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Contour hedgerows and other soil conservation interventions for hilly terrain*

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Abstract. Management of hillside cropland is a critical issue in the tropical world because of the extreme pressure on the land itself that results from the decision to farm what would be considered in many countries as marginal land.

Practices such as contour hedgerows and other soil conservation techniques could be more effective if they are installed or aligned in such a way that they maximize the land capability potential in various sectors of typical soil catenas; and if biological control crops including trees, grasses and shrubs are spatially arranged to take advantage of their intrinsic biological potential to accommodate to the edaphic dissimilarities of steep hillsides.

Spatial arrangements of annual and perennial crops in natural geosequences are discussed, and suggestions are given on how spatial considerations can be matched to preferred crop mixes of trees, shrubs and grasses, in an attempt to halt erosion and better protect the environment. Land use planning on a physiographic and soil capability basis is proposed, but acknowledges that effective implementation is subject to a determined campaign to extend both the theory of sound land management and the provision of technical assistance to peasants to demonstrate the concepts and to interpret the results of the practices.

This paper explores certain aspects of physiographic and edaphic similarities and constraints of peasant farming practices on steep slopes, and offers some theoretical bases upon which hedgerow technology can be applied to improve water and plant relations, ameliorate environmental effects and be initiated by individual farmers at little cost. A range of other soil conservation or agroforestry techniques, as used in Haiti is described; and a simple monitoring or measurement model to determine the amount of soil saved is provided, and the possibility of teaching the methods to minimally trained field technicians is explored, pursuant to encouraging farmers to give greater attention to the value of soil conservation and proper land use planning.

Introduction

Site considerations

Among the various physical factors that most affect the performance of crops within a given climatic regime are: elevation, slope, land form, rainfall regime, and soil type. The FAO has written very detailed guidelines for evaluation of over two dozen factors [FAO 1983]. Aspect is quite important in temperate

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climates, but is somewhat less of an obvious factor in tropical, particularly equatorial, climates and latitudes. Basic factors such as elevation have an influence in the choice of species which might be recommended.

In the tropics the upper elevations have somewhat lower temperatures and oftentimes reduced solar insolation due to cloud cover. Precipitation is often greater, in the main, as well; and distinct rainfall zones can usually be related to altitudinal belts. Soil pH is affected by the combined factors, and together with the soil depth differences which are the result of gravitational effects, erosion processes and age of parent materials, the landscape can be viewed as a mosaic with soil catenas that have a much more pronounced manifestation of both possibilities and realities than in flat lands. Land form is one factor that usually has an effect on precipitation, wind velocity and temperature, elevation notwithstanding. Even at low latitudes where sun angle is more constant throughout the year, the northern exposures are cooler and retain more soil moisture than do southern ones, for those places north of the Equator.

At higher elevations, air temperatures are cooler and soil moisture is generally greater, all other things being equal. Why is all of this so important?

Site factors are universally applicable to interpretation but not generally subject to change or control. Furthermore, site differences are not as noticeable in terrain that is more or less uniform over broad expanses, where elevation differences are slight or where depth of soil is not limiting. In mountainous countries, by contrast, all of the site factors take on important implications because of the wide variations that may be found at any given location. Land and soil capability potential is compartmentalized into small but discrete microsites that have importance with respect to fertility status and productivity potential, but are not always recognized as the entities that they are. It requires a good deal of vision to take maximum advantage of their production potential and yet maintain the stability of the fragile ecosystems in which they occur. One such strategy is that in the lowlands of Nepal where the focus is on improving agricultural productivity in order to stem the pressure to expand cultivated areas into the hills [Kumar and Hotchkiss, 1988]. Proper land use management, therefore, is the one variable that can be strengthened to overcome the limitations that exist in site factors.

Spatial priorities

In Third World countries there is a premium on quality land, and with increased population pressure, it is most important to preserve productive agricultural land for agricultural pursuits. This is largely being done, but the problem then becomes the use of non-agricultural lands for intensive agriculture. Trespassers and marginal farmers are more apt to seek out steep lands, cut-over forest and the like, because of their lower value, remoteness or absence of protection by the owners. When land use for crops goes beyond what would generally be classified as Class I—III lands, by the USDA classification (USDA 1951), then degradation becomes more serious. The overexploitation of fragile Class IV—VI lands for annual crops leads to declining yields but also threatens the usefulness of the land for pasture, range and forestry, as well. However, it is on the marginal lands that the agroforestry technique of contour hedgerows can perhaps be of the greatest benefit in the preservation of land quality. And by reducing erosion and ameliorating soil quality, contour hedgerows, when practiced on marginal lands, contributes to the stabilization of watersheds and thus to better preserve and protect downstream areas.

Some spatial priorities that might be considered may differ among the most broadly defined land uses, such as crop land, range land, forested land and marginal land. Marginal agricultural lands that were forest only a few decades ago constitute a major source of concern because of their lower ranking in terms of inherent soil capability as crop land, but also because typical hillside cropland that has recently come under cultivation tends to have excessive slope, with thin, stony profiles [Pellek and Talbot, 1988]. A shift from land use theory to actual implementation on land owned by farmers bears out the fact that marginal land often is marginally managed. In much of the Third World poor farmers are eager to accept the help and guidance that they believe will benefit them. In some cases the interest is limited to listening to technical advice, in other cases it may involve the provision of goods and services that the farmer will apply in his or her own way. It will not be possible or practical to expect that simple agroforestry interventions or the more expensive mechanical means of erosion control will be embraced by all farmers. Land tenure issues limit the interest in, and willingness to participate in the programs. Cost of materials and labor limitations associated with the more complex programs of erosion control are more restrictive. Furthermore, even when the land is owned outright and materials or labor are not limiting, parcels in valleys and on toe slopes have higher production capabilities, thus call for different management strategies than for parcels along ridges or in upper slopes.

Land tenure restrictions and absentee ownership impediments may mean that not every farmer in a watershed will participate. Also, even though farmsteads or plots lower down the slopes would benefit more from hedgerows and less from tree crops, the individual plots on slopes are still subject to universal gravitational effects that can be managed. The spatial circumstances of individual plots can be exploited. Not all farmers will take advice, but unless it is proposed as part of a systematic and programmatic strategy, piecemeal implementation of such structures as rock walls and contour hedgerows for erosion control on an individual farm basis will have little impact within a watershed. In any case, there is a sizeable constituency that is quite receptive to ideas and there are enough interventions to fit with a variety of circumstances, that it should be incumbent on governments and development workers to provide the best advice possible regarding the wise use of resources and protection of the very environment upon which farmers depend for their livelihood.

Planning better land use-getting started

Expatriate development workers who are called upon to plan soil conservation or agroforestry programs are often limited in their effectiveness by a relative lack of familiarity with the country or countries where the currently popular agroforestry and soil conservation solutions tend to attract the most interest and frequently the most development monies. Problems with local languages and ignorance of cultural attitudes among the peoples they are expected to serve are major concerns, and cannot be mastered in the short run. Without the confidence and full participation of the clientele, no program can be expected to work. However, much can be accomplished during the learning stages by employing some standard tools.

To get the fastest start and the most comprehensive overview of an unfamiliar country, it is prudent to commence with a careful analysis of topographic, soil survey, land use and/or soil capability maps — if they are available. Slope maps and other special use maps can be made from such base maps, to put the problems and potential solutions in a broad perspective even before leaving the office for the first time. The bigger the program and the bigger the country, the greater the need to employ the tools that will save scarce financial and human resources. Proper pre-field planning also allows one to set priorities and compartmentalize geographic areas on land capability — not political grounds. Getting started in an area where good results are most likely and where technical approaches can be tested, refined and validated in the shortest period of time, is more likely to attract the attention of the farmers who are the ultimate beneficiaries, as well as the donor agencies who are always looking for positive cost/benefit indicators of the efficacy of the interventions. Furthermore, if the program or project is limited in terms of funding, the maps should be able to assist the planner to decide which area(s) is/are the one(s) with the greatest potential to serve the largest population concentration; or, on the other hand, the areas that could be eliminated because of edaphic and/or climatic constraints.

Multiple uses and agroforestry crops

Among the many uses for agroforestry: crops, fuel, fodder, green manure, food, poles, posts, fruit, shade and environmental protection immediately come to mind. The preferred use in the mind of a farmer, however, will limit the use because not all of the possible uses can be realized with the same plants, or all of the uses manifested at the same time. Given enough land and various types of germplasm, however, it should be possible to realize many of the benefits concurrently if spatial priorities are employed to maximize the land capability potential of the soil resources and the intrinsic characteristics of the plant species. Efficient use of agroforestry interventions should match the land capability with the crop associations themselves. Although that has been done in some societies and farming systems for many years, land capability limitations need to be incorporated in the planning stages when agroforestry concepts are not already an integral part of the local farming systems. Land capability aspects should also be integral to the development programs where agroforestry would be appropriate. The deeper and more fertile soils of valleys should be favored for crop production. Often the higher valued crops have water requirements that can only be met by concentrating their production on the better soils of valley floors, alluvial terraces, and the like. Upland Oxisols on plateaus or gently sloping land also have good potential, if well managed. Contour hedgerows that produce usuable fodder, green manure and some fuelwood are quite often more profitably installed in lowland toe slopes adjacent to better agricultural soils because they provide quicker growth and more useful products there, than they do in upper slopes where thin soils and insufficient ground water may restrict their usefulness. When the cost of installation or the amount of seed to establish hedgerows are limiting factors, it would be wise to set priorities regarding hedgerows. In general, soil and water conservation interventions should begin on the upper slopes to prevent damage to the lower slopes. But hedgerows may have fewer multiple uses in the marginally productive sites of the upper slopes, and the planner should consider trees and pasture, instead (Fig. 1).

Multiple use hedgerows

Most hedgerows have been established with a single species, often the one for which viable seed was most available. The qualities that one looks for in a hedgerow plant include: vigor, fast growth, nitrogen fixation, copious biomass and useful byproducts. A combination of species within the same hedgerow is also possible, and is quite practical, so long as the range of end uses is satisfied. In steep terrain of anything greater than 10% slope, one of the principal reasons for hedgerows is erosion control; and in those places the byproducts might be of secondary importance, except to the farmer.

The principles of land capability potential apply everywhere, but in lieu of concrete examples of a universal nature to make the point, an example from Haiti is offered. Haiti is a good example because it offers a worst-case scenario of exploitative land use, has a high population of rural peasantry, vast areas of steep terrain in which the effects of cropping on marginal lands are manifest; and the opportunity to witness and measure the impact of the many soil and water conservation interventions that are either being implemented, or are proposed.

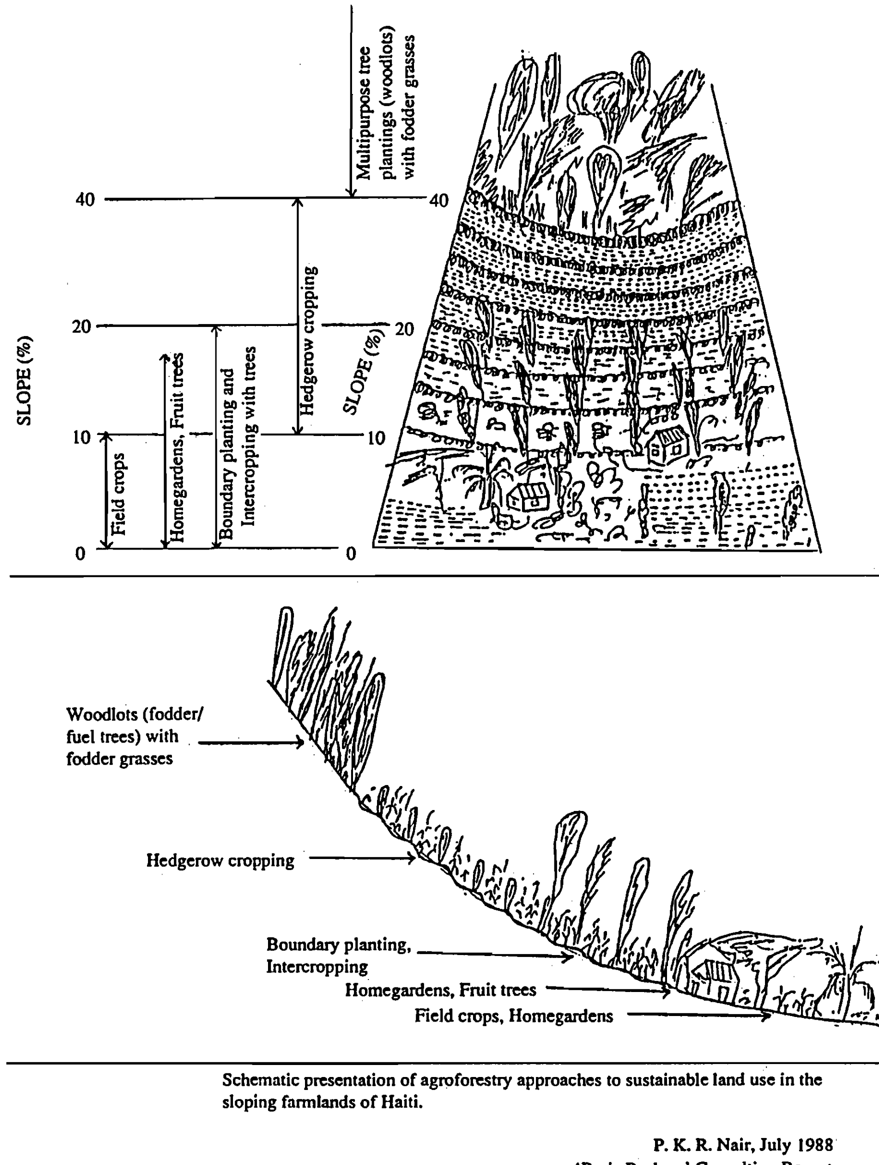

Fig. 1. Schematic of spatial allocation of agroforestry crops.

Haiti — a case study

Due to its mountainous nature and high population base of almost six million persons on 27,000 square kilometers of land, Haiti relies upon a disproportionate amount of steep hillside to meet much of its agricultural production. Two or more crops a year are grown in most areas as a result of a bimodal rainfall distribution and the possibilities of multicropping. Rainy seasons, hence cropping seasons are usually April to July, and September to November in most of the country. The intensive activity on the land during these periods places a premium on efficient soil and water management. During the intervening dry periods, on the other hand, there is an equally important and complementary premium on water conservation, one aspect of water management. The drastic consequences of past land exploitation and poor management practices over the past two hundred years have resulted in Haiti, with its large rural peasantry, having a worst-case reputation for environmental degradation. Not all of the blame for degradation, however, can be traced to the population pressures and farming practices alone. Steep slopes and thin soils carry their own biophysical risks and hazards which can and do impact upon soil and water resources, and their management.

Climate and soils

Haiti is located in the high latitude tropics between 18—23 degrees North Latitude. Its position and mountainous terrain have created extremes of weather and temperature regimes which vary greatly with altitude [Erlich et. al., 1985]. Haiti's land area of 27,700 square kilometers is primarily mountainous, with 63% of all land having slopes greater than 20%, and only 29% with slopes less than 10%. Soil depth over vast areas of uplands seldom exceeds 25 cm; in many places it does not exceed 10—15 cm. Erosion is the most serious problem affecting the agricultural sector.

A number of donor organizations and governments and their respective bilateral and multilateral development projects have taken a serious look at combatting erosion in Haiti, while also trying to halt the concomitant decline in land productivity. The U.S. Agency for International Development (USAID), the largest donor with several programs in natural resource management, takes a comprehensive view of soil and water conservation as part of its "hillside strategy", which has as the thrust of its current and planned agricultural project activities, the development and extension of sustainable agricultural production systems in the rain-fed, multi-crop, peasant rural communities where the majority of Haitians live.

In Haiti, the high proportion of land that is strongly sloping has a distinct influence on agricultural practices and crop productivity. Much of Haiti is underlain by various grades of limestone that degrades into karst topography characterized by thin soils that are also very erosive. Soil depth seldom exceeds one-half meter, except in the lowlands where it has accumulated over centuries of erosion. In a few places, however, plateaus and table lands occur; and land parcels there have usually deep soils. As a result, only 11% of the land has a high potential for agriculture; 32% of the land is on slopes that require careful soil and water conservation measures; and 54% of the land should be in pasture, tree crops or in a natural state, but is increasingly being farmed [USAID, 1989]. Soil and water resources themselves are viewed as inputs in the management strategy.

In a quest to halt environmental degradation and to achieve more sustainable agricultural practices, the USAID mission in Haiti and its grantees and contractors have been putting a great deal of emphasis on developing and refining a suite of hillside technologies that include contour hedgerows, mechanical devices, contour plowing, and other agroforestry components. The most prominent and widespread of these is the hedgerow technology, if for no other reason than they are the cheapest and most convenient to install.

Toward a hedgerow technology for Haiti

Hedgerows, when installed along the contour, have several distinct advantages over crop arrangements under the traditional agricultural systems of Haiti. Some of the potential advantages of hedgerows are:

Water relations

1. Perennial crops with deep root systems increase the depth of penetration of surface water.
2. Added depth of penetration of surface water increases storage efficiency in the solum.
3. Perennial crops with deep root systems may help to break up hardpan which may inhibit water movement in the profile and into aquifers.
4. Root channels of deep-rooted perennial crops improve infiltration rates and downward percolation of rainfall and irrigation water.
5. Year-round transpiration of perennial crops in the tropics increases overall humidity in crop canopies.
6. High humidity in the canopies of tall perennials increases the water use efficiency in the shorter annual plants.
7. Hedgerows serve as windbreaks, decreasing the variation in the relative humidity in the alleys, thus improving the evapotranspiration status of annual plants.
8. Water cycling efficiency is improved. Because of the water pumped from the subsoil by the deep root systems of perennial plants, capillary water around superficial roots increases and osmosis is facilitated.

Plant relations

1. Root masses tend to improve the tilth and overall physical structure of the soil fabric.

2. Soil fertility is regulated through nutrient cycling and organic matter deposition of perennial crops.
3. Mineral cycling efficiency is improved as nutrients in the sub-soil are cycled through the plant tissues and are returned to the soil surface through the shedding of leaves and other plant parts.
4. Litter layers on the surface decrease evaporation in surficial soils. The infiltration of water is directly proportional to the thickness of litter layers.
5. Additional quantities of organic matter, over time, improve the working qualities of the top soil, its texture and moisture retention capacity.
6. Litter layers under perennials reduce the surface temperature.
7. Permeable litter layers improve gas exchange by maintaining tilth.
8. Nutrients that are cycled regulate the chemical balance throughout the profile by redistributing nutrients to the topsoil.
9. Nutrient stores in litter and surficial soils are more prone to be transported downstream in lateral transport and gravitational overland flow. Thus, nutrients are spread around the farmstead. Nevertheless, the hedges limit this movement within farmers' plots.
10. Litter layers under perennial plants tend to be thicker than under annual crops and add to the moisture holding capacity.
11. Hedgerows that produce both green manure and litter barriers have the potential to improve or maintain soil fertility, as well as to check erosion, simultaneously.

Environmental effects

1. Contour barriers help to dissipate the force to overland flow of water and to spread it, lessening the risk of erosion. In major storms this effect may be slight.
2. Water that stays on the land longer is more beneficial to crops.
3. Living terraces can serve as effective wind breaks.
4. As they mature, vegetative barriers of perennials become more effective against erosion.
5. Living terraces are soil and water conserving. As the slope gradient changes over time, they become even more efficient.
6. Vegetative barriers of multipurpose species become more productive with age, in some cases.
7. With the ability to spring back, vegetative barriers of upright perennials can usually withstand the cascading effects of stones and soil from above.
8. As they grow in diameter, the stems of perennials in a line become thicker and stronger; and serve as better traps for soil particles.
9. Soil accretion upslope of vegetative barriers is richer than interrow soils, due to the high content of top soil eroded from above, and from the surface debris washed down.

Economic factors

1. Hedgerows are quick and inexpensive to install through direct seeding.
2. Hedgerows are long lasting and require little or no maintenance, depending on the species used.
3. The hedges can be a source of fodder, green manure, fuel and other material; and can be designed to produce fruit and other edible crops for human consumption.
4. Hedgerows can be planted by a single farmer, using materials that are, or could be readily available on the farm.
5. Income can be derived directly from hedgerow crops, indirectly from savings resulting from fertilizer enrichment by the green manure produced, fodder for animals, etc.; or both.

The recommended spacing between rows of hedges that has been proposed for Haiti [Weigel and Zimmermann, 1987] and adopted by the Agroforestry Outreach Project is:

Slope%	Distance (m)
5—10	20—17
10—15	17—13
15—25	13—8
25—35	8—6
35—50	6—4
50+	4—2

Constraints and disadvantages of hedgerows

Many farmers who opt for establishing hedgerows often do not realize the amount of labor required to maintain them after they are installed. Among those who do, they are loathe to follow the prescribed spacing because of the amount of land that they perceive to be giving up in the process. Also, some species such as *Leucaena leucocephala* that produce an abundance of seed, have quick germination and growth and are thus likely candidates for direct seeding, are also those most likely to become weedy if they are not trimmed back on a not infrequent basis. Widely spaced hedges do not provide an adequate quantity of vegetative matter for soil improvement and erosion control. On the other hand, closely spaced hedges are the equivalent of forestry.

Despite the objections in giving up additional land, many farmers are cautiously willing to experiment with single and double hedges of multi-species perennial tree and/or shrub crops. Multi-species hedgerows have the potential to provide a variety of goods and environmental services, all at the same time, but could easily become so complex that farmers may not embrace them. The challenge of the extension worker is to convince the farmers that despite the initial extra management, changes in the spatial arrangement will ultimately benefit him.

Insect and disease infestations, slow growth and poor product quality are other factors which may reduce the appeal and value of hedgerows in the eyes of potential users. A quick growing and well adapted direct seeder such as *Sesbania grandifolia* does not produce good quality wood in the first place, thus is not valued for that purpose in hedgerows, but its appeal is further eroded when it shows a propensity to either disease or insect damage.

If proper site or soil matching and choice of species is not considered, the possibility of establishing healthy hedgerows is compromised. In mountainous countries, hedgerows hold out great promise because of their effectiveness on contours, within the limits of economic feasibility and their physiological and biological potential. The presence of hedgerows also encourages contour tillage.

Hedgerows should not be viewed as a panacea for all sites, in all conditions of slope. *Sesbania grandiflora* in Haiti, in addition to being subject to insect attack, is not very drought resistant. When seeded on slopes that have thin soils, or in zones of marginal rainfall, *Sesbania* is a marginal performer.

There are many other interventions that have been important means of stabilizing the soil, with various costs and benefits associated with them. Although they are in common use, to one extent or another, throughout the world, Haiti has a fairly comprehensive suite of both agroforestry and soil conservation methodologies. Among them are:

Agroforestry [AF] and soil conservation [SC] interventions and application used in Haiti

1. Terrasses Vives (living terraces) [AF], [SC]

The planted grasses, shrubs, or woody perennials on the contour, particularly in moderately sloping to strongly sloping land, for the purpose of erosion control, production of fodder, green manure and/or edible commodities.

2. Haies Vives (hedgerows) [AF]

Similar to living terraces, but may also be found on land that is not particularly sloping. The emphasis in "hedgerow" technology is on the layout, architecture and species composition of the hedgerow itself. They are generally established on the contour and used as filter strips.

3. Bandes Enherbées (strip cropping) [AF], [SC]

Similar to haies vives and terrasses vives, the bandes enherbées are strips with forage crops. Grass strips typically are 1—5 m in width.

4. Alley Cropping [AF]

A complementary land use system wherein the chief emphasis is put on the crops between the adjacent hedgerows which are generally comprised of fast growing legumes.

5. Rampe de Paille (litter terraces) or Fascinage [SC]

A traditional Haitian technique whereby straw, sticks, and dead branches or other material is interwoven in contoured lines on the hillside. The "rampes de paille" are anchored with pegs that are driven into the ground, also along the contour.

6. Clayonnage (wattle fence) [SC, AF]

Similar to rampe de paille or fascinage, the clayonnage is used to plug small gullies. The sticks are generally stronger than those used for fascinage, and are selected for their ability to sprout in the soil.

7. Structures Mecaniques, Cordon de Pierre and Structures Bio-Mecaniques [SC]

All of the above "structures mecaniques" are soil conservation interventions which employ stone, dry masonry or, in some cases, concrete contour walls, gully plugs and check dams to impede overland flow of water and to trap the soil behind them. In the case of "structures biomechaniques," shrubs, grasses, or perennials are also planted either above or below the structure to take advantage of the impeded moisture to promote more rapid growth. Developing roots also stabilize the structures themselves. In Haiti, mechanical structures have proven largely ineffective, in some cases, because of the high rate of in situ infiltration and percolation of rainwater, and also because of the general absence of soil fines, particularly clay, that could act as a barrier to the movement of soil particulate matter; and finally, because of a lack of maintenance.

One special type of gully plug structure known as "seuil en pierres sèches" or loose rock check dam is a prominent structure of stones anchored into the ground. It normally has a length of 1-10 m and a height not to exceed 2 m. Some exceptional ones attain a length of 18—20 m. The stones are stacked up pyramid-like from a base of 1½ to 2 times wider than the height of the "seuil". An apron is built downstream of the dam to protect it against water scouring. Due to the amount of material, skill and labor involved in construction, series of "seuil en pierre sèches" are attempted only where there are excess stones nearby and where there is an ample work force.

8. Canal de Contour (hillside ditches) [SC]

A moderately deep trench (30—60 cm) dug into the soil along the contour to trap and diffuse rainfall. Although contour canal digging could be justified on its own merits, in most cases the canal itself is part and parcel of the "terraces vives," "bandes enherbées," and "structures biomecaniques." The canal itself is overlooked where it is part of the more sophisticated approaches undertaken.

9. Canal de Diversion (diversion canals) [SC]

They are similar to the hillside ditches except that they have a slope of 1—3% to carry excess overland flow to normal drainage channels. Their use is limited in Haiti because of the skill necessary not to exceed the 3% slope, above which erosion in the canals may intensify in the drainage channels.

10. Billonage (earthen ridges) [SC]

They are the complements of the canals de contours and are built on the contour between the canals. Whereas the canals themselves hold water and prevent overland flow, the ridges enhance root development by providing tilled, free draining seedbeds for the target crops. They also protect the soil against rill erosion.

11. Bassin de Sedimentation (sediment basin) [SC]

These small basins are dug in the downstream sections of treated ravines and gullies. They trap excess sediment and store water, therefore increasing the infiltration rate of water in mid-stream while decreasing sediment deposits on usually valuable land.

Applications of terminology

Numbers 1—4 above may be described as hedgerow systems. It must be said that terms such as "living terraces" or its common variants, e.g. "rampes vivants", "leucaena hedgerows", etc. are not really synonyms, nor are they true terraces. The "terraces" are seldom more than 1/2 m wide. True terraces are rarely seen in Haiti, but where they exist they are quite effective.

The main disadvantages with the structures that rely on stone are the high labor input and the limitations on sources of materials. Although they are stronger than vegetative barriers, maintenance is a much more costly proposition, and they do not have the potential of providing direct income. In some areas large basins that hold water are dug downstream of a series of checkdams. These do have value for watering livestock and fish raising. Currently, there are only few reliable data available on the efficacy of any agroforestry or soil conservation interventions as practiced in Haiti. In light of the enormous attention being given to the promotion of the wide variety of interventions, and to the actual expenditures being made, it would be justified to call for some fundamental research on costs and benefits.

Haiti has the advantage of being in the limelight vis à vis the development efforts being made, partly as a result of the terrible environmental degradation that has already been wrought. It is already an example of post-climax environmental mismanagement resulting from excessive land hunger and exploitative agricultural practices; but, on the other hand, it is also an example of what can be done to minimize or even halt the effects of accelerated erosion, particularly of the steepest and most marginal of lands.

Calculating surficial area, effective surface soil volume, and total volume of soil conserved behind hedgerows

The monitoring of soil conserved behind hedgerows is an overlooked but important means of convincing farmers to install hedgerows and then to maintain them. Increases in crop yields is the decisive factor, however. The measurements required are simple ones, and can easily be learned by farmers, technicians or others who may be involved in hedgerow activity. Three aspects of monitoring are useful descriptors in evaluating the changes in the microenvironment, but only three parameters are needed to make the estimates.

I. *Surficial area*

Length $(\alpha) \cdot$ Width (β) = Area, where,

(α) = length of hedgerow (and) linear zone of soil affected by the terracing effect.
(β) = width of zone of terracing effect. Estimated by a straight line marking the region of soil accretion above the hedgerow; and measured at the point of "~~zone~~ zero slope" uphill in the terrace.

Example: Hedgerow of 30 m length and 1 m width of visual soil accretion:

$$\begin{aligned} \text{Area} &= (\alpha) \cdot (\beta) \\ &= 30 \text{ m X } 1 \text{ m} \\ &= 30 \text{ m}^2 \end{aligned}$$

II. *Effective surface soil volume*

Volume of a solid with two rectangular and two triangular faces is = $(\alpha) \cdot (\beta) \cdot (\delta)$

V = $0.5[(\alpha) \cdot (\beta) \cdot (\delta)]$ where,
(α) = length of hedgerow.
(β) = width of zone affected by terracing, as in I above.
(δ) = height of terrace formed, measured from the root collar of emerged hedgerow plants.

Example: Same hedge of 30 m length and 1 m width shows 0.5 m of soil accretion, measured from the root collar to the surface of soil upslope of the hedge.

$$\begin{aligned} \text{V} &= 0.5(\alpha \cdot \beta \cdot \delta) \\ &= 0.5(30 \text{ m} \cdot 1 \text{ m} \cdot 0.5 \text{ m}) \\ &= (7.5 \text{ m}^3) \end{aligned}$$

This assumes no concave or convex subsurface irregularities. Although an overhead view of this figure would appear to be a rectangle, the slope effect reduces the effective surface area and volume to about half the amount of that of a rectangle. That is to say, crops on the upslope side have minimum benefit from a slightly enriched accreted profile but crops nearest to the hedgerow have new profiles of enriched soil equal in depth to (δ).

III. *Total volume of soil conserved*

A. *General case*
For polygons, volume (V) =

$$V = 2\int_0^{\alpha} \frac{\delta}{2}\left[\beta\ \frac{(\beta \cdot n)^x}{{}_{\alpha}n}\right] dx$$

$$V = \frac{\delta}{2}\left[\beta x - \frac{\beta x^{(n-1)}}{{}_{\alpha}n_{(n-1)}}\right]\Bigg|_0^{\alpha}$$

$$V = \frac{\alpha \cdot \beta \cdot \delta}{2}\left[\alpha - \frac{\alpha}{n+1}\right]$$

$$V = \frac{\alpha \cdot \beta \cdot \delta}{2}\left[\frac{n}{n+1}\right]$$

where (α) = length of hedgerow.
(β) = width of zone affected, as in I.
(δ) = height of terrace formed, as in II.
(n) = mass number of polygon. In triangles, n = 1, in parabolas, n = 2, and in rectangles, n = 10.

B. *Specific case*
Volume for rectangular polygon:

$$V = 2\int_0^{\alpha} \frac{\delta}{2}\left[\beta\ \frac{(\beta \cdot n)^x}{{}_{\alpha}n}\right] dx$$

$$V = \frac{\alpha \cdot \beta \cdot \delta}{2}\left[\frac{n}{n+1}\right]$$

reduces to (V) $= 5\,\dfrac{\alpha \cdot \beta \cdot \delta}{11}$

Example: $(\alpha) = 30$ m, $(\beta) = 1$ m, $(\delta) = 0.5$ m

$V = 6.8\ m^3$

This formula is the most conservative of all. Although the integral formula is probably beyond the ability of most field workers to understand, the formula to which it reduces,

$V = [(\alpha)(\beta)(\delta) \div 2]\,[(n) \div (n+1)]$

seems within their grasp when algebra is used. Since the ideal polygon used in II is only an approximation of any soil body without surface irregularities, it will overestimate actual volume. The difference between the value in formulas in II and III is 10.3%.

Of the two it may be better to use the simpler formula. In any case, a verification of the hypotheses must be based on the measurements of length, width and height of actual soil bodies as they exist in the field. Their boundaries are easy enough to see on the basis of visual differences in soil color and apparent texture, and their superior fertility is presumed in their description as the "zone of enrichment" [P. K. R. Nair, 1988, personal communication].

Only a few estimates to date have been made on the impact of the zone of enrichment as it pertains to the amount of soil saved on individual farm plots in Haiti. However, with about 1.4 million meters of hedgerows already established in Haiti, and using the conservative observations of (β) = 1 m and (δ) = 0.5 m, the volume saved to date is of the order of 350,000 m^3. Converted to mass with an assumed bulk density of 1.0 g/cm^3, it amounts to 350,000 tonnes of soil.

The principles of soil conservation which are largely theoretical in the above example were also employed in a survey of 739 erosion control structures in ravines through the use of stone check dams in Cape Verde in West Africa. In fact, the theory behind making sequential measurements of

Table 1. Volume of soil retained after a single seasonal rainfall of 130 mm, Ribeirao Feijao, Saltos, Santiago, Cape Verde.

		Date of Observations					
		29/7/82			26/10/82		
Dam #	Lgt m	Hgt m	Dist m	Hgt m	Dist.(a) m	Vol.(a) m^3	Vol.(mx) m^3
3A	56	2.8	23	1.8	18	902	454
3B	52	2.1	15	0	0	546	546
3C	21	0	41	0	0	832	832
3D	14	0.7	4	0	0	18	18
3E	27	1.7	16	0.4	16	184	43
3F	25	1.7	16	1.1	10	170	69
3G	18	2	15	1.2	10	135	54
3H	26	1.8	20	0.8	14	234	73
3I	21	1.1	9	0	0	52	52
3J	18	1.5	17	0.7	14	115	44
3K	16	1.3	9	0	0	62	62
3L	15	1.3	8	0	0	49	49
3M	17	0.6	7	0	0	18	18
3N	21	0.5	8	0	0	38	38
3O	14	0.9	9	0	0	38	38
Totals						3393	2390

erosion and, conversely, saving the soil behind structures was first developed there. Although other parameters were also measured to describe the dynamics of torrent control in a widespread system of checkdams there, the basic parameters of length, width and height of the checkdams were all that were required to make fairly accurate estimations of the amount of soil saved behind the checkdams.

If anything, the erosion in Cape Verde is worse than in Haiti, with or without the influence of agricultural practices. In an attempt to understand the dynamics of erosion, a small case study was conducted in the 41.8 ha sub-watershed of Ribeirao Feijao, Saltos, on the island of Santiago in 1982. The sub-watershed was chosen because of the adequate number of newly constructed rock checkdams, few of which had gone through a complete rainy season, thus enabling the investigator to study the before-after effects in the dynamics of erosion, checkdam efficacy and the temporal changes in land use behind checkdams as a result of topsoil accretion. The results are given in Table 1.

Table 2. Branch-drainage checkdams (inventorized only) Ribeirao Feijao, Saltos, Santiago, Cape Verde.

Checkdam #	Length m	Height m	Dist.(mx) m	Vol.(mx) m^3
3L, B11	28	2.2	11	169
3L, H	19	1.7	7	56
3L, L1R	13	0	10	91
3L, L11	12	0.8	6	288
3L, L21	15	1.5	8	45
3L, K	17	1.3	6	44
3L, K21	20	2	6	60
Total				753

Discussion

Volume of soil retained behind stone checkdams depends, in part, on the shape of the margins of catchment basins found upstream of the structure. Once dammed up, the sediment basin formed an apparent triangle, rectangle or parabola. The basin formed was determined by spotting the position where the slope gradient upstream was equal to zero. In the example used in Table 1, all of the checkdams except one were constructed in the dry season, thus could be checked for slope gradient when sediment did not prevent viewing the shape and extent of the potential sediment basin upstream. Furthermore, absolutely no rain fell in the interim period when the checkdams were being constructed. A re-measurement of the system of checkdams in Rireirao Feijao, after a single rainfall of 130 mm between 29 July and 26 October 1982, permitted a verification of the before-after hypothesis.

The volume of soil retained, VnX, in Table 1 was not the total volume, however. A branch drainage (Table 2) should be included, but since the checkdams there were not monitored in the same way, the soil retained can only be estimated. Nevertheless, an overall estimation of erosion can be calculated by summing up the values for the main and branch drainages and then multiplying the bulk density of the soil by the total volume retained. If it can be assumed that all the checkdams in the branch drainage in Table 2 were filled in, the total erosion from the hillsides in Ribeirao Feijao, as a result of a single rainfall episode, can be estimated, as follows:

VnX (main drainage) + VnX (branch) = Gross Erosion
The bulk density of the volcanic soil was estimated at 0.9 g/cm^3, thus,
0.9 g/cm^3 X [VnX (main) + VnX (branch)] = Erosion
= 0.9 X 106 g X [2829 m^3 + 753 m^3]
= 0.9 X 106 g X [3143 m^3]
= 2,828,700 Kg
= 2,829 MT

The area of the drainage upstream (the sub-watershed of Ribeirao Feijao) of Checkdam 3A, the last and lowermost one in the series was calculated to be 41.8 ha. Therefore, the erosion that was recorded as a result of the before-after calculation of sediment entrapment, when put on a hectare basis, was:

$$\frac{2{,}829\ \text{MT}}{41.8\ \text{ha}}$$

$$= 67.7\ \text{MT/ha}$$

References

Erlich M, Conway F, Adrien N, LeBeau F, Lewis L, Lauwerysen H, Lowenthal I, Mayda Y, Paryski P, Smucker G, Talbot J and Wilcox E (1987) Haiti country environmental profile: a field study. USAID, Port-au-Prince, Haiti, 120 pp

FAO (1983) Guidelines: land evaluation for rainfed agriculture. FAO Soils Bulletin No. 52. 1983

Kumar, Shubh K and Hotchkiss David (1988) Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal. International Food Policy Research Institute, Res. Report 69

Nair PKR (1988) Technical evaluation of living hedgerow gardens. Pan American Development Foundation, Port-au-Prince, Haiti. 17–30 July 1988

Pellek, Richard R and Talbot PR (1988) Misperceptions of deforestation in Haiti: problems of available data and methodology. AMBIO 17(3): 245–246

U.S. Agency for International Development (USAID) (1989) USAID/Haiti: Strategy paper for FY 1989/1990, January, 1989

U.S. Department of Agriculture (1951) Soil survey manual. U.S. Gov't. Print. Office, Washington, DC 503 pp

Weigel G and Zimmermann. Th (1987) Gid gwosilvikol (pwowiswa). Caritas, Haiti, Port-au-Prince 81 pp