Chapter 13

Agricultural erosion in the Ecuadorian Andes

A NATURAL AND HISTORICAL PHENOMENON

THE SITUATION

Although Ecuador is a small country (270 000 km^2) in terms of the South-American continent, it contains a remarkable mosaic of landscapes. This variety, which encompasses the juxtaposition of cold, temperate and hot ecosystems within a short space, is a result of the huge mountain barrier of the Andes, locally called the *Sierra*. This range, running from north to south through the centre of the country, is bordered on the west by the Pacific coast and on the east by the Amazonian foothills. Wedged between two low plains, the Sierra is hence a classic mountain environment with striking variations in altitude.

Human activity, traditionally agricultural, has had to adapt to this high mountain environment. Early on, during the two thousand years preceding the Spanish conquest, the Sierra was the centre of a flourishing agriculture, for the population, which never exceeded 200 000, was able to develop an approach that was in harmony with the environment. These long-ago societies spontaneously practised crop diversification and land use involving different ecological zones, and developed an irrigation system with channels following the contour of a tight network of terraces. Over the centuries, the troubled history of the Spanish conquest and more recently the social effects of population pressure have forced an imbalance in the relationship between human beings and environment. At present the agricultural frontier is expanding upwards and is coming up against the constraints imposed by mountains (those of climate and slope). This is the context that has seen the development of the *minifundio* area – which, in the very difficult conditions of foodcrop plots of less than 1 hectare, is now facing acute erosion problems.

SOIL EROSION: DIAGNOSIS AND SOURCE

A NATURAL PHENOMENON: A MOUNTAIN ENVIRONMENT

The Sierra is an enormous mountain barrier, 100 to 120 kilometres wide, made up of two parallel ranges (the *Cordilleras*) with a depression between them formed by a succession of fault basins. The main landforms are as follows:

TABLE 43
Agrarian structure in Ecuador 1954-1985: number of holdings and area occupied (expressed as percentages)

Size in ha	1954		1974		1985	
	Number	Area	Number	Area	Number	Area
0-20	90	17	85	19	83	20
20-100	8	18	12	34	15	44
> 100	2	64	2	48	1	35

- **In the intra-Andean zone** there are two distinct tiers within watersheds. Below 2 400 m the terrain is relatively flat (0 to 20% slope) with scattered shrubby xerophytic plant cover. The people live in small villages and grow irrigated crops: sugar cane, fruit trees and vegetables. Evidence of erosion can be seen everywhere – not only in the irrigated areas where there is insufficient control over water, but also in the areas poorly protected by the shrubby plant cover. However, most of the Sierra landscapes lie on the second tier between 2 400 and 3 200 m, which has the following features:
  - a tight network of ravines and *cañones* – evidence of active headward erosion -where slopes are over 70%; there is very little agriculture, and only shallow soils;
  - flat runon areas (less than 10% slope) where the large cattle ranches (*haciendas*) are found; the landforms between these areas and the ravines are much less regular (25 to 50% slopes), with a pronounced shrinking of small maize plots in the face of long-standing and very active erosion;
  - either pediment-terraces or débris cones, rising up to the mountainous zone; on slopes of less than 25% animal husbandry flourishes on large- or medium-sized farms (*haciendas* with hundreds of hectares, or *fincas* with tens of hectares); higher up, between 3 000 and 3 200 m, are the first escarpments, where the first wave of *minifundios* has been established, a development that has led to increased erosion.
- **On the ranges or *cordilleras***, the Andean highlands start at 3 200 m (De Noni and Viennot 1985), and it is here that *minifundios* have spread extensively in the last ten years. Potato, onion, broad bean, barley, quinoa, lupin, etc. are grown as high as 3 800 m, where extensive sheep and goat-rearing takes over – and sometimes llamas, which can go as high as 4 400 m. The ever-increasing inroads of agriculture in this environment is reflected in active degradation.
- **Lastly, on the outer slopes**, gradients are even steeper (over 70%). Erosion is localized and depends on soil instability, which increases as the natural vegetation and pastures are steadily replaced by tropical crops.

The Andes thus constitute an environment very prone to erosion (through the action of rain and humans), since there is a relationship between slope, speed of flow, volume of runoff and intensity of erosion.

AN HISTORICAL PHENOMENON: *MINIFUNDIOS* AND *HACIENDAS*

The Sierra is the region of the country with the greatest population pressure on land. As a general rule, heavy population densities, varying from 50 to over 200 per km^2 (Ambato region) (Delaunay 1989), characterize the *minifundios*. The distribution of farm units (number and area), based on Ministry of Agriculture censuses, is given in Table 43.

For all years, *minifundios* (0 to 20 ha) account for more than 80% of the farm units, but occupy only 20% of the arable land and are located mostly in places where it is hard to get a good return. The good flat land in the watershed is managed by the *haciendas* for extensive cattle ranching. This paradoxical situation is the outcome of an historical process with three key phases (De Noni 1986):

- the historical consequences of the Spanish conquest were dramatic, leading to a general decline in population (through war, disease, etc.); in practice, the indigenous people were treated as slave labour and were herded together on to huge estates, which then quickly developed into the large farms better known as *haciendas*;

- since the beginning of this century, Ecuador has seen a remarkable expansion in population, particularly in the rural sector; in 1586, the population of the whole country was about 150 000; between 1780 and 1886, it doubled from 500 000 to 1 000 000; and between 1886 (Estrada 1977) and 1989 it increased tenfold, reaching 10 500 000;

- in the face of the widespread discontent of a rapidly growing population, on 11 July 1964 the military government then in power passed an agrarian reform law with the aim of abolishing the virtual condition of servitude (*huasipungo*) to which the numerous labourers on the *haciendas* had been reduced since the conquest; the large landholders were to surrender their privileges and give up a part of their land; this is how the *minifundio* agrarian system developed, with the units being run by small peasant farmers who were now free landowners; in reality, however, the *haciendas* kept the best land for themselves, yielding only inhospitable land to the agrarian reform.

HAZARDS: THE IMPACT OF EROSION ON THE AGRICULTURAL ENVIRONMENT

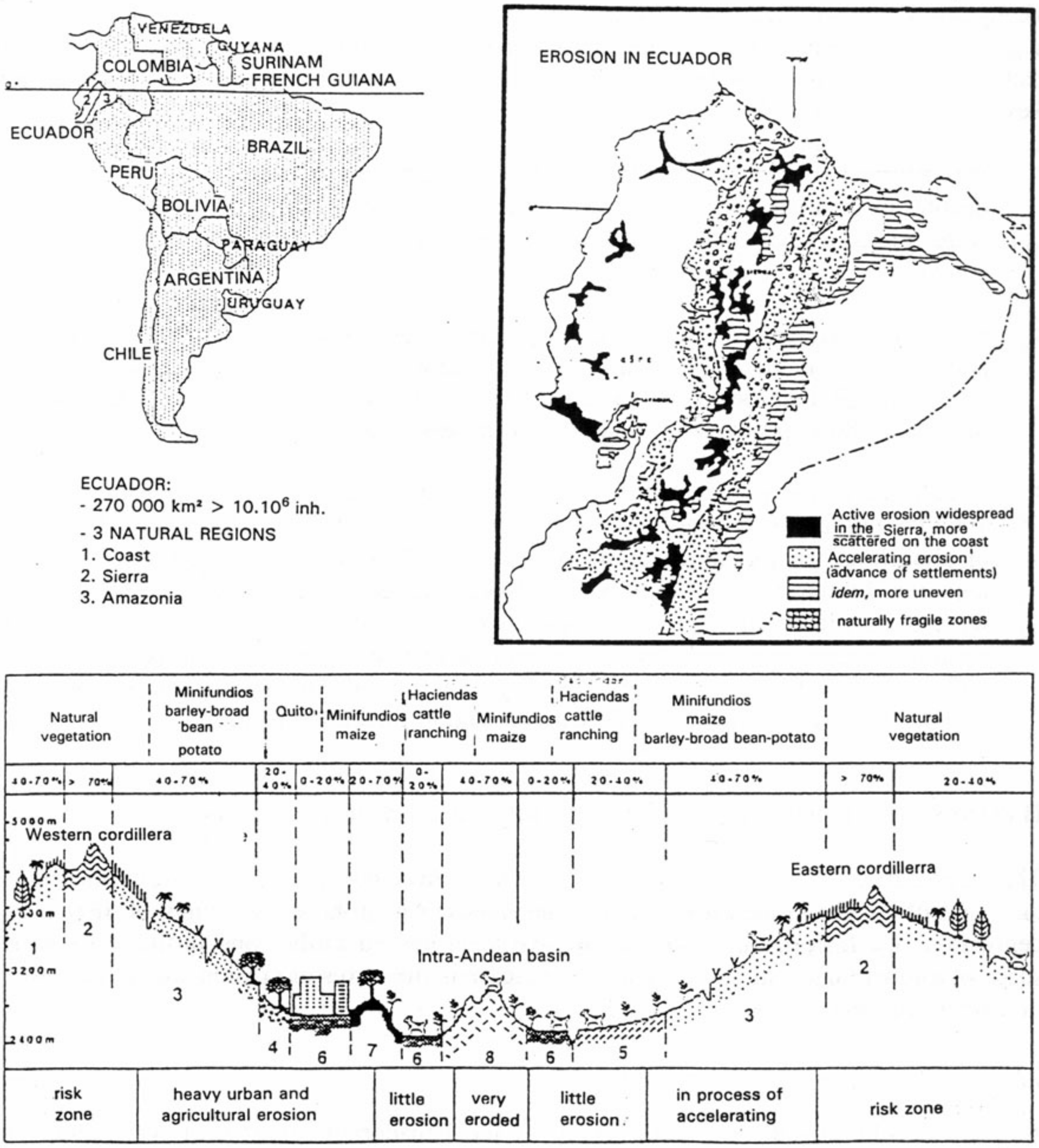
The combination of a mountainous landscape and heavy population pressure on the land is the cause of the chronic erosion found in the Andes. Along the whole length of the Andean depression, the frontiers of colonization have been pushed further and further back in the space of a few years, with a proportionate increase in the forms of erosion and in the amount of abandoned land.

EXTENT OF AGRICULTURAL EROSION

According to the results of a joint survey by the Ecuadorian Ministry of Agriculture and Animal Husbandry and ORSTOM on the main processes of erosion in Ecuador (Almeida, De Noni *et al.* 1984, De Noni and Viennot 1987), 50% of the country’s area (70% of it in the Andes, and 30% in the coastal and Amazonian regions) is affected by processes of degradation. In the Andes, the most degraded region, there are two distinct zones:

- the intra-Andean basin (1 500 to 3 000 m) where very little arable soil is left; in the northern and central sections of the basin there is a formation of hardened volcanic ash, locally called *cangahua*, remarkable for its extent and its depth, and sterile for agricultural use; this formation appears when soil and volcanic ash have been scoured by erosion;

FIGURE 83
Soil erosion and conservation in Ecuador (DNA-ORSTOM project)



MAIN UNITS IN TERMS OF LANDFORMS AND SOIL

Landforms	Caldera, neck	Gullied slopes, cones 1 3 4	Pediment-terrace 5	Horst, graben 6 7	Extinct volcano 8
Soils	cryandept orthent	dystrandept hydrandept	arguistoll hapludoll	haplustoll/ *cangahua*	*cangahua* durustoll
OM %	9 to 12	6 to 15	5	3 to 4	< 1
pH	5.5	5 to 6	> 7	> 7	7 to 8.5
CEC meq/100 g	2 to 10	15 to 40	20 to 80	20 to 50	20 to 30
T/S %	10 to 80	2 to 50	80 to 100	100	100
Granulometry	SL	L	AL	AL	LSA
Remarks	coarse elements	H% 50 to 250%	smectite		hardened CO_3Ca

TABLE 44
Soil loss on 50 m² plots (1981-84 and 1982)

Year	ALANGASI		ILALO	
	Mollisols and *cangahua*		Mollisols and *cangahua*	*Cangahua*
	Various treatments (maize, pasture) t/ha	Degraded pasture t/ha	Maize t/ha	Fallow t/ha
1981-84	62	314	631	71
1982	58	204	421	58

- the highlands and outer slopes of the two ranges (3 200 to 4 000 m) where active erosion develops as the agricultural frontier advances – as it has continuously over the last twenty years. Although soil cover is still present throughout these regions, it is showing alarming signs of degradation in some places.

PREDOMINANCE OF WATER EROSION

During the nine-month Sierra cropping cycle from September to May, water erosion is very active (wind erosion is not considered here, since it is more localized and has little effect on crops), mainly in the following forms (De Noni and Trujillo 1989):

- diffuse and concentrated runoff is the most widespread form, whatever the geological origin of the soil – pyroclastic formations in the northern and a large part of the central Sierra, and volcanic-sedimentary material in Loja province in the south; land affected by this process has shallow soil with truncated horizons, and is scored by erosion in U or V shapes according to how cohesive and granular the soil is; these linear forms quickly develop into badlands;

- runoff combined with small mass movements (15 to 20% slopes), a process seen in soils with a discontinuous texture, where a clayey soil of volcanic origin, rich in montmorillonite, lies over a hard *cangahua*-type formation; the processes work together, shaping the soil surface into eroded precipices as high as 3 or 5 metres; this happens in the northern and central parts of the Sierra (Carchi, Pichincha and Chimborazo provinces);

- mass movement is confined to the Cumbe area, south of the Cuenca basin, where the whole landscape has a moutonné appearance; erosion takes the form of creep, with humps and hollows developing in hilly landscapes with clayey non-volcanic soil.

HIGHLY ACTIVE RUNOFF PROCESSES

Other studies by the DNA-ORSTOM project on 50 m² cultivated runoff plots (10 x 5 m) also show the extent of runoff caused by human activity. Table 44 groups together soil loss for the period 1981-1984, as recorded on two plots in the Quito basin – at Alangasi on a 28% slope and at Ilalo on a 33% slope (De Noni, Nouvelot and Trujillo 1984 and 1986). The year 1982, during which most of the erosion occurred, is shown in a separate column.

TABLE 45
Annual soil loss and rainfall on 100 m^2 plots

		Year 86-87			Year 87-88		
		Total annual rainfall mm	Control plot with crop	Bare tilled fallow	Total annual rainfall mm	Control plot with crop	Bare tilled fallow
TUMBACO	Erosion t/ha/yr Runoff coeff. %	478	3.02 3.7	12.9 6.6	457	42.18 4.4	82.82 15.5
CANGAHUA	Erosion t/ha/yr Runoff coeff. %	366	3.8 1.6	56 5.9	308	6.89 1.9	83.6 11.1
MOJANDA	Erosion t/ha/yr Runoff coeff. %	588	1.15 0.9	5.9 2	547	0.52 1	96.94 8.4
RIOBAMBA	Erosion t/ha/yr Runoff coeff. %	537	1.44 0.9	56.9 23.3	532	52.2 15.5	198.7 21.3

TABLE 46
Development of agricultural production in the Sierra 1970-85 (in tonnes)

CROPS	1970	1975	1980	1985
Barley	79 087	62 801	24 350	26 723
Maize	167 990	90 247	45 266	35 421
Wheat	8 1000	64 647	31 113	18 464
Potato	541 794	499 371	323 222	423 186

Since 1986 the project has expanded its scope, establishing larger runoff plots (20 x 5 m = 100 m^2) located throughout an area stretching 800 km along the Sierra, from Pichincha province in the north, to Loja province in the south. There are two types of plot: a bare, tilled plot, in accordance with Wischmeier's prescription (Wischmeier and Smith 1978, Roose 1968) and a control plot using local crops and practices. The bare Wischmeier plot is not only a fundamental scientific reference plot, but in the present case also reflects the real features of the farm year – fallow poor in leafy vegetation and soil bare at the time of sowing barley. For the period 1986-88, the results are given in Table 45.

The following are the main lessons to be drawn from the results:

- Events of spectacular erosion on cultivated soil: for example, on the 50 m^2 plots monocropped with maize, erosion exceeded 600 t/ha.

- Irregular erosion from one year to another: at Alangasi and Ilalo soil losses in 1981, 1983 and 1984 were low compared with 1982, when most of the erosion occurred. The results also vary considerably from one year to another on the individual station; for example, in 1987-88 16 times more soil loss than in 1986-87 was recorded at Mojanda, and 7 times more at Tumbaco on the Wischmeier plots, and 32 times more at Tumbaco on the control plot.

- The absence of a regular erosion season during the year (most of the erosion is the result of the five most erosive rainstorms, out of a total of some forty erosive rainstorms per year per station): the amounts of rain in the individual rainfalls are not the only explanation of soil losses. In calculating correlation coefficients for the years 1986-87 and 1987-88, it appears that the best correlations with the weight of eroded soil are recorded with IM15 or IM30, although the maximum intensities in the Sierra are only low to average: 15 to 45 mm/h. The "R" values on the erosivity index are therefore only moderate, rarely exceeding 100: 60 at Cangahua, 90 at Tumbaco, and 100 to 110 at Mojanda and Riobamba. However, all these figures are also subject to annual variations, and can be considerably higher and extremely erosive. On the Ilalo plot (50 m^2), erosion was over 400 t/ha/yr in 1982; an IM15 of 90 mm/h was responsible for 270 t/ha/day of lost soil, and another of 70 mm/h for 120 t/ha/day.

ABSENCE OF CONSERVATION METHODS AND FOOD DEFICIT

The history of land use clearly brings out two distinct types of farmer: rich landowners on the *haciendas*, and marginalized peasant farmers on the *minifundios*. The latter are forced by sheer necessity to produce more in order to survive: driven into a marginal environment, they have been obliged to push the environment beyond its limits, with the result that all along the Sierra today there is a striking absence of erosion control practices suited to the environment (De Noni, Viennot and Trujillo 1986). For example, on the densely cultivated highlands of Chimborazo and Cotopaxi provinces, there are some perfunctory soil conservation structures consisting of hedges and small ditches. The latter are very shallow (20 to 40 cm) and steeply sloping (20 to 25%) in comparison with a conventional ditch, so that they cannot channel excessive water, and rapidly become gullies. Similarly, hedges, usually composed of *sigses* (*Gybernium*), are placed randomly in relation to the main slope. Moreover, these structures, set on the edges of plots, are only rarely combined with contour tilling.

There is also systematic destruction or abandonment of early agricultural structures inherited from pre-Columbian societies. These remains (Gondard 1983), mostly bench terraces, are made with risers built of stone or blocks of hardened ash. At Pimampiro in Imbabura province, the risers are deliberately knocked down to make room for large plots mechanically tilled in the direction of the slope. Similarly, near Zhud in Cañar province in a recently settled area with medium-sized holdings, wide concave terraces dating from the Cañari civilization are appearing from beneath the shrubby vegetation (*chaparral*) during clearing. At Punin and Flores, as well as Colta and Chunchi, all in Chimborazo province, at an altitude between 3 200 and 3 600 m, and on steep slopes (40 to 60%), there are real terraces separated by risers several metres high. Here again, the intermediate risers have been abandoned or destroyed, leaving only those that lie along property boundaries, so that they now border excessively wide and sloping "pseudo-terraces", which are totally unsuited to local conditions.

Certainly in order to survive, but also in the hope of entering the market economy, the small farmers have oriented the *minifundios* toward the crops that provide the basic local foodstuffs – cereals (maize, wheat and barley) and tubers (potatoes). However, natural limitations have prevented the development of profitable farming, so that the situation of the *minifundios* is now very precarious: in some regions self-subsistence is barely assured, while surplus production is rare and depends on a year of exceptional yields. Ministry of Agriculture data on levels of farm production over the past 15 years clearly illustrate this crisis situation (Table 46).

TABLE 47
Conservation methods tested on improved 1 000 m^2 plots

Stations	Slope %	Crops		Conservation methods	SOil losses t/ha/yr		Annual runoff coefficient %	
		86-87	87-88		86-87	87-88	86-87	87-88
TUMBACO	20	maize	maize	grass strips with three forage species	1.08	0.42	1.5	0.8
CANGAHUA	20	maize	maize	*cangahua* walls	0.45	0.33	0.1	0.5
MOJANDA	40	barley/potato/beans		sod walls and large quinoa-covered ridges	0.38	0.19	0.3	0.1
RIOBAMBA	20	potato/beans/barley		grass strips with mixed cropping (barley, beans)	0.43	7.6	0.3	6.2

It can be seen that there was a huge and generalized fall in yields of all these crops between 1970 and 1980, particularly for maize and wheat, which form the traditional staple diet of the rural population.

SUGGESTED IMPROVEMENTS [Plate 22]

Given their physical isolation in the highlands, *minifundio* farmers mainly need more on-the-spot technical assistance. Various forms of State intervention need to be increased: the organization of practical training in mountain farming, instruction in the use of fertilizers, selected seed, and of course conservation techniques, etc. Relations between *minifundio* farmers, technicians and agricultural scientists must be increased without delay, while combining research and development activities.

The programme of international co-operation between the National Agricultural Directorate (DNA) of the Ecuadorian Ministry of Agriculture and ORSTOM was designed in this context. It is a relatively pioneering project for the country, and indeed for the whole Andean region (De Noni and Viennot 1987, 1989), which has set up research stations on the farmers' land which are jointly managed with the farmers themselves. The stations have large runoff plots of 1 000 m^2 (50 x 20 m) for study of the effects of erosion on land under crops when improved with some simple conservation structures. The stations were set up in 1986 at the same time as the previously mentioned 100 m^2 plots (see Table 46) in order to allow comparison of the effects of erosion under traditional farming methods (100 m^2 plots) and under improved methods (1 000 m^2 plots). While the plots were being laid out, a socio-agricultural field survey was carried out to determine the various farming systems used in the research area, with particular emphasis on identifying conservation methods. In the absence of traditional practices, it was decided to test the effectiveness of simple semi-pervious contour structures in combating runoff energy, with the structures gradually developing into pseudo-terraces (Roose 1971; 1986; 1987a, b). An effort was made to keep as close to farmers as possible, using materials commonly used in the region, generally to fence off plots. The three main types of structure were thus as follows: low walls made of clods of earth or blocks of hardened volcanic ash (*cangahua*), or, more simply, grass strips, either grazed or cropped (quinoa or lupin). The methods tested over the period 1986-88 gave the results seen in Table 47.

These data demonstrate that simple conservation systems within the reach of the local farming community – contour ridging combined with grass strips or low earth walls – can noticeably reduce erosion. On all the improved plots, whatever the station, earth loss is minimal and erosion tolerable – usually less than 8 t/ha/yr and often close to 1 t/ha/yr. Yields are also better; for example, at Mojanda the potato harvest was 4.3 t/ha on the control plot and 7.6 t/ha on the improved plot.

At Riobamba, for the period from 20 September to 12 November 1987 (the sowing date), three erosive downpours resulted in a soil loss of 33.8 t/ha on the traditional plot where seedbeds had been prepared, while erosion on the improved plot was only 1.1 t/ha for the same period and the same tillage. And at Tumbaco, rainfall on 19 October 1987 alone, in the middle of the fallow period and one month prior to sowing (on 18 November), caused a soil loss of 34 t/ha, while the improved plot lost only 140 kg over the same period.

Although encouraging, these preliminary data show that not all the problems have been overcome, and that before launching awareness and extension programmes it is essential to carry out observations under both experimental and on-site conditions. This remark is based on the example provided by the changing size and shape of the grass-clod walls on the Mojanda station. Initially they were about 30 cm high, made up of two layers of earth clods. Then, although erosion on the plot was insignificant (0.2 to 0.3 t/ha/yr), in the course of the cropping year the farmer moves considerable amounts of soil from the top to the bottom of the plot with the broad blade of his mattock (*asadon*). Digging or hoeing always starts at the foot of a wall, creating a hollow at the base, and the soil is then drawn towards the bottom of the plot until another wall comes in the way. These simultaneous processes of hollowing out in front of walls and filling up behind them meant that the walls had to be heightened several times, rising from 30 to 130 cm during the 20 months of observations, while the initially straight slope steadily developed into terraces. It is estimated that almost 40 tonnes of soil per 100 linear metres accumulates behind the walls in this way each year.

CONCLUSIONS

As one of the major mountain barriers in the world, the Andes constitute an environment that is naturally prone to erosion. Erosion has also been exacerbated in Ecuador over at least the past two decades by the impact of the *minifundio*, with a troubled history that has led to small farmers being sidelined onto inhospitable land. Thanks to work carried out jointly with the local small farmers, the DNA-ORSTOM project has blazed a new trail, carrying out trials that demonstrate that erosion control is not an impossible challenge, despite natural limitations and the weight of history. Using simple structures suited to local conditions and accepted by the local people, this approach should lead to conservation of soil fertility, guarantee better harvests, and effect an all-round improvement in farmers' living standards within a single generation.

Land husbandry

Components and strategy

FAO SOILS BULLETIN

70

Food and Agriculture Organization of the United Nations