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SUSTAINABLE HILLSIDE FARMING SYSTEMS FOR THE EASTERN CARIBBEAN

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ABSTRACT

Soil erosion on tropical hillside lands is an increasing problem. Traditional subsistence farming practices of shifting cultivation, especially without soil and water conservation measures are unsustainable. Agronomic and physical measures to reduce soil erosion and render hillside agriculture sustainable are outlined. A case study in Saint Lucia showed that terraced, strip-cropped and contour-drained hillside plots had low rates of soil loss, with the terraced plot showing the least soil loss. However, the terraced plot showed the lowest overall crop yield due to soil disturbance during construction and the smaller land area available for planting. An economic analysis of construction and maintenance costs indicates that expensive bench terraces are beyond the means of most small farmers, and that government support or incentives are needed for implementation of these techniques.

1.0 INTRODUCTION

The Eastern Caribbean chain of islands is situated on a volcanic ridge between latitudes 12-17°N, longitudes 60-62°W. Being of relatively recent geological origin, these volcanic islands have mountainous topography. Yearly average temperature is between 24-28°C. Annual average precipitation is close to 2000 mm for valleys and coastal plains, and up to 4000 mm in the mountain ranges. Banana, cocoa, coconut, nutmeg, tuber crops and vegetables are the main export crops. In most of this region, small farmers (< 4 ha) produce one-half or more of most commodities, mainly using shifting cultivation techniques. However, in Saint Lucia for example, only 22% of land has a slope of less than 10° (CCA and IRF, 1991). Deforestation of steep lands for banana production leads to severe erosion problems. The high rainfalls and high seismic activity of this region contribute to slippage of inappropriately used hillside lands. Rill and sheet erosion have caused extensive downstream silting and loss of soil productivity. In order for these Caribbean island communities to be self-sufficient in food and survive on a long-term basis, it will be necessary for them to implement sustainable land management practices, such as sloping land use restrictions and soil conservation techniques. The development of sustainable agroecosystems on hillsides is particularly important in the Caribbean where a large proportion of cultivated farms is located on steep lands. In most of the world, about 50% of the land has slopes above 8% (**Table 1**), (Purnell, 1986), while in Saint Lucia and most of the Eastern Caribbean islands, over 90% of the land mass falls in this category. However, in many regions of the world including the Caribbean, when no other land is available, lands with slopes of up to 100% are being used for short-term crops with full knowledge of the likelihood of erosion to bedrock within 3-5 years (Cook, 1988).

2.0 FACTORS INFLUENCING SOIL EROSION IN EASTERN CARIBBEAN

There are several factors which influence soil erosion in the eastern Caribbean, and affect the sustainability of hillside agroecosystems.

Intense and heavy rains ranging from 75-100 mm/hr are quite common in the humid tropics and precipitation tends to be higher on the uplands. The important role of impact velocity has been well illustrated by covering bare plots with thin gauze and

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SLOPE %	AFRICA	ASIA		AMERICAS			TOTAL AREA Mha	TOTAL AREA AS %
		South West	South East	South	Central	North		
0-8	58	45	40	52	35	36	3340	51
8-30	34	31	31	30	40	50	2107	33
>30	8	24	29	18	25	14	1048	16

Table 1: Estimated Percentage Areas of Sloping Lands in Tropical Regions (Purnell, 1986)

illustrated by covering bare plots with thin gauze and thus reducing soil loss by up to 100 fold (Hudson and Jackson, 1959; Williams and Joseph, 1970). Furthermore, tropical soils tend to be low in organic matter. This reduces soil stability. Deforestation leads to increased soil temperatures which in turn results in more rapid humus breakdown, greater N volatilisation and nutrient loss through erosion.

Considering that shifting cultivation on hillsides in humid tropical regions such as the Caribbean generally occurs on slopes ranging from 26-47% (15-25°) (Sheng, 1982), it is important to understand the slope-erosion relationship. Under extreme conditions, erosion can vary as the square of the slope (Hudson and Jackson, 1959), but generally beyond a certain slope erosion no longer increases. While soil loss increases sharply with slope, runoff increases slowly with slope, particularly at higher slopes (Roose, 1975, Lal, 1990).

3.0 OFF-SITE EFFECTS OF SOIL EROSION

While the on-site effect of soil erosion, particularly the loss of nutrients and topsoil are important, many of the most devastating effects of soil erosion occur downstream of affected farms (Clark et al., 1985).

These impacts are related to two main contaminants: sediment and erosion-associated contaminants. Sediments increase turbidity, and this reduces light penetration. This leads to reduced aquatic plant productivity, greater temperature stratification and reduced mixing of water layers. Poor visibility can affect predatory fish that use visual cues, or mating of other species. Poor visibility also makes waters more dangerous for recreastional swimming and boating. Silting of harbours and contamination of beaches are also known to occur in Saint Lucia and other Caribbean islands.

The accumulation of sediments on the sea or river bed can choke macrophytes and fill in spaces between rocks where many invertebrates live and small fish spawn. Sedimentation can rapidly fill lakes or reservoirs, particularly where dams are built, greatly reducing their useful lifetime. Silting in of waterways results in the need for dredging to maintain commercial boat traffic. It also results in a raising of the river bed and decreasing the capacity of flood control reservoirs behind dams, which can in turn lead to greater upstream flooding. High sediment loading in reservoirs increases the cost of water treatment for municipal supplies.

4.0 METHODS OF SUSTAINABILITY

The aim of soil conservation is to obtain the maximum sustained level of production from a given area of land while maintaining soil loss below a threshold which theoretically permits the rate of soil formation to keep up with soil erosion (Morgan, 1986). Studies of the mechanics of soil erosion conclude that the strategies for soil conservation must be based on:

a) covering the soil to protect it from raindrop impact,

b) increassing the infiltration capacity of the soil to reduce runoff,

c) improving the aggregate stability of the soil,

d) methods of drainage which minimise the amount of runoff flowing over the land surface.

Many of the following soil conservation techniques and their specific application to the Caribbean region are summarised and discussed by Gumbs (1987).

5.0 AGRONOMIC METHODS

One of the easiest methods to reduce erosion is to minimise rainfall impact on the soil itself. Such methods are often given preference over other measures as they are less expensive and usually fit more easily into traditional cropping systems.

The canopy and abundant ground litter of native tropical forests provide excellent cover and such forests are particularly important on steep hillsides where they bind soil and minimise the risk of slippage. On steep slopes (> 30%), agroforestry is often the only sustainable production system possible. Multistoried tree gardens, for example, can actually reduce soil loss compared to natural rainforest vegetation (Wiersum, 1984). In such systems, loss of cover by removal of weeds or forest floor litter can greatly increase soil loss, while the use of cover crops or mulch can do much to limit erosion.

In an agricultural context, reducing soil loss must be undertaken both temporally and spatially in order to be effective. Temporal control of erosion was accomplished by leaving the soil fallow or by using continuous cropping. Given population pressures, very little land is left fallow in the Caribbean, but continuous cropping is more commonly used. It is especially important to re-establish cover through mulching or rapid planting when extensive soil disturbance occurs during harvest. A rapidly growing grass or legume cover crop can serve this purpose and serve as forage for cattle.

A crop's ability to prevent erosion can be expressed as the C factor, representing the ratio of soil loss under the crop to that under bare soil conditions. Some crops affording the poorest cover include maize, cassava and pineapple, while many legumes such as cowpea and mung bean afford good cover. Increasing planting density, particularly for crops affording poor cover can significantly reduce soil losses. Since the area of soil protected from rain increases with crop canopy development (Wilkinson, 1975), a cassava cultivar, for example, with an early developing canopy can significantly reduce soil loss compared to a standard cultivar (Lal, 1990).

Multiple cropping may involve either multiple crops in time (rotations) or in space (on the same land). In Saint Lucia, the combination of banana and tree crops, e.g., coconut is quite common, and banana-legume rotations are also promoted (Walker, 1987). Multiple cropping on a parcel of land, a common practice in tropical countries, maintains high soil cover, while minimising the risk of complete crop failure. In the Caribbean, such cropping has been practiced for many years, particularly on the kitchen garden scale (Morgan, 1986). Strips of grass, trees or any close-growing crop across the slope trap water-borne particulate matter from upland runoff, and reduce runoff velocity. Strip-cropping is most effective in reducing soil erosion on land where terraces or contour tillage are impractical due to uneven slopes and in areas of moderate rainfall. The use of rapidly growing trees such as Leucaena leucocephala and Gliricidia sp. as an intercrop allows stabilisation of hillsides, natural terrace formation and serves as a source of firewood. Mulching through maintenance or application of crop residues on the soil surface decreases raindrop impact, slows water flow and increases infiltration. Soil faunal activity is also stimulated, promoting soil structure and increasing permeability (Gumbs, 1987). In the tropics, the added benefits of reduced soil temperatures and increased soil moisture are beneficial and can increase yields of coffee, banana and cocoa (Morgan, 1986). The advantage of mulching is that it is low cost, low technology, and the mulching material is generally easily obtained. However, in some cases, mulches can harbour pests and diseases which affect crops (Gumbs, 1987). Also, on some steeper slopes, the increased infiltration and thus increased soil moisture may induce land slippage (Lal, 1990). However, in most cases, it is a simple and effective soil erosion control method.

6.0 PHYSICAL MEASURES

These methods rely on the manipulation of surface topography or soil structure to control the flow of water. They are often only effective in controlling the transport phase of the erosion process but do little to prevent soil detachment. Therefore, agronomic methods of soil conservation need to be applied in concert with mechanical methods in order to achieve effective soil erosion control.

Tillage pattern, on the contour or otherwise is important in determining both runoff and soil loss. For example, while contour tillage may have little effect on soil loss, tillage up-down the slope can drastically increase soil loss as it allows runoff to reach erosive velocities and form gullies when channelled in the small waterways created (Alegre et al., 1990). On gentle slopes, contour tillage reduces surface runoff by impounding water in small depressions, thus decreasing rill development. However, under conditions of high rainfall, slope and soil erodibility, breakovers from rows can release water indiscriminately over the slope, causing extensive damage as the volume of water increases with each succeeding row (Schwab et al, 1981).

Appropriately situated drainage ditches can also serve to reduce soil loss. Storm water diversion drains at the top of cultivated fields divert upland runoff from the cultivated area. Cutoff drains at intervals within the cultivated field limit overland flow and thus prevent surface runoff from achieving the high velocities necessary to the formation of rills and gullies. Such drains, commonly referred to as contour drains are commonly found in the Caribbean.

Artificial waterways, built wide and shallow may be necessary to convey water downslope from diversion and contour drains. On slopes exceeding 25 % slope, checkdams, weirs or stepped waterways must be used to slow downslope flow, and trap sediment, and as such are also useful in gully stabilisation.

While terracing is an excellent soil conservation technique, it is very labour-intensive, costly and tends to make mechanised operations difficult (Lal, 1990). However, on slopes greater than 20%, they are often the only recommended practice. In Jamaica, hillside ditches and bench terraces at one site reduced soil loss by 70% (Sheng and Michaelson,1973). While terraces can theoretically be built on any slope with deep soil, Scheng (1986) recommends limits of 35% for machin-built terraces, 45% for hand-built terraces and 58% for intermittent, 2 m wide terraces for the Caribbean. Spacing, width, grade and riser height and slope are dependent on slope, soil conditions and the crop to be grown. Recommendations for terraces in a Caribbean context are given by Scheng (1986), but due to stability and maintenance problems, terracing is of little practical significance in the Eastern Caribbean unless high value crops are grown (Cracknell, 1986).

7.0 SOME AGRICULTURAL MANAGEMENT PRACTICES FOR HILLSIDE ECOSYSTEMS IN SAINT LUCIA - A CASE STUDY

Three soil conservation systems: contour drainage, strip-cropping and terracing were designed and established on separate adjacent plots on hillside farmlands in the Roseau river basin in Saint Lucia (61°00' W and 13 °57' N) in 1988. A control plot with no form of soil conservation, except a storm water diversion drain at the top of the plot was also established. A detailed description of soil types, topography, and runoff and soil loss measurement was given by Norville (1990), and Madramootoo and Norville (1993). The objective of this study was to demonstrate possible management systems for hillside banana cultivation, and to measure their relative benefits.

All plots, except the non-banana strips of the strip-cropped plot were planted to bananas, in a triangular array with a 2.6 m spacing between individual plants. The terraced plot was located in a steep area, sufficiently large to provide the slope length for four 2.5 m wide terraces. These were of the conservation bench type, with a 1% grade and minimum reverse bench grade of 5%. The strip-cropped plot was also located in a large area since it required several crop strips. Strips were 15 m wise and field drains were placed below each non-banana strip. The contour drained plot was located in an area of moderate size and slope. The characteristics of the plots are summarised in **Table 2**.

8.0 RUNOFF AND SOIL LOSS

Runoff (**Table 2**) was least for the terraced plot where the benches probably provided increased opportunity for infiltration, and the shorter flow length reduced shallow subsurface flow which was prevalent in the low considering that the plots were newly constructed and that ground cover was sparse for a significant portion of the measurement period. With the exception of the Warwick clay type soil which was prone to slumping, soils showed little or no erosion. It was clear from field observations that on most occasions, soil loss was due more to slumping of the terrace risers and at the sides of some drains, than to sheet erosion. Even with the slumping of the terrace risers particularly in August and September 1988, soil loss rates from the terraced plot were quite low.

Another significant factor contributing to low soil losses may have been the cover provided by weeds and crop residue. Indigenous grasses thrive in the rainy season and their control becomes a significant aspect of plot maintenance. Regular weeding ensured the weeds were always under control, but the constant rainfall contributed to their rapid resurgency. These grasses do not only influence erosion by providing ground cover, but their deeply penetrating root systems also bind the soil together and increase resistance to dislodgement of soil particles by overland flow. Pruning of banana leaves and suckers and other crop management practices which provide crop residue, also increase the extent of cover, and this is likely to be greater as the crop develops.

PARAMETER MEASURED	PLOT			
	CONTROL	CONTOUR-DRAINED	STRIP-CROPPED	TERRACED
Area (ha)	0.32	0.56	0.80	0.78
Length of drains (km/ha)	0.21	0.95	0.41	0.71
Average slope	16°	17°	21°	20°
Plot length	75 m	85 m	82 m	67 m
Runoff (mm)2	0.6 - 203.6	2.1 - 199.2	3.2 - 155.1	1.3 - 94.7
Soil loss (kg/ha)z	0.01 - 1.77	0.07 - 16.88	0.2 - 28.86	0.01 - 6.62
Yields of banana (kg/ha)	10104	12799	11377 cucumber 6102 s. potatoes 3024	8411[y]
Construction costs (EC$)x	2990	5565	5425	6350
Yearly maintenance costs (EC$)	-	375	500	500

Table 2: Summary of Characteristics of Hillside Research Plots in Saint Lucia

[z] For rainfall events ranging from 14.2 to 211.1 mm
[y] Based on cultivated area only
[x] US$1.00 = EC$2.7 (1988/89 costs)

greater as the crop develops. A significant feature of the erosion data is the large proportion of the soil loss recorded in one or two rainfall events. These varied from plot to plot, but for the terraced and strip-cropped plots, for example, over 60% of the total soil loss was recorded in two rainfall events (Madramootoo and Norville. 1993). Other studies in the Caribbean have recorded similar results (Sheng and Michaelsen, 1973; Gumbs and Lindsay, 1982; Gumbs et al., 1985). This emphasised the erosive nature of large tropical storms.

9.0 CROP YIELD

The highest banana yields were obtained on the contour-drained plot, while the lowest were on the terraced plot (**Table 2**). The high level of topsoil disturbance and exposure of the subsoil in the construction of the terraced plot may have resulted in reduced soil fertility, and thus in relatively low yields. Crop yields would likely increase after the soil stabilised, and after the full effect of fertilization was realised. Sheng and Michaelsen (1973) found yields of yams were less on bench terraces than from check plots with no conservation systems, until three years after terrace construction. Thereafter, yields increased. The results of this study probably reflect a similar situation. The strip-cropped plot had the added advantage of producing almost as much bananas as the contour-drained plot and two other crops, i.e., cucumbers and sweet potatoes. Sweet potatoes gave good yields except in the lower strip where high soil moisture levels attributable to subsurface flow caused extensive roping of the tubers.

10.0 CONSTRUCTION COSTS

Major constraints to the widespread implementation of soil conservation systems are the costs of establishment and maintenance. In Saint Lucia, the limited financial returns from small-scale subsistence farming are insufficient to allow most farmers to invest in soil conservation.

The limited data available at this stage are insufficient to perform a comprehensive economic analysis such as that presented by Wiggins (1981) for hillside plots in the Acelhuate basin in El Salvador. However, the available data provide information on the capital and maintenance costs of the systems for the 1988/89 seasons. These costs are presented in **Table 2**. Costs given relate strictly to work associated with land preparation, land-forming and establishment of conservation structures. Costs associated with crop establishment are not taken into account. Costs of machinery hire were based on prevailing rates for the use of government-owned machinery on agricultural projects. It should be noted that these costs related to specific field layouts and that these costs will vary depending on other field, drain or terrace layouts. The cost of constructing the contour-drained and stripcropped systems were approximately the same. However, terrace construction was significantly more expensive.

The level of investment required for establishing these systems cannot be provided by the average small farmer in Saint Lucia. Contour drainage and strip crops can be done by individual land-owners using hand tools, shovels, etc. However, terraces require tracked machinery. If farmers are encouraged to implement soil conservation measures, some level of subsidy would be required to make the practices financially attractive. The necessity for subsidies is further justified by considering the off-farm benefits of erosion control: reduced sedimentation in rivers, harbours and beachfronts, which affect the society as a whole and as such, the costs should not be borne solely by the farmers.

11.0 MAINTENANCE COSTS

Maintenance work mainly involves the removal of silt deposited in drains and terraces and the repairs to the slopped drains. In all cases, maintenance activities are labour-intensive. The strip-cropped and terraced plots require the most labour input and thus cost more, while the contour drain plot required the least maintenance (**Table 2**).

Maintenance is recommended during the dry season. Additional maintenance may be necessary after damage caused by heavy rains in the wet season. Such damage most often involves the slumping of terrace risers and ditch banks. This would be particularly prevalent during the first rainy season after construction. Maintenance of these structures can be done by individual land-owners using hand shovels.

12.0 SUMMARY

Soil erosion limits the agricultural productivity of tropical hillside lands and results in the loss of an important natural resource. Erosion rates are proportionately related to rainfall and impact velocity, land slope and length, soil infiltration rates and inversely related to surface roughness. Soil erosion has adverse on-site and off-site effects on the environment.

Methods for sustainable usage of hillside lands are either:

a) agronomic and based principally on increasing ground cover, or

b) physical and based principally on increasing grouind roughness and diversion of runoff.

Wherever possible, hillside forests should remain intact. Multistoried tree gardens where the soil surface is not cleared of debris or is mulched can keep erosion to a minimum. Grass strips or other runoff impeding structures can be used to filter out sediment from overland runoff and can eventually lead to the formation of natural terraces. Strip-cropping and alley-cropping reduce erosion for much the same reasons. Choice of cultivars/species with quickly developing canopies and of denser planting patterns can significantly reduce soil erosion. Mulching provides excellent soil coverage and reduces runoff through increased infiltration, greater surface roughness. However, it can harbour plant pests and pathogens. Minimum tillage, and contour tillage reduce soil erosion on small slopes but are increasingly ineffective on steep slopes. Storm water diversion drains above agricultural lands remove potentially erosive runoff originating above the watershed. Field drains on the contour shorten slope lengths and divert excess runoff to structures designed to dispose of it safely. Terraces, while expensive, are one of the few highly effective systems for crop production on very steep slopes.

Terraced, strip-cropped and contour-drained hillside plots in Saint Lucia showed low rates of soil loss, with the terraced plot showing the least soil loss. However, the terraced plot showed the lowest yield, given the soil disturbance during construction and the smaller land area available for planting. The cost of implementing terraced systems in the Caribbean cannot be borne solely by small farmers. A financial incentive scheme is necessary to encourage the use of soil conservation techniques. The entire population should help bear the cost of soil conservation.

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