance seemed to be the labor constraints, requiring 37 man days/ha/yr for bench terraces and 12 man days/ha/yr for both hillside ditches and orchard terraces (Blustain 1982)

The advantage of bench terraces is that they constitute, under many circumstances, the most effective method of controlling soil loss on steeplands The above-noted studies demonstrate the considerable effectiveness of bench terraces in controlling soil loss on steeplands compared to using no conservation method at all The greatest barrier to installing terraces is high labor and maintenance costs Once the initial investment is made the terraces must be maintained, otherwise they can increase the risk of landslides and in some cases, increase soil loss Furthermore, unless installed correctly, terraces can concentrate water and make the erosion problems worse Reduced cropping area, competition with traditional practices, and technologically difficult design specifications are additional disadvantages to complex terrace systems The feasibility and benefits should therefore be considered in the context of local variables, such as labor resources, risk factors and land use before a decision regarding the installation of bench terracing efforts is made

Convertible and Intermittent Terraces

Both the convertible and intermittent terraces have the same design characteristics as bench terraces, the main difference is based on when they are built (Figure 3) Intermittent terrace construction is staggered over a period of three to four years and is planned so that a complete bench terrace system is achieved in a number of years Initially, only one of every three terraces is constructed The reason for doing this is to spread labor requirements over several years Convertible terraces are widely spaced bench terraces alternating with strips of untreated hillsides for mixed farming systems The benches are used for cultivating staple foods while the unchanged slopes are used for semi-permanent tree crops If the need arises, they can be converted into terraces for staple food cultivation The terrace spacing should be calculated in the same way as for hillside ditches (Table 3)

Naturally Formed Terraces

Broad base, formally constructed bench terraces are often not practical because of the high labor demand or need for machinery, and simpler variations of bench terracing may be more appropriate and effective (Sheng 1986) Simpler and less expensive terracing systems include natural terraces (Figure 4) Natural terraces are divided into three types according to the material that is used to retain the soil and form a terrace over time stone retention walls, soil bunds (*fanya juu*), and live barriers using grasses, trees and/or shrubs Natural terraces are preferred to bench terraces where labor or money for formal bench terracing is lacking Vegetation barriers obstruct sediment transport and continue to grow as the sediment accumulates to form a terrace Rock wall and soil bund terraces obstruct sediment transport and eventually a terraces is formed behind the barrier Often trees will be planted at the edge of the rock barrier or soil bund to help stabilize the structures Vegetation barriers take longer to form a terrace than if a terrace is physically

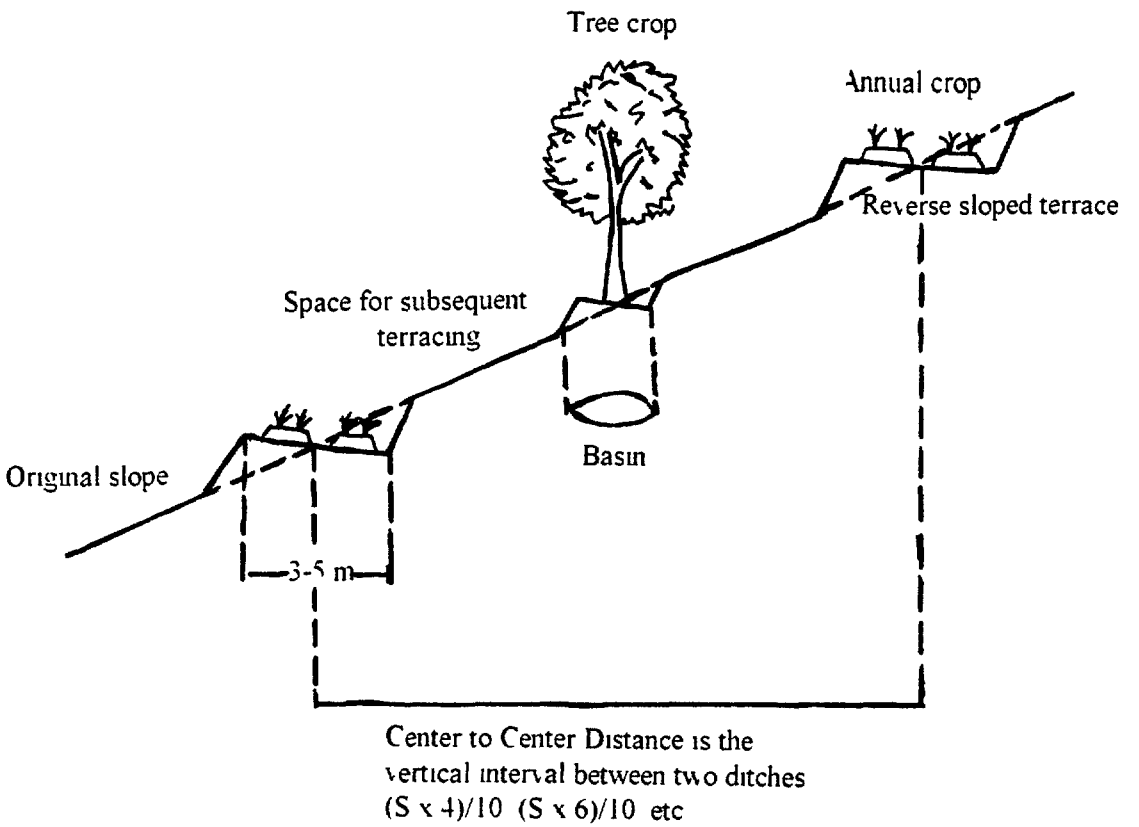


Figure 3 Cross-sectional view of convertible terrace (FAO 1988)

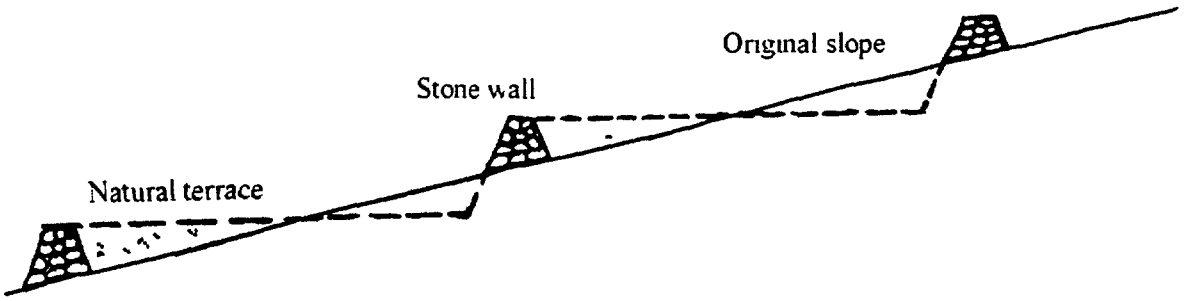


Figure 4 Cross-sectional view of natural terrace system (FAO 1988)

constructed, but they are less labor demanding (Shaxson et al 1989) Materials for creating a barrier include rocks, soil and/or crop residues, shrubs, and grasses Natural terracing is often suitable for small farms, replacing the broad based terraces used more often on large farms Natural terraces can be constructed on steep slopes but are recommended for use on slopes that are not more than 12%, and on soils with a fair rate of infiltration (Sheng 1977, 1982, Shaxson et al 1989)

Stone Retention Walls

Construction of stone retention walls, sometimes in conjunction with hillside ditches, is a common method of natural terracing techniques in Central and South America Stone retention walls are structures built along the contour of the slope with the purpose of slowing down and diverting rainfall, controlling erosion off of steeplands and forming a natural terrace over time (Figure 4 and 5) The following design is recommended for the construction of rock retention walls (Figure 6) (LUPE 1996)

1) Dig out a ditch along the contour 20 cm deep and 30-60 cm wide where the base of the wall will be built (30 cm base for 50 cm height, 45 cm base for 75 cm height, and 60 cm base for 100 cm height)
2) Rocks carried from the field are usually used and built up to 1 m in height with large rocks, then filled in with small pebbles or soil
3) Trees can be planted at the base of the wall to protect from soil movement and live barriers (grasses) should be planted 10 cm above, along the edges of the terrace (Figure 9) It is important that once the soil has filled in completely behind the wall it, the wall should be raised, as it will no longer serve to block runoff and prevent soil loss

The advantages of rock retention terraces include that they are (Williams and Walter 1988)

- effective at reducing soil loss
- require less maintenance and therefore have lower labor costs than bank terraces
- terraces that can be constructed without physically leveling the land
- rock on the surface becomes a resource rather than an hindrance
- require little knowledge of terrace engineering
- represent a long-term investment

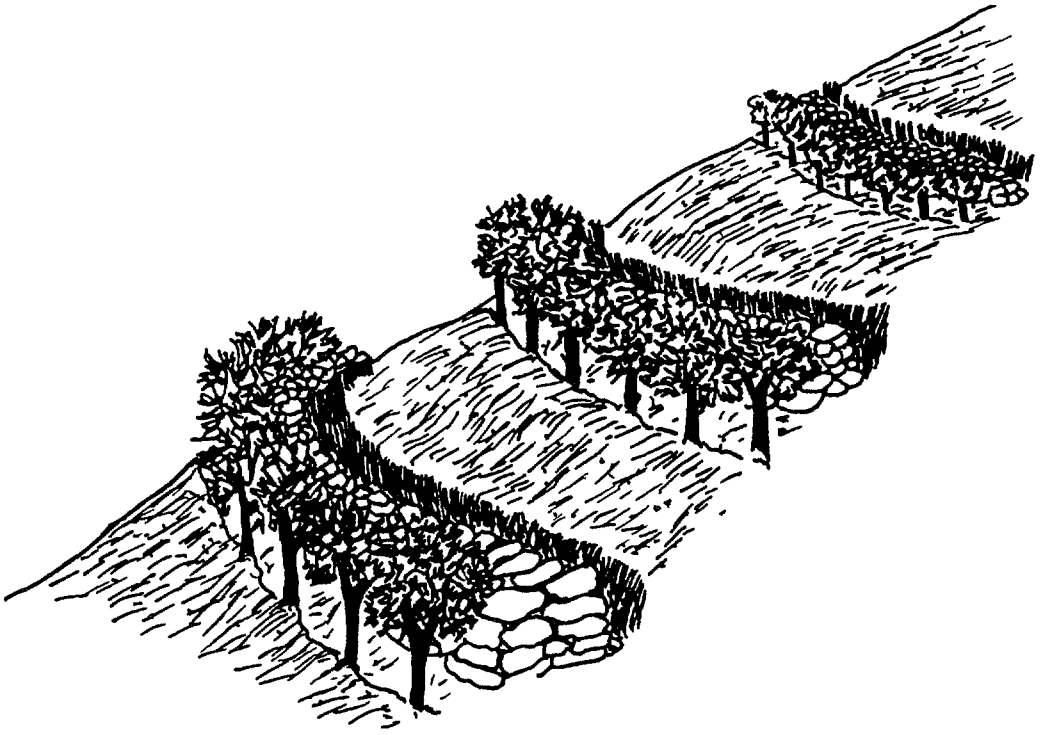


Figure 5 Natural terrace system using rock retention walls, combined with grass barriers and shrubs for wall stabilization (LUPE 1996)

The disadvantage is that stone walls take longer to reduce runoff and erosion than formally constructed bench terraces and they are still more labor intensive than soil bunding and live barriers Furthermore, it is not clear how much greater the benefits are compared with these other practices compared with the greater costs

Various studies have been conducted investigating the effectiveness of rock terracing Table 2 gives a summary of these In Java, Indonesia, a variety of terrace designs were studied with traditional cropping patterns, yielding soil loss of 12 6 tons/ha/yr from traditional plots compared with 5 7 tons/ha/yr from ridge terraces (constructed stone barrier/bunding type) Stone and soil terracing were effective in controlling erosion but not as effective as bench terraces, which reduced soil loss to 1 5 tons/ha/yr (Fagi and Mackie 1988) A study in Sierra Leone showed soil loss of 41-55 tons/ha/yr under traditional rice cultivation being reduced to 30 tons/ha/yr and under traditional cassava a reduction from 11-55 to 4 4 tons/ha/yr with stone wall terracing However, soil bunding reduced this to 18 and 17, respectively, indicating soil bunds to be more effective than stone walls as a barrier (Lal 1990, Millington 1982) Furthermore, the labor requirement is lower for soil contour bunding than stone bunding or bench terraces, with contour bunds requiring 19 man hours/100 m, stone barriers requiring 31 man hours/100 m and bench terraces requiring 708 man hours/100 m in Sierra Leone on 31% slopes (Millington 1982) Likewise, in El Salvador on 30% slopes stone walls with drains require 279 man

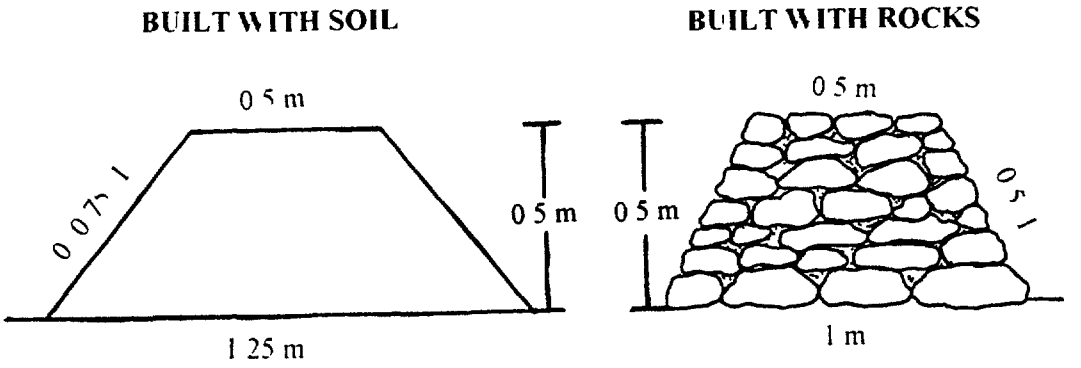


Figure 6 Rock retention wall design

days/ha/yr, while bench terraces require 266 man days/ha/yr and grass barriers require only 43 on 40% slopes (Wiggins 1981), although other estimates of 100 man days/ha/yr have been given (Sheng 1979) Labor requirements vary greatly In Sierra Leone, stone bunding requires only 31 man days/ha/yr on 31% slopes and in West Africa 180 man days/ha/yr are needed (Durand 1984 in Roose 1988, Millington 1982) (Table 7)

However, stone wall terraces were demonstrated to be ineffective in the Dominican Republic on slopes of 30% under mixed crop cultivation, where soil loss off of rock wall terraces was measured at 163 tons/ha/yr while soil loss off of non-terraced, traditional farming plots with mixed grains was measured at 187 tons/ha/yr, only slightly higher (Veloz and Logan 1988) In this case, erosion from both plots was extremely high and terraces were not working sufficiently to control soil loss In the same study, where there was a no-tillage system in place, soil loss measured only 2 tons/ha/yr, a considerable reduction for a less labor demanding practice (Veloz and Logan 1988) Nor were stone barriers effective in reducing runoff in the same study Runoff from rock wall terraces was measured at 142 mm/ha/yr, while off of traditionally cropped fields it was 166 mm/ha/yr and only 11 mm/ha/yr off the no-tillage plots under average precipitation of 1530 mm/ha/yr on 30% slopes (Veloz and Logan 1988) In Java, runoff from ridge terraces was 4963, 1305 and 990 mm/ha/yr in three sites while under traditionally cropped fields runoff was less, at 4263 4, 885, and 390 mm/ha/yr, respectively, under the same conditions at the three sites (1945 mm annual precipitation) (Fagi and Mackie 1988)

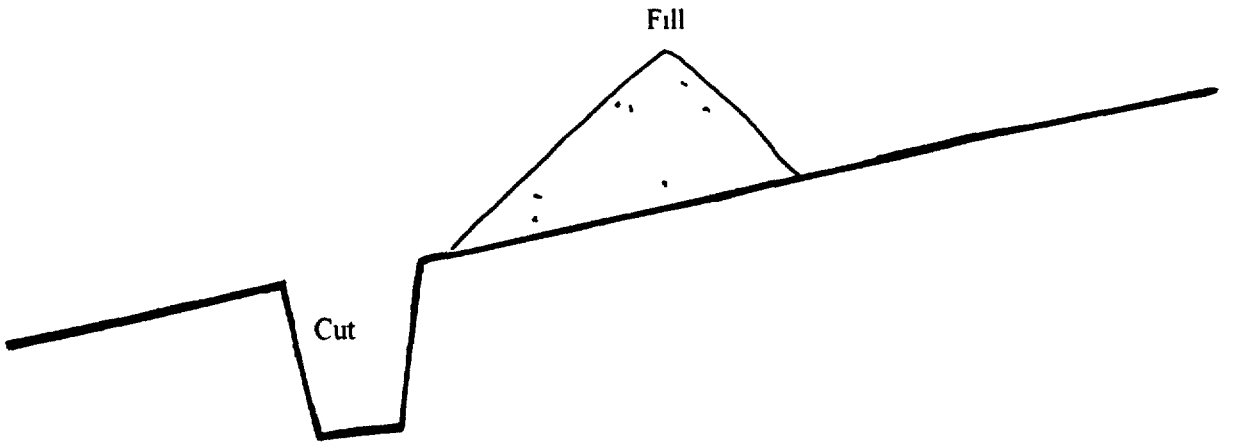


Figure 7 Cross-sectional view and design of *Fanya juu* natural terraces

Soil Bunding or Fanya juu Natural Terraces

Fanya juu is a form of progressive or natural terracing, common to Africa and Indonesia (Figure 7) *Fanya juu* is (Swahili meaning 'throw up') where the excavated soil is thrown uphill to form a ridge The runoff is captured by the ditch and allows the water to infiltrate slowly The bunds should be 1 m wide at the base and 0 5 m wide at the top (pyramid-like form), with a height of 0 5 ms They should be designed so that the top of the lower bund is level with the middle of the slope to the next higher bund The disadvantages of *fanya juu* terraces include high labor costs for construction and maintenance, irregularity of width of terraces and bunds, and inconvenient access, particularly in using agriculture machinery

Measurements in Ethiopia show the potential effectiveness of *fanya juu* contour bunds, where over a two year period this terrace system reduced soil loss from 123 tons/ha/yr under traditional cultivation to 56 tons/ha/yr on 28% slopes (Kejela 1992 and Keddeman 1992) A second site with 12% slopes demonstrated soil loss under *fanya juu* of 73 tons/ha/yr the first year and 39 tons/ha/yr the second year (1985 and 1986 measurements), both on soils that demonstrated soil losses of 269-322 tons/ha/yr with 16% slope under badland conditions (Kejela 1992) In Sierra Leone, traditional cropping systems resulted in 41-55 tons/ha/yr while soil bunding resulted in soil losses of 18 tons/ha/yr under 31% slopes (Lal 1990, Millington 1982) (Table 2)

Research on nutrient loss from runoff and erosion, primarily associated with eroded sediments showed significant decreases in nutrient loss using *fanya juu* terraces (Kejela 1992) (Table 8) A study was conducted on *fanya juu* terrace systems and total losses of N and P were calculated in *Birr*/ha/yr for 1985-1986 (2 07 *Birr* Ethiopia = $1 US) On *fanya juu* terraces a 766 7 *Birr*/ha/yr loss was calculated compared to a 1613 *Birr*/ha/yr loss

on traditional fields and 2524 *Birr*/ha/yr on degraded land without cover (Kejela 1992) On traditional cultivation under 28% slopes there was a loss of 61 kg/ha of N and 31 5 kg/ha loss of P, while under *fanya juu* systems only resulted in a 26 3 kg/ha loss for N and 13 2 kg/ha loss for P Graded bunds reduced these losses further to 16 7 and 12 2 kg/ha for N and P, respectively Under badlands with grass cover only there was a loss of 128 kg/ha for N and 51 kg/ha loss of P *Fanya juu* systems also increased the infiltration rate from 0 2 cm under traditional fields to 5 5 cm on 28% slopes, a dramatic increase of the amount of water able to percolate into the soil column *Fanya juu* terraces significantly increased nutrient availability in this case and thus reduced economic loss

In Kenya, crop production and yield increases were measured and a cost/benefit analysis conducted (Tjernstrom 1992) The study showed a 47-84% relative difference in yield increase between *fanya juu* terraces and non-terraced plots (on 9-16% slope in 700-1200 mm) The mean annual income was 55% higher for terraced fields than non-terraced The cost benefit analysis calculated that the *fanya juu* terracing has an Internal rate of return (IRR) of 59% because costs of construction and maintenance are low compared to long-term benefits The study used a 390 man days/ha/yr labor requirement for traditional agriculture plots and 454 man days/ha/yr for terraced plots in the cost/benefit calculations (Tjernstrom 1992) The weighted average difference in maize and bean yield between terraced and non-terraced land used was 400 kg and 77 kg, respectively The conclusions of this study are in sharp contrast to a similar study also conducted in the same region of Kenya (Machakos District) on *fanya juu* terracing, whose IRR was 10% Pagiola (1994) concluded that it would take 48 years to break even with *fanya juu* terracing, given the costs that go into the construction The study used USLE soil loss estimates of 46 3 tons/ha/yr, equivalent to a mean reduction in topsoil depth of 3 mm/yr given the soil's bulk density of 1 52 g/cm^3, and 107 man days/ha/yr for construction costs (Pagiola 1994) One of the differences between the two studies was the yield difference Tjernstrom (1992) used a fixed yield difference, which Pagiola (1994) did not Tjernstrom (1992) used measured differences in the field and Pagiola (1994) used calculations based upon estimated factors and the two studies had very different Internal rates of return However, the contrast of the findings of these two studies illustrates the difficulties involved in estimating economic costs, benefits and tradeoffs for different soil conservation practices

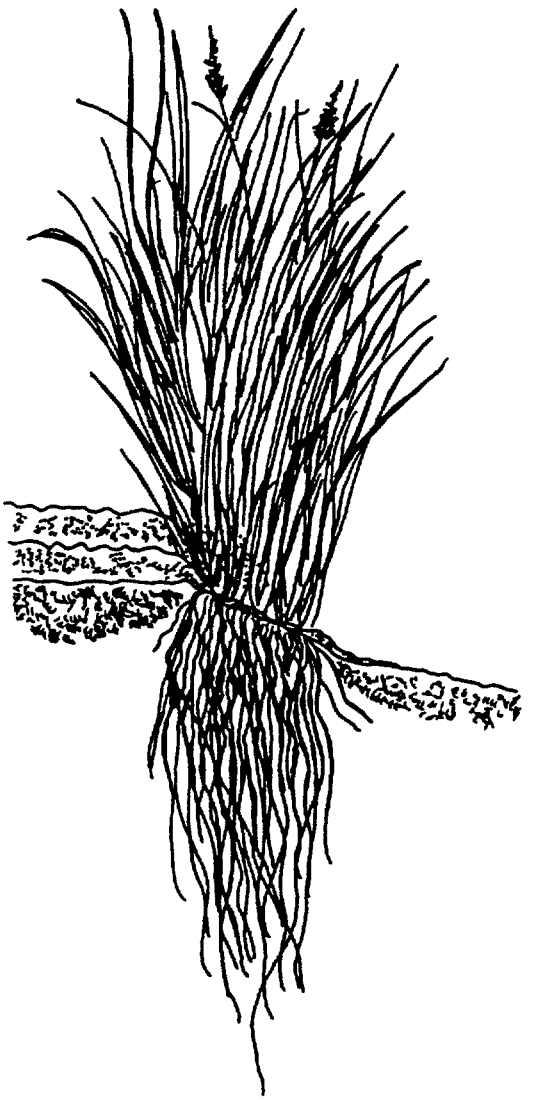


Figure 8 Grass barrier used to form natural terraces Cross sectional view showing soil accumulation behind barrier (LUPE 1996)

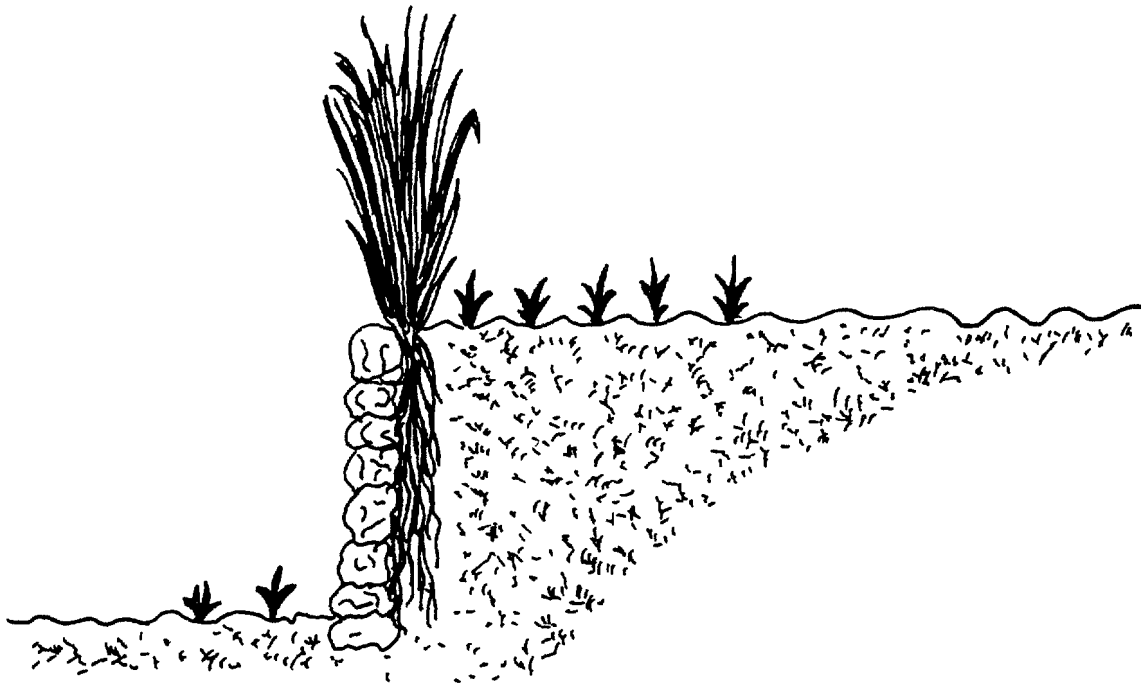


Figure 9 Cross-sectional view of grass barrier combined with rock wall to create a natural terrace (LUPE 1994)

Live or Vegetative Barriers using Grasses Shrubs and Multi-purpose Trees

Planting grasses, shrubs or trees along the contour is a common method of stabilizing the soil with roots and creating a natural terrace by providing a barrier to runoff and soil erosion (Figure 8) Slope stability is governed by load weight, slope geometry and the resistance provided by the strength of the soil-root system (Morgan and Richson 1995) Live barriers are herbaceous perennial plants with dense growth and strong root systems which are resistant to the overland flow of water and serve to block soil particles as they move down the gradient Live barriers serve to control erosion by reducing the velocity of runoff, improving the infiltration rate and retaining soil (LUPE 1996) The fine roots (1-20 mm in diameter) contribute most to soil reinforcement (O'Loughlin 1984 in Wu 1995) Grasses, legumes and small shrubs can have a significant reinforcing effect to a depth of 1 5 m and trees can enhance soil strength to 3 m or more (Wu 1995)

Combining vegetation with physical rock or soil structures is highly desirable to reduce the risk of hillside slippage (Figure 9) Vetiver (*Vetiveria* spp) is a commonly used grass for live barriers and considered the most effective for erosion control (BOSTID 1993) Napier or Elephant grass (*Pennisetum purpureum*) is also commonly used for erosion

purposes, recommended for slopes up to 30% slopes (LUPE 1996) However, it has the disadvantage that it cannot be used in a single line like Vetiver, the stalks are weaker, the gaps between them too wide for it to stem heavy runoff and it's roots are shallow Lemongrass (*Cymbopogon citratus*) is common in Central America, Citronella (*Cymbopogon nardus*) is found in Africa and Asia, Rhodes grass (*Chloris gayana*) is sometimes used as a Vetiver substitute in Africa and is cultivated for fodder and Panic grass (*Panicum* spp) or "kisosi" is used as an erosion hedge on gentle slopes (BOSTID 1993) *Calamagrostis festuca* was planted in bands above terraces used by the Incas to protect the soil and spread runoff

Advantageous characteristics of a grass used for erosion control are

- Rigid leaves to slow overland flow and trap sediment
- Root system that have strong, vertical, deep-penetrating roots but limited horizontal root growth, which reduces competition for crops
- Growth pattern which is not so aggressive as to require high labor input for pruning
- Easy and inexpensive to establish
- Free of insects and diseases
- Durable and hardy, capable of surviving in many soil types under a wide range of climates
- If livestock access is controlled, grass species may be grown for harvest in a cut and carry forage system
- If livestock grazing is not controlled it is better to use an unpalatable species

LUPE (1996) recommends Lemongrass, King grass (Hybrid of *P purpureum* x *P typhoides*) for use on slopes up to 20-25% and Vetiver grass (*Vetiveria* spp) for use on slopes up to 60% (LUPE 1996) Natural terraces up to 4 m high have been formed with Vetiver grass barriers alone (Leonard 1992a)

Vetiver and other grasses are mainly propagated by root division and slips The slips be planted at a distance between 15 and 20 cm, and buried 5 cm deep in a line along the contour, angled slightly uphill (LUPE 1996) Hedges are formed by jabbing slips into holes or furrows close together (10 cm) but if plants are scarce, up to 20 cm apart, although the hedge will take longer to close (BOSTID 1993) Grasses should be cut back when they reach a height of 75 cm to 1 m (LUPE 1996) A second method of planting uses cane laid flat, cut the length of 4 nodes Once these start growing roots and stalks they can be transplanted to the site Parameters for planting Vetiver grass are listed in Table 9 (Leonard 1992a)

Multipurpose and Nitrogen Fixing Trees (NFT's) are also commonly used for stabilizing terraces and are best planted below the soil or stone barrier for roots to penetrate and stabilize the barrier (Figure 5 and 10) This system can

Table 9. Recommended distance and specifications for planting vetiver (Leonard 1992a)

Recommended Distance for Live Barriers on the Contour of Varying Slopes			
Slope (%)	Distance between barriers (m)	Slope (%)	Distance between barriers (m)
20	9 5	36	6 00
22	9 0	38	5 75
24	8 5	40	5 50
26	8 0	42	5 25
28	7 5	44	5 00
30	7 0	46	4 75
32	6 5	48	4 50
34	6 25	50	4 50

Figure 10 Live barrier terrace system using multi-use shrubs/trees (LUPE 1994)

be used in several types of agroforestry systems such as alley cropping, *Taungya* or hedgerows and borders (Lal 1990) Trees most apt for lining terraces should have deep tap roots, improve soil nutrients (NFT's), preferably have other beneficial uses, such as fodder or fuelwood and be capable of regrowth after severe pruning These trees are generally managed by pruning annually prior to the growing season to reduce shading and otherwise limit competion with agricultural crops *Leucaena leuecophala* and *Gliricidia sepium* are two commonly used species, although there is a wide variety of species within different regions On slopes up to 30% trees can be planted as a live barrier alone rather than along a terrace Planting distance of 5-7 m between rows of trees and 25-50 cm between individual trees in one row is generally recommended, but in more arid zones 7-10 m may be more effective (Leonard 1992b) Each year at the onset of the planting season they should be cut back to 0 5-1 m in height and cut every 6-10 weeks to prevent shading and competition with the crops, but should be left to grow during the dry season for fuelwood, fodder and organic material (Leonard 1992b)

Studies show that grass barriers can be effective in reducing soil loss In the Dominican Republic, a grass barrier combined with hillside ditches on 30% slopes reduced soil loss from 1254 tons/ha/yr on a bare plot and 187 tons/ha/yr under mixed traditional cropping with no conservation to 81 tons/ha/yr using grass barriers On the same site, runoff was reduced from 579 and 166 mm/ha/yr (bare plot and traditional, respectively) to 111 mm/ha/yr under grass barriers (Veloz and Logan 1988) However, a no-till conservation system reduced runoff to 11 mm/ha/yr and reduced soil loss to 2 tons/ha/yr at the same site In El Salvador, where study results demonstrated 110-127 tons/ha/yr soil loss under traditional cropping with maize and beans on a 30% slope, grass barrier terraces with maize and beans reduced soil erosion to 71 5 tons/ha/yr (Sheng 1979) In Indonesia, no conservation plots on 33-38% slopes under peanuts and corn with, produced 4 tons/ha/yr of soil loss and grass barrier bunds produced 0 7 tons/ha/yr (Siebert and

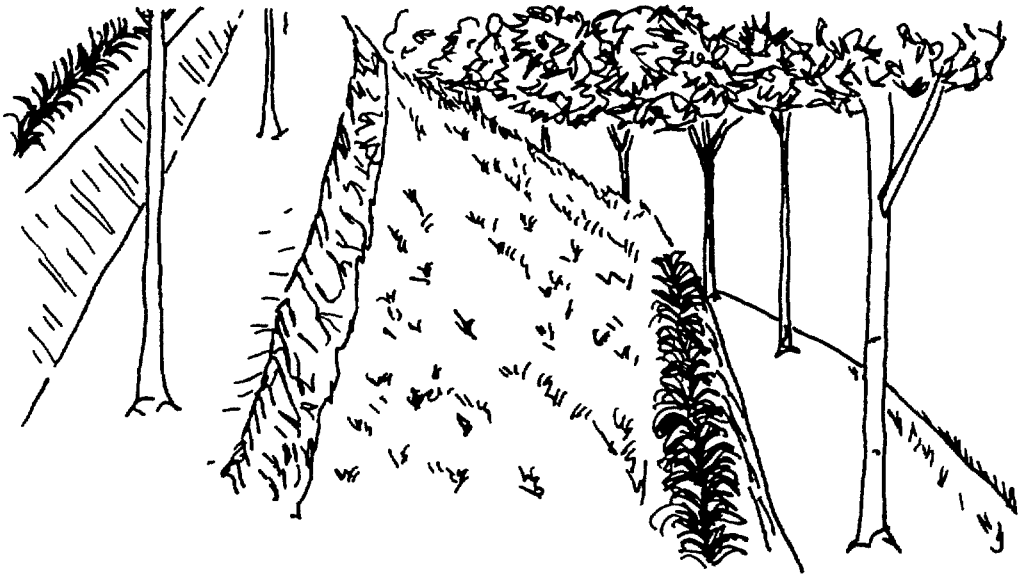


Figure 11 Orchard and intermittent terrace system

Belsky 1990) Results showed that terraces reduced soil loss by 70% while grass barriers reduced soil loss by 79-86%, clearly demonstrating that grass barriers would be more cost effective than terraces (Siebert and Belsky 1990) (Table 2) A study in Ethiopia demonstrated reduced nutrient loss on 12% slopes from 84 5 kg/ha/yr on traditional no conservation plots to 69 kg/ha/yr for N and 15 5 to 9 9 kg/ha/yr for P under grass strip barriers (Kejela 1992) (Table 8)

Although grass barriers alone may not be as effective as bench terraces in reducing soil loss and runoff, combined with bench terraces, stone barriers and/or hillside ditches they can be very effective The advantage is that grass barriers are less labor demanding In El Salvador, on 40% slopes, they require only 43 man days/ha/yr, while hillside ditches with barriers require 143 man days/ha/yr, bench terraces require 283 man days/ha/yr and stone wall barriers with drains require 310 man days/ha/yr (Wiggins 1981) (Table 7)

Orchard Terraces and Individual Basins

Orchard terraces are a discontinuous type of narrow, reverse sloped bench terraces, applicable on slopes up to 58% (Sheng 1977, 1989) (Figure 11) The spacing between two orchard terraces is determined by the planting distance of the tree crop Spaces between trees should be protected by permanent vegetative cover One orchard terrace will usually serve two rows of trees The width for each terrace is 1 75 m and the area of the platform is determined as A= L x Wb, where L is the length of the terrace and Wb is the width of the bench (FAO 1982, Sheng 1986) (Table 3) LUPE (1994) suggests 5% reverse slopes (15 cm for a platform of 1 5 m wide) and that they be used for permanent crops Specifications for hand made orchard terraces are given in Table 10 (FAO 1988)

Individual basins are small round benches used for planting individual plants (Figure 12) The diameter is adjusted to the needs of the tree crop Recommended para-

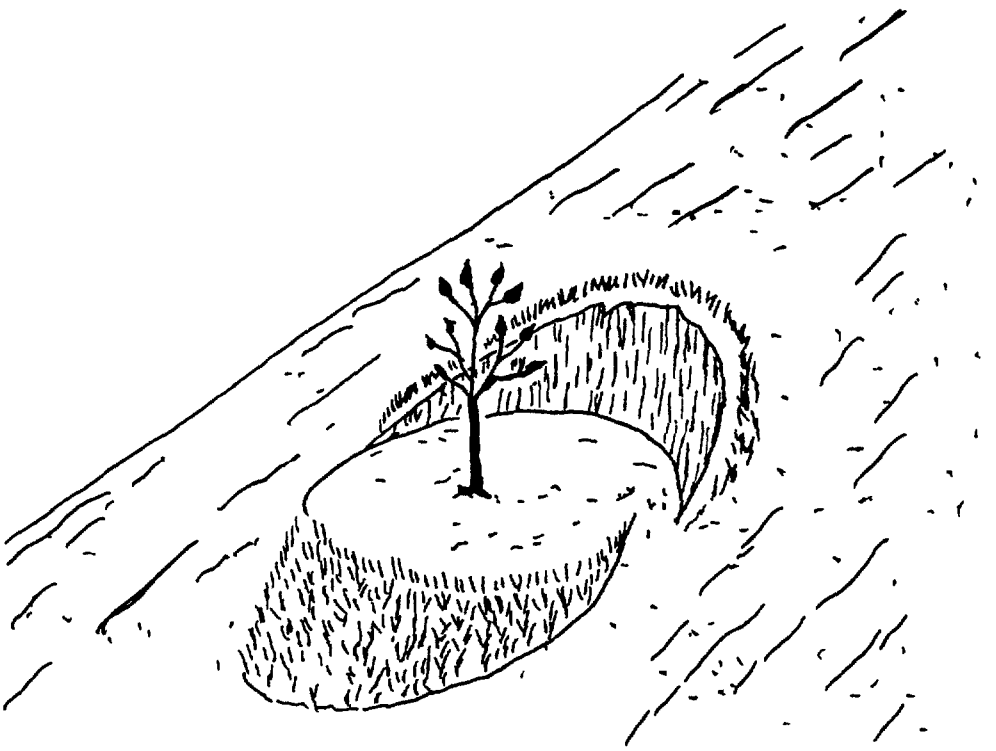


Figure 12 Individual basin terrace (LUPE 1994)

Table10 Specifications for hand made orchard terraces with 6 x 6 m tree spacings, an horizontal interval of 10 5 m and a platform width fo 1 75 m (FAO 1988)

Slope		SPECIFICATION											
%	Grade	U	TVI (m)	RH (m)	Hr (m)	Wr (m)	Wt (m)	HI (m)	L (m)	A (m^2)	Pb (%)	C (m^2)	V(m^3)
48	25 6	0 75	1 31	0 18	0 75	0 56	2 87	10 5	952	1667	16 67	0 33	314
50	26 6	0 75	1 40	0 18	0 79	0 59	2 93	10 5	952	1667	16 67	0 35	333
52	27 5	0 75	1 49	0 18	0 84	0 63	3 01	10 5	952	1667	16 67	0 37	352
54	28 4	0 75	1 59	0 18	0 89	0 67	3 09	10 5	952	1667	16 67	0 39	371
56	29 2	0 75	1 69	0 18	0 94	0 71	3 17	10 5	952	1667	16 67	0 41	390
58	30 1	0 75	1 80	0 18	0 99	0 74	3 23	10 5	952	1667	16 67	0 43	409

U = Riser Slope
TVI = Theroetical Vertical Interval
RH = Reverse Height
Hr = Height of the riser

Wr = Width of the riser
Wt = Width of the terrace
HI = Horizontal Interval
L = Length of the terrace per ha

A = Area of the benches (flat area) per ha
Pb = Percentage of the benches
C = Cross section of the terrace
V= Volume of the cut per ha

meters for individual basins are 1 5 m in diameter and a 10% reverse slope (15 cm), with a vertical interval of 0 75 1 to 1 1 for the horizontal vertical interval (LUPE 1994) The advantages of basins include the retention of soil moisture, particularly if mulched, reduced need for weeding, and that they can be constructed on uneven terrain and shallow soils

In Java, Indonesia, a variety of terrace designs were studied, yielding 106 4 tons/ha/yr of soil loss for traditional plots and 9 6 tons/ha/yr for individual terraces Only bench terraces controlled soil loss better in this particular site, demonstrating soil loss of 7 5 tons/ha/yr Ridge terraces showed increased soil erosion of 150 tons/ha/yr (Table 2) Individual basins require approximately 12 man days/ha/yr on 44-60% slope for construction in El Salvador (200 basins in 1 ha), less labor requirements than for orchard terraces which require 112 man days/ha/yr or natural terraces which require 100 man days/ha/yr for 15% slopes (Wiggins 1981)

Summary of Terrace Designs

Design specifications for all terrace systems vary with site conditions (topography, precipition), soil type, design of terrace system, and slope Factors affecting which soil conservation method is most appropriate include precipitation patterns (distribution and intensity), soil type, structure and texture, topography (steepness and length of slope), agricultural practices, socioeconomic and cultural influences, and the costs and benefits from erosion and runoff control (LUPE 1994)

Past research studies, summarized in Table 2, are useful for giving critical insight about the effectiveness of soil conservation practices and in assessing the use of terracing as a soil conservation method for particular locales However, difficulty exists in comparing across sites to extrapolate meaningful generalizations for making decisions One constraint in making comparison analysis is the differences in the area and size of the field catchments used for measurement Varying lengths of the test plots can produce vastly different erosion measurements Compounding this problem is the large amount of gray literature on the subject and the difficulty of obtaining specific information about plot sizes in many cases These constraints should be kept in mind in comparing study results and drawing conclusion from them However, the data results, when viewed together and comparatively, lead to the conclusion that, as structures used to reduce the slope of the hillside, adapted to specific site conditions, terraces can effectively reduce soil loss and runoff Several studies indicated that crop yield can be increased with terracing, as can total aboveground biomass, organic matter content and nutrient availability (Table 8)

The economic factors to consider that influence which method of soil conservation is appropriate for use include labor (Table 7) and material costs for construction and maintenance compared with benefits received through either increased crop productivity or longevity of production (as a result of increased nutrient availability in the soil, water holding capacity, and maintenance of soil structure) Because the costs and benefits of terraces as a conservation measure have not been well researched, these factors are difficult to evaluate

EFFECTIVENESS OF ROCK WALL TERRACES IN A SOUTHERN HONDURAS STEEPLAND FARMING SYSTEM

Background of Rock Wall Terrace Programs in Southern Honduras

Approximately 80% of the total land area in Honduras is classified as steeplands (slopes greater than 20%) These steeplands were historically forested and are the source of the country's river systems Rapid population growth and a shortage of arable lowland has resulted in peasants clearing the steeplands to grow food Approximately 75% of the basic grain (e g , maize, sorghum, beans) production in Honduras is derived from steepland cultivation (USAID 1980), thus these lands are the foundation of food production in the country Basic grains provide 75% of the dietary energy requirements and 64% of the protein for households in southern Honduras

Over 60% of steepland farms are less than 5 ha in size (Lopez-Pereira et al 1990) Most households struggle to meet their subsistence needs from these lands The desperate situation of these farmers is reflected by the fact that approximately two-thirds of the children in southern Honduras receive inadequate nutrition at some point during their first five years (DeWalt and DeWalt 1987) A survey of steepland farmers showed that achieving the minimum level of grain production needed for family consumption was their primary objective (Lopez-Pereira 1990) These facts indicate that steeplands are an important resource used by the peasant farmers to try to meet their subsistence needs Therefore, while it is environmentally preferable that steeplands remain forested for watershed protection, subsistence necessities and socio-political pressures make it impractical to expect that the government would remove farmers from steeplands in the foreseeable future

Forest clearing, heavy grazing and traditional "slash and burn" practices on the steeplands (cultivated fields with more than 50% slope are not uncommon) 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 professionals working in the region on natural resource management issues is that this trend has continued to the present

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 season, make cleared fields very susceptible to erosion It is vital in this type of environment that the erosive raindrop energy be dissipated by striking cover before reaching the soil It is also vital that the soil be tied into the hillside to prevent landslides when the soil is wet The tree cover historically present on the slopes met these needs by providing complete canopy and litter cover and by tying the soil to the hillside with their deep roots When the trees are removed through traditional slash-and-burn cultivation practices, lands in southern Honduras with 60% slopes have been documented to have an average erosion rate of 92 tons/ha/yr (Thurow et al 1998) To provide perspective on this number, this represents a loss of about 0 7 cm soil depth Since the topsoil on these slopes is often only 10-20 cm deep, it is clear that such land use cannot be practiced for more than several decades

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 This task was approached by organizing participating farmers into community groups of 10-20 individuals The groups would then participate in the construction of soil conservation structures on

each member's farm This organization provided a labor pool that could meet the physical demands of construction that were often beyond the scope of an individual farmer

Rock walls were built during the dry season because during the cropping season there is a labor shortage associated with the effort needed for planting, weeding and harvesting There is competition for labor in the dry season as well, since many individuals will leave the area to earn cash working as seasonal laborers on lands that produce crops such coffee, cantaloupe and sugar cane Therefore, the labor effort was subsidized by the extension program

Rock walls, built to a height of about 1 m, were constructed along the contours of the slope at intervals of 6 m These construction parameters were a compromise between the farmers concerns and engineering guidelines Standard engineering equations for calculating the construction criteria for rock wall terraces (Table 4) indicate that the walls should be much taller and closer together to achieve maximum soil erosion protection on the +50% slopes in the region In fact, FAO guidelines do not recommend terraces be constructed on slopes greater than 47% (FAO 1977) because of the need for very narrow benches and extremely high walls which become difficult to protect and maintain The farmers were reluctant to participate in a program advocating tall, very closely spaced walls -- 1 m tall and 6 m spaced walls were the tallest, closest configuration that could achieve general consensus for farmer participation This meant that when the walls filled in with sediment the slope of a 50% terrace bench would be reduced to about 35% Therefore, maximum protection that would be associated with bring the bench grade to 0% slope was not attainable Nevertheless, this compromise in construction design was still felt by the farmers and the extensionists to offer worthwhile benefits

The first step in the construction design was to excavate a foundation trench about 50 cm deep for the retaining wall This trench was dug to create a firm foundation for the wall The soil removed from the foundation trench was deposited up-slope The area behind the wall was a convenient place to deposit subsoil where it would gradually be covered by eroded topsoil moving downslope The second step was to bring rocks to the wall construction site Rocks were collected from the field and brought to the site either by hand or using two-man stretchers Even though large rocks were plentiful in the fields, it was a very rigorous task to lift and move them into place while traversing steep slopes The final step was to build the retaining wall The largest rocks were placed at the bottom of the trench and fitted together The space between the big rocks was filled with small rocks Since no cementing material was used to hold rocks together, excess water drains through the wall when the soil becomes saturated

To strengthen the rock walls, Leucaena seedlings (*Leucaena leucocephala*) were planted along the base of the walls Leucaena are multipurpose trees that provide nitrogen rich mulch to the soil and they are a convenient source of fuelwood The trees are managed by pruning them when they reach about 2 m tall back to a height of about 1 m

Informal on-farm interviews indicate that 7-10 years after construction all of the farmers perceived their terraced land as being more productive than adjacent unterraced parcels (Thompson 1992, Sierra 1996) Rapid depletion of soil moisture and low fertility were given as the main constraints to crop growth on the unterraced sites A testament to the perceived value of rock walls is that farmers voluntarily maintain them without further subsidies Small farmers faced with a choice between maximizing present income or making an investment in long-term benefits from investments in soil conservation techniques will usually opt for maximizing present income, even though this implies potential destruction of their natural resource base in the long-term (Ashby 1985) Therefore, even though farmers in the region readily recognize the advantage of having rock wall terraces in their fields, the arduous labor demands associated with building rock walls, and the possibility of earning cash if willing to work as a seasonal migrant, result in very few people building 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 vegetation barriers (AID 1989)

Farmers expressed that it was especially useful to have terraces during a drought when the crops on the eroded, shallower soils of the non-terraced fields show signs of drought stress sooner, sometimes resulting in a suppressed or complete failure of grain yield Farmers in the region complain about the increased frequency and consequences of drought This perception is not supported by long-term precipitation records, but makes sense because reduced soil depth associated with erosion results in reduced ability of the soil to store water Shallower soils mean that crops deplete the stored soil water sooner and are stressed for more frequent and longer periods Therefore, the perceived frequency and consequences of drought stress increase, even though there is no evidence to support a change in the amount or temporal distribution of rain The need for moisture storage is particularly important in regions such as southern Honduras where there is normally a dry period (canicula) which occurs mid-way through the growing season The rock terraces help to keep the soils on the hillside, thereby helping to maintain soil moisture storage capability

It is necessary to consider a variety of factors when evaluating whether a investment in a conservation technology is worthwhile The following text includes data on how 10-year old rock terraces have influenced the water, soil and production characteristics compared to adjacent portions of fields where terraces were not installed Future articles in this Soil Management Collaborative Research Support Program (CRSP) series will evaluate the water, soil and production dynamics of other conservation treatments (i e , vetiver grass barriers, gliricidia fallow and mulching) The costs and benefits of all of these conservation treatments will be analyzed and compared in future articles in this series

Effects of 10-year Old Rock Wall Terraces

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 current upland systems, and how each of these factors is influenced by practical soil and water conservation technologies is being evaluated The insight gained through this research feeds back into improved technology that is then disseminated by the LUPE extension effort

Study Area

The effects of 10-year old rock wall terraces on the water, soil and production dynamics was documented on the hillside farms of Los Espabeles, Namasiqüe (13°14'N, 87°05'W -- located 15 km southeast of Choluteca, Honduras) (Figure 13) This area has a climate characterized by a wet season (May-October) and a dry season (November-April) The first portion of the wet season is known as the "primera" (May-July), the second portion is known as the "postrera" (August-October) The wet season is interrupted by several weeks of dry period in July or August, called the "canicula" (Arias and Gallaher 1987) The average annual precipitation ranges from 1800 to 2900 mm and is distributed in a bimodal pattern Rainfall occurs mainly as intense thunderstorms The mean annual temperature is 26°C and varies little among seasons (Proyecto Manejo de Recursos Naturales 1984)

The study area is located within the Sampile-Guasaule River Basin which is characterized by steep foothills and mountains of uplifted basalt and granite formations which cover 62% of the land area A flat coastal plain extends from the foothills to coast Most of this upland area lies between 200 to 500 m above sea level Due in part to the rough topography of the Namasigue sub-watershed, there was a large amount of variability in soil pedogenesis The

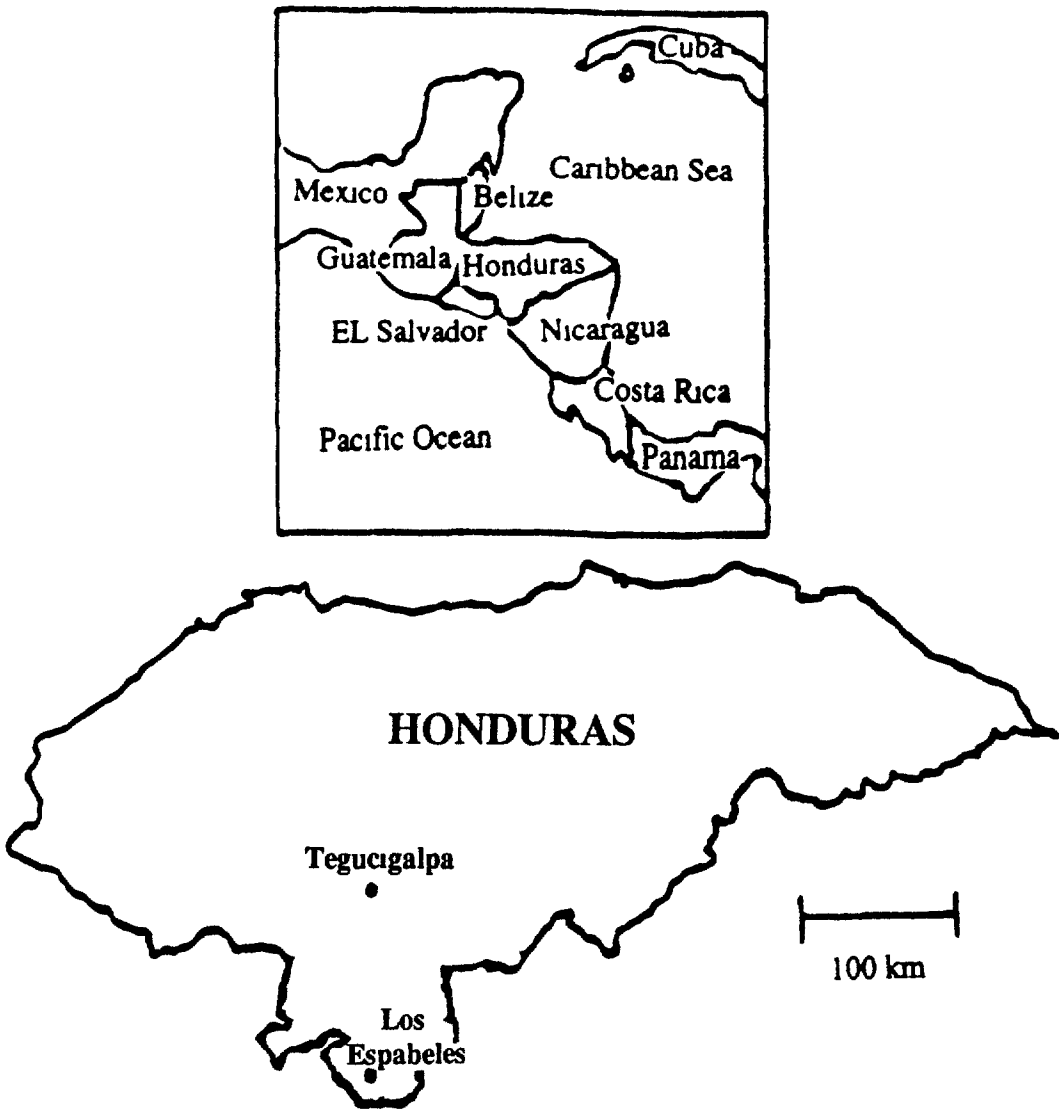


Figure 13 Location of the Los Espabeles, Honduras study area

soils were derived from sedimentary parent material overlying intrusive volcanic rocks such as dioritic granite The soils derived from basaltic material were preferred by farmers for their relatively higher base status and corresponding fertility Slopes with soils of low fertility, derived from granitic material, are avoided for use as cropland and are instead cleared and used for cattle grazing

The soils of the study site were classified as fine-loam, mixed, isohyperthermic Typic Ustropepts (Inceptisol) with high degrees of base saturation (>80%), using the classification criteria of the Keys To Soil Taxonomy (Soil Survey Staff 1992) and Munsell color charts (Munsell 1975) Topsoil depths ranged from 7 cm at the top of the ridges at the field edge to 31 cm near the base of the slopes, with means for ranging from 14 to 17 cm A change in color from the A to Bw horizons of the soils at the study site was apparent The soils had an ochric epipedon over a cambic endopedon The surface horizons had moderate very fine granular structure, and the Bw horizons had weak fine granular structure There was some evidence of clay illuviation in the Bw horizons, but not enough illuvial clay to result in an argillic subsurface horizon

Planting begins with the onset of the rainy season, which starts about the second week of May Maize is typically intercropped with land-race sorghum varieties called "maicillos criollos" These tropical sorghums are three to four meters tall, drought tolerant, and sensitive

Table 11 Comparison of runoff and sediment between unterraced and 10-year old terraced fields at Los Espabeles, Honduras Means within each month followed by the same letter are not significantly different (P≤0 1)

Month	Rainfall (mm)	Runoff (mm)		Sediment (kg/ha)	
		Terraced	Unterraced	Terraced	Unterraced
June	430	9 b	16 a	614 a	628 a
July	198	12 b	30 a	616 a	397 a
August	738	12 a	17 a	271 a	173 a
September	569	7 b	19 a	54 a	58 a
October	487	13 b	59 a	231 a	284 a
Total	2422	53 b	141 a	1785 a	1540 a

to photoperiod Intercropping maize and sorghum provides the farmers with a means of increasing total productivity per unit land area while reducing the risk of being dependent on a monocrop

Different maize and sorghum arrangements are used by the farmer depending on the date of planting or the position of maize and sorghum seed 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

NRMP and LUPE extension efforts have been successful at convincing many of the farmers in the study area not to burn their fields in preparation of planting Therefore, mulch was present on both the non-terraced and terraced portions of the study area Land preparation and planting using the slash and mulch method requires from 12 to 23 man-days/ha compared to only about 6 man-days/ha for the traditional slash and burn method, nevertheless, most farmers felt that long-term benefits of not burning more than offset the extra labor cost

Runoff and Erosion

The 1 m tall rock walls built at 6 m intervals on the hillside farms in 1985 had completely filled to the top with sediment by 1992 As a result, the original hillside slope of 50% has been changed to a terrace slope of 35% Each wall, including the area occupied by stabilizing Leucaena trees, was about 1 m wide, therefore the cultivatable land area was about 5 m wide for rock walls spaced at 6 m intervals

The runoff and erosion rate on terraced and non-terraced land was measured during 1995 by installing six 2 m wide by 5 m long enclosed runoff plots Three replicates were obtained for each treatment (10-year old terraces and adjacent non-terraced portions of the fields) Runoff and sediment loss was measured by collecting the runoff and then filtering the sediment from thoroughly mixed runoff subsamples

The terraced plots had significantly less runoff than the non-terraced plots (Table 11) Total runoff from the terraced and non-terraced fields was 2 1 and 5 4% respectively of the total rainfall Figure 14 shows the relationship between runoff and storm size class means

Relatively little soil loss was measured on both the terraced and unterraced plots (Table 11) The small plot size of this study only enables estimates of interrill erosion, which was substantially controlled by the use of mulch and

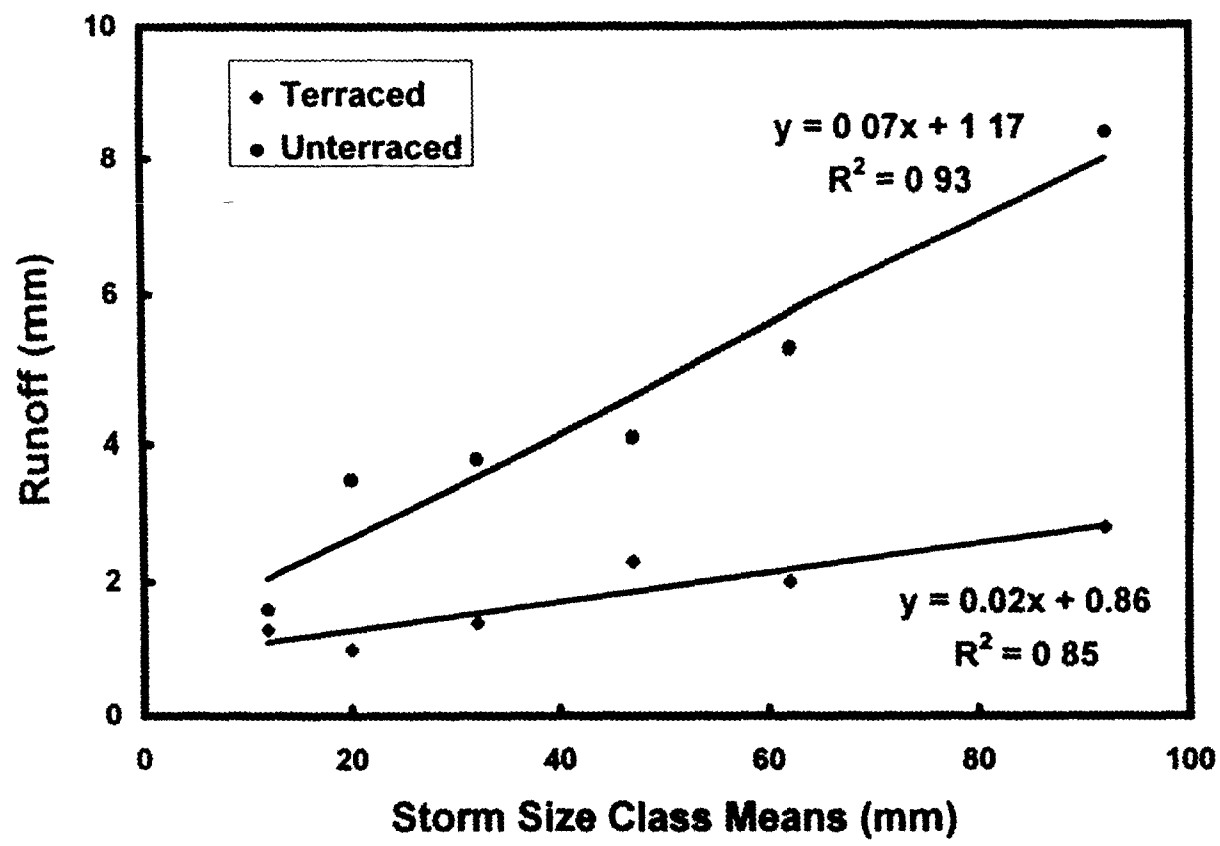


Figure 14 Correlation analysis of runoff (mm) and storm size class means on unterraced and 10-year old terraced fields, Los Espabeles, Honduras

minimum tillage Thurow et al (1998) documented that most of the sediment loss that occurs on the fields of this region is associated with land slips, a process that occurs at a scale too large to be detected by the small plots used in this study

Since the soil had filled to the top of the 1 m rock wall, these data indicate that the rock walls are no longer effective at retaining sediment moving as a result of interrill erosion Under these circumstances it will be necessary to increase the height of the walls to retain additional eroded material The amount of sediment yield per mm of runoff during the growing season is illustrated on Figure 15 This pattern indicates that interrill soil erosion risk was greater at the onset of the rainy season when crop cover was not well established and declines as the crop cover increases The lack of enough cover to protect the soil against the impact of raindrop allows the detachment of soil particles, increasing the amount of sediment in the runoff

Soil Characteristics

Based on the United States Department of Agriculture (USDA) classification, soil particles smaller than 2 mm in diameter are divided into three broad categories depending on size, particles of 2 - 0 05 mm diameter are called into sand, those of 0 05 - 0 002 mm diameter are called silt, and the <0 002 mm particles are called clay Particle-size was determined using the pipette method (Kilmer and Alexander 1949) The samples were dispersed with sodium hexametaphosphate without pre-treatment to remove organic matter or cementing

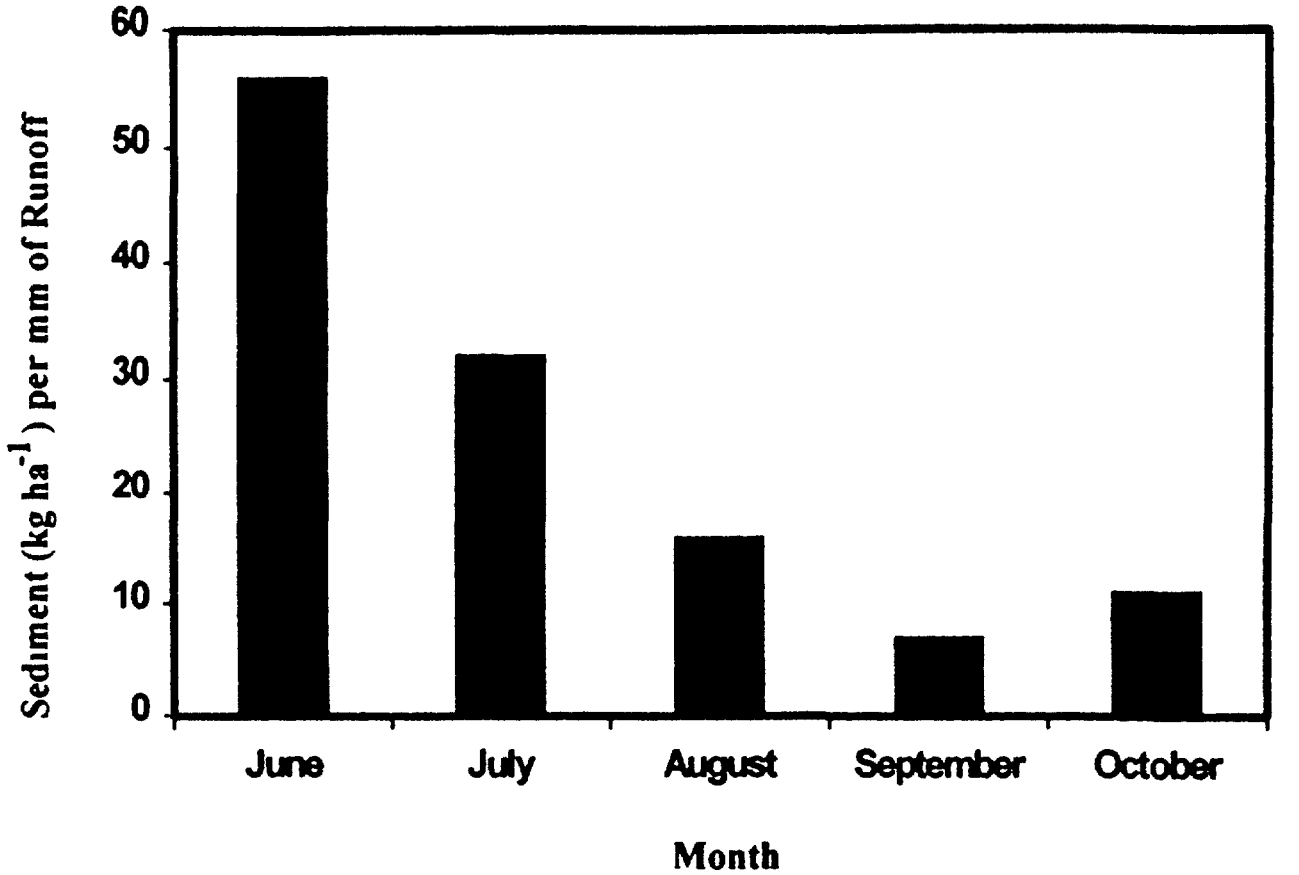


Figure 15 Sediment yield (kg/ha) per mm of runoff, Los Espabeles, Honduras

agents The soil texture tended to be a loam over a clay to silt loam The percentage of coarse fragments (> 2 mm) in the upper 30 cm was estimated by visual examination of soil profiles (Table 12)

Since individual soil particles have afairly constant density, the density of a volume of soil will vary according to the amount of air space in the soil Bulk density refers to a mass per unit volume characteristic of soil Bulk density decreases as the porosity, tilth and structure of a soil increases Soil bulk density (Table 13) was determined using the core method (Black 1965) The good soil structure, reflected in part by the relatively low bulk density for this type of soil texture, contributed to rapid infiltration and permeability of the soils The saturated conductivity averaged about 250 mm/hour Saturated conductivity was measured by saturating a micro-plot with water by use of a portable rainfall simulator and then measuring the difference between water applied and runoff collected over a period of time (Thompson 1992) These inherent soil characteristics mean that rill erosion risk is low because it takes an exceptionally intense and protracted rainy period to result in substantial runoff

Water retention was measured at water potentials of -330, -1,000, -5 000 and -15,000 kPa by the pressure plate method (USDA-SCS 1984) Available water holding capacity for the fine-earth fraction was determined gravimetrically as the difference in water retention between -330 and -15,000 kPa Plant available water is measured by the difference between soil water content at -330 kPa and -15,000 kPa There was no difference in water

Table 12 Characteristics of the top 30 cm of soil collected at different locations within unterraced and 10-year old terraced fields, Los Espabeles, Honduras (Thompson 1992)

	Water Potential for Soil < 2 mm				Texture			Rock Portion of Soil Profile	Plant Available Water
	-300 kPa	-1000 kPa	-5000 kPa	-15000 kPa	Sand	Silt	Clay		
	(%)				(%)	(%)	(%)	(%)	(mm)
Terrace									
Upper	31 2	27 1	22 7	21 6	37	31	32	38	25
Middle	31 7	25 9	23 1	21 5	35	32	33	25	33
Lower	32 4	27 8	23 4	22 5	36	33	31	14	38
Unterraced	31 3	26 9	23 6	22 1	40	32	28	28	28

retention capability for the fine-earth fraction in the upper 30 cm of soil when terraced plots were compared to control plots However, when available water content was adjusted for the amount of rock material in the soil, it becomes apparent that the terraced plots have greater water storage potential because there is more fine soil and less rock Surface rock cover was 5% on the terraces and 14% on the adjacent non-terraced portion of the field The top 30 cm of non-terraced sites was 30% rock whereas the terraced site was 38% at the top, 25% in the middle, and 14% at the bottom (Table 12)

Organic matter content of the soil was determined by the wet oxidation of carbon (Hons 1988) The relatively high soil organic matter at 0-15 cm depth is attributable to the accumulationof crop residues, addition of pruned foliage from Leucaena trees planted along the rock walls and the no-till system of planting (Table 14) Soil organic matter was significantly greater on terraced land for the 15-30 and 30-45 cm depth than on the non-terraced land There were significant differences in soil organic matter at different locations within terrace transects Soil organic matter content was greatest at the location immediately above the wall, the location where eroded soil particles from upslope would accumulate

Organic matter content of the soil is important since it influences many other soil properties such as infiltration rate, water retention capability and nutrient content Soil organic matter helps in maintaining good soil structure thus allowing more water infiltration and consequently reducing runoff Furthermore, soil organic matter increases cation exchange capacity which reduces potential losses of bases such as K, Ca, and Mg

Available nitrogen was extracted using a KCl solution and then determined using auto-analyzer instrumentation Available nitrogen content was significantly greater in the terraced land than in non-terraced land at 0-15 and 15-30 cm depth (Table 14) Nitrogen levels at 0-15 cm on the terraced plot were 20 times greater than on the non-terraced fields Available nitrogen was significantly different between localities and soil depth in terraced and non-terraced land The areas immediately above and below the rock wall had the greatest nitrogen content The high content of available nitrogen in these locations along the wall is probably due to the presence of Leucaena trees planted along the base of the rock wall These trees have the ability to fix atmospheric nitrogen and provide a nutrient rich mulch Available nitrogen always decreased with soil depth and below 30 cm was at very low concentrations (<2 ppm) These patterns in available nitrogen are expected due to the large accumulation of organic matter in the 0-15 cm depth and the probable high mineralization occurring in this zone In the tropical and subtropical climatic zones where variable charge soils are more extensive, soil organic matter is the major source of nitrogen for crop production (Fox 1980)

Table 13 Comparison of soil characteristics between unterraced and 10-year old terraced fields at Los Espabeles, Honduras Capital letters that follow the numbers are used to indicate difference within rows and small letters compare the difference within columns Numbers followed by the same letter are not significantly different ($P \leq 0\ 1$)

Soil Depth (cm)	Bulk Density ($g\ cm^{3}$)		Soil pH		Available Phosphorus (ppm)		Exchangeable Potassium (ppm)	
	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced
0-15	1 34 A e	1 38 A d	6 4 A a	6 5 A a	15 0 A a	17 0 A a	289 9 A a	264 3 A a
15-30	1 49 A d	1 52 A c	6 1 A b	5 9 A b	15 0 A a	13 0 A b	170 7 A b	120 7 B b
30-45	1 56 B c	1 60 A b	5 8 A c	5 9 A b	10 1 A b	10 3 A c	127 7 A c	126 7 A b
45-60	1 60 B b	1 72 A a	5 7 A c	5 9 A b	4 8 A c	8 6 A c	104 6 A cd	51 7 B c
60-75	1 66 A a	1 74 A a	5 6 B d	5 8 A b	2 7 B c	9 3 A c	84 8 A d	54 0 B c

Soil Depth (cm)	Available Sulfur (ppm)		Exchangeable Calcium (ppm)		Exchangeable Magnesium (ppm)		Exchangeable Sodium (ppm)	
	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced
0-15	35 1 A a	35 6 A a	3246 A a	3046 A a	338 A a	307 A c	26 9 A b	18 7 A a
15-30	30 5 A b	27 3 A b	2511 A a	1890 B b	309 A ab	306 A c	29 1 A ab	19 3 A a
30-45	28 9 A b	28 0 A b	2013 A c	1569 B c	312 B ab	395 A b	30 4 A ab	21 7 A a
45-60	28 5 A b	23 7 A b	1639 A d	1488 A c	290 B ab	430 A ab	31 5 A ab	24 7 A a
60-75	30 1 A b	27 0 A b	1546 A d	1672 A bc	282 B b	451 A a	32 0 A a	32 3 A a

Soil reaction (pH) is an expression of the H^{+} ion Soil pH is commonly determined by mixing soil and water together in a 1 1 ratio Since soluble salts in the soil can affect the water pH value, pH may be measured using calcium chloride or potassium chloride solutions instead of distilled water to overcome this problem (Foth and Ellis 1988) Soil reaction was determined in duplicate using both 1 1 soil-to-water and 1 1 soil-to-1 N KCl mixtures (Soil Survey Staff 1972) An electronic pH meter equipped with a combination glass-calomel electrode standardized against pH 4 0 and 7 0 buffer solutions was used The soil pH of the site was slightly acidic (Table 13)

Calcium, magnesium, potassium, and sodium exchangeable cations adsorbed to soil particles and in soil solution represent the exchangeable bases Because the cations provide the major supply of plant nutrients, their absolute and relative amounts are important factors influencing plant growth Exchangeable bases divided by the CEC at pH 8 2 is referred to as the base saturation Extractable bases were determined in 1N ammonium acetate leachate (pH 7 0) following procedure 5B5 of the National Soil Survey Laboratory (SCS 1984) The concentration of bases was determined by atomic absorption analysis and summed in $cmol_c$/kg of soil The soils had high cation exchange capacities (23 8 - 30 2 $cmol_c\ kg^{1}$) determined using 1N NaOAc (pH 8 2) following a modified procedure of USDA Handbook 60 (U S Salinity Laboratory Staff 1969) The soils also had high base saturations (79 - 81%) determined in 1N ammonium acetate leachate (pH 7 0) following procedure 5B5 of the National Soil Survey Laboratory (SCS 1984) throughout the soil profiles of both the terraced and non-terraced sites (Table 13)

There was a consistently lower content of exchangeable bases (Ca, Mg, K, Na), soil organic matter and sulfur in the portion of the terrace immediately below the rock wall when compared to the values immediately above the rock wall These data suggest that these

Table 14 Comparison of soil organic matter and nitrate-N in soil as a function of depth at different locations in unterraced fields and along transects through 10-year old terraced fields, Los Espabeles Honduras Capital letters compare the difference within rows and small letters compare the difference within columns Location 1 is the first meter above the rock wall, location 2 is the second meter above the rock wall, etc The terraces were 5 m wide The mean values for the portion of the field adjacent to the terraced portion is listed in the unterraced column Numbers followed by the same letter are not significantly different ($P \leq 0.1$)

	Soil Organic Matter (%)					
	Terraced					Unterraced
Soil Depth (cm)	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	
0-15	7 6 A a	6 9 AB a	6 3 AB a	6 0 B a	5 7 B a	5 6 B a
15-30	4 1 A b	3 7 A b	4 1 A b	3 9 A b	2 8 AB b	1 9 B b
30-45	2 3 A c	2 8 A b	2 7 AB c	2 4 AB c	2 1 AB b	1 3 B c
45-60	1 4 A c	1 6 A c	1 8 A d	1 3 A d	1 8 A b	0 9 A d
60-75	0 8 A c	1 1 A c	1 8 A d	1 3 A d	1 7 A b	0 8 A d

	Content of Nitrate-N (ppm)					
	Terraced					Unterraced
Soil Depth (cm)	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	
0-15	54 0 A a	44 3 AB a	49 0 AB a	29 0 AB a	57 3 A a	2 0 B a
15-30	13 0 A b	7 7 AB b	11 7 A b	10 7 A b	2 3 B b	1 0 B b
30-45	4 7 AB c	5 7 A b	3 0 BC c	1 3 C c	1 0 C b	1 0 C b
45-60	1 0 B c	2 7 A b	1 0 B c	1 0 B c	1 0 B b	1 0 B b
60-75	1 0 B c	1 7 A b	1 0 B c	1 0 B c	1 0 B b	1 0 B b

nutrients are being transported with sediment or runoff and accumulate immediately behind the rock wall Concentration of Ca, Mg, Na, K, S and organic matter for the 0-15 cm depth immediately behind the rock wall were respectively 19, 15, 22, 53, 13 and 33% greater than the location immediately below the rock wall

Phosphorus occurs in both organic and inorganic forms in the soil A large portion of the phosphorus is fixed or in insoluble inorganic compounds The more soluble fractions of soil phosphorus are generally called "available phosphorus" with respect to plant growth Available phosphorus was determined using a solution of 1 4M ammonium acetate in 0 025M H_4EDTA analyzed using a Inductively Coupled Argon Plasm Spectrophotometer There was no consistently significant difference in phosphorus concentration on the terraced and non-terraced sites (Table 13), both were phosphorus deficient to a degree that would limit crop growth and yield

Crop Production

Within each terrace replicate, a transect was established for each sample date that was 1 m wide and 5 m long (i e , the distance between rock walls along the 5 m transect) Standing crop was measured in adjacent 1 m^2 plots across each of the three sample terraces Sampling was done once a month from June to August The transect locations within each of the terraces were randomly selected Clipped samples were air dried and then oven dried at 60°C for 24 hour prior to weighing

There was a significantly greater standing crop on the terraced field than the non-terraced field throughout most of the growing

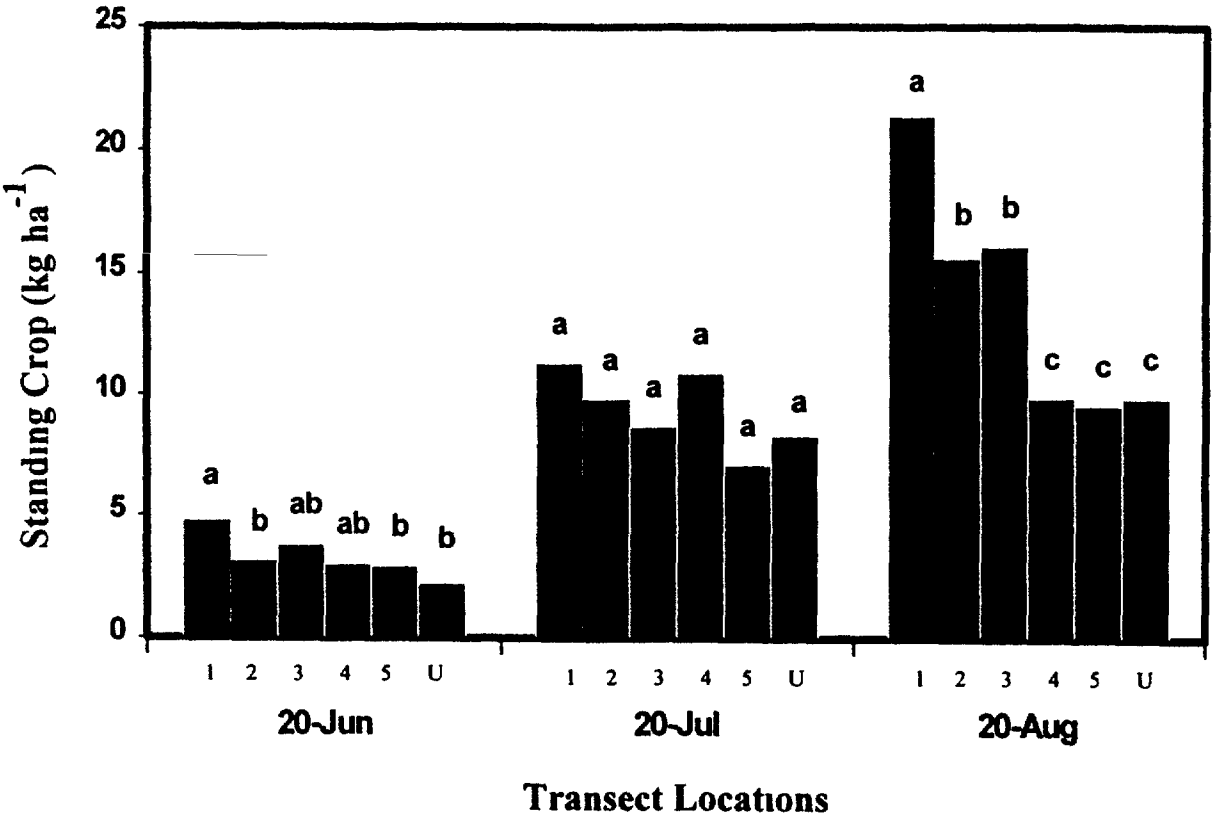


Figure 16 Comparison of stand crop between unterraced fields and localities along a transect within 10-year old terraced fields Location 1 is the first meter above the rock wall, location 2 is the second meter above the rock wall, etc. The terraces were 5 m wide U is the mean from adjacent unterraced land Means within each month followed by the same letter are not significant (P < 0 1)

season This better growth was primarily attributable to the area immediately behind the rock walls where deep sediment had accumulated (Figure 16) Grain yield was 70% higher from the terraced field (2 2 tons/ha) than from the unterraced plots (1 3 tons/ha) Foliage and total biomass at harvest time was 32 and 39% greater, respectively, on the terraced field than on the non-terraced field

The production on upper portions within a terrace were similar to the non-terraced land (Figure 16) These measurements were made during a year with above average rainfall Observations by farmers indicate that crop production differences are much more pronounced during drought years

Even though the nitrogen content was high in the soil immediately above and below the rock walls (associated with Leucaena mulch) (Table 14), standing crop was significantly greater above the wall Indeed standing crop on the area immediately below the rock wall was similar to the low yields of the non-terraced land This indicates that nitrogen was not the limiting factor to production Instead the lower production on these sites may be due to the low water holding capacity of this eroded area

In summary, the differences between the terraced and adjacent non-terraced sites are derived from the accumulation of the soil behind the terraces The greater soil depth results in a combination of greater water holding capacity and greater nutrient concentrations Less runoff reduces flooding hazard downstream and puts more water into the soil which is either stored for crop use during a dry period or eventually contributes to stream baseflow The combination of greater amounts of stored water and nutrients in the deeper soil results in significantly greater crop production on the terraced sites

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