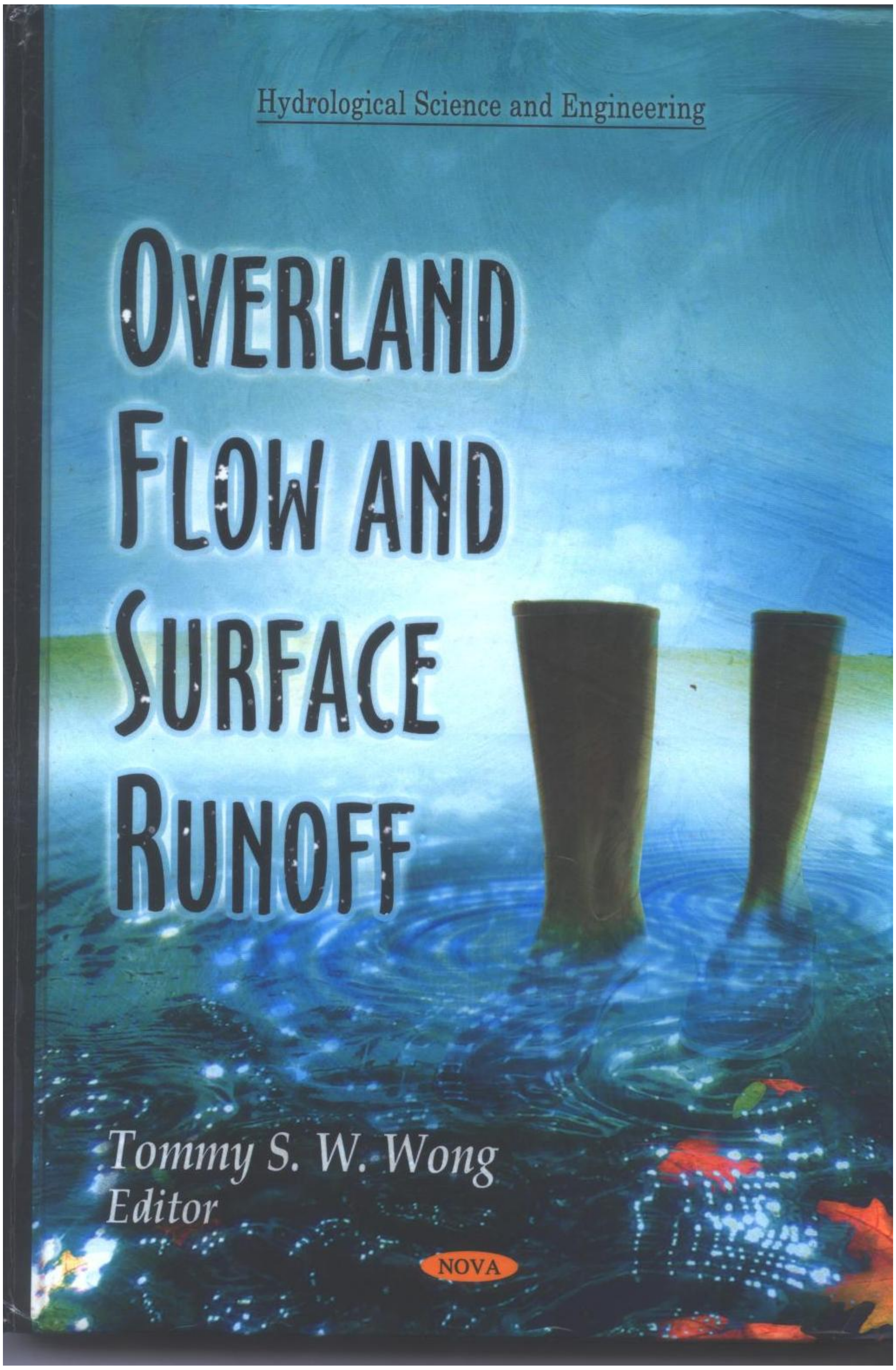

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Chapter 6

EFFICIENCY OF OVERLAND FLOW AND EROSION MITIGATION TECHNIQUES AT RIBEIRA SECA, SANTIAGO ISLAND, CAPE VERDE

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ABSTRACT

Cape Verde, off the coast of Senegal in western Africa, is a volcanic archipelago where soil and water conservation techniques play an important role in the overall subsistence of half a million inhabitants. The steep slopes in the more agricultural islands are a result of their volcanic origin. The country is located in the Sahel, and is characterized by a very irregular wet season, with high intensity rainfall events. The hard conditions led during the first half of the twentieth century to frequent cycles of drought with severe implications for the local populations. Large numbers of deaths occurred due to famine, and there was a decrease in the number of inhabitants by more than halve on some islands.

To retain the soil and soil moisture was therefore a matter of survival, and the Cape Verdeans implemented over the last half century a number of soil and water conservation techniques that affect the whole landscape. In this chapter, we report the monitoring of a number of slope soil and water conservation techniques, such as terraces, "half moons", live barriers, etc., together with two agricultural management strategies, involving the planting of corn and beans on the one hand, and peanuts on the other, with a semi-quantitative methodology, to evaluate their effectiveness. A discussion is given on the

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costs and effectiveness of the techniques to reduce overland flow production and therefore erosion, and to promote rainfall infiltration.

Several variables were measured along 25 metres transects: soil resistance to penetration, percentage or rock outcrops, percentage of organic matter cover, percentage of vegetation cover, and two indexes derived from the observation of erosion and accumulation features.

Results show the efficiency of the various soil conservation measures, despite the intensive use and the harsh soil mobilization techniques used to plant beans, maize and peanuts at steep slopes. Soil and water conservation techniques play an important role in the sustainability of local communities' livelihoods in fragile environments such as those in rural Cape Verde.

INTRODUCTION

World-wide over 1 billion souls are chronically hungry due to extreme poverty, while up to 2 billion lack food security intermittently due to varying degrees of poverty (FAO, 2009). The situation is particularly worrying in dry arid and semi-arid climates, as a result of global change (i.e. climatic, technological and demographic). These changes imply alterations in the socio-economic structure, on water and land use and on management practices.

Aridity and the associated vagaries of climate variability have often constrained the development of human societies; they may even have fostered major technological advances such as agriculture, the invention of irrigation systems, or settlements. Entire civilizations have disappeared in the past for not being able to cope with externally driven climate changes, or because the land management they practised was unsustainable in the environments in which they occurred. The challenge we face has a scale that has not been witnessed in historical times (Hughes and Diaz 2008, Verstraete *et al.* 2008). The dependency of modern societies from a continuous massive amount of water resources can only be paired with the demand for fossil fuels.

Climate change and desertification will have a major impact on the poorest and therefore most vulnerable part of the global population (Liu *et al.* 2008). Due to the little amount of water available, drylands are highly vulnerable to climate change and other processes such as population growth. The livelihood security of small holders in these regions is still intimately linked with the local agro-ecological productivity, largely constrained by water availability (Enfors and Gordon 2008).

The future of a billion people in drylands whose livelihoods (and often lives) depend on natural resources is at risk from desertification exacerbated by climate change (Verstraete *et al.* 2008). In addition, the increasing crushing pressure in areas where fast global changes are occurring, lead to a sharp degradation of the livelihoods and to overspread poverty and underdevelopment. Bad management and excessive pressure over scarce resources further deteriorates the life of those living in African regions (e.g. Mbow *et al.* 2008). An integrated approach to the problem, combining social and biophysical viewpoints, and links local knowledge with the scientific endeavour are vital if the world is not to fail these people (Verstraete *et al.* 2008).

Human-induced soil degradation worldwide has affected 1966 million hectares or 15% of the total land area. The "Global assessment of soil degradation" (GLASOD) project estimates that 65% of the African agricultural land, 31% of permanent pasture land, and 19% of forest and woodland has already been degraded (Sivakumar and Wills 1995).

Developing countries are experiencing a sharp population growth, which increases the difficulty of a sustainable resources management. In the past, at low population pressure farmers shifted from a cultivated site to an uncultivated one before significant decline in crop yield could set in, thus leaving the fields to replenish soil fertility under natural regrowth. However, with rapid population growth, fallow periods have shortened (Bationo *et al.* 1998). The past decades have shown high population increases, the breakdown of traditional shifting cultivation systems, and a rapid decline of land productivity and soil fertility in particular Bationo *et al.* 1998.

Demographic growth often results in severe environmental and social problems, including the lack of adequate water supply and food security (Langergraber and Muellegger 2005). Unless there is some technological breakthrough, it is doubtful that even current economies and living standards (or even populations) of some of the African regions can be maintained (Loucks and Gladwell 1999).

The main causative factors of human induced soil degradation are deforestation, overgrazing, agricultural activities, overexploitation of the vegetation for domestic use, and (bio)industrial activities (Sivakumar and Wills, 1995).

Many west African farmers are food-insecured. Poverty, environmental degradation, and low agricultural productivity are interlinked and have increased the food gap (Bationo *et al.* 1998). Areas of soil degradation are extensive in sub-Saharan Africa in the regions bordering the Sahara and Kalahari deserts (Bationo *et al.* 1998).

According to Williams and Balling (1994), 332 million hectares of African drylands are subjected to soil degradation, which represents one third of the entire area of dryland soil degradation in the world (Bationo *et al.* 1998).

Drylands, defined as areas with low and irregular precipitation, cover 41% of the Earth's terrestrial surface, of which 10–20% of this land type are already degraded due to overuse (Millennium Ecosystem Assessment 2005). The two billion of the world's inhabitants of drylands have the lowest incomes and highest infant mortality of all global population groups.

The arid and semi-arid zones of sub-Saharan Africa cover about 41% of the area and are characterized by low, erratic rainfall (300–600 mm per annum), and infertile deplenished soils (Sanchez 2002). In the semi-arid zone of sub-Saharan Africa, especially the rural savannah zone, poverty and food insecurity are interlinked and widespread and are strongly linked to the natural resource endowment (water, soils and vegetation).

Land and water degradation, overgrazing, and slash and burn agricultural production practices have led to significant environmental degradation and food shortages. The capacity of most African countries to manage climate change is limited, due to widespread poverty, recurring droughts, inequitable land distribution, the dependence on rain-fed agriculture and other factors which are described in the IPCC 2001 (McCarthy *et al.* 2001).

The combination of high exposure and low adaptive capacity makes Africa's ecosystems vulnerable to loss of ecosystem functions and services such as biomass production. In comparison to all other regions of the world, the agricultural productivity per unit of water (''crop per drop'') in the semi-arid zones is the lowest worldwide (Rockström *et al.* 2004). The increasing vulnerability of societies and ecosystems leads to a downward spiral of ecological and social degradation and consequently to an increase in disasters.

Adding to the vagaries of demographic growth and socio-economic degradation, the IPCC confirmed that most published climate change scenarios indicate temperature increases for most of Africa, while expected rainfall trends vary (Christensen *et al.* 2007). There is a general consensus that climatic variability will increase, leading to an increase in droughts and floods and to growing uncertainty about the onset of the rainy season. Climate change thus affects the hydrological cycle, water resources, agriculture and ecosystem performance and services. This resource degradation enhances proneness to conflicts, and makes Africa even more vulnerable (Nyong 2005).

A simulation of cropping boundaries for the year 2050 implies that large areas at the margins of current arable lands will no longer be suitable for cropping (Thornton *et al.* 2002). Since about 65% of sub-Saharan Africa's population live in rural areas and depend mostly on rain-fed agriculture (World Bank 2000), to improve food security and livelihoods becomes a matter of utmost importance and urgency. The current level of dependency on irrigated land is very low (less than 2% of the cultivable land), therefore rain-fed agriculture increasingly plays central role in sustaining rural livelihoods and meeting food requirements. The challenge in this region is to optimize crop production per drop of rain, i.e. increase green water.

The extent to which water resources development contributes to economic productivity and social well-being is seldom appreciated, although all social and economic activities rely heavily on the supply and quality of freshwater. As populations and economic activities grow, many countries are rapidly reaching conditions of water scarcity or facing limits to economic development. African regions face major challenges to meet the Millennium Development Goals on eradicating poverty and hunger. It is estimated that 45–50% of the population live in extreme poverty and the level of malnutrition is high (Enfors and Gordon 2008).

Under the actual circumstances of population growth, water resources available per inhabitant will decrease sharply, in some cases more than 50% by 2025, even without climatic change (FAO 2003). An even more striking problem which will worsen in the near future is that water will become gradually less available to ensure the population's daily needs (Greenland and Nye 1959).

As groundwater levels in many areas are falling, rivers dry up and climate patterns change, water is being recognised more widely as a valuable natural resource (Correia *et al.* 2005). Unless there is some technological breakthrough, it is doubtful that even current economies and living standards (or even populations) of some of the regions can be maintained (Greenland and Nye 1959).

Soil degradation and productivity loss is a biophysical process (soil, climate and vegetation) driven by socio-economic and political factors. The main biophysical processes involved, accelerated soil erosion and salinization, reduce soil quality and rooting depth, decrease vegetal cover, reduce biomass productivity, and accentuate vagaries of climate especially low and variable rainfall (Lal 2001).

The low, insufficient and irregular rainfall is a major challenge to profitable farming in dry areas (Inanaga *et al.* 2005). As rainfall amounts and distribution in this zone are usually suboptimal, moisture stress periods often occur during one or more stages of crop growth causing very low crop yields (Oweis and Hachum 2006).

Adding to climate variability, various types of State interventions in agriculture and global market fluctuations appear to have been the main underlying causes of environmental degradation (Mbow et al. 2008).

The Traditional Soil and Water Conservation Techniques

Semi-arid areas in Africa face climatic variability at different temporal scales. High natural inter-annual climatic variability is expressed as droughts and floods; a high seasonal variability leads to dry spells (Usman and Reason 2004). Farmers in dryland areas developed strategies, to cope with this uncertain and erratic rainfall patterns (Ngigi 2003).

In dryland ecosystems water is the major limiting factor in agricultural production systems, and the performance of landscape functions relies heavily on the availability of water.

In the Sahelian zones of west Africa prominent indigenous soil and water conservation techniques include stone bunds on slopes, contour stone bunds, stone terraces, stone lines, earth bunds, and planting pits (Savonnet 1976, Roose 1990), and permeable rock dams. Roose (1989) reviewed the results of 30 years of research at ORSTOM and CIRAD on soil and water conservation, and concluded that the major factors in curbing erosion are vegetation cover, cultural practices and slope management.

A vast variety of traditional as well as innovative in situ soil and water conservation practices exist, (eg. Critchley and Mutunga 2003, Ngigi 2003, IWMI 2005). Typical in situ soil and water conservation practices structures are linear structures (e.g. embankment of stone or earth as contour bunds, and/or grass strips) which are sometimes sophisticated, such as the Tera system in Sudan (van Dijk and Ahmed 1993) and terracing as practiced in East Africa. Semi-circular bunds are common in the semi-arid zones of Western Africa, such as half moons or Demi lunes (Barry and Sonou 2003). Pitting cultivation also takes place in the form of Zai in Burkina Faso (Kassogue *et al.* 1996, Ouedraogo and Kaboré 1996, Fatondji *et al.* 2001; Kabore and Reij 2004), Tassa in Niger (Hassan 1996), or the Chololo pits and Ngoro pits of the Matengo people in East Africa (Mutunga and Critchley 2001, Kato 2001, Mati and Lange 2003, Malley *et al.* 2004). The different systems differ mainly in the size of the pits. In general, biomass production is improved by applying mulch in the pit before planting. Other approaches, such as conservation tillage, improve infiltration ability on the field scale (Stroosnijder 2003).

In the context of agricultural production in African drylands, soil and water conservation practices such as rainwater harvesting provide an opportunity to stabilize agricultural landscapes in semiarid regions and to make them more productive and more resilient towards climate change (Wallace 2000, Lal 2001). Stabilization of the agricultural landscape includes the restoration of degraded cultivated and/or natural grazing lands. There are many marginal water sources that could be used more efficiently such as road and land runoffs that are normally lost through erosion processes (Prinz and Malik 2002).

Rainwater is collected from fields, house roofs and streets, and can be stored in underground tanks or open ponds. In situ Rain Water Harvest practices mainly help to overcome dry spells, as the soil, which is the main storage site of in situ Rain Water Harvest practices, serves only some days to weeks as a storage system (Falkenmark *et al.* 2001). By manipulating the soil surface structure and vegetation cover and density, evaporation from the soil surface and surface runoff can be potentially reduced, infiltration is enhanced and thereby the availability of water in the root zone increased. In situ Rain Water Harvest practices need low technical efforts compared to larger scale water harvesting schemes but show only comparatively short-term effects on soil water availability compared to temporally (storage) or spatially (spate irrigation) extended systems (Falkenmark *et al.* 2001).

The introduction of soil and water conservation techniques modifies landscape functions at different spatial scales. In what concerns hydrological functions, infiltration structures modify water flows in the landscape mainly by enhancing water infiltration at plot scale (Wakindiki and Ben-Hur 2004).The velocity of runoff is reduced, and the water is collected behind the structures. Soil moisture was found to increase significantly below semi-circular bunds in Burkina Faso (Zougmoré *et al.* 2003) and in run-on basins in South Africa (van Rensburg *et al.* 2004). The greater number of soil macropores enhances infiltration due to increased biological activity at vegetation strips, as shown for Australian drylands (Ludwig *et al.* 2005). Few direct field measurements were made on the impact of soil and water conservation techniques on groundwater recharge. Nevertheless, when inquired about it, local populations tend to indicate that those techniques enhance water availability (e.g. Mutekwa and Kusangaya 2006).

Soil and water conservation techniques not only trap surface water but also reduce runoff. Aquatic and wetland ecosystems downstream of the structures might not receive enough surface runoff to maintain and sustain their functionality.

Irrigation is often considered the best way of making farmers less dependent on erratic rainfall. However, this policy had limited success because of the build-up of salt in irrigated soils, a problem which does not usually occur in runoff farming because of the better quality of runoff water from very small catchments (FAO 2003). Another solution, specially in areas not suitable for irrigation, is to invest in soil and water conservation measures at slope scale to improve overland flow infiltration and therefore increase the amount of green water. Depending on slope, rainfall, and farming practices, as well as on the quality of design and maintenance, soil erosion is reduced under soil and water conservation structures (Herweg and Ludi 1999, Schiettecatte *et al.* 2005). These structures act as sediment traps, and therefore can enhance nutrient availability at the structures, as was shown for traditional Zai in Niger (Fatondji 2002).

Soil and water conservation techniques enhance biomass production per unit area. They can completely change the character of an arid landscape as reported in the ''Savannization'' project in the northern Negev, where trees have been planted in a largely tree-less semi-arid landscape (Warren 1995). The relationship between soil and water conservation practices and landscape heterogeneity refers to the number of plant patches, the spatial and temporal structure of the patches as well as their composition:

Sustainable Livelihoods

Increased and sustained crop yields are vital for food security in rural communities. Several studies have shown that in many cases, crop yields are higher when soil and water conservation practices are applied (e.g. Jones and Tengberg 2000). Soil and water conservation structures such as tera (van Dijk and Ahmed 1993) mainly serve to reduce crop failure during dry spells and droughts and thus help to enhance food security. Valuable mechanisms in this context are a prolonged vegetation period caused by early planting as well as an improved ability of crops to survive dry spells (Falkenmark *et al.* 2001). Increased efficiency of rainwater use can be reached by supplementary irrigation (Rockström *et al.* 2002, 2004). Enhanced infiltration favours groundwater recharge and refilling of wells. Nevertheless, due to reduced downstream runoff, conflicts might arise between neighbours competing for available water resources. In densely populated areas of Kenya, such communal conflicts have been minimized through the adoption of a sophisticated technique of collecting street runoff and distributing the rainwater (Mutunga and Critchley 2001, Ngigi 2003). Under erratic rainfall conditions in the semi-arid zone of sub-Saharan Africa, a major contribution to improving crop production can be anticipated from improved and up-scaled Soil and Water conservation practices. Fostering and improving these technologies in a sustainable way, while taking biodiversity aspects into account, offers a means of minimizing the risk of drought, crop failure and ecological refugees. The social and economic sustainability of soil and water conservation practices depend largely on the extent of involvement by farmers and the communities in general. The more local communities are involved in planning, the higher the possibility that structures will be maintained and benefits are shared (Bangoura 2002). Resilience is the ability to buffer sudden and large external impacts in that the major functions of landscapes as described above are maintained by socio-economic as well as ecological adaptability (Folke *et al.* 2004). Soil and water conservation practices used to restore degraded areas improve resilience in enhancing socio-economic as well as ecological adaptability. This is achieved by improving productivity (Lal 2001, 2004, Rockström *et al.* 2004).Socio-economic adaptability may be improved by increased food security, extra income and consequently enhanced and sustainable livelihoods. However, this certainly is not enough to enable achievement of the Millennium Development Goals (MDGs) although it may reduce pressure on land and natural resources. Humans therefore are not only a cause of degradation but can be the driving force for restoration processes due to their efforts. The way land degradation issues are managed and sustainable development pathways are defined is governed by the institutional context in which certain policies are made and implemented (Verstraete *et al.* 2008). The policies and investment strategies chosen to increase agricultural production will affect water use, the environment and the extent and depth of rural poverty (Fraiture and Wichelns 2009). Without improvements in land and water productivity or major shifts in production patterns, the amount of crop water consumption in 2050 must increase by 70–90%, depending on actual growth in population and income (Fraiture and Wichelns 2009). Producing enough food to meet future needs will require water development and management strategies that promote improvements in food security while maintaining the productivity of our land and water resources and enhancing environmental amenities (Molden 2007). To this end, it is necessary, specially in steep slopes of arid and semi-arid environments, to maintain the soils in place and the water within the soils, therefore increasing green water amount and therefore crop productivity. Central to this problem is the capture of all the overland flow following the heavy intensity rainfall events that take place in the tropics. This paper presents some of the techniques used at Cape Verde slopes and discusses, based on semi-quantitative surveys, their efficiency.

CAPE VERDE

The Cape Verde archipelago, off the African West coast, off shore from the promontory from which it took his name, is located in a wide zone characterized by arid and semi-arid climates that crosses Africa from the Atlantic to the red sea (Amaral 1964)

Cape Verde is an island state comprising 10 islands (Santo Antão, São Vicente, Santa Luzia – uninhabited – São Nicolau, Sal, Boavista, Maio, Santiago, Fogo and Brava) and 13 islets, about 450 km off the West African coast, near Senegal. The islands are of volcanic origin, relatively small in size, geographically dispersed and are located in a zone of high meteorological aridity. Three of the inhabited islands are relatively flat, while the remaining islands are very mountainous. Together, the islands occupy a total of 4.033 km^2 in surface.

Like other sahelian countries, Cape Verde suffers the catastrophic effects of drought, only in a more aggravated manner. This climate is characterized by extremely insufficient and irregular rainfall, combined with the small amount of land available and high propensity to soil erosion, is the main cause of the structural weakness of the agriculture sector.

Rains in Cape Verde are, essentially, a result of the annual movement of the Intertropical Front that originates a wet season from July to October. The rainfalls are concentrated during the months of August and September, at which time between 60% and 80% of the annual amount of rainfall is discharged.

Rainfalls vary greatly from one year to another, not only in what concerns their distribution in time and space but also in what concerns their global annual amounts. Precipitations fall frequently under the form of intense rainfall, and often, in certain localities, the total annual precipitation is produced in two or three isolated events. There is a significant increase in rainfall with the altitude and a marking difference between the wet slopes, exposed to the NE trade winds, and those much drier, located windward.

Considering the annual average rainfall values (P), as an index of climate classification, the following types of climate would correspond to each one of the islands:

- Sal and Boa Vista: extremely arid ($P<100$ mm)
- São Vicente, São Nicolau and Maio: arid ($100 < P < 200$mm)
- Santo Antão, Fogo, Santiago, Brava: semiarid ($200< P<500$mm)

The main characteristic of the archipelago is the extreme irregularity of precipitations. Frequent droughts and crises (i.e. famines) were registered and are recurrent in the history of the people republic of CapeVerde (Amaral 1964, Carreira 1977, Silva 1995). The resulting effects of XX century droughts were felt in a particular way, taking into account the strong demographic pressure over the scarce natural resources, and the total toll of deaths due to famine. The succession of long dry periods, alternating with brief wetter periods is a characteristic of the Cape Verde climate.

The annual rainfall has been gradually decreasing since the 1960s, causing negative impacts on agricultural production levels and water supply. About 13% of rainfall infiltrates in the soil recharging groundwater. Twenty percent is lost through superficial runoff and the rest through evaporation.

Cape Verde history is full of dramatic events of scarcity and famines responsible for the death of thousands of persons. From the XVI to the XIX centuries, the islands administrations register at least 27 famines and epidemics. In the first half of the XX century, seven famines occurred (Table 1). Despite the close relation between the famines and the occurrence of dry years, other factors contributed to the high number of deaths, which in the 1947-1948 famine killed one in five inhabitant in Cape Verde. In the decade of 1940s alone, the famines were responsible for the death of almost half of the population of Cape Verde.

Table 1. Famines and number of deaths during the XX century (Lesourd 1995)

Year	Deaths due to famine
1903-1904	16118
1911-1915	?
1916-1918	?
1921-1922	17595
1923-1924	?
1941-1943	24463
1947-1948	20813

Amaral (1964) refers that in the Santiago Island alone, the population decreased by 65% in the 1947-1948 crisis. The chronic mal-nutrition induced the occurrence of epidemics and death, and anthropophagic cases occurred under famine crisis.

Famines were enhanced by: (i) The little attention to the problem given by the colonial authorities and the colonial production structure. (ii) The disastrous management of the environment, as a result of an excessive and uncontrolled exploitation, mainly by goats that increased soil erosion in the steep slopes.

The problems with the nourishment decreased sharply after the 1950s. Following the last big famine (1947-1948), the colonial authorities took several measures to mitigate the famine problems in the archipelago. These included the construction of terraces and dams to reduce the erosion risk and to conserve soil and water, and the forced emigration to other colonies. Those measures allowed the mitigation of famine during dry years (1958-1959, 1969-1970, 1971-1974). The famine disappeared from Cape Verde.

Tackling Adversity

At the time of its independence in 1975, the Archipelago of Cape Verde was considered one of the poorest in the world (Lesourd 1995). Despite the rather modest start, Cape Verde holds now the position 106 (out of 177 countries) in the Human Development Index (Human Development Report 2006), being in 88th place in what concerns life expectance at birth and 91st place on GDP per capita. It shows a vigorous constant increase in all the indices by comparison with the other Sub-Saharan Countries.

After independence, policies were implemented to supply food to the populations in distress, with a food programme adapted to the needs. This included a massive investment in soil and water conservation techniques that completely changed the landscape, and were to a large extent implemented during crisis periods.

During these periods, in order to help the population, widespread working brigades were created, and paid the necessary for survival. The "Frentes de Alta Intensidade de Mão-de-Obra" (High Intensity Manpower Fronts) (FAIMO) brigades paid a meagre salary in exchange for the construction of common infrastructures, including soil and water conservation works. This meagre payment allowed them to survive during dry spells and completely changed the landscape, now a hymn to soil and water conservation.

Nevertheless, these programs were unable to take numerous families from endemic poverty. These, with very low incomes, can barely provide for their food. The families leaded by women are the more vulnerable (Lesourd 1995).

Soil and Water Conservation Strategies, Techniques and Practices

Alike any other Sahel country, Cape Verde has been much affected by desertification phenomena, although extreme efforts are being made to contradict the process. Water resources are a fundamental factor of a successful goal achievement in the practice of watershed management.

Unfortunately it has been noted that the water supply has decreased steadily as a result of various processes, namely, changes in vegetation cover, climate, increase of population pressure and unsuitable technological advances.

Specifically in case of Cape Verde, recurring and sporadic rainfall, poorly distributed in space and time, combined with appointed adverse factors, play a role of prominence for the aggravation of the desertification process, which culminates with additional inappropriate human´s interventions direction (road constructions, poor agriculture practices, etc).

To face the overwhelming problems of desertification, a strategy was adopted under the National Program to combat the desertification, together with the Poverty Alleviation Program to promote Soil and Water Conservation Actions.

The main aim is to maintain the soil in place and the water within the soil. To this end, several techniques were ubiquitously implemented throughout the landscape, providing barriers made of stones and/or vegetation, or providing overland flow traps such as the half moons used to improve the conditions to plant trees.

The barriers consisting in construction of contour stone walls and contour furrows (ridges), and terraces, vegetated with drought tolerant species, such as Aloe vera, Leucaena leucocephala, Furcraea gigantean, Jatropha curcas, Prosopis juliflora, etc. In this study we do not include the check dams, a strategic tool for watershed management, an important touchstone of the Cape Verde soil and water conservation strategy,

Soil and Water Conservation Techniques at Slope:

The most common structures of this nature built in Cape Verde are:

i) Terraces, and contour stone walls on slopes higher than 20% for fruit tree plantations, fodder and forestry species;
ii) Contour stone walls and contour furrows (ridges) to increase water infiltration on the slopes, reduce superficial runoff and the erosion;
iii) In addition, Cape Verde is one of the countries in the world with higher per capita investments in afforestation, because it is seen as an important soil and water conservation strategy.

Figure 1. Construction of Contour Ridges for planting – Santiago Island.

Contour Stone Wall

Contour stone wall is a soil stabilizing mechanical structure built along the contour, using medium and small sizes rock, found on site. The spacing between the contours depends on the topography of the treated land, and normally it is spaced between 8 to 15 metres. The main advantage is to it stabilize the slopes, slowing runoff, promotes the infiltration capacity, and traps sediments. The technique is well suited for small scale application on farmer's rainfed fields. The water and sediment harvested improve the yield. Implementation is fast, cheap and easy. It makes it possible for woman to carry out the work, since the sizes of the rocks are easy to handle. Unavailability of local stone increases the contruction time, and price. In some cases the contour stone walls can be associated with vegetation strips.

Contour Furrows (Ridges)

The construction consists of parallel ridges (made of earth) on the contour lines spacing of between 1 and 2 metres. The soil is excavated and placed downslope to form a ridge, and collects runoff (on the furrows) from the catchment between ridges. A diversion ditch may be necessary to protect the system against runoff from outside. The technique is very effective, for rainfed cropping in semi-arid areas where the soil is fertile and easy to work. It is also very effective in upslope locations, where the cultivation of some fruit trees is acceptable. The implementation is fast, cheap and easy. It cannot be used for slopes with slope angles equal or higher to 50%. It may require new technique of land preparation and planting, which will rise an acceptance problem.

Figure 2. Slope treated with contour ridges combined with Furcraea gigantean (locally named "Carapati") – S. Jorge, Ribeira Seca.

Terraces

Terraces are earth embankment, or a combination ridge and channel, constructed across the field slope that intercepts, detains and safely conveys runoff to an outlet. Terraces are most effective when used in a planned conservation system that includes a combination of practices such as conservation tillage, crop rotations, contour farming and field borders. They represent an effective on erosion reduction and sediment transport, and require little maintenance, when properly built. Terraces are relatively expensive to build, and require qualified technicians.

Figure 3. Slope treated with Contour Stone Walls combined with Leucaena leucocephala (locally named "Linhacho") – Achada Costa, Ribeira Seca.

Afforestation

Afforestation is a priority in Cape Verde as a soil and water conservation strategy. It is often associated with other techniques, "namely half moons" or contour furrows and ridges. It is a largely a "government initiative", for which local people are paid for, either during normal periods or under drought episodes, under the FAIMO programmes. Works are planned and supervised by qualified technicians. Forests are mainly planted with soil and water conservation purposes, and are often found at the tops of slopes in very steep locations.

Figure 4. Slope treated with Contour Stone Walls combined with *Aloe vera* (locally named "Babosa") – Achada Costa, Ribeira Seca.

Methodology

To assess the effectiveness of the soil and water conservation techniques at slope level, 25 meters transects were performed, downslope at the various soil and water conservation techniques.

At each metre, 5 measurements of soil compaction were made with a pocket penetrometer, the percentages of litter and vegetation were measured, along with the percentage cover of rock outcrops and stones. A 0 to 5 scale was developed for erosion and accumulation, gathering the length and severity of these two phenomena, with 0 meaning no evidence, and 5 a massive developed gully or accumulation, covering more than 70% of the space.

Figure 5. Slope treated with contour stone walls combined with agro-forest species– Achada Costa, Ribeira Seca.

Figure 6. Terraces built on slope, planted with rainfed crops (corn and beans) - S. Jorge, Ribeira Seca.

RESULTS

Soil Resistance to Penetration

Soil resistance to penetration is on average lower than 1 kg.cm^{-2}, with the exception of soils in undisturbed forest areas (Figure 7). Several other land uses show high average resistances to penetration, namely terraces and undisturbed soils under forest or fallow.

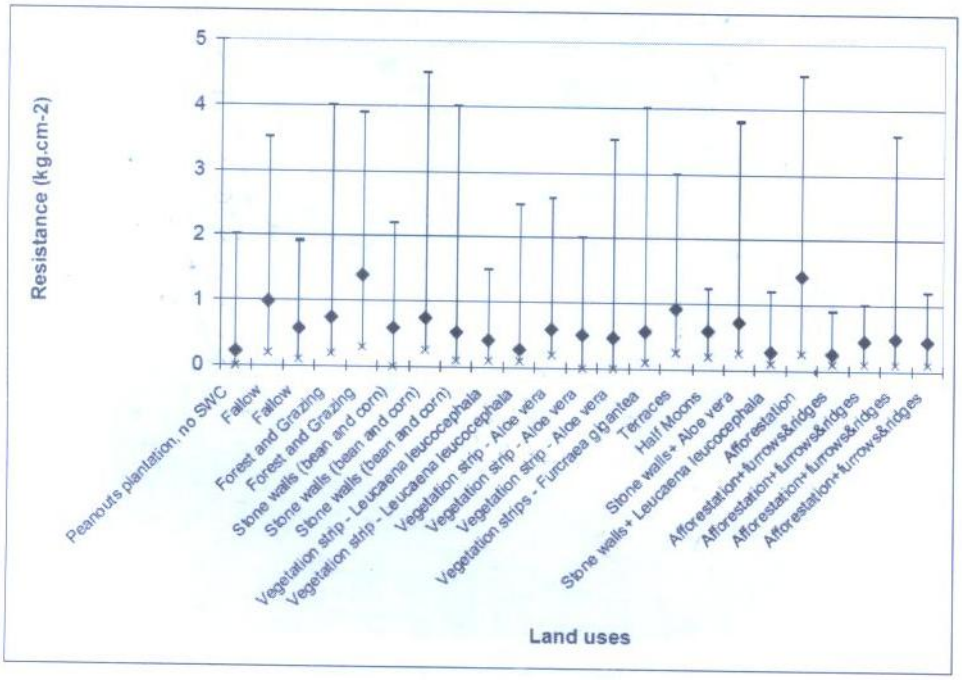

Figure 7. Soil resistance to penetration for different land uses and soil and water conservation techniques.

The lowest values of soil resistance to penetration can be found in newly disturbed areas for agriculture or afforestation, such as those areas where recent afforestation was performed and there are still furrows and ridges with little or no consolidation.

If included within a soil and water conservation technique, most of the sediment and water will flow from the base of one barrier to the slope rupture created by the subsequent barrier a few metres downslope.

Rock Outcrops and Stones

The availability of rock outcrops and stones (Figure 8) is to a large extent dependent on the parent material. In areas with large amounts of stones the percentage cover is quite high, especially if the slopes are steep and soil and water conservation measures poorly implemented (with insipient contour stone walls).

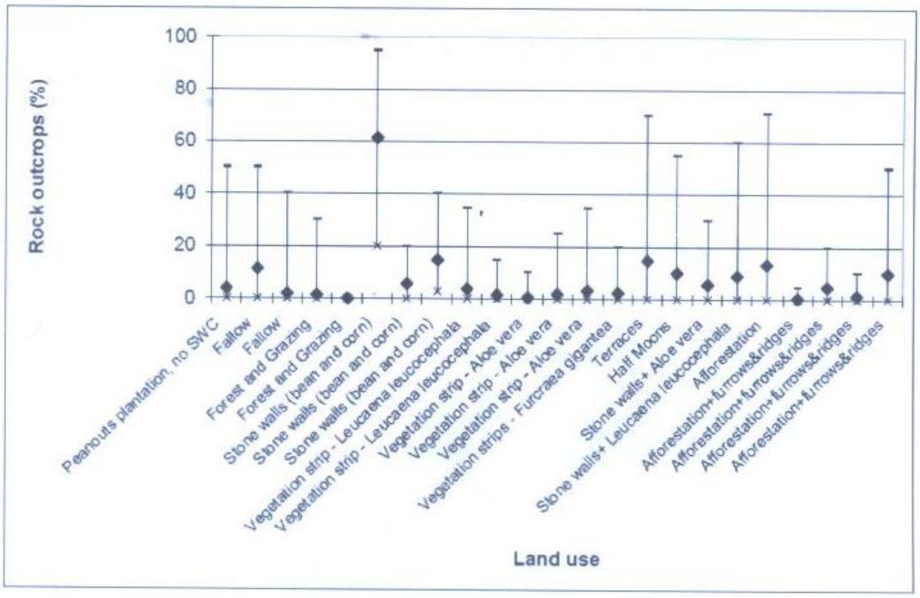

Figure 8. Rock outcrops and stone cover for different land uses and soil and water conservation techniques.

Terraces and half moons, where stones cover a significant percentage of the surface, also show values above 10%, on average. All the other techniques produce less than 10% stone cover, mainly because stones are absent from in the soil or parent material.

This explains why in some places farmers choose to implement vegetation contour barriers, because stones are not available.

These present the lowest stone cover, in some cases the maximum content do not exceed 10%. Where available, contour stone walls are often reinforced with one of the species used to form live contour barriers.

Organic Matter Cover

The amount of litter cover in the soils varies widely, although in the majority of the cases the averages are lower than 40%. Nevertheless, for a significant number of soil and water conservation techniques, the maximum organic cover exceeds 80%, while in almost all cases, the minimum value is zero, or close to zero (Figure 9).

The broad distribution within each land use reveals a tendency to patchiness, with some areas of bare soil while others may have patches of litter layer covering almost the entire measurement area.

The patchiness can play an important role in overland flow generation and on erosion yields, since it reduces the continuity of hydrological and erosion processes downslope, thereby reducing soil and water loss.

The higher values are found in the undisturbed forests, whose plantations were established a few decades ago. The smallest values are found in the soils frequently disturbed by agricultural practices, typically in the areas with soil and water conservation measures.

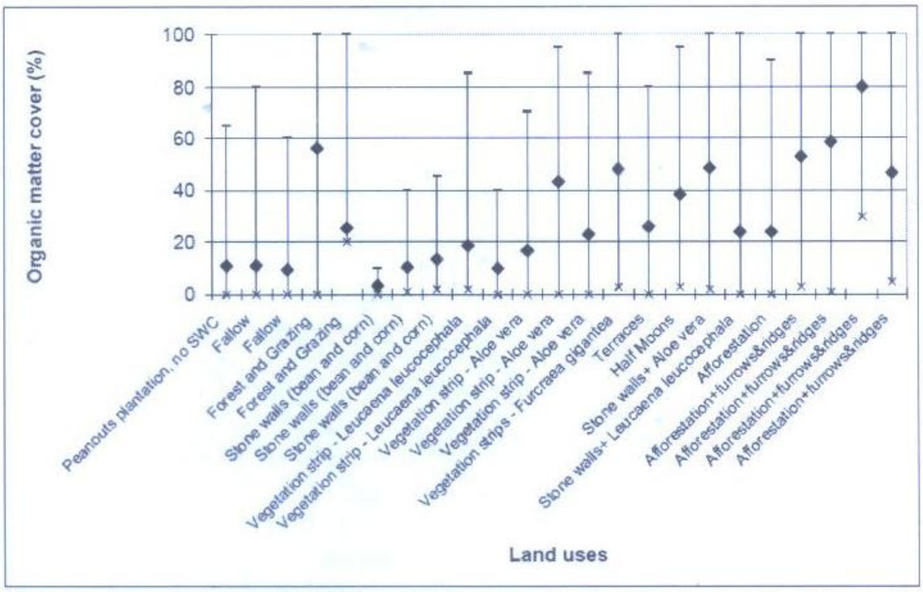

Figure 9. Organic matter cover for different land uses and soil and water conservation techniques.

Vegetation Cover

In addition to the litter layer, the percentage of soil covered by grasses and bushes was also monitored. In some cases the values were higher than for the litter cover, namely for those areas where vegetation was not removed from the soil due to agricultural practices, either because the crops were still in place or because the soil and water conservation measure were implemented in non agriculture land (i.e. forest and grazing areas) (Figure 10).

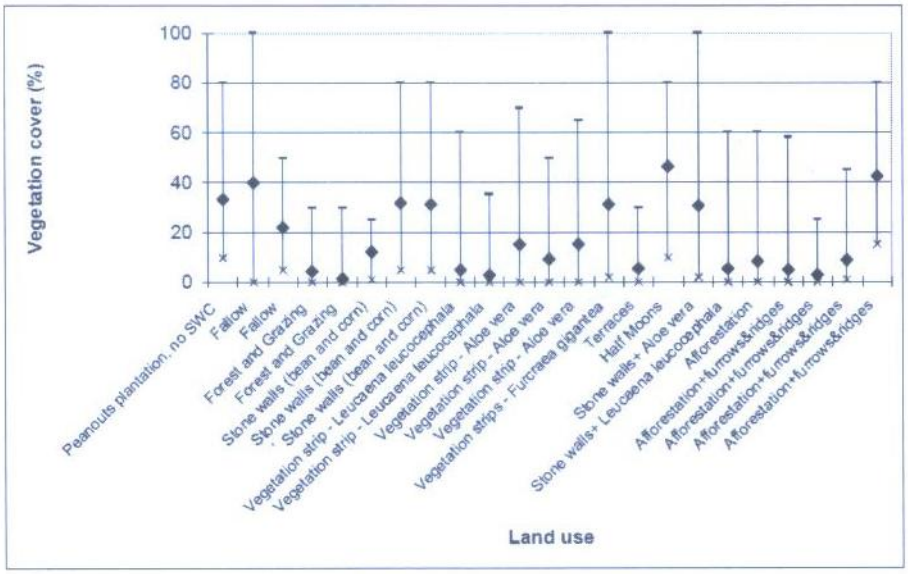

Figure 10. Vegetation cover for different land uses and soil and water conservation techniques.

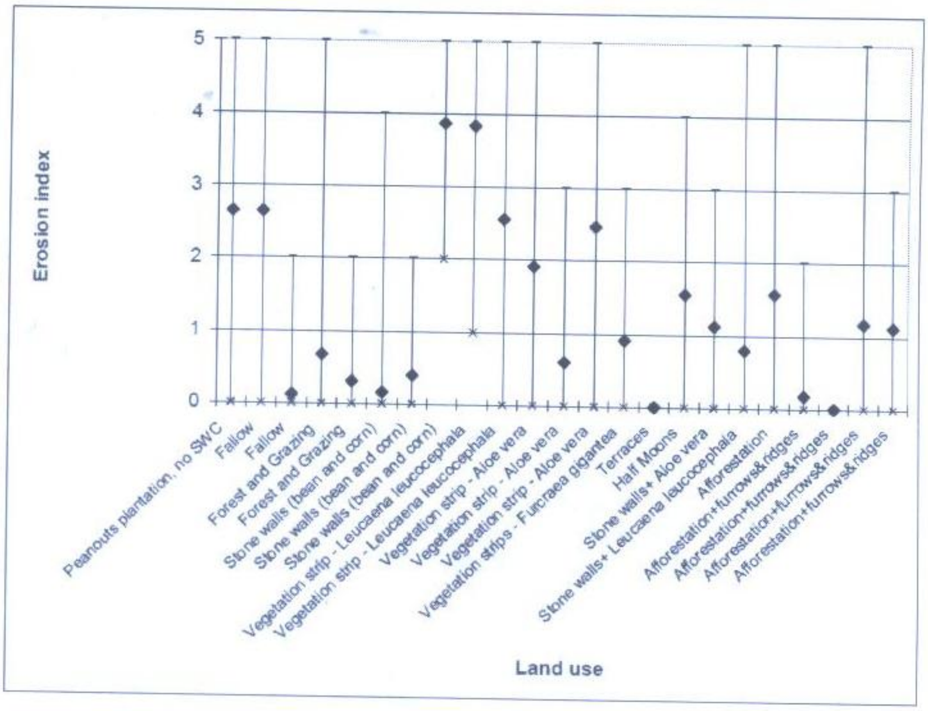

Figure 11. Erosion features index for different land uses and soil and water conservation techniques.

The soil and water conservation techniques that use vegetation (i.e. contour vegetation strips) present higher values than those with stone barriers. Some of the forest plots present the highest vegetation covers, probably due to the protective environment trees provide to the understorey vegetation (shade).

Erosion Index

Erosion features present a more scattered pattern (Figure 11). Some of the land uses present typically lower vestiges of erosion features, namely forested areas and the terraces. The soil and water conservation measure have distinct and sometimes contradictory values. This has to do with several factors, namely the slope angle, the conservation status of soil and water conservation techniques in place. The lowest concentration of erosion features is found in the terraces and in the newly planted forest, with furrows and ridges still undisturbed.

Accumulation Index

The accumulation features index is partly dependent on the erosion feature index, in the sense that if the erosion values are high and the accumulation values are equally higher, this probably means that the erosion processes are of short cycle. This would mean that sediments eroded upslope would be immediately deposited in the first slope angle rupture downslope, and therefore erosion is not very important at slope scale. This is the case of the vegetation strips made with *Leucaena leucocephala*, or with *Furcrea gigantean*.

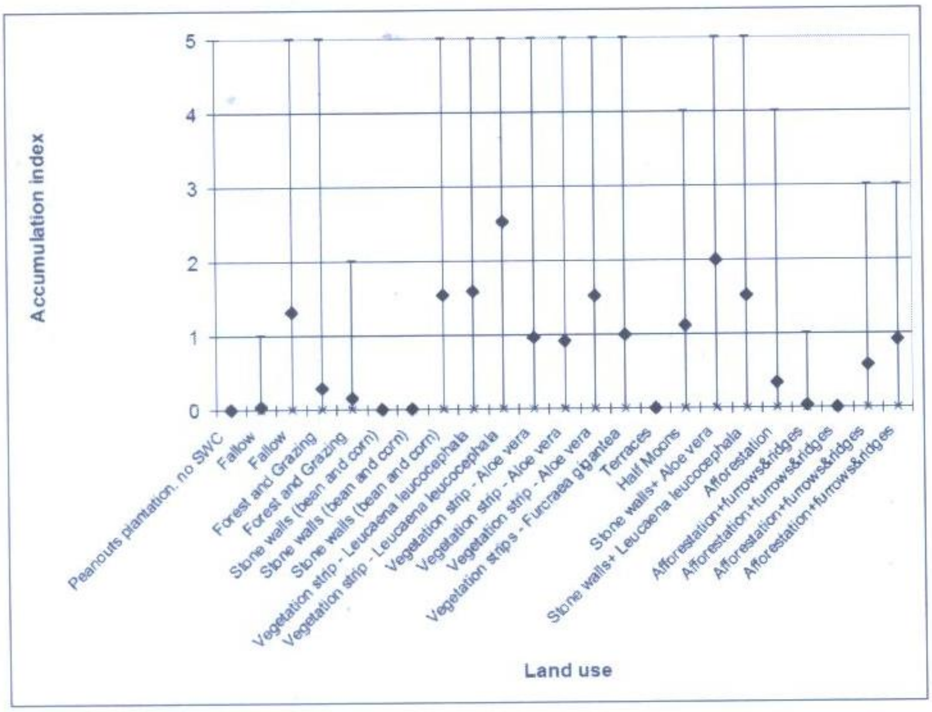

Figure 12. Accumulation features index for different land uses and soil and water conservation techniques.

Although the erosion features index is high, the accumulation features index is also high, which means that the erosion at slope scale is not high.

Nevertheless in some cases, erosion feature index is high and the accumulation features index is low. In those cases this represents an effective export of sediments from the slope to the river channels, and therefore an effective erosion and degradation due to hydrological processes.

In this context the worst cases are those without soil and water conservation techniques, either used for agriculture or under fallow (Figure 12). This implies that the vegetation strips have an important role in soil and water conservation. In fact, many of the erosion features are produced by men, resulting of their use of steep slopes for rainfed agriculture. The erosion would be inevitable in any case. The accumulation features show that despite the high erosion rates, sediments are trapped just below in the next vegetation strip.

CONCLUSION

Mastering overland flow may have an important impact in the livelihood of traditional communities in arid and semi-arid environments. The Cape Verde history is paradigmatic of the importance of soil and water conservation for sustainable development. Prior to the 1950s' famines were frequent in the archipelago, charging an incredible high toll in deaths and emigration.

With the implementation of soil and water conservation techniques, right after the last famine, that took place in 1947/48, and despite a perceived decrease in the annual rainfall, there are no registers of deaths by famine ever after. To maintain the water in the soil and the soil in place has paid off, and the population more than duplicated when compared with the number of inhabitants previous to the 1940s' crisis.

To this end contributed also a significant improvement on the governance, specially after the independence.

The different soil and water conservation techniques used in very steep slopes (some with slope angles exceeding 25°) have different efficiencies, but all of them, from the vegetation strips, the afforestation the terraces or the contour stone walls, single or associated with vegetation strips, have a positive effect on soil and water conservation, despite the disturbance produced by men, while performing agriculture practices.

In no other place in the world soil and water conservation techniques play such an important role in the overall sustainability and livelihood of local communities as in Cape Verde.

REFERENCES

Amaral I (1964) Santiago de Cabo Verde. A terra e os Homens. Memórias da Junta de Investigação do Ultramar, nº 48 (segunda série), Lisboa, 444p. (in Portuguese)

Bangoura S (2002) Water harvesting techniques in West and Central Africa. In: Dupuy A, Lee C, Schaaf T (Eds.), *Proceedings of the International Seminar on Combating Desertification: Freshwater Resources and the Rehabilitation of Degraded Areas in the Drylands*, Samantha Wauchope, fushia publishing Paris, N'Djamena, Chad, October 30 to November 4, 2000, pp. 20–26.

Barry B, Sonou M (2003) Best practices in rainfed agriculture in West Africa. In: Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa, Bloemfontein, South Africa, April 8–11, 2003. ARC-Institute for Soil, Climate and Water, Pretoria, South Africa, pp. 60–74.

Bationo A, Lompo F, Koala S (1998) Research on nutrient flows and balances in west Africa: state-of-the-art. *Agriculture, Ecosystems and Environment*, 71, 19-35

Carreira, A (1977) Cabo Verde (Aspectos sociais. Secas e fomes do século XX). Ulmeiro, 1ª Ed. Depósito Legal n.º 4764/84 (in Portuguese).

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Raïsänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Correia MJ, Fonseca F, Azedo-Silva J, Dias C, David MM, Barrote I, Osório ML, Osório J (2005) Effects of water deficit on the activity of nitrate reductase and contents of sugars, nitrate and free amino acids in the leaves and roots of sunflower and with lupin plants growing under two nutrient supply regimes. *Physiologia Plantarum*, 124: 61-70.

Critchley WRS, Mutunga K (2003) Local innovation in a global context: documenting farmer initiatives in land husbandry through WOCAT. *Land Degrad. Develop*. 14, 143–162.

Enfors EI, Gordon LJ (2008) Dealing with drought: The challenge of using water system technologies to break dry land poverty traps. *Global Environmental Change* 18, 607–616.

Falkenmark M, Fox P, Persson G, Rockström J (2001) Water Harvesting for Upgrading of Rainfed Agriculture. Problem Analysis and Research Needs. SIWI Report 11. Stockholm Environmental Institute.

FAO (2009) The State of Food Insecurity in the World 2009. Economic crises – impacts and lessons learned. *Food and Agriculture organization of the United Nations*. ISBN 978-92-5-106288-3.

FAO (2003) A perspective on water control in southern Africa. Support to regional investment initiatives. *Land and Water Discussion Papers* 1, pp. 1–36.

Fatondji D (2002) Organic fertilizer decomposition, nutrient release and nutrient uptake by millet crop in a traditional land rehabilitation techniques (Zai), in the Sahel. In: *ZEF Ecology and Development Series No. 1,* Cuvillier Verlag, Bonn.

Fatondji D, Martius C, Vlek P (2001) Zai—a traditional technique for land rehabilitation in Niger. ZEF news 8, 1–2.

Folke C, Carpenter S, Walker S, Scheffer M, Elmquist T, Gunderson L, Holling CS (2004) Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Evol. Syst.* 35, 557–581.

Fraiture C, Wichelns D (2009) Satisfying future water demands for agriculture. *Agricultural Water Management*, In Press.

Greenland DJ, Nye PH (1959) Increases in the carbon and nitrogen contents of tropical soils under natural fallows. *J. Soil Sci*. 10, 284-299.

Hassan A (1996) Improved traditional planting pits in the Tahoua department, Niger. An example of rapid adoption by farmers. In: Reij, C., Scoones, I., Toulmin, C. (Eds.), Sustaining the Soil. *Indigenous Soil and Water Conservation in* Africa. GB9705029.

Herweg K, Ludi E (1999) The performance of selected soil and water conservation measures—case studies from Ethiopia and Eritrea. *Catena* 36, 99–114.

Hughes MK, Diaz HF (2008) Climate variability and change in the drylands of Western North America. *Glob. Planet. Change*. 64, 111–118.

Human Development Report (2006) Beyond scarcity: Power, poverty and the global water crisis. United Nations Development Programme (UNDP), 1 UN Plaza, New York, New York, 10017, USA, ISBN 0-230-50058-7.

Inanaga S, Eneji AE, An P, Shimizu H (2005). A recipe for sustainable agriculture in drylands. In K. Omasa, I. Nouchi and L.J. De Kok (eds). Plant responses to Air Pollution and Global Change. Springer-Verlag (Tokyo), 285-293.

IWMI (International Water Management Institute) (2005) Technology adoption and dissemination. http://www.iwmi.cgiar.org/africa/west_africa/projects/AdoptionTechnology/Technology_Adoption.htm (online).

Jones J, Tengberg A (2000) The impact of indigenous soil and water conservation practices on soil productivity: examples from Kenya, Tanzania and Uganda. Land Degrad. Develop. 11, 19–36.

Kabore D, Reij C (2004) The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso. International Food Policy Research Institute, Washington. http://www.ifpri.org/divs/eptd/dp/papers/eptdp114.pdf (online).

Kassogue A, Komota M, Sagara J, Schutgens F (1996) Traditional SWC techniques on the Dogon Plateau, Mali. In: Reij, C., Scoones, I., Toulmin, C., (Eds.), Sustaining the Soil. *Indigenous Soil and Water Conservation in Africa*, pp. 69–79.

Kato M (2001) Intensive cultivation and environment use among the Matengo in Tanzania. ASM 22, 73–91.

Langergraber G, Muellegger E (2005) Ecological Sanitation-a way to solve global sanitation problems? *Environmental International*, 31, 433-444.

Lal R (2004) Carbon sequestration in dryland ecosystems. *Environ. Manag*. 33, 528–544.

Lal R (2001) Potential of desertification controls to sequester carbon and mitigate the greenhouse effect Climatic Change 51: 35–72.

Lesourd M (1995) État et société aux îles du Cap-Vert.Collection « Hommes et Sociétés » Éditions Karthala, Paris, 524p. (in French)

Liu J, Fritz S, van Wesenbeeck CFA, Fuchs M, You L, Obersteiner M, Yang H (2008) A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change Global and Planetary Change 64 222–235.

Loucks DP, Gladwell JS (1999) Sustainability Criteria for Water Resource Systems. *International Hydrology Series*, Cambridge University Press. ISBN: 0 521 56044 6.

Ludwig JA, Wilcox BP, Breshears DD, Tongway DJ, Imeson AC (2005) Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* 86, 288–297.

Malley ZJU, Kayombo B, Willcocks TJ, Mtakwa PW (2004) Ngoro: an indigenous, sustainable and profitable soil, water and nutrient conservation system in Tanzania for sloping land. *Soil Tillage Res*. 77, 47–58.

Mati BM, Lange M (2003) Emerging practices in water management under rainfed agriculture in eastern Africa. In: Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa (WCT), Bloem Spa Lodge and Conference Centre, Bloemfontein, South Africa, April 8–11, 2003. ARC-Institute for Soil, Climate and Water, Pretoria, South Africa, pp. 60–74.

Mbow C, Mertz O, Diouf A, Rasmussen K, Reenberg A (2008) The history of environmental change and adaptation in eastern Saloum–Senegal—Driving forces and perceptions. Global and Planetary Change 64 210–221.

McCarthy J, Osvaldo F, Canziani NA, Dokken DJ, White KS (Eds.) (2001) Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press, UK, pp. 1–1000.

Millennium Ecosystem Assessment Board (2005) Living beyond our means; Natural Assets and Human Well-being; Statement from the Board, Washington.

Molden D (2007) Trends in water and agricultural development. In Water for food Water for life – A comprehensive assessment of Water Management in Agriculture. International Water Waste Management Institute, Earthscan, Washington, pp 57-90. ISBN: 978-1-84407-396-2.

Mutekwa V, Kusangaya S (2006) Contribution of rainwater harvesting technologies to rural livelihoods in Zimbabwe: the case of Ngunduward in Chivi District. *Water SA* 32 (3), 437–444.

Mutunga K, Critchley W (2001) Farmers' initiatives in land husbandry. UNDP—Office to combat desertification and drought (UNSO/ESDG/BDP) and Sida's Regional Land Management Unit.

Ngigi SN (2003) Rainwater Harvesting for Improved Food Security: Promising Technologies in the Greater Horn of Africa. GHARP, KRA, Nairobi, Kenya.

Nyong A (2005) A message to the G8 summit. *Nature* 435, 1148–1149.

Ouedraogo M, Kaboré V (1996) The ''zai'': a traditional technique for the rehabilitation of degraded land in the Yatenga, Burkina Faso. In: Reij C, Scoones I, Toulmin C (Eds.), Sustaining the Soil. *Indigenous Soil and Water Conservation in Africa*, pp. 80–92.

Oweis T, Hachum A (2006) Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management* 80 57–73.

Prinz D, Malik AH (2002) Runoff farming. Article prepared for WCA infoNet. http://www.wca-infonet.org

Rockström J, Folke C, Gordon L, Hatibu, N, Jewitt G., Penning de Vries F, Rwehumbiza F, Sally H, Savenije H, Schulze R (2004) A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Phys. Chem. Earth* 29, 1109–1118.

Rockström J, Barron J, Fox P (2002) Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Phys. Chem. Earth* 27, 949–959.

Roose E (1989) Gestion conservatoire des eaux et de la fertilité des sols dans les paysages Soudano-sahélien de l'Afrique Occidentale. ICRISAT, Soil, Crop and Water Management Systems for Rainfed Agriculture in the Sudano-Sahel zone: Proc. of an Inter. Workshop, 1-6 Jan, 1987, ICRISAT Sahelian Center, Niamey, Niger, A.P. 502324, India.

Roose E (1990) Méthodes traditionnelles de gestion de l'eau et des sols en Afrique de l'Ouest. Définitions, fonctionnement limites et améliorations possibles. *Bulletin Erosion* No. 10, 98-107.

Sanchez PA (2002) Ecology—soil fertility and hunger in Africa. *Science* 295, 2019–2020.

Savonnet G (1976) Les Birifor de Diepta et sa reÂgion insulaire du rameau Lobi. Atlas des structures agraires au Sud du Sahara. 16 Paris, ORSTOM.

Schiettecatte W, Ouessar M, Gabriels D, Tanghe S, Heirman S, Abdelli F (2005). Impact of water harvesting techniques on soil and water conservation: a case study on a micro catchment in southeastern Tunisia. *J. Arid Environ.* 61, 297–313.

Silva ALCe (1995) Histórias de um Sahel insular. Edições Spleen, Praia, Cabo Verde, 2ª edição, 175p. (in Portuguese).

Sivakumar MVK, Wills JB (Eds.) (1995) Combating land degradation in sub-Saharan Africa: summary proceedings of the International Planning Workshop for a Desert Margins Initiative, 23-26 January 1995, Nairobi, Kenya, Patancheru 502324, Andhra Pradesh, India.

Stroosnijder L (2003) Technologies for improving rain water use efficiency in semiarid Africa. In: *Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa*, Bloemfontein, South Africa, April 8–11, 2003. Pretoria, South Africa. ARC Institute for Soil, *Climate and Water*, pp. 60–74.

Thornton PK, Kruska RL, Henninger N, Kristjanson PM, Reid RS, Atieno F, Odero AN, Ndegwa T (2002) Mapping Poverty and Livestock in the Developing World. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Usman MT, Reason CJC (2004) Dry spell frequencies and their variability over southern Africa. *Clim. Res*. 26, 199–211.

van Dijk J, Ahmed MH (1993). Opportunities for expanding water harvesting in sub-Saharan Africa: the case of the teras of Kassala. *Gatekeeper Ser*. 40, 1–18.

van Rensburg LD, Botha JJ, Anderson JJ (2004) The nature and function of the infield rainwater harvesting system to improve agronomic sustainability. ICIDFAO International Workshop.

Verstraete MM, Brink AB, Scholes RJ, Beniston M, Smith MS (2008) Climate change and desertification: Where do we stand, where should we go? *Global and Planetary Change* 64 105–110.

Wakindiki IIC, Ben-Hur M (2004) Indigenous soil and water conservation techniques: effects on runoff, erosion, and crop yields under semi-arid conditions. *Aust. J. Soil Res*. 40, 367–379.

Wallace JS (2000) Increasing agricultural water use efficiency to meet future food production. *Agric. Ecosyst. Environ*. 82, 105–119.

Warren A (1995). Comments on conservation, reclamation and grazing in the northern Negev: contradictory or complementary concepts? http://www.odi.org.uk/pdn/papers/38a.pdf (online).

Williams MAJ, Balling RC (1994). *Interactions of desertification and climate*. Geneva, Switzerland, 230 pp.

World Bank, (2000). *World Development Report* 1999/2000. Oxford Press.

Zougmoré R, Zida Z, Kamboua NF (2003). Role of nutrient amendments in the success of half-moon soil and water conservation practice in semiarid Burkina Faso. *Soil Tillage Res*. 71, 143–149.