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# Environmental aspects of sustainability :
# Soil and fertility management in Reunion Island

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# Relationships between land use, fertility and Andisol behaviour: examples from volcanic islands

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**Abstract.** Soils developed on volcanic parent materials have many intrinsic qualities favourable to cropping. However, fertility decreases dramatically when they are badly managed. A short review and case studies from Réunion and Guadeloupe highlight the special characteristics of these soils, and their response to management.

The interplay of cropping systems and physical characteristics of Andisols is first considered through the example of *Pelargonium* and food crop systems in Réunion. Progressive decrease in production and cropping potential shows in falling yields as well as in the overall decline of the system. The example of banana production in Guadeloupe highlights the increase in inputs needed to realise the land's potential and to maintain yields, in particular more tillage and pest treatment.

In both cases, these trends are connected to the co-evolution of soil characteristics and cropping systems. They lead to an increase of risks with less security and less scope in the choice of cropping systems. Technical solutions in the form of erosion-control measures, rotation and planting techniques have been developed and prove to be relevant and consistent in their benefit.

**Keywords:** Andisols, cropping systems, soil fertility, Pelargonium, bananas, Réunion, Guadeloupe

## INTRODUCTION

Andisols are found mostly in volcanic zones at high altitudes and are widespread throughout the world in these environments.

Initially, they are loose, friable, and often rich in nutrients, and support a wide variety of production systems. However, as they are often sloping and subject to high rainfall, they may suffer erosion and deterioration of the cultivation layer if poorly managed.

The purpose of this paper is to show how land use seems to be a function of soil behaviour and vice versa.

## ANDISOLS AND FARMING SYSTEMS IN THE FRANCOPHONE WORLD

### *Geography, pedogenesis and the major characteristics*

Soils resulting from the break-down and weathering of basic volcanic material cover only small surface areas on a global scale, but they are very widely distributed, especially in wet inter-tropical areas. Being friable and loose to a good depth, free from stones, and well supplied with nutrients, they are usually densely settled. They occupy upland and piedmont zones (East Africa, Cameroon, Central America, Mexico and the Andes) and cover most of certain islands in the West Indies, Indian Ocean, South Pacific, Indonesia and Melanesia (Quantin, 1972), including the French Overseas Departments of Réunion, Guadeloupe and Martinique.

Soils with andic behaviour and properties can develop from massive basaltic lavas under heavy rainfall conditions, and more rarely from igneous rocks under certain geochemical conditions (Kimble, 1998). However, they mainly result from the fast weathering of fine basaltic, andesitic or trachytic ashes, and recent pyroclastic deposits, according to two major weathering processes: hydrolysis of volcanic glass and complexing by organic acids.

According to altitude and climate, the same soil sequence is observed on these parent materials in many tropical island settings: the Andisols (Andepts) exhibit a dominant halloysitic character at low altitudes (1200 mm rainfall), and then become allophanic then gibbsitic with increasing annual rainfall (Colmet-Daage & Lagache, 1965; Quantin, 1972; Zebrowski, 1975). Table 1 summarizes some physical and chemical data from an Andisol in Réunion and in Guadeloupe.

In the field, the Andisols show two main horizons. One can easily identify the dark A horizon, overlying reddish brown or yellowish brown B horizons. Because of the nature of the ashfall, the horizons are generally horizontal and the transition from A to B horizon is distinct.

Andisols generally have a granular structure in the A horizons due to disturbances of root mat and soil fauna, enhanced by the accumulation of organic matter (5 to 20% o.m.). The B horizons typically feel loamy and 'puffy', due to low density and to high allophane and water content, and they still contain an important amount of humus (1 to 5% o.m.), despite their lighter colour. In the field, B horizons appear massive, without aggregates, but rich in microporosity. However, weak subangular blocks can easily be excavated.

Under forest and natural vegetation or on slight slopes, A horizons are usually thick (20 to 60 cm depth). Under crop-

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Table 1. Chemical and physical characteristics of two Andisols.
Desaturated Andisol (Dystrandept) in food crops in Réunion, 1000 m altitude, 1500 mm rainfall, original parent material: trachytic pyroclastic deposit (15 000 years).

| Depth (cm) | Horizon | $pH_{H2O}$ | N (%) | C (%) | P (ppm) | CEC (mmol) | Water content (%) | Bulk density ($g\,cm^{-3}$) |
|---|---|---|---|---|---|---|---|---|
| 5–15 | A | 5.8 | 7.5 | 8.3 | 596 | 16.3 | 66 | 0.75 |
| 40–60 | B | 5.7 | 5.3 | 7.2 | 246 | 10.4 | 120 | 0.53 |

Desaturated Andisol (Dystrandept) under banana in Guadeloupe, 250 m altitude, 3500 mm rainfall, original parent material: andesitic ash deposit (20 000 years).

| Depth (cm) | Horizon | $pH_{H2O}$ | N (%) | C (%) | P (ppm) | CEC (mmol) | Water content (%) | Bulk density ($g\,cm^{-3}$) |
|---|---|---|---|---|---|---|---|---|
| 0–25 | A | 5.25 | 5.1 | 5.6 | 138 | 6.1 | 80 | 0.8 |
| 25–50 | B | 6.25 | 1.8 | 2.6 | 7 | 2.2 | 158 | 0.5 |

P: bioavailable phosphorus, by Olsen-Dabin method, CEC: cation exchange capacity, by Hexamin-Cobalt method; C: total carbon, by Anne method; N: total nitrogen by Kjeldahl method. Water content and bulk density measured at field conditions, using in-field core method (200 $cm^3$).

ping systems, erosion by water is so severe that few relict profiles remain. On steep slopes, nearly all tilled soils have lost their A horizons, leaving B horizons exposed to desiccation.

These soils present unique physical, mechanical or water-related properties, that are subject to rapid change under cropping systems. The wide diversity of production systems implemented on these soils is also a characteristic.

### *Andisols and the cropping systems: two case studies*

In Réunion, andic soils cover half of the total surface area (Raunet, 1991), and constitute 80% of cultivated land producing sugarcane, *Pelargonium*, vanilla, fruit trees, cereals, vegetables, fodder crops and forest.

On the leeward coastal slopes, between altitudes of 700 and 1200 m with annual rainfall of 1200 to 1800 mm and a marked dry season, Andisols that have formed on ash support rainfed hoed crops, horticultural production (in particular the 'rosat' *Pelargonium*, for perfume) and food crops. Erosion of A horizons by water is one of the major problems. As an average value over all the cropped Andisols, soil loss in the rainy season may be 50 t $ha^{-1}$ $year^{-1}$, and when cyclones occur, as much as 200 t $ha^{-1}$$year^{-1}$ has been measured (Bougère, 1988). This can lead to abandoning plots.

In areas where the rainfall is better distributed, and when the altitude allows, Andisols can also support plantation or export cash crops. On the windward side of Reunion Island it is sugarcane. Under sugarcane, the soils are well protected from erosion but workability is often determined by the location (slope, accessibility, limited trafficability) and the plots are often not easy to reach with harvest and transport machinery (Perret, 1997).

In the Southern part of Guadeloupe, banana plantations replaced sugarcane in the 1970s. Today systems are most commonly mechanized monocultures, with replanting every 3 or 4 years. Soil fertility is considerably lower than in perennial banana plantations on the leeward coast of the island. Maintaining yields requires frequent applications of pesticide and fertilizer, and the structural state of soil is deteriorating, accompanied by anaerobiosis, necrosis and parasite infestation of rooting systems (Dorel, 1990). The heavy machinery used in replanting accounts for this deterioration.

## PHYSICAL PROPERTIES OF ANDISOLS: A BRIEF REVIEW

The study of Andisols began in the 1950s with issues relating to trafficability (Birrell, 1952). These issues become critical in the case of cultivation on slopes and/or with heavy rainfall.

The physical components of soil fertility discussed below interact closely with crop emergence, the development and function of rooting systems, the choice in cropping systems and trafficability.

### *Thixotropy and irreversible desiccation*

In volcanic areas in the wet tropics, andic type soils are always found in sequences from brown halloysite soils (Andic Tropept) through slightly desaturated (Eutrandept) then desaturated Andisols (Dystrandept) to allophanic waterlogged Andisols (Hydrandept) in areas of heavy rainfall (Colmet-Daage & Lagache, 1965; Quantin, 1972; Zebrowski, 1975).

Moist andic material, although not rich in lattice clays, contains 80% of fine non-crystalline material. This results in affinity for water and very high porosity (Paterson, 1976; Rousseaux & Warkentin, 1976; Egawa, 1977; Wada & Wada, 1977; Maeda *et al.*, 1977). Despite the high water content, the material is friable and feels moist rather than wet, but adheres strongly to working parts of machinery. Aggregates show considerable structural stability.

Under heavy pressure, the soil abruptly becomes liquid, a phenomenon known as thixotropy. When pressure ceases, the liquid material reverts to its solid state (Perret, 1992). This characteristic directly determines the behaviour of machinery on Andisols leading to limited trafficability, pronounced wheel-slip and destruction of upper soil layers and clogging of working parts of the machinery (Wesley, 1973; Maeda *et al.*, 1983).

When a drying threshold is reached, which varies according to mineral parameters, the hydrated microporous structure of reclaimed Andisols progressively collapses irreversibly. This entails a drop in affinity for water and destruction of clods, accompanied by an increase in the stability of fine aggregates, and the formation of pseudo-sands (Maeda & Warkentin, 1975). Microporosity diminishes and is replaced in part by inter-particle macroporosity which favours accelerated flow of fluids, and mineralization of newly formed organic compounds (Colmet-Daage *et al.*, 1972; Kubota, 1972; Tuncer *et al.*, 1977).

These alterations to the physical environment and water content lead to changes in the microbial population and fauna. Likewise, the transport of the soil by runoff water is facilitated and this triggers erosion. There is a marked structural boundary between the dried-out layer and the moist underlying B horizon, which results in capillary discontinuity and problems of root penetration (Dorel, 1993).

These processes start as soon as Andisols subjected to a dry season are brought into cultivation. At first they affect the top few centimetres of soil and the subsequent progression depends on the cropping system. Hoeing, which periodically denudes the soil and involves redistribution of the upper layer, increases the depth of the soil layer affected, and tilling triggers these processes throughout the depth of cultivation (Ogawa *et al.*, 1988; Perret, 1992).

Classical soil indicators such as apparent density or total porosity are not sufficient to describe the processes at work in these soils with high water content.

### *Structural states and cropping systems*

In cultivated horizons, various processes are found: several cycles of desiccation generate a coarse, stable skeleton from the amorphous matrix characterized by continuous microstructure of the B horizon. Biological activity reinforces this tendency to microaggregation and cultivation involves mechanical forces that can re-fractionate these elements. More marked localized mechanical forces (paths, tracks, regular hoeing and ploughing of upper layers) then cause these structures generated by desiccation to evolve towards a powdery fine silty material, that is easily displaced by wind and water.

Field observation of an Andisol profile reveals the marked structural duality between the horizons. In the moist state, the deep B material presents a smooth, continuous fabric with no visible cracks or aggregates. In contrast, the upper horizon is always clearly structured.

When the original A humus layer is preserved, it often comprises very stable aggregates, mainly produced by fauna. If the deepest weathered B horizon occurs at surface level following erosion/removal of the A horizon, it has a particulate, finer structure, due to irreversible drying. Aggregation then depends mainly on the degree of desiccation reached and mechanical forces involved.

Clods can have very different characteristics. In the case of undisturbed A humic horizons, the clods are porous cohesive units composed of coarse aggregates. Cultivation gradually reduces this cohesion causing these structures to degrade into particulate aggregates produced by the action of implements (Perret, 1992). In the case of mechanized systems in intensive banana or sugarcane production, tightly packed clods are common, as results of high mechanical pressures (Dorel, 1993).

## CROPPING SYSTEMS ON ANDISOLS AND FERTILITY: EXAMPLES

The sustainability of a cropping system can be described using many different indicators: water balance and mineral budgets, field observation of soil profiles, farm work schedule, financial budgets and socioeconomic indicators. The physical properties of Andisols are closely related to agricultural practice. On steep uplands, it is the efficiency of erosion control in cropping systems that chiefly determines sustainability, but mechanized tillage also causes deterioration of fertility.

### *Shifting or fixed systems*

In traditional shifting *Pelargonium* cultivation systems in the uplands of Réunion, composted residues from distillation of the *Pelargonium* plants are all returned to the land, without any extra mineral fertilizer in the early years. Considerable erosion related to hoeing practices is accompanied by a gradual drop in yields and the mineral fertilization that is then introduced has only a palliative effect. Indeed, the deterioration in yields and the fall in work productivity caused by weed encroachment and crop failure lead to abandoning of the fields. New plots are then cleared and cultivated.

Fixed systems, which are taking over from the shifting systems since the end of the 1970s, prove to be catastrophic, since they use the same technology without being able to restore soil fertility by bush fallow.

The land tenancy system known as 'colonage', widely practised in Réunion, constitutes an obstacle to the establishment of anti-erosion measures. Colonage is a kind of annual tenant-farming, in which the farmer shares the produce with the owner of the land, who chooses the cropping, and provides most of the inputs. Fertilizer contributions are small because of cashflow problems that progressively increase. Associated food crops compete with the *Pelargonium* in the farm work schedule at the time when gaps are replanted (low inputs cause high death rate in *Pelargonium*, mainly because of soil-borne disease). Weeds grow profusely and farmers attempt control by tillage. For lack of available land, the farmer cannot abandon the plots to clear new ones, and for lack of family labour, he reduces the area under cultivation and runs a very unstable cropping system with low productivity in relation to land and labour. Without mineral fertilizer, *Pelargonium* cropping declines and is replaced by food crops. It no longer provides enough compost to stem erosion, the more so because compost is earmarked for vegetable production.

Table 2 gives an example of this degradation in *Pelargonium* cropping systems, through the decrease in overall production of essential oil, as well as through the decrease of land productivity.

Shifting cultivators depend on farming for only a small part of their family income, and although they are today a marginal category, the numbers are still considerable.

Figure 1 shows a model of the overall soil and fertility degradation process under traditional cropping systems in Réunion highlands.

Table 2. The decrease in the production and productivity of *Pelargonium* essential oil in Réunion (Chastel, 1992).

| Year | 1972 | 1981 | 1989 |
|---|---|---|---|
| Total production (t) | 120 | 64 | 16 |
| Average yield† ($kg\ ha^{-1}$) | 30 | 23 | 10 |

† average yield calculated after estimated cropping area.

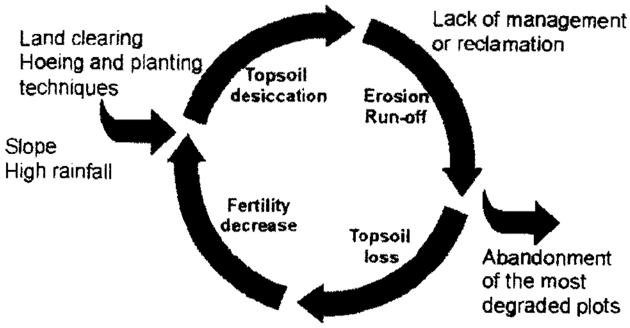


Fig. 1. Degradation processes in traditional agricultural systems growing *Pelargonium* and food crops on Réunion.

Table 3. Soil surface properties and behaviour under rainfall simulation, according to cropping practices and surface management (Perret *et al*, 1996b; Perret, 1992)

| Soil use and management | Ksat† ($mm\ h^{-1}$) | MWD‡ (mm) | Soil loss§ ($kg\ h\ ha^{-1}$) |
|---|---|---|---|
| Long-term fallow | 250a | 2.50a | 0–0 |
| *Pelargonium* monoculture on degraded bare soil (hoed) | 40b | 1.10b | 208–635 |
| *Pelargonium*/food crop rotation on bare soil (herbicide) | 60b | 1.11b | 10–207 |
| *Pelargonium* with kikuyu grass cover | 105c | 1.41c | 0–7 |

Ksat and MWD: different letters show significant differences between sites, tested by student's $t$-test at $P = 0.1$.
† Ksat: conductivity at saturated soil, in field measurement with disc infiltrometry.
‡ MWD: aggregates' mean weight diameter from laboratory experiments.
§ Soil loss: average values from measurement with rainfall simulations under intensities of 45–72 $mm\ h^{-1}$.

*Attempts at intensification*

Land reform has encouraged the development of owner-farmed systems, efforts to open-up isolated areas and other land developments in Réunion. Owners are turning towards market gardening as soon as they have access to water for irrigation, during the dry winter period. Secondary inter-row crops (bean, maize, tomato) are tending to disappear. Manure is provided by introducing beef or goat units onto the farms. These small livestock units also provide mobilizable capital and cash flow reserves when times are difficult. Similarly, *Pelargonium* cultivation is often maintained because it ensures minimum income whatever the weather conditions and whatever the inputs.

In these systems, large regular application of organic manures and erosion control measures limit soil deterioration. (e.g. planting in rows at optimal densities, plant-covered ridges with fodder cane or agroforestry). The use of herbicides often enables a reduction in hoeing, and frequently the only mechanization is the knapsack sprayer.

Rotation with vegetable crops (often tomato) and sugarcane is often practised where altitude is suitable, it is seen as a means of soil rehabilitation by the farmers, as confirmed by field observations (Perret *et al.*, 1996b).

Weed control is sometimes not achieved at the end of the wet season, and plants that multiply vegetatively can become invasive (e.g. *Phalaris arundinacea, Oxalis sp., Cyperus rotondus*). Increased workload and shortage of labour can lead the farmer to resort to ploughing to avoid manual hoeing. Good quality ploughing buries these weeds efficiently, but it is rarely well performed by the contractors. Furthermore, other weed species invade the ploughed land (e.g. *Raphanus raphanistrum*) and erosion problems are aggravated.

In cropping systems based on *Pelargonium* and food crops, resorting to tillage is not justified by the needs of the crops. Only tobacco makes good use of deep soil preparation, achieving 10–15% higher yields than with minimum tillage. *Pelargonium* and food crop yields are generally lower following ploughing, when compared to yields obtained from furrowing or planting by hand in holes (Michellon & Garin, 1985). Thus, the adoption of no-tillage and permanent cover crops seems to be beneficial. Table 3 summarizes changes in soil physical behaviour related to cropping system. These data show increased permeability resulting from plant cover, and that crop rotation cannot by itself restore soil properties.

Young farmers with training are gradually giving up *Pelargonium* production to specialize in market gardening in response to grants, the emergence of urban markets and improved communications. The organic matter essential for vegetable production is purchased from penned livestock units at low altitudes, or produced on-farm from cows or goats.

The problem of erosion is often taken into account at field scale (tillage and planting according to contour line, hedges as plot boundaries). But the tillage necessary for vegetable production can cause considerable soil loss in the cyclone season, because of the small crop cover. Minimum tillage and direct drilling, coupled with manure application prove to be effective in such systems (Michellon & Garin, 1985).

*Intensive mechanized production*

Banana plantations were established on the leeward coast of Guadeloupe at the beginning of this century on young soils on steep slopes. Following the decline of sugarcane in the 1970s, banana cultivation spread over the mechanizable level parts of the windward coasts, on older halloysite soils and on Andisols.

Today, the larger part of the banana plantations on Andisols are replanted every 3–4 years and sometimes more frequently. Replanting requires repeated passes by heavy machinery to destroy the previous plantation and then to prepare the soil. The energy required for these operations is considerable: whereas only about 1300 kWh are required in halloysitic clays on Andisols as much as 2300 kWh are used during the 15–20 $h\ ha^{-1}$, (data collected in Guadeloupe; Perret *et al.*, 1996a).

In some upland areas there are also non-mechanized perennial banana plantations. Accounting for only small areas, on some farms, banana is produced in rotation with market garden crops or pineapple.

The impact on rooting systems and soil fertility varies from system to system. In perennial non-mechanized banana, the absence of any mechanized intervention preserves the friable structure of the topsoil, with its high inter-aggregate porosity, and avoids deterioration. The deep horizon (B) has a smoother structure with high tubular porosity. Water and air movements are satisfactory. The roots are healthy and spread down to a depth of 60 cm.

Table 4. Soil surface characteristics according to banana cropping practices: data range (min–max) or average from field experiments (Dorel, unpublished data).

| Cropping system | Ksat† (mm $h^{-1}$) | Macroporosity‡ |
|---|---|---|
| Mechanized cropping system, frequent replanting | 36 – 295 | 25 |
| Non-mechanized, perennial plantation | 220 – 480 | 85 |

† Ksat conductivity at saturated soil, in field measurement with disc infiltrometry.
‡ Macroporosity % of overall porosity, laboratory measurement from pressure plate method.

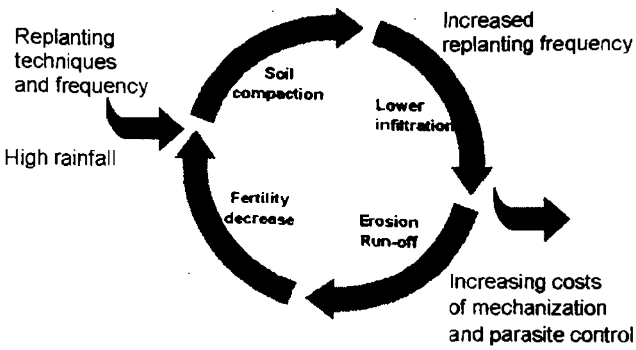


Fig. 2. Degradation processes in intensive banana production in Guadeloupe.

The repeated forces exerted on soils in mechanized cultivation, aggravated by high rainfall (up to 4000 mm $year^{-1}$), lead to soil structure degradation (Table 4), associated with symptoms of root death due to waterlogging. Most of the healthy functional roots are in the topsoil where the structure is friable. Earthing up by hand produces a volume of soil that is better aerated and favours healthy root development at the base of the plant. However the volume concerned is small, and root development stops on the fringes of the mound causing apex necrosis.

Nematodes, mainly *Radolphus similis*, which are parasitic on the roots of banana trees, cause considerable loss of production leading to an increase in use of costly nematicides. In intensive monoculture, applications of nematicide are systematic and frequent (3 per year) but provide only limited control of the parasite.

When healthy plant stock are obtained from *in vitro* culture, very low populations of nematodes are observed for the first 20 months, without any treatment. Incidence of root necrosis is under 20%. From the 20th month, reinfestation of certain plots occurs progressively, accompanied by 50% incidence of necrosis.

Loridat (1989) showed the pathogenic character of *Cylindrocladium sp.*, a fungus found on banana roots. It is frequently detected on Andisols under monoculture. Rotation with a single-year cycle of pineapple does not eliminate it. In contrast, it has never been detected on plots with a rotation of 5 to 10 years pineapple, or on rotation involving *Bracharia spp.*

Figure 2 shows a model of the soil and fertility degradation process under mechanized banana cropping systems in Guadeloupe.

To improve the sustainability of these banana plantations, work has been done on these rooting problems (Dorel, 1990). The system developed is based on:

(1) planting healthy micropropagated seedlings in soil that has been cleared of disease by a long rotation;
(2) chemical treatment against nematodes based on regular nematode analyses rather than systematic use of chemicals;
(3) increased time intervals between replanting, which reduces frequency of intervention by heavy machinery.

Adoption of cropping systems of this nature, which limits physical and pest damage to roots, has been shown to ensure better use of fertilizer, reduced nematode treatment and, increased productivity of banana plantations with reduced costs.

## CONCLUSIONS

Andisols have many intrinsic qualities that favour their use for cropping. However, they prove to be very sensitive and their fertility decreases when they are badly managed. The combined effects of slope and high rainfall lead to a very high but variable erosion risk, according to cropping practices. The absence of erosion control measures, along with hoeing in the traditional cropping systems, and the tilling practices in the intensified market gardening systems, have disastrous consequences. Erosion causes deterioration of soils, a decrease in plant vigour and proliferation of weeds.

In industrial banana units, frequent mechanized operations cause deterioration of soil structure, which has severe consequences on yields and production costs.

In these situations, there are increasing problems of weed control, soil-borne disease, erosion and runoff, with more anoxia, necrosis and parasite infestation of rooting systems, reduced infiltration rate and greater trafficability problems. These show up in falling yields, and in increased inputs (mechanical preparation and pest treatment in particular), and greater risks, i.e. less scope and less security in the choice and implementation of cropping systems, and likewise in achieving yield.

The examples developed here underline the interplay between cropping systems and the physical characteristics of Andisols, and also the permanent interaction between the potential of the soil, husbandry, and sustainability of the systems.

The emergence, or the abandonment, of farming practices enabling soil protection are dependent on socioeconomic factors that are often outside the control of the farmers themselves (land tenure, land distribution, management of labour, economic environment, markets, etc.). The promotion and spread of relevant innovative cropping systems requires those concerned at local level to be familiar with these factors, even if they cannot gain control over them.

The most recent research shows that the deterioration of the structural state and the fertility of Andisols can be reversed by fairly straightforward practices: direct drilling, permanent plant cover during cropping, agroforest hedging, manure and organic matter application (Perret *et al.*, 1996b), the use of *Bracharia* fallow in rotation with banana (Dorel, 1993).

Current research programmes in Réunion and Guadeloupe consist in building on farmers' experience and husbandry, at the same time as testing and promoting alternative technologies including use of cover crops, agroforestry and planting of more healthy plant material.

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# Soil rehabilitation and erosion control through agro-ecological practices on Reunion Island (French Overseas Territory, Indian Ocean)

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**Abstract**

On the western slopes of Reunion Island, the trends in cropping systems for perfume pelargonium are causing serious erosion problems. This paper reviews the causes of these trends, presents the consequences of this deterioration, and assesses the agro-ecological solutions by means of cover plants and hedging with agroforest species. Firstly, the short term effects of cover plants (*Lotus uliginosus, Pennisetum clandestinum*) associated with the pelargonium crop are considered. Using rainfall simulation, it is shown that such associations have immediate effects in controlling erosion, although runoff is not significantly reduced. The more long-term effects of this type of cover are then compared with pelargonium monoculture on bare soils, and with pelargonium in rotation with stable crops. The effect of hedging along plot boundaries is also observed. Descriptions of soil profiles highlight the advantages of plant cover, in improving soil structure and biological activity. Near hedges, the same tendencies are even more marked. Soil hydraulic conductivity, measured in the various situations, confirms the complementarity of cover plants and hedges in association. The plant cover reduces erosion, with only a slight increase in water infiltration. At the same time, soil under hedges gives rise to very high water conductivity which should enable a large proportion of runoff water to be absorbed.

*Keywords:* Erosion control; Andisol; Cropping systems; Pelargonium; Soil rehabilitation; Cover plants; Hedging; Reunion Island

## 1. Introduction

### *1.1. Background*

On the western side of Reunion Island (21°05'S–55°20'E) deep volcanic ash soils are found at altitudes of 500–1500 m, according to climatic conditions. These andisols (Andepts) first exhibit a dominant halloysitic character, and then become allophanic and gibbsitic (Zebrowski, 1975; Raunet, 1991).

The pelargonium cropping zone (*Pelargonium* spp., complex hybrid) occurs between 800 m and 1200 m. This perennial plant is grown in the open field. Leaves and young stems are harvested and

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water-distilled for essential oil extraction. The successive cuttings for distillation (four to five per year) give it a bushy habit (40–80 cm high).

At lower altitudes sugar-cane dominates. Fallow land, natural or productive forest, and grassland cover the higher areas. The mean annual temperature range is 16–19°C. Mean annual rainfall is 1200–1700 mm with 70% falling between January and April, mainly related to tropical depressions or cyclones. This high-intensity rainfall causes considerable runoff and soil loss from agricultural land, aggravated by the slope (averaging 15%), low conductivity and poor aggregation of degraded soils (Perret, 1993).

Cropping systems also encourage erosion, because they are mainly based on hoed crops, i.e. pelargonium, vegetables, and various other food crops (Garin, 1987). Traditional systems were based on itinerant cultivation, alternating with long term fallow that restored soil fertility, but surface management aiming to prevent erosion was poor, mainly because farmers were not landowners. Some traditional conservative techniques are now neglected, for instance the planting of vetiver grass as plot boundaries and its use by the farmers for thatching material.

### 1.2. Changes and consequences

The shift to sedentary agriculture on the part of farmers is accompanied by changes in cropping systems, after the development of land-ownership settled farmers on their own land. This trend is a result of reforms in land-ownership, implemented over the last thirty years, where large estates were divided up and sold to small farmers. Settled farming is also the result of pressures on land, which increased with the opening-up of the area by road construction, coinciding with land reform. The greater number of farmers led to a reduction in uncultivated land available, which in turn gradually prevented the practice of the traditional itinerant pelargonium cropping system.

These sedentary cropping systems are now causing very serious soil damage and erosion that are no longer counterbalanced by the previous practice of arboreal fallow. Long-term monoculture and weed control by hoeing encourage soil degradation and lead to a decrease in fertility. For all crops, inputs are increasing (disease control, inputs of organic matter and chemical fertilizer) but yields continue to decline, thus wasting money and labour (Michellon, 1986). Erosion is so severe that few relict profiles remain. Nearly all tilled soils have lost the A horizon and now expose the Bt horizon, and even the deep-indurated horizon (volcanic tuff) or pyroclastic scree in the most degraded sites (Raunet, 1991).

On the pelargonium cropping zone, field erosion averages 20 T $ha^{-1}$ in an average year. It amounts to 50–200 T $ha^{-1}$ in years characterized by high rainfall and cyclones (Bougère, 1988; measurements on standard USLE plots). In any case, it is well in excess of tolerable limits for soil loss, generally accepted in the tropics as being between 5–15 T $ha^{-1}$ according to El-Swafy et al. (1982), and as less than 1 T $ha^{-1}$ according to Lal et al. (1991). Downstream, silting constitutes a major pollution problem for coral reef ecosystems (Stieljes, 1993).

In the face of such limitations, farmers are relinquishing the most degraded land and pelargonium cropping. At present, farming systems are evolving towards complex mixed cropping systems, sometimes associated with livestock (goats or cattle). However, the persistence of hoeing on almost all cropped fields has meant that erosion is still a very significant factor.

### 1.3. Strategy

Sustainable agriculture implies "successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources" (Technical Advisory Committee, 1989, cited by Lal et al., 1991). The Reunion Island pelargonium cropping zone obviously needs sustainability. Thus, soil erosion is the main factor to be addressed as a priority, to establish new conservative systems along with productive cropping systems (Lal, 1989; Smith et al., 1992) and to develop more natural landscape features (Thomas and Kevan, 1993).

On severely eroded volcanic ash soils situated in Latin America, reclamation has been based on mechanical rehabilitation, i.e. terracing and levelling (Nimlos, 1992). In the present situation, agro-ecological practices are being tested, notably systems that associate pelargonium with a cover plant grown in open fields. Cover plants show good potential for restoring soil and fertility, improving different soil characteristics (Lal, 1975; Lal et al., 1991), i.e. aggregation and pore space, water infiltration, erosion and runoff resistance, nutrient cycling, low input requirements, and organic matter. This cropping system has been allied with agroforestry, using *Calliandra* hedges as plot boundaries to improve runoff control and soil rehabilitation. *Calliandra* also gives wind protection and green fodder.

This paper describes and quantifies the components of soil degradation and rehabilitation, in order to assess the cropping systems proposed. These systems are part of an overall strategy aimed at sustainability, which includes diversification and integration of small farming systems (Ikerd, 1993).

## 2. Materials and methods

### 2.1. Experimental sites:

The CIRAD research station of Trois-Bassins, lying between altitudes of 950 m and 1020 m, is the main site for the study of pelargonium cropping on Reunion Island. Mean annual rainfall is about 1500 mm. The andisols (Andepts—Dystrandepts) overlay volcanic ashes, and slopes average 15–20%. On this station, all plots were primarily degraded as a result of long-standing pelargonium monoculture with hoeing (15 years). However, degradation level depended on the plot position on the landscape and on boundaries management. The plots were severely degraded where situated on steep slopes or without any green boundaries. On shoulders or terraces, the soil was moderately degraded, i.e. with a thin A horizon remaining.

Since 1984, different cropping systems have been carried out on the plots. The plots size varies from 1000 $m^2$ to 3000 $m^2$, similar to farmers' plots.

In order to quantify the short term effect of cover crops, water runoff and erosion processes were first studied on severely and moderately degraded hoed soils under pelargonium monoculture, then on soils recently covered (1 year) with kikuyu grass and trefoil. In order to study these processes, rainfall simulation was carried out. Then, different plots were selected in each type of pelargonium cropping system in order to describe profiles, soil structure and fauna, to identify aggregate size patterns and to assess stability and water transfer. All the situations selected were previously degraded:

1. a long-standing hoed pelargonium monoculture (25 years, Plot 19) (severely degraded bare soil); it is the control plot of the station
2. a six-stage rotation involving pelargonium with food crops (since 1984: six crop cycles (tobacco/maize-potato/maize-bean/maize), then 6 years of pelargonium cropping, and finally potato–maize in 1993; Plot 16) (non-degraded bare soil)
3. pelargonium associated with kikuyu grass (*Pennisetum clandestinum*) planted in 1989 (Plot 2), and association between pelargonium and greater bird's foot trefoil (*Lotus uliginosus*) planted in 1990 (Plot 1) (covered soil).

In addition, the effects of *Calliandra* on soil structure and water infiltration were studied. Profiles were determined and analyses carried out under the hedge, and 1 m from the hedge. In order to examine the way in which soils evolve from the *Acacia/Lanthana* colonized fallow land to the degraded soil under pelargonium monoculture, a profile and physical characteristics were determined for fallow land close to the experimental site.

### 2.2. Rainfall simulations

An infiltrometer sprinkler was used, with repetitions on each situation. This rainfall simulator was developed by Casenave (1982), and is equipped with a deflector nozzle fixed to the top of a 4 m tower. The nozzle oscillates, continuously producing droplets at a pressure of 100 kPa. Droplet size, impact velocity and kinetic energy are known parameters, and are consistent with natural rainfall. The intensity varies according to the range of oscillation. The surface area of the basic test plot is 1 $m^2$. Plot slope is between 8% and 20%, and rainfall intensity can be varied from 36 mm $h^{-1}$ to 83 mm $h^{-1}$.

This method was used in order to give a more controlled and structured data set. However, some standard USLE test-plots (100 $m^2$) on degraded hoed soils were previously monitored under natural rainfall. These results can be compared with those obtained from rainfall simulation tests.

### 2.3. Profile descriptions and soil fauna assessment

In each situation (Plots 1, 2, 16 and 19, long term arboreal fallow-land) the soil profile was described, highlighting in situ structures, earthworm numbers and activity, and root systems. Soil invertebrates were studied according to the current Tropical Soil Biology and Fertility recommendations (Anderson and Ingram, 1989): 25 cm ×25 cm ×30 cm deep soil monoliths were sampled. The delimited block is divided into three layers, 0–10 cm, 10–20 cm, 20–30 cm, then hand-sorted for macro-invertebrates. Ten replications were carried out on each plot. The invertebrates were preserved in 4% formaldehyde and 70% ethylic alcohol. Population density and biomass were quantified according to the following groups: Chilopod, Diplopod, Isopod, Ants, Earthworm, and other groups.

Soil invertebrates are classified according to their feeding habits and distribution in the profile (Lavelle et al., 1992). Epigeic species live and feed on the soil surface. These invertebrates effect litter comminution and nutrient release, and need high moisture-content in the litter. They are mainly arthropods (Isopod, Diplopod, Chilopod). Anecic species remove litter from the soil surface through their feeding activities. They are mainly earthworms and ants. Endogeic species live in the soil and feed on organic matter and dead roots. The main group is earthworms. Anecic and endogeic species can redistribute considerable quantities of top soil, mineral elements and organic matter through their activities. Their displacements through the profile enhance macroporosity and aggregation.

### 2.4. Aggregate size and stability, and organic matter

Aggregate size and stability measurements involve wetting and then separating aggregates into various sizes by sieving 30 g samples through a nest of sieves under a gentle flow of water to cause as little mechanical disruption of the aggregates as possible. Meshes of 5 mm, 2 mm, 1 mm, 0.5 mm, 0.2 mm and 0.05 mm were used. The mean weight diameter (MWD) of aggregates (Van Bavel, 1949) is equal to the sum of the products of (1) the mean diameter of each size fraction $d_i$ and (2) the proportion of the total sample dry weight $w_i$ occurring in the corresponding size fraction, when summation is carried out over all $n$ size fractions, including that which passes through the finest sieve:

$$\mathrm{MWD} = \sum_{i-0.025}^{3.50} (d_i W_i) \textit{ thus},$$

$$0.025\,\mathrm{mm} \le \mathrm{MWD} \le 3.50\,\mathrm{mm}$$

3.5 mm is the mean diameter of the fraction remaining on the 2 mm mesh; 0.025 mm is the mean diameter of the fraction passing through the 0.05 mesh.

The same analysis was carried out on a duplicate 30 g sample, previously exposed to 20 kHz ultrasonic (us) energy at 30 J $mL^{-1}$ in water (e.g. 75 W × 120 s (300 mL of water). This treatment shatters and abrases the aggregates (North, 1979; Gregorich et al., 1988). Then, a new mean weight diameter $\mathrm{MWD}_{\mathrm{US}}$ is calculated. The stability index is given as:

$$S = \frac{\mathrm{MWD}_{\mathrm{us}}}{\mathrm{MWD}} \textit{ thus}, 0 < S \le 1$$

Many experiments have been carried out on andisols (Perret, 1993). The results show that S ranges from 0.3 (very poor stability) to 1 (full stability).

These parameters were measured on ten samples from each situation, taking into account the local area around *Calliandra* hedges. In addition, measurements of total organic carbon (Anne method) and nitrogen (Kjeldahl method) were carried out on each sample.

### 2.5. Tension infiltrometer: water transfer

Near each profile, tension infiltrometry was carried out to determine hydraulic conductivity K($h$). A disk infiltrometer at multiple suctions was used, developed from Clothier and White (1981) and Perroux and White (1988). It allows field measurement of K($h$), from saturation (suction: 0 mm) to different negative pressures $h$, up to a −200 mm suction. Six repetitions per suction were conducted.

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## 3. Results and discussion

### 3.1. Runoff and soil loss processes: short term effects of cover plants

From 45 rainfall simulation experiments, runoff intensity $R$, soil carriage $C$ and rainfall intensity $I$ data have been correlated according to the degree of soil degradation and surface management. Fig. 1 shows the rainfall intensity threshold for runoff initiation, about 36 mm $h^{-1}$. After this, runoff increases with rainfall, with a limit calculated from points representing maximum runoff intensity for a given rainfall. The equation is as follows:

$$R = 1.231 \times I - 46$$

Points close to this limit represent uncovered, severely degraded hoed soils. Below this limit are found moderately degraded hoed soils and covered soils. The two covered plots are regarded as comprising the same treatment (kikuyu and lotus covered soils) because their results are very close. The slope of the line indicates that infiltration $F$ (rainfall less runoff) is not a constant: it decreases according to rainfall intensity, certainly from slaking and surface structure deterioration by heavy rain. This is confirmed by the time threshold for runoff initiation, which is 8 min on average with 50 mm $h^{-1}$ rainfall, and only 2 min for 70 mm $h^{-1}$ rainfall. Below 36 mm $h^{-1}$ there is no runoff. In addition, it has been demonstrated that slopes below 20% have no effect on runoff intensity.

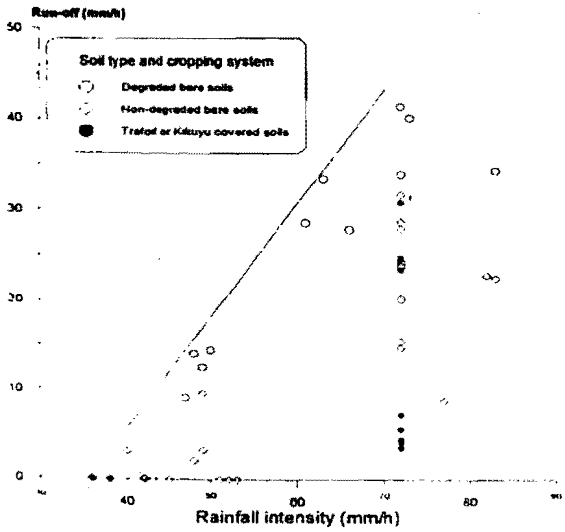


Fig. 1. Variations of runoff with rainfall intensity, related to soil degradation level and surface management.

Table 1
Rainfall simulation data, i.e. runoff, infiltration, and soil loss average figures, correlated with rainfall intensity $I$, soil management, and level of degradation

| Soil type and management | $n$ | Runoff (mm $h^{-1}$) | Soil loss (kg $h^{-1}$ $ha^{-1}$) |
|---|---|---|---|
| Degraded hoed soils (Plot 19) | 14 | 13a–31a | 208a–635a |
| Non-degraded hoed soils (Plot 16) | 19 | 2bc–22ba | 10ba–207ba |
| Covered soils (Plots 1 and 2) | 12 | 0cb–15cb | 0c–7c |

Rainfall intensity 45–72 mm $h^{-1}$; slope more than 8–20%; soil loss expressed as oven-dried soil weight.
Different letters, related to runoff and soil loss data, show significant differences between sites, tested by Student's $t$-test at $P = 0.1$.

Live mulches provide little reduction of runoff. Table 1 shows, however, that kikuyu grass and trefoil cover considerably reduce particle transport. Thus, the most important effect of cover is to protect soil against raindrop impact, and to decrease velocity and carrying capacity of surface flow. The effect of cover plants on structure and fauna improves water infiltration, but not to the extent of completely absorbing runoff from heavy rain.

Soil transport data collected from rainfall simulation on 1 $m^2$ test-plots are very close to data obtained for natural rainfall on 100 $m^2$ test-plots (standard USLE model). The latter provide results that are difficult to use in modelling erosion processes or in comparisons of cropping systems and parameters. They do, however, provide information on soil transport on a larger scale, including the effects of the length of slopes and of runoff accumulation, and the influence of long periods of rain or of frequent successive bouts of rain. Maximum soil transport averaged 3000 kg $h^{-1}$ $ha^{-1}$ over 3 days, in cyclone rainfall conditions (February 1988), on degraded hoed soil with a 10% slope, just after a potato harvest (Bougère, 1988). This amounts to soil ero-

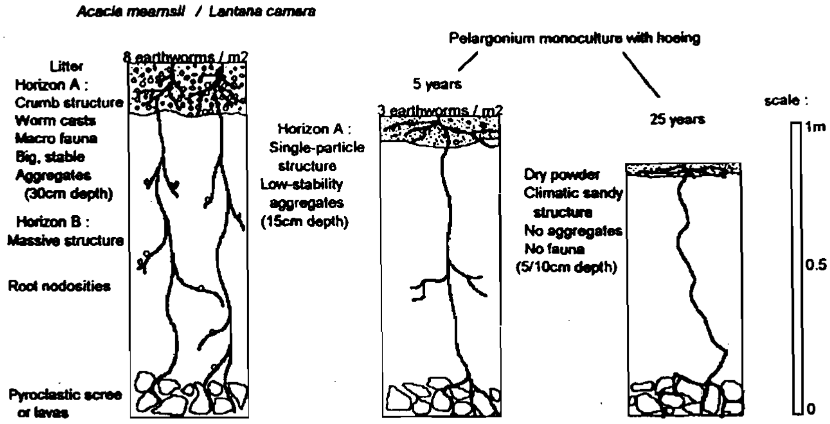


Fig. 2. Evolution of soil profile from bush-fallow to long-time pelargonium monoculture (Plot 19).

sion to an average depth of 30 mm during a single climatic event.

### 3.2. *Profile evolution: earthworms, structure and root systems*

Fig. 2 shows the evolution of profiles from fallow to long-standing pelargonium monoculture, which leads to soil losses, structure degradation, and decrease in biological activity. This overall deterioration results in loss of fertility which considerably decreases yields. In addition, weed control becomes impossible to manage (Michellon, 1986). Currently, the situation of tilled soils is mostly close to the third profile. New cropping systems have been put forward to diversify production, protect the soil, and restore fertility and yields (Michellon and Perret, 1994). Fig. 3 shows the evolution of profiles according to rotation, cover plants and cropping systems after 3 years on previously degraded hoed soils.

Six-stage rotation with food crops supplies organic matter (manuring before planting). These systems protect soil structure and soil fauna, and increase pelargonium yields (Michellon, 1986). *Lotus uliginosus* and *Pennisetum clandestinum* provide live cover, controlled with selective herbicides. The roots of cover plants restore structure and stimulate the development of macro-fauna. In addition, many associations increase yields and facilitate low-input weed control (Michellon and Perret, 1994). Other

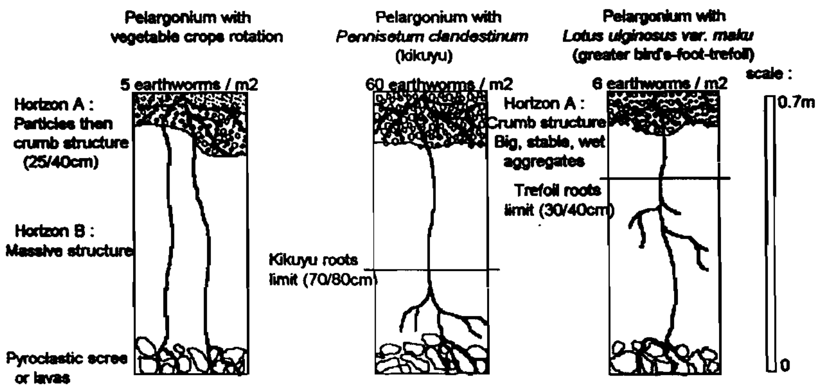


Fig. 3. Evolution of soil profile according to new cropping systems (Plots 16, 2 and 1).

Table 2
Invertebrate population densities, according to soil management

| | Worms | Chilo-pod | Iso-pod | Diplo-pod | Ants | Others | Total |
|---|---|---|---|---|---|---|---|
| | ($m^{-2}$) | | | | | | |
| Fallow | 232a | 42a | 541a | 682a | 13a | 595a | 2126a |
| Plot 19 | 0b | 0b | 0b | 8b | 115b | 21b | 261b |
| Plot 1 | 10c | 37ca | 80c | 170c | 141cb | 203c | 1403c |
| Plot 2 | 58d | 29dca | 27dc | 578da | 144dcb | 179dc | 1125dc |

Different letters, related to the population density data, show significant differences between sites, tested by Student's $t$-test at $P = 0.1$.

cover plants tested include legumes (Kenyan white clover (*Trifolium semipilosum*), perennial peanut (*Arachis pintoï*), and tick clover (*Desmodium* sp.)).

### 3.3. Soil macro-fauna: invertebrate density

Table 2 shows the influence of the soil management on the density of some invertebrate groups. Long-time monoculture with hoeing results in a marked reduction of soil fauna. Conservative systems show significant potential for restoring the fauna. Soil macro-fauna seems to be both an effect and a condition of soil restoration: cover plants result in an increase in organic matter (litter, roots) and in topsoil moisture content. These conditions encourage the development of earthworm and arthropod populations. These invertebrates groups can turn over a significant proportion of top soil and organic matter, and this is accompanied by physical effects on soil structure and hydraulic characteristics (Table 3). Earthworm activity results in a network of galleries and in macro-aggregates (worm casts) that increase percolation of water. The comparison between Tables 2 and 3 clearly shows the relationship between earthworm density and aggregate size (MWD).

### 3.4. Assessment of profiles, structure, water transfer, and evolution of organic matter

Table 3 summarises data characterising profile evolution according to cropping systems. Infiltration measured in rainfall simulation is very close to saturated conductivity measured with disk permeameter (about 40 mm $h^{-1}$ on degraded hoed soils). These data confirm the increased permeability resulting from plant cover, especially under hedges, because of restoration of soil structure. Soil fauna increases the turnover of organic matter and mineralization below the cover plants. At the same time, it can be seen that crop rotation cannot by itself restore soil properties.

### 3.5. Calliandra hedges to manage runoff

*Calliandra* hedges also provide forage during the dry season (the livestock providing manure for vegetable crops) and improve soil protection and runoff absorption. They also function as windbreaks for crops during cyclones (Tassin et al., 1995). Fig. 4 shows the evolution of soil structure according to distance from hedges. Under the hedge, a 1 m band

Table 3
Evolution of some soil properties according to cropping practices and surface management

| Soil use and management | Ksat (mm $h^{-1}$) | MWD (mm) | S | C (g 100 $g^{-1}$) | N g 1000 $g^{-1}$ |
|---|---|---|---|---|---|
| Long term fallow | 250a | 2.50a | 0.92a | 17.2a | 13.5a |
| Pelargonium monoculture on degraded hoed soil (Plot 19) | | | | | |
| Open field | 40b | 1.10b | 0.52b | 7.1b | 6.2b |
| 1 m from *Calliandra* hedge | 70c | 1.60c | 0.60b | 8.0bc | 7.9bc |
| Under *Calliandra* hedge | 225a | 2.36a | 0.84acd | 8.4c | 6.7b |
| Pelargonium/food crop rotation on bare soil (Plot 16) | 60bc | 1.11bd | 0.76c | 7.1b | 5.6b |
| Pelargonium with kikuyu grass cover (Plot 2) | 105d | 1.41bcd | 0.83acd | 6.9b | 7.3bc |
| Pelargonium with trefoil cover (Plot 1) | 70c | 1.37bcd | 0.87ad | 8.7c | 9.0c |

Different letters, related to runoff and soil loss data, show significant differences between sites, tested by Student's $t$-test at $P = 0.1$.

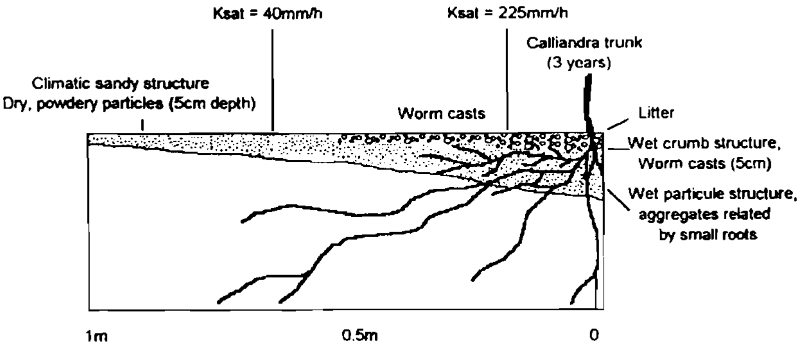


Fig. 4. Spatial evolution of a degraded hoed soil profile according to *calliandra* hedgerow distance (Plot 19).

of improved soil forms 2 years after planting, and it becomes significantly effective 3 years after planting. The *Calliandra* rooting system, shade, and the micro-climate under the hedge, as well as the organic matter supplied by the foliage, all stimulate earthworm populations and activity. The worms create a 5 cm layer with worm casts and stable organic crumb structure. Below this, the initially degraded structure is wetter and firmly held by rooting systems. Disk permeameter measurements show improvement in infiltration. The soil below the hedges seems to be able to absorb runoff. Tassin et al. (1995) showed the significant increase of macro-porosity below the hedge.

## 4. Conclusion

In Reunion Island high rainfall intensity results in considerable runoff from catchments at high altitude. This causes soil loss, which directly damages agricultural systems and substructures. Downstream, muddy torrents damage coral reef and lagoon ecosystems. Agro-ecological practices have been tested for runoff reduction. Live cover results in an immediate and marked reduction in soil losses. Two years after planting, *Calliandra* hedges speed up the development of soil fauna, restore structure and macroporosity, and increase permeability in their local area. These associated and complementary cropping practices can achieve complete erosion and runoff control in a short time. In addition, they can restore soil fertility to the whole field.

Biological management systems of this nature efficiently prevent erosion, and they should be able to compensate for lack of physical management systems in Reunion mountain areas. Elsewhere, in similar circumstances, they are an alternative to expensive mechanical operations (such as terracing, ridge and levelling tillage along contours, and so forth). They should also improve cropping systems and the move towards more productive agriculture, with low inputs and pesticide use. This agro-ecological approach can genuinely achieve sustainability in tropical catchments, improving or protecting many components, upstream and downstream: agricultural systems, soil and water resources, landscapes and ecosystems.

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CHAPTER 6

# *Agroecological Practices as Tools for the Sustainable Management of Catchments Susceptible to Erosion: Réunion Island*

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## INTRODUCTION

On the small island of Réunion, in the Indian Ocean (Figure 6.1), population growth coupled with urban development on the coastal strip has resulted in intense pressure on the remaining agricultural systems which are fragile due to their situation on steep slopes experiencing high rainfall. On the island's western side (21°05′S, 55°20′E), deep volcanic ash soils range from 500 to 1500 m in elevation, according to climatic conditions. These andisols (Andepts) first show a dominant halloysitic character, then turn allophanic and gibbsitic (Zebrowski, 1975; Raunet, 1991).

Pelargonium (*Pelargonium* spp.) is the dominant crop, grown between 800 to 1200 m for the extraction of oil to be used in the perfume industry. Leaves and young stems are harvested and then water-distilled for essential oil extraction. At lower altitudes, sugar-cane dominates. Fallow lands, natural or exploited forests, and grasslands cover the higher areas. Mean annual temperatures range from 16 to 19°C. Mean annual rainfall ranges from 1200 to 1700 mm with 70% between January to April, mostly during tropical depressions or cyclones. These high-intensity rainfall events induce important runoff and soil losses on agricultural fields, enhanced by slope (averaging 15%), low conductivity and poor aggregation of degraded soils (Perret, 1993).

*The Sustainable Management of Tropical Catchments*. Edited by David Harper and Tony Brown.

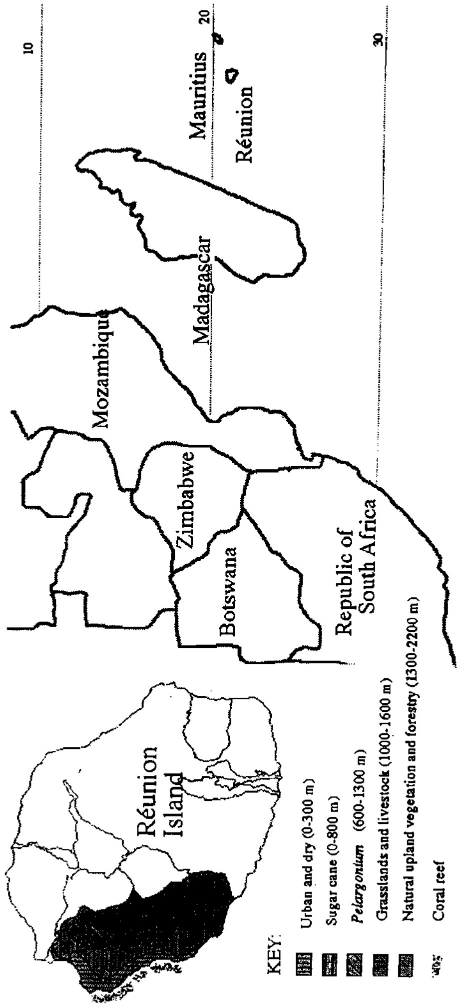


Figure 6.1 Location of Réunion Island, and illustration of vegetation zonation with altitude



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The land husbandry also encourages erosion because it is mainly based on hoed crops (not only pelargonium, but also various food crops and vegetables (Garin, 1987)). Traditional systems were formerly based on shifting cultivation, alternating with long-term fallow which restored soil fertility, but with poor surface management to prevent erosion; this was mainly because farmers were not landowners.

At the present time, population settlement has forced farming systems to develop more intensive cropping practices, such as long-term monoculture without fallow, and weed control with hoeing. These practices increase soil degradation and lead to a decrease in fertility. For all crops, inputs have to increase (i.e. plant-health treatments, organic matter, mineral fertilisers) but still cannot overcome a decrease in yield and greater costs in both labour and money (Michellon and Garin, 1985).

Erosion is now so severe that few relict profiles remain. Nearly all tilled soils have lost the A horizon and now expose the Bt horizon, or even the deep-indurated horizon (volcanic tuff) or pyroclastic scree in the most degraded conditions (Raunet, 1991). Within the *Pelargonium* growing-zone, field erosion averages 20 t $ha^{-1}$ during a usual year. It amounts to 50–200 t $ha^{-1}$ during a rainy and cyclonic year (Bougère, 1988; measurements with standard erosion plots). It widely exceeds the tolerable soil-loss limit, usually accepted in the tropics as 5-15 t $ha^{-1}$ (El-Swafy et al., 1982). In the coastal strip where drainage streams discharge this eroded silt, serious damage is being caused to coral reef ecosystems (Stieljes, 1993) and concern is being expressed about drinking water quality from aquifers at risk from pesticide and fertiliser influx.

Under such constraints, farmers progressively abandon the most degraded fields and *Pelargonium* culture. Currently, farming systems are evolving towards complex mixed-cropping systems, sometimes associated with goat or cattle breeding. But the persistence of hoeing on almost all of the cropped fields maintains erosion at very high rates. The steepness of the soils makes them unsuitable for mechanical rehabilitation (e.g. terracing and levelling, Nimlos 1992; Chapter 8) and so biological methods need to be investigated. "Agroecological" practices are increasingly being seen to fit small tropical farming systems (ICRAF, 1993), often using cover plants, legume intercropping and hedgerow planting (National Research Council, 1983; Lal et al., 1991).

## *TOWARDS A MANAGEMENT STRATEGY*

Sustainable agriculture implies "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (Technical Advisory Committee, 1989, cited by Lal et al., 1991). The Réunion Island *Pelargonium*-growing area needs to become sustainable. In such conditions, soil loss is the primary factor to be taken into account, for establishing new soil conservation and productive cropping systems (Lal, 1989; Smith et al., 1992), and for developing the features of a more natural landscape (Thomas and Kevan, 1993). These systems are part of the global strategy towards sustainability, that includes diversification, integration and synthesis (Ikerd, 1993).

On severely eroded volcanic ash soils in Latin America, successful reclamation techniques have been based on mechanical methods such as terracing and levelling tillage (Nimlos, 1992; Chapter 8). The agroecological practices that are also most promising are the use of cover plants to restore soil and fertility (Lal, 1975; Lal et al., 1991), improving its different components such as aggregation and pore space, water infiltration, erosion and runoff resistance, nutrient cycling and soil organic matter. In Réunion a suitable plant for integration with the *Pelargonium*-growing system was *Calliandra*, using hedges as plot boundaries for increasing runoff control and soil restoration. *Calliandra* also provides wind protection and green fodder, as well as being resistant to insect attack. The aim of this work is to describe and quantify the components of soil degradation and restoration, and to assess the suggested agroecological changes.

## METHODS

The CIRAD station of Trois-Bassins (ranging from 950 to 1020 m in elevation) is the main site for *Pelargonium* horticultural research in Réunion Island. Its mean annual rainfall is about 1500 mm with 70% between January and April. The andisols (Dystrandepts) cover volcanic ash, with a surface slope steepness averaging 15–20%. Water runoff and erosion processes were first studied on severely and moderately degraded bare soils under *Pelargonium* monoculture, and compared with *Pelargonium* cultivation associated with Kikuyu-grass (*Pennisetum*) and trefoil (*Lotus*) covered soils.

During July 1993, different plots on each *Pelargonium* harvesting system were analysed for soil structure and fauna, for aggregate size, stability and organic matter and for water transmission, taking into consideration the distance from *Calliandra* hedges. All plots had been severely degraded by long-term *Pelargonium* monoculture. The systems investigated were:

1. A long-term *Pelargonium* monoculture (25 years; plot 19).
2. A *Pelargonium* six-course rotation with food crops (six crop-cycles: first year–tobacco/maize (2 cycles/year), second year–potato/maize (2 cycles/year), third year–bean/maize (2 cycles/year), then 6 years in *Pelargonium* cropping, then potato/maize cropping cycles in 1993; plot 16).
3. *Pelargonium* association with kikuyu-grass (*Pennisetum clandestinum*, planted in 1989; plot 2).
4. *Pelargonium* association with greater bird's-foot-trefoil (*Lotus uliginosus*, planted in 1990; plot 1).

A sprinkler infiltrometer was used, developed by Asseline (1981) and Casenave (1982). It uses a deflector-nozzle fastened at the top of a 4 m high tower. The nozzle oscillates and continuously produces drops under 100 kPa pressure. The drop size, impact velocity, and kinetic energy are constant, and consistent with natural rainfall. The intensity varies as a function of the oscillation. The elementary plot surface was 1 $m^2$. Plot steepness ranged from 8 to 20%; rainfall intensity ranged from 36 to 83 mm $h^{-1}$.

On each situation, a soil profile was described, with particular reference to *in situ* structures, earthworm number and activity, and root system structure.

Aggregate size and stability were measured on a 30 g sample which was wetted, then separated into various size fractions by sieving through a nest of sieves under a gentle water flow to cause as little mechanical disruption of the aggregates as possible. Sieves with openings of 5.00, 2.00, 1.00, 0.50, 0.20 and 0.05 mm were used. The mean-weight diameter (*MWD*) of aggregates (Van Bavel, 1949) is equal to the sum of products of (a) the mean diameter of each size fraction $d_i$ and (b) the proportion of the total sample dry weight $w_i$ occurring in the corresponding size fraction, when the summation is carried out over all *n* size fractions, including the one that passes through the finest sieve:

$$MWD = \sum_{i=0.025}^{3.50} (d_i w_i) \qquad \text{thus, } 0.025\ \text{mm} \leq MWD \leq 3.50\ \text{mm} \tag{1}$$

3.00 mm is the mean diameter of the remaining fraction on the sieve with an opening of 2.00 mm; 0.025 mm is the mean diameter of the fraction that passes through the sieve with an opening of 0.05 mm.

The same experiment was carried out with another 30 g sample, previously exposed to 20 kHz ultrasonic energy of 30 J mL$^{-1}$ in water (e.g. 75 W × 120 seconds ~ 300 mL of water). This treatment causes both shattering and abrasion of the aggregates (North, 1976, 1979; Gregorich et al., 1988). Then, a new mean weight diameter $MWD_{us}$ was calculated. A stability index was used:

$$S = MWD_{us}/MWD \qquad \text{thus, } 0 < S \leq 1 \tag{2}$$

Previous experiments carried out on andisols have shown that *S* ranges from 0.3 (very poor stability) to 1 (full stability) (Perret, 1993).

In addition, a measurement of the total organic carbon (Anne method) and nitrogen (Kjeldahl method) were carried out on each sample.

Near each profile, tension infiltrometry was carried out in order to determine hydraulic conductivity $K_i$. The Triple Ring Infiltrometer at Multiple Suctions (TRIMS, Thony 1990) was developed from Clothier and White (1981) and Perroux and White (1988). It allows field-measurements of $K_i$ from saturation to different negative matrix pressure *i*, to −200 mm.

## RESULTS AND DISCUSSION

### *RUNOFF AND SOIL-LOSS PROCESSES*

From 45 rainfall simulation experiments, runoff intensity (*R*), transported soil (*C*) and rainfall intensity (*I*) were related to soil degradation level and surface management. Figure 6.2 shows a rainfall-intensity threshold for runoff, starting at about 36 mm h$^{-1}$. After this, runoff increases with rainfall, according to a limit line calculated from the points that represent a maximum runoff intensity for a given rainfall. The equation is:

$$R = 1.23I - 46 \tag{3}$$

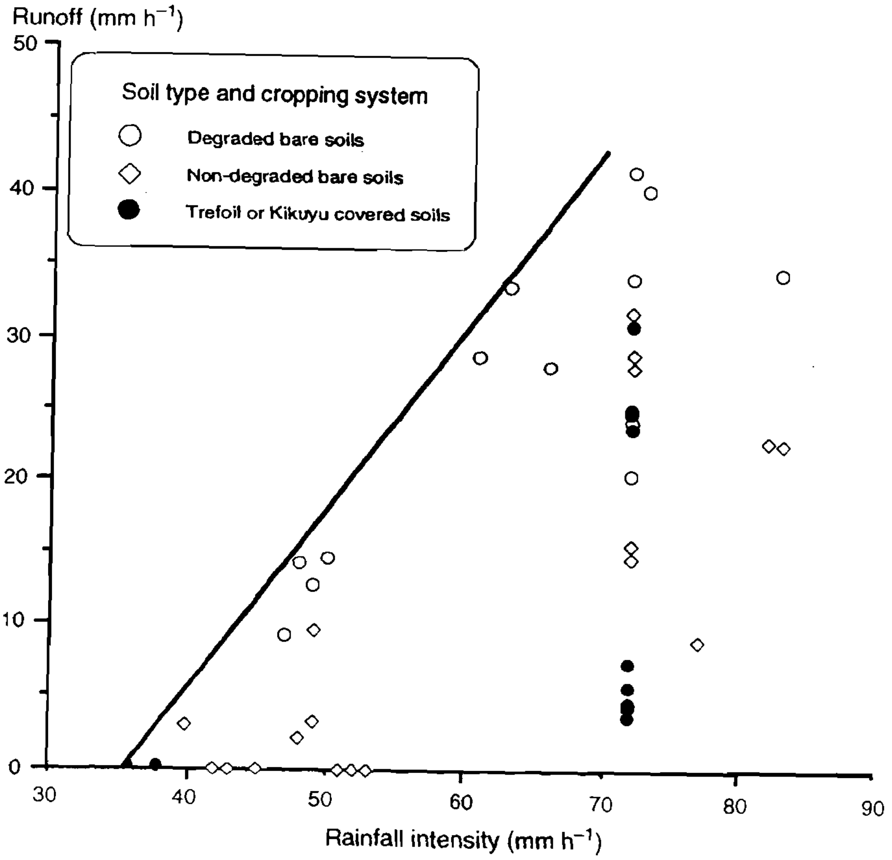


Figure 6.2 Variation in runoff with rainfall intensity under different soils and management

The points next to this limit represent exposed, severely degraded soils, with low roughness. Below this limit are moderately degraded soils and covered soils. The line indicates that infiltration, $F$ (= rainfall less runoff), is not a constant, but decreases as a function of rainfall intensity, most probably due to slaking and surface structure degradation under strong rainfall. It is confirmed by the time-threshold for the commencement of runoff, which was 8 minutes on average under 50 mm $h^{-1}$ rainfall, and only 2 minutes under 70 mm $h^{-1}$ rainfall. Below 36 mm $h^{-1}$, there was no runoff. In addition, gradients of less than 20% had no effect on runoff intensity.

Live mulches cause little reduction of runoff, but kikuyu-grass and trefoil cover strongly reduce sediment transport (Figure 6.3). Their most important effect is to protect soil against raindrop impact, and to decrease velocity and carrying capacity of overland flow. Cover plants have an effect on structure and fauna to give better water infiltration, but this does not cause enough improvement to completely absorb runoff induced by strong rainfall. Table 6.1 summarises the effect of soil covering on runoff and erosion control, at different rainfall intensities. The cover plants' most important effect is to reduce erosion. Under strong rainfall, runoff remains important.

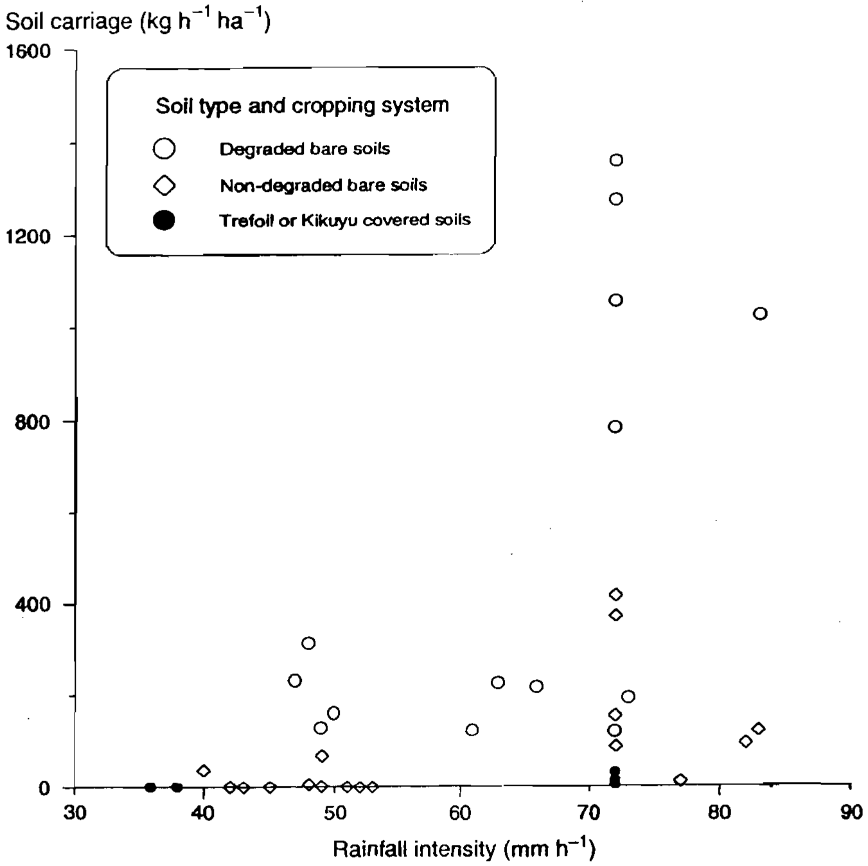


Figure 6.3 Variation in soil loss with rainfall intensity under different soils and management

Table 6.1 Rainfall simulation data for different rainfall intensities and soil managements

| Soil type and management | $n$ | Runoff (mm $h^{-1}$) | | Soil loss (kg $h^{-1}$ $ha^{-1}$) | |
|---|---|---|---|---|---|
| | | $I = 45$ | $I = 72$ | $I = 45$ | $I = 72$ |
| Degraded bare soils | 14 | 13 | 31 | 208 | 635 |
| Non-degraded bare soils | 19 | 2 | 22 | 10 | 201 |
| Kikuyu/trefoil soils | 12 | 0 | 15 | 0 | 7 |

Slope over 8–20%; soil loss expressed as oven-dried soil weight

Sediment transport measured during simulated rainfall on elementary 1 $m^2$ plots is very similar to that measured under natural rainfall, on 100 $m^2$ plots. These plots give results that are difficult to use for modelling erosion processes or to compare cropping systems and parameters. However, they do give information on sediment transport at a larger scale, including slope length effects, runoff accumulation, and long-term or successive rainfall influence.

The maximum sediment transport was approximately 3000 kg $h^{-1}$ $ha^{-1}$, over 3 days during a cyclonic rainfall (February 1988), on a degraded bare soil (with a 10% slope steepness), just after a harvest of potato (Bougère, 1988). That is the equivalent of soil erosion averaging 3 cm surface lowering during a single severe climatic event.

## *SOIL PROFILES: EARTHWORMS, STRUCTURE AND ROOT SYSTEMS*

Figure 6.4 shows the changes in profiles from fallow to long-term *Pelargonium* monoculture, which leads to soil losses, degradation of structure, and loss of biology. This progressive degradation results in fertility loss, and strongly decreases yields. In addition, weed control becomes impossible to manage effectively (Michellon, 1986). Currently, most tilled soils are similar to the third profile and so there is an urgent need for new harvesting and soil husbandry systems.

New cropping systems have been developed to diversify production, to protect the soil and to restore fertility and yields (Michellon et al., 1991). Three examples of these are illustrated in Figure 6.5, which shows the recovery of profiles following rotation and cover-plant cropping systems, 3 years old, on a previously degraded bare soil.

A six-course rotation with foodcrops also supplies organic matter (manuring before planting) and protects soil structure and biology, increasing *Pelargonium* yields (Michellon, 1986). *Lotus uliginosus* and *Pennisetum clandestinum* provide living cover, which may be controlled with selective herbicides. Cover-plant roots restore structure and speed up the recolonisation by macrofauna. They do not compete with crops for water availability (Veillet, 1993). In addition, many associations increase yields and may allow low-input weed control (Burle, 1993). The other cover plants that have been tested are chiefly legumes (e.g. Kenya white-clover *Trifolium semi-pilosum*, perennial peanut *Arachis pintoï*, tick-clover *Desmodium* sp.).

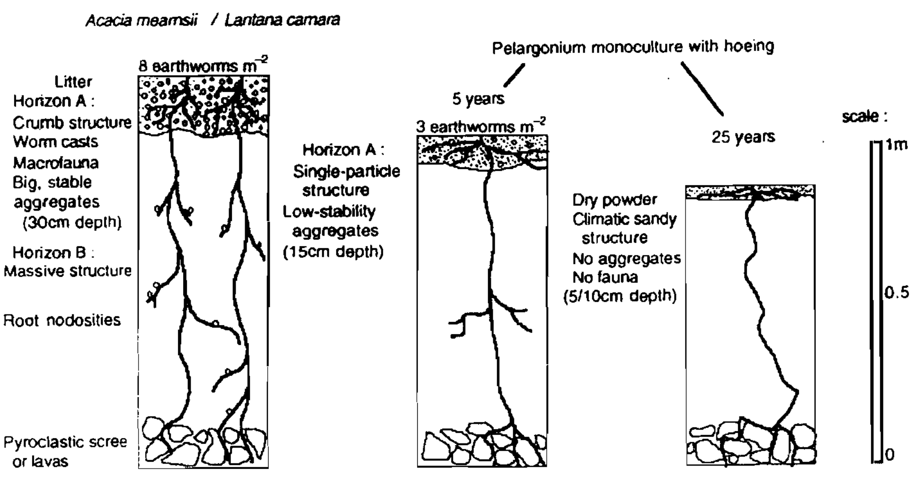


Figure 6.4 Changes of soil profile from bush-fallow caused by *Pelargonium* monoculture (plot 19)

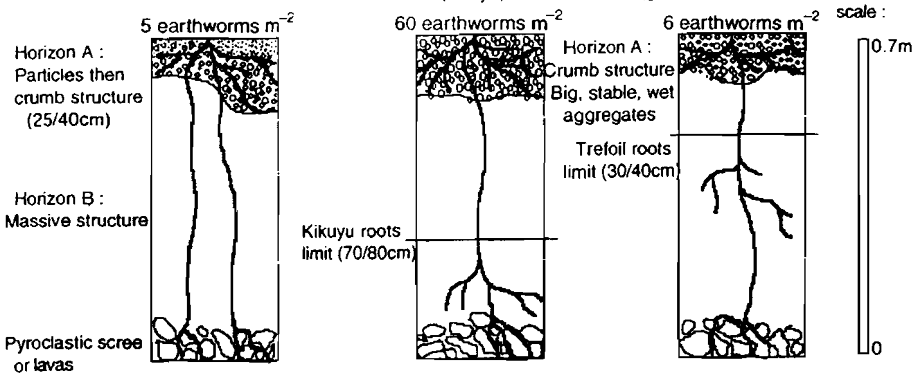


Figure 6.5 Restoration of soil structure by new cropping systems (plots 16, 2 and 1)

## *QUANTIFYING STRUCTURE, WATER TRANSMISSION AND ORGANIC MATTER EVOLUTION*

Table 6.2 summarises the development of profiles under different cropping systems. Infiltration measured under rainfall simulations is very close to saturated conductivities measured with a disk permeameter (about 40 mm $h^{-1}$ on degraded bare soils). These data show the increased permeability under covered conditions, and especially under the hedgerow, due to soil structural restoration. Soil fauna increases the turnover of organic matter and mineralisation beneath cover plants. Crop rotation alone cannot restore soil properties.

## CALLIANDRA *HEDGEROWS AS A TOOL FOR MANAGEMENT OF RUNOFF*

In addition to different rotation and *Pelargonium* cultivation, the use of *Calliandra calothyrsus* hedgerows has been proposed, to provide forage during the dry season (to

Table 6.2 Restoration of soil properties under different cropping practices and surface management

| Soil use and management | $K_{sat}$ (mm $h^{-1}$) | *MWD* (mm) | *S* | C (g 100 $g^{-1}$) | N (g 1000 $g^{-1}$) |
|---|---|---|---|---|---|
| Long-term fallow | 250 | 2.50 | 0.92 | 17.2 | 13.5 |
| *Pelargonium* monoculture on bare soil: | | | | | |
| – open field | 40 | 1.10 | 0.52 | 7.1 | 6.2 |
| – 1 m from the *Calliandra* hedgerow | 70 | 1.60 | 0.60 | 8.0 | 7.9 |
| – under the *Calliandra* hedgerow | 225 | 2.36 | 0.84 | 8.4 | 6.7 |
| *Pelargonium*/food crop rotation on bare soil | 60 | 1.11 | 0.76 | 7.1 | 5.6 |
| *Pelargonium* with kikuyu-grass cover | 105 | 1.41 | 0.83 | 6.9 | 7.3 |
| *Pelargonium* with trefoil cover | 70 | 1.37 | 0.87 | 8.7 | 9.0 |

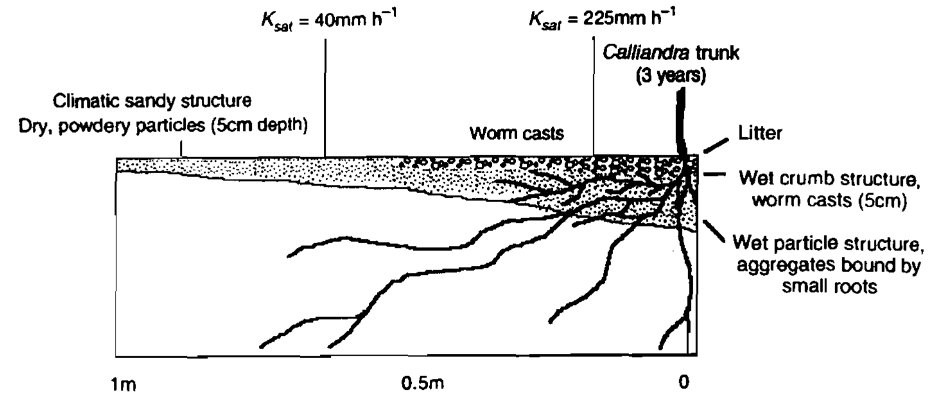


Figure 6.6 Restoration of a degraded soil profile by the protection of *Calliandra* hedgerow (plot 19)

feed animals that supply manure for vegetable crops), and to intensify soil protection and absorption of runoff. They also provide a wind protection for crops during cyclones (Maréchaux, 1993).

Figure 6.6 shows the spatial development of soil structure and fauna with distance from a hedgerow bottom. Under the hedge, a 1 m wide zone appears 2 years after plantation, and becomes significantly effective 3 years after plantation. *Calliandra* roots, the shade and microclimate under the hedge, and organic matter supplied by foliage drops, all improve earthworm numbers and activity. The earthworms then create a layer approximately 5 cm deep with their worm casts which develops into a stable organic crumb structure. Beneath this, the initially degraded structure becomes wetter and bound by fine roots. Disk permeameter measurements show an infiltration improvement. The soil below the hedgerows seems to be able to absorb runoff.

## CONCLUSIONS

In Réunion Island, high-intensitiy rainfall induces important runoff in the high-altitude catchments, causing soil loss that directly damages agricultural systems and substructures. Downstream, eroded soil damages coral reef and lagoon ecosystems.

The solution to this problem lies with changes to agroecological practices. Live covering results in an immediate and important reduction of soil losses. Two years after planting, *Calliandra* hedgerows speed up soil fauna recolonisation, restore soil structure and increase local permeability. These associated and complementary cropping practices can quickly lead to complete erosion and runoff control. In addition, they can restore soil fertility of the whole field.

Because these biological management practices efficiently prevent erosion, they should compensate for the lack of any physical management techniques in Réunion's mountainous areas. Elsewhere, in similar circumstances, they could replace expensive mechanical operations, such as terracing, ridge and contour tillage. They also should improve husbandry systems to give a more productive agriculture, with low inputs and pesticide use. This agroecological approach can lead to sustainability in tropical catchments, improving or protecting all the components of the catchment: agricultural systems, soil and water resources, landscapes and ecosystems.

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CHAPTE

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CARLOS SCH
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# CIRAD at a glance

CIRAD is a French scientific organization specializing in development-oriented agricultural research for the tropics and subtropics. Its mission is to contribute to the economic development of these regions through research, experiments, training, and dissemination of scientific and technical information.

CIRAD operates through its own research centres, national agricultural research systems, or development projects in more than 50 countries.

CIRAD emphasizes on agronomic research through an inter-disciplinary and multi-scale approach. This commitment, which involves cropping and farming systems research, economic analysis, social approaches, management and decision-making support, modelling techniques, seems to be relevant with regard to the challenge of emerging agriculture support and natural resource management within the rural communities in South Africa. And it does not rule out the resort to biotechnology, product processing, crop protection, commodity subsectors approach, as recognized areas of excellence of CIRAD.

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CIRAD

Centre de coopération internationale en recherche agronomique pour le développement

# Farming systems, agricultural economics and rural development

A selection from CIRAD publications list

# Farming development

## Agricultural research and innovation in tropical Africa

Outside of the agro-industrial sector, the adoption of complete "technical packages" has been partial and selective, following patterns, unanticipated by the research system, that reflect constraints operating at the farm level. Agriculture in this region cannot hope to respond to the challenges lying ahead without major efforts by national and international research.

**P.-M. Bosc, H. Hanak-Freud - CIRAD-SPAAR, 1995**
**Ref. 389 - Isbn 2-87614-213-9 - Issn 1251-7224 - English**
**120 F**

## Amélioration du sorgho et de sa culture en Afrique de l'Ouest et du Centre

*Improvement of sorghum and its cultivation in West and Central Africa.* Research on varietal improvement, entomology, weeds and agronomy and extension operations are of direct benefit to researchers and development agents working on sorghum.

**Sc. Ed.: A. Ratnadass, J. Chantereau, J. Gigou - CIRAD/ICRISAT, 1998**
**Ref. 683 - Isbn 2-87614-304-6 - Issn 1264-112X - French/English**
**200 F**

## L'appui aux producteurs ruraux

*Support to rural producers.* This guide, intended for development agents and group leaders, takes stock of field intervention aspects. It presents extension methods, ways of funding local development and developing the role of women; local planning, diagnosis and monitoring-evaluation approaches; training and producer organization tools, contracts between protagonists, etc.

**M.-R. Mercoiret - Karthala-Ministère de la Coopération, 1994**
**Ref. 546 - Isbn 2-86537-520-X - French**
**170 F**

## New marketable species in Africa

A set of ten leaflets on lesser known species of Africa gives a lot of information: botanical and commercial ones, denominations, wood description, technical, chemical and energy properties, list of their uses. Easy to read, they have been written especially for importers, users and architects.

**Cirad-ITTO, 1989**
**Ref. 345 - Isbn 2-85411-009-9 - English**
**110 F**

## Operational ecology in a semi-arid tropical zone

The notion of operational ecology means to associate researchers and decision-makers in operations covered by development projects. Since 1978, the principle of gearing ecological approaches towards operations has been applied in numerous circumstances, as the basis for a scientific approach geared towards the successful transformation of ecosystems.

**J.-F. Duranton, M. Launois M. - CIRAD-Ministère de la Coopération, 1978**
**Ref. 677 - English**
**10 F**

## Pathologie caprine et productions

*Goat pathology and production.* The papers presented at the Niort International Conference (France, 1989) covered an extremely wide range of subjects: slow viruses; pathology and meat production; pathology and production systems; general pathology; goat mycoplasmoses; mammary pathology and milk production; reproductive pathology and parasitism.

**Sc. Ed.: G. Perin - CIRAD, 1993**
**Ref. 406 - Isbn 2-87614-117-5 - Issn 0297-4444 - French/English/Spanish**
**250 F**

## Appui pédagogique à l'analyse du milieu rural dans une perspective de développement

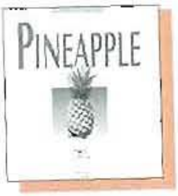
*Teaching methods in support of development-oriented analyses of rural environments.* Studies in Burkina Faso, Nepal and Togo illustrate the systemic approach via an analysis of the rural environment and regional farming systems, followed by a study of production system functioning, pinpointing the diagnosis at plot level.

**L. Bedu, C. Martin, M. Knepfler, M. Tallec, A. Urbino - CIRAD, 1987**
**Ref. 436 - French**
**100 F**

## Breeding banana and plantain for resistance to diseases and pests

Articles present the aims and carrying out of several breeding program of banana and plantain: plant-related and pathogen-related constraints, improvement strategies, synthesis and prospects, abstracts and posters. Development of a network of banana breeders/geneticists was recommended.

**Sc. Ed.: J. Ganry - CIRAD-INIBAP, 1993**
**Ref. 565 - Isbn 2-87614-108-6 - English**
**300 F**



## Pineapple: quality criteria

This book, illustrated by a lot of photographs, present the optimal characteristics of fruit quality and the principal defects to be found both at the production stage and at consumer stage. This presentation will make it possible for the different links in the chain, from the producer to the tradesman, to clearly define any faults and to determine their causes and remedies.

**A. Soler - CIRAD, COLEACP, 1982**
**Ref. 604 - Isbn 2-87614-078-0 - English**
**150 F**

## Production et valorisation du mais à l'échelon villageois en Afrique de l'Ouest

*Maize production and valorization on a village scale in West Africa.* The seminar took stock of knowledge and of development operations concerning maize growing systems, pre and postharvest mechanization, maize and maize by-product processing and the socio-economic conditions for producing, promoting and marketing maize on a village scale.

**CIRAD, FSA-UNB - CIRAD, 1995**
**Ref. 533 - Isbn 2-87614-206-6 - Issn 1264-112X - French/English**
**200 F**

### Caractérisation et la valorisation du sorgho

*Characterization and promotion of sorghum.* The use of sorghum as a human food source in developing countries constitutes the major theme of this bibliography: 857 references reviewing all aspects of current knowledge, from the sorghum grain (structure, physical characteristics, biochemical composition) to its processing and the quality and nutritional value of the finished product.

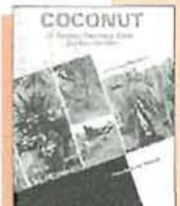
G. Fliedel, A. Marti, S. Thiébaut - CIRAD, 1996
Ref. 639 - Isbn 2-87614-217-1 - Issn 1160-3283 - French/English
280 F

### L'igname, plante séculaire et culture d'avenir


*Yam, a secular plant and a crop with a future.* By virtue of its strong cultural roots, yam is a research topic that interests the majority of countries in the South. This work looks at every aspect of the plant, from breeding to consumption, and identifies R&D approaches that could be taken in conjunction with those involved in the sector.

J. Berthaud, N. Bricas, J.-L. Marchand - CIRAD, 1998
Ref. 687 - Isbn 2-87614-313-5 - French/English
300 F

### Coconut: a pictorial technical guide for smallholders




This illustrated color handbook is a practical manual on coconut production and processing at village level. It is designed for smallholder technology transfer in a government-sponsored coconut project using the Project Management Unit approach. It describes how to perform certain tasks in chronological order.

R. Bourgoing - CIRAD, 1991
Ref. 158 - Isbn 979-8213-00-9 - 118 plates - English
250 F

### Institutional changes for sustainable agricultural and rural development

Liberalization leads to a deep reshaping of institutions. In a lot of cases, liberalization drives the transition process from subsistance and public driven agriculture economy to market economy. The privatisation of major agricultural services changes the role of the State: complementarity and interaction are necessary.

M. Griffon, A. Hilmi - CIRAD-FAO, 1998
Ref. 685 - Isbn 2-87614-311-9 - English
120 F

### Economie institutionnelle et agriculture

*Institutional economics and agriculture.* What can institutional economics contribute to an analysis of agricultural situations? This seminar at Indiana University took stock of the possibilities of applying institutionalist theories to the agricultural and rural sectors in tropical Africa and dealt with: new institutional economics, public choice theory, institutional analyses and design, regulation schools.

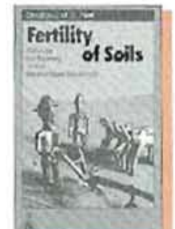
Sc. Ed.: M. Griffon - CIRAD, 1994
Ref. 550 - Isbn 2-87614-180-9 - French/English
150 F

### Manual for the preservation of wood in the tropics

This manual written for a large readership is divided into three parts. 1. Protection of logs against insects and fungal attacks; treatment rules. 2. Temporary protection of freshly-cut lumber and peeled veneers against the same attacks. 3. Wood protection before use against deterioration agents, natural durability, wood preservation, treatment processes.

C. Déon - CIRAD, 1990
Ref. 357 - Isbn 2-85411-007-2 - English
190 F

### Fertility of soils: a future for farming in the West African savannah




Thirty years of investigation, and a renewed comprehensive interpretation of research data on soil fertility, show that sustainable agricultural growth could be a practicable possibility to match the requirements of a fast-growing population in a savannah region.

C. Piéri - CIRAD-Ministère de la coopération et du développement, 1991
Ref. 27 - Issn 0937-3047 - Isbn 3-540-53283-8 - Isbn 0-387-53283-8 - English
Distributed by Springer-Verlag

### Manual of forest botany: tropical Africa


Volume 1 deals with generalities about trees, shrubs and herbaceous plants. It also outlines the various formations in tropical Africa and gives a great number of practical details concerning collecting and conserving botany samples. Volumes 2a and 2b deal with successive families of plants (trees, shrubs and herbaceous plants) represented in dense, moist or dry forests and in savanna and steppes.

R. Letouzey - CIRAD, 1986
Ref. 287 - Isbn 2-85411-003-X - English
390 F

### Finance and rural development in West Africa

The discussions on relaunching rural development in West Africa are increasingly highlighting the key role of financial aspects on a micro-economic level. This seminar took stock of the knowledge acquired and the research available to rural households and established an inventory of the initiatives taken by financial service agencies in rural areas.

Sc. Ed.: C. Cuevas, M. Benoit-Cattin - CIRAD-CTA, 1992
Ref. 449 - Isbn 2-87614-111-6 - French/English
150 F

### Le microfinancement dans les pays en développement

*Microfunding in developing countries. Evolution, theories and practices.* This compilation of bibliographical references enables an in-depth study of the issues related to microfunding: changes in economic thinking since the start of the 1990s, how to diagnose situations and implement, monitor, assess the impact of and regulate microfunding systems.

C. Lapenu, B. Wampfler, M.-C. Duchamp - CIRAD, 1997
Ref. 669 - Isbn 2-87614-290-2 - Issn 1160-3283 - French
140 F

# Farming systems, agricultural economics and rural development

### Rubber: a pictorial technical guide for smallholders

This fully-illustrated rubber technology book has been developed for the smallholder rubber farmers in Indonesia. It presents all the activities required for the establishment and maintenance of a rubber plantation. Several chapters illustrates and describes in detail, in simple language, how to perform the task required.

M. Delabarre, D. Benigno - CIRAD, 1994
Ref. 507 - Isbn 2-87614-148-5 - 68 plates - 400 figures - English
240 F


### Les semences d'arachide. Groundnut seed. Las semillas de maní

This special issue of the journal *Oléagineux* is a collection of data intended for anyone needing to know what selected varieties are available, where to obtain them, how to produce the necessary seeds, protect them from pests, store them and check their quality. It contains various articles, technical data sheets for selected varieties widely available in different West African countries, and an analytical bibliography.

CIRAD, 1983
Ref. 157 - Issn 0030-2082 - French/English/Spanish
120 F


### Special bananas

This issue of the journal *Fruits* gives a detailed coverage of research on banana and plantain conducted in recent years at IRFA (Institut de recherches sur les fruits et agrumes) within an international context. A general section is followed by another one comprising updates on specific topics: genetic improvement, crop protection, agronomy and physiology.

CIRAD, 1990
Ref. 237 - Issn 0248-1294 - English
100 F

### Systems-oriented research in agriculture and rural development

The CD-ROM contains the proceedings of the international symposium held in Montpellier, France. It assembles the texts of the papers and posters presented at the symposium, the lectures and speeches of the plenary session, the summaries of the papers and the debate reports for the seven workshops, and the symposium newsletter.

Sc. Ed.: M. Sébillotte - CIRAD, 1997
Ref. 656 - CD-ROM - French/English/Spanish
300 F

### Systems-oriented research in agriculture and rural development

Agriculture can no longer be dissociated from rural development, and rural development from global change. The systems approach has gained wide acceptance. Development-related interdisciplinary research stresses the importance of a dynamic approach and the interaction between farming systems and their natural and socioeconomic environments.

Sc. Ed.: M. Sébillotte - CIRAD, 1996
Ref. 655 - Isbn 2-87614-251-1 - English
200 F

### Techniques for agricultural watershed

The case of southern Saloum, Senegal. A 24-minute video produced by ISRA, CIRAD and ORSTOM, under the auspices of the CORAF-R3S network. The results of this pluridisciplinary research programme are presented and recommendations are made about quantifying water damages and possible developments. Some tools for reflection are given.

P. Perez, M. Sene - CIRAD, 1995
Ref. 527 - Video (Pal) - English

### Spécial vergers tropicaux


*Tropical orchards special*. This issue offers technical and scientific information for research scientists and people involved in the tropical fruit industry with short updates (new cropping strategies, propagation techniques), and detailed summaries (germplasm management, hybridization and selection projects, genetic analyses, identification and control of new parasites and pests). As an introduction, main trends and consumer requirements are considered from an economic perspective.

CIRAD, 1995
Ref. 538 - Issn 0248-1294 - French/English
306 F


### Towards a doubly green revolution

Working with and not against the variability of systems and making agriculture profit from the knowledge acquired by the ecological sciences. The doubly green revolution aims to increase production without depleting the environment nor affecting the biodiversity. With scientists and decision makers from developed and developing countries, the seminar allowed a better understanding of the challenges related to food security and renewable resource management in the world.

Sc. Ed.: M. Griffon - Fondation prospective et innovation-CIRAD, 1997
Ref. 660 - Isbn 2-87614-257-0 - English
100 F

### Sustainable land management in African semi-arid and subhumid regions

Thirty papers bring together experiences of scientists from francophone, anglophone and lusophone countries in Africa. They review the biophysical, economic and social information on sustainable land use in the various parts of Africa. Policy recommandations and research priorities for sustainable land management systems are given.

F. Ganry, B. Campbell - CIRAD-SCOPE-UNEP-Ministère de la coopération, 1995
Ref. 575 - Isbn 2-87614-184-1 - Issn 1264-112X - French/English
250 F

### Transformation alimentaire du manioc

*Cassava processing for food purposes*. In the tropical countries that consume cassava, various constraints and innovations affect the development of technologies, processing methods and the food use of cassava. Bioconversion mechanisms and the effect of each operation on product characteristics and quality are discussed, along with the improvement of traditional processes.

Sc. Ed: T. Agbor Egbe, A. Brauman, D. Griffon, S. Treche - CIRAD-CTA-ORSTOM, 1995
Ref. 620 - Isbn 2-7099-1279-1 - Issn 0767-2896 - French/English
Distributed by ORSTOM Éditions

**International cooperation**
With over 90 countries in Africa, Asia, the Pacific region, Latin America and Europe.

**Researchers posted in 50 countries**
CIRAD's teams work within national organizations or as technical support in development operations.

**Research centres in France**
CIRAD's research centres are located in the greater Paris area, Montpellier, and in the French overseas departments and territories:

- Guadeloupe,
- Martinique,
- French Guiana,
- Réunion,
- Mayotte,
- New Caledonia,
- French Polynesia.

**Staff**
1800 people including 900 senior staff.

**Budget**
1 billion francs.

The French organization specialized in agricultural research for the tropics and subtropics

# CIRAD

has a mandate to contribute to rural development in hot regions through: research, experimentation, training operations in France and abroad, and scientific and technical information. Its operations include agronomic, veterinary, forestry and agrifood research.





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- Agronomy and environmental and natural resources management (AGER)
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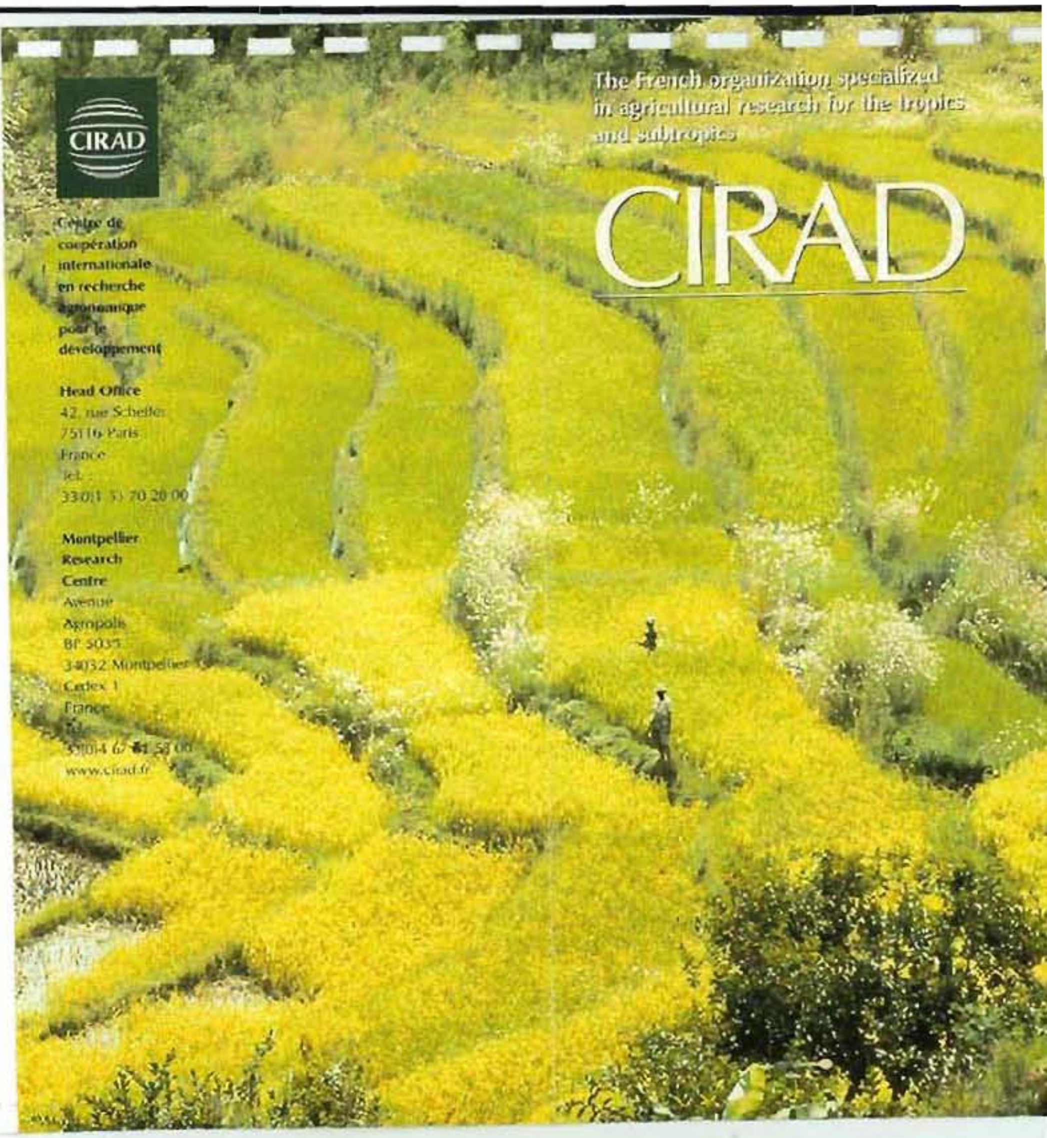
- Agronomy
- Biotechnology and Plant Genetic Resources (Biotrop)
- Economics, Policies and Markets (Ecopol)
- Plant Modelling (Amap)
- Crop Protection



The French organization specialized in agricultural research for the tropics and subtropics

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