Influence of soil protection techniques on runoff, erosion and plant production on semi-arid hillsides of Cabo Verde

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Abstract

A combination of human, climatic, geomorphological and pedological factors has led to extensive degradation of the soils of the Cabo Verde Islands. To survive in fragile conditions, the stabilisation of the farming systems and the maintenance of high and sustainable yields have become absolute priorities for farmers. The project described here is part of a programme of water resource optimisation on the island of Santiago in a semi-arid mountainous area near Godim. The objective of this study was to evaluate the influence of two conservation techniques (light mulching with maize (\textit{Zea mays} L.) haulms and hedging with bushes and grass) on runoff, erosion and phytomass production under natural rainfall. The main data were collected on five runoff plots of 100 m\textsuperscript{2} and 10 pairs of 4 m\textsuperscript{2} plots scattered over the hillslope. Although, rainfall erosivity was higher than in Sahelian areas, runoff occurred only for rainfall higher than 40 mm and intensities over 40 mm/h. Soil losses reached 12 mm/year on bare plots, 48 mm with traditional crops, 3.1 mm with hedges and less than 0.03 mm under mulching on 50\% slopes. This study confirmed that mulching alone, or associated with the plantation of hedges, reduces runoff and erosion on the steep slopes of the Cabo Verde mountains. However, the ability to improve the use of the water resources by grain-producing crops in semi-arid regions was questionable. Plant material for mulching was only available and efficient during the wet years. The efficiency was therefore irregular and depended on the abundance of rainfall, weed production and the degree of satisfaction of plant water and nutrient requirements at the critical moment when the crops are in flower. Hedges of \textit{Leucaena leucocephala} (Lam.) De Wit or \textit{Cajanus cajan} (L.) Huth (Congo pea), without ditches or banks, planted on the flat and mulched could contribute to the supply of fodder in the dry season as well as blocking rivulet runoff and erosion in the Sahelian area. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Cabo Verde; Erosion; Water balance; Biomass production; Hedges; Mulch

1. Introduction

A combination of human, climatic, geomorphological and pedological factors has resulted in extensive degradation of the natural environment over the whole of the Sudan–Sahel region of Africa including the Cabo Verde Islands.

Owing to the environmental degradation, particularly hostile climate and demographic pressure, the stabilisation of the farming systems and the maintenance of high and sustainable yields have become absolute priorities. In semi-arid countries, where rainfall is not only responsible for the degradation but is also the main factor determining yields, efforts...
must be continued to develop sustainable systems of agriculture acceptable by the local population. The systems should be designed to reduce climatic risks and stabilize production of food crops (and forage), a driving force for family farms, through the efficient and rational management of the resources, i.e., the soil, the water and the phytomass (Roose, 1987, 1996a).

In Cabo Verde, where problems of erosion and lack of water are frequent (Mannaerts, 1986; Meyer and Lopes, 1993), the government has ever-greater reasons for finding sustainable solutions. The National Institute for Agronomic Research for Agricultural Development (INIDA) and the research part of the Agriculture and Farming Development Programme (PRODAP) have, since 1993, been cooperating in a programme of water resource optimisation on the island of Santiago in a semi-arid area near Godim. The region is mountainous and volcanic, and current agricultural practices cause extensive degradation due to runoff in spite of the minimum tilling techniques used. The programme aims to improve the management of rainwater by reducing surface runoff to give the plants a better supply of moisture increasing the yields of both crops and forage-livestock farming is the mainstay of small family farms (Barry et al., 1995).

Covering at least 30% of the soil with a small quantity of waste plant material, i.e., 1–4 Mg ha\(^{-1}\) tonnes per hectare of crop residue, weeds, etc., has given interesting results in countries with environmental conditions different to those of Cabo Verde (Lal, 1975; Scopel, 1994). Based on these studies, two techniques were tested to improve the productivity of soils, while protecting them against runoff and the resulting erosion. The two techniques were covering the ground with a light mulch of maize haulms (1500 kg dry matter ha\(^{-1}\)) and contour planting of hedges made up of an association of bushes [Leucaena leucocephala (Lam.) De Witt] and Poaceae [Pennisetum purpureum Schum., Vetiveria zizanoides (L.) Nash ex Small and Digitaria horizontalis Wild] along the contour lines.

The aim of the present article was to report findings concerning the influence of mulching and hedging conservation techniques on runoff, erosion, water balance and phytomass production under natural rainfall, over areas of different sizes (4–100 m\(^2\)). On the bases of the study, a new soil and water conservation approach for cultivated Sahelian volcanic steep slopes was proposed.

2. Materials and methods

2.1. Study site

Santiago is the largest island (1000 km\(^2\)) of the Cabo Verde archipelago. It has a dry tropical climate which is Sahelian, montane and insular and is subjected to the drying influence of the trade winds. The study site (Fig. 1) (Bertrand, 1996) is located in the central part of the upper watershed of Ribeira Seca, more precisely in the Godim area at an altitude of between 250 and 500 m.

Mean annual rainfall, calculated over the last 24 years is 304 mm. However, for plant growth, it is not simply the total rainfall that is important but how the rainfall is distributed through the year (Lopez, 1992). The rainy season is centred around August–September (36 and 32%) with an asymmetric distribution over the other months (July, 5%; October, 15% and November, 3%). Rainfall shows both a high inter-annual variability — about 50% — and intensities reaching between 80 and 130 mm/h for at least 15 min. As the maximum daily rainfall from 1973 to 1996 follows Gumbel’s law, it is possible to calculate the daily rainfall \(R_{dmax}\) (90–95%) for recurrences of 2, 5 and 10 years as equal to 47, 76 and 140 mm, respectively. The mean annual evaporation potential is 1210 mm and the mean annual temperature about 22°C (25°C in the wet season).

The current landscape is agricultural and strongly affected by man: the original forest stands have disappeared, cultivation has spread to even the steepest slopes (up to 60%), the Poaceae steppe and the tree savannah have seriously suffered and the countryside appears artificial due to the installation of anti-erosive devices on numerous hillsides. The current agricultural system in the rainy zones of Santiago has come to a crisis point in productivity and in forage yields and will shortly do so for water supply.

At the foot of the hills, where the slope is relatively slight (less than 25%), the ishumic soils, classified by FAO as similar to Vertisols, have a relatively low humus content and are highly structured compositions in which swelling clays predominate, conferring a high capacity for storage of water and nutrients (Bertrand,
However, the plots studied, representative of the steep slopes tilled in the Godim region, were mainly located on steep slopes (35–60%) which have a layer of softened rock known as a regosol on top of ashy volcanic material. These soils are subjected to erosion and also tend to mass flow, sliding downhill under the frequent movements of livestock and farmers. Considering the dynamic balance between pedogenesis and morphogenesis which seems to occur, more developed soils would probably become established and productivity would be improved if erosion was efficiently controlled by suitable practices and by sustainable management of the biomass (Roose, 1996a). Table 1 shows that a superficial layer with a sandy-clay texture covered the granular substratum. The thin covering of soil, low in organic matter, nitrogen and phosphate, can be classified as a regosol on a volcanic substrate (Orgâos) (Bertrand, 1993). The apparent dry densities measured were low (0.99 to 1.11 ± 6%).

### 2.2. Runoff and erosion experiments

Runoff and erosion measurements were made on plots of 100 and 4 m². The layout of the experimental area consisted of five plots, each 20 m long (Fig. 2). Plots 1–4 were 100 m² and kept under cultivation with maize and beans (*Phaseolus* spp.) and plot 5 (50 m²) was kept bare to determine the soil erodibility index, *K* (Wischmeier et al., 1971). The main treatments received by each plot are summarised in Table 2. Plot P1 used conventional farming practices and served as regional control. Plots 2 and 3 were mulched and 3 and 4 had hedges. Plot 5 which had no crops planted was cultivated at the same frequency as the others. It served as the international control, i.e., the standard plot in the USLE model of Wischmeier and Smith (Wischmeier and Smith, 1978). As usual for watersheds (with only annual replication) simple regression was used to analyse the effect of mulching on runoff and erosion: there were 10 pairs of 4 m² plots on different parts of the hillside.

### Table 1

<table>
<thead>
<tr>
<th>Plot</th>
<th>Horizon</th>
<th>Particle distribution (g kg⁻¹)</th>
<th>Clay (0–2 μm)</th>
<th>Total loam (2–50 μm)</th>
<th>Total sand (50–2000 μm)</th>
<th>Apparent density (g kg⁻¹)</th>
<th>Organic matter (g kg⁻¹)</th>
<th>Total nitrogen (g kg⁻¹)</th>
<th>Pz05 (pg kg⁻¹)</th>
<th>CEC (Cmol (+) kg⁻¹)</th>
<th>pH (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–10 cm</td>
<td>Mean ± s(A)</td>
<td>216 ± 15</td>
<td>158 ± 8</td>
<td>624 ± 18</td>
<td>1.00 ± 0.02</td>
<td>11.9 ± 1.6</td>
<td>0.84 ± 0.11</td>
<td>14.8 ± 2.6</td>
<td>673 ± 22</td>
<td>7.2 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>10–50 cm</td>
<td>Mean ± s(A)</td>
<td>200 ± 35</td>
<td>125 ± 24</td>
<td>673 ± 22</td>
<td>1.1 ± 0.01</td>
<td>7.8 ± 2.1</td>
<td>0.56 ± 0.18</td>
<td>12.4 ± 2.6</td>
<td>51.8 ± 7.5</td>
<td>7.3 ± 0.2</td>
</tr>
</tbody>
</table>

*Standard error.*
The crops were planted and managed (every metre, three seeds of a locally used variety of maize plus six seeds of three different varieties of bean were planted in a hole on its own individual micro-terrace) following traditional practices. The number of seed clumps per hectare was therefore about 10 000. The seeds were sown dry and the hoeing was done manually. In 1993, hedges were planted in shallow ditches parallel to the contours on plots 3 and 4. They were composed of a row of bushes (*L. leucocephala*) planted every 50 cm and a row of Poaceae (*P. purpureum*, *V. rizanoides* and *D. horizontalis*) transplanted every 15 cm to stabilise the downhill bank of the ditch. Mulch, composed of maize haulms (1500 kg dry wt ha$^{-1}$, covering 30–40% of the surface of the soil), was spread evenly over the soil on plots P2 and P3 at the start of each growing season. Note that after two seasons, only a third of the mass of haulms remained, there is therefore rapid mineralisation of organic matter and a certain amount was buried during tasks such as hoeing and harvesting.

### Table 2
Crops and conservation treatment of the 100 m$^2$ runoff plots (Godim, Santiago)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Area (m$^2$)</th>
<th>Plant cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1: cropped regional control</td>
<td>100 (20×5)</td>
<td>Maize/bean association</td>
</tr>
<tr>
<td>P2: light mulching over whole plot</td>
<td>100 (20×5)</td>
<td>Maize/bean association</td>
</tr>
<tr>
<td>P3: light mulching over whole plot + three hedges</td>
<td>100 (20×5)</td>
<td>Maize/bean association</td>
</tr>
<tr>
<td>P4: three hedges 8 m apart</td>
<td>100 (20×5)</td>
<td>Maize/bean association</td>
</tr>
<tr>
<td>P5: bare international control</td>
<td>50 (20×5)</td>
<td>Bare cultivated fallow</td>
</tr>
</tbody>
</table>
2.3. Soil and plant measurements

A rain gauge and an automatic rain chart recorder gave the depth of rainfall and its intensity. After each rain, the amounts of water and earth gathered in the collection channels, the sluice tanks and the storage tanks downhill of the plots were measured. Physical-chemical analysis of the eroded material was carried out at the CIRAD Laboratory (Montpellier, France). Finally, after the operations of sowing, hoeing and harvesting, dry mechanical erosion, i.e., the earth pushed downhill by men and tools, was measured in the collection channels. This “tillage erosion” is amplified by labourers and livestock crossing the steep hillsides. The erosion plot method gives relative values for erosion and runoff which can be compared for the various types of treatments, but does not give an absolute value for erosion at one point of the hillside (Roose, 1996a).

As the gravimetric method would be too destructive on the very steep plots, the degree of water saturation of the soil was measured in situ by time domain reflectometry (TDR) which has given excellent results in volcanic soils. The soil moisture was recorded twice a week using TDR probe access tubes set in the plots and in the hedges. Measurements were made every 10 cm down the length of the tubes. The mean variability of the measurements was low — about 1–1.5% for any given tube and 3–4% for tubes in a given plot. Finally, to assess the dynamic state of the water and the variations of the stock in the soil, the water pressure was followed in the soil at different depths: 10, 20, 30, 40, 60 and 80 cm.

The state of the soil surface and the degree of plant cover gave fundamental information for understanding the runoff and erosion processes. The most significant parameters were measured by the method of “quadrat points” (Roose, 1996b): the proportion of covered soil surface with a high runoff potential (superficial flaking, sedimentation crust, stones held in the bulk of the soil, rills and rivulets), the proportion of open soil (clods < 1 cm and fine earth), the proportion of covered soil absorbing the energy of raindrops (aerial vegetation), and the energy of running water.

Observations were made of how the roots of the maize–bean association colonised the soil during the period of vegetative growth (30 days) and at the start of female flowering of the maize (60 days). During these periods, the root system is already well established. The vertical grid method developed by Chopart (Ruelle et al., 1990) was applied: centred on a clump of seeds, a 1 m² grid with a 3 cm x 3 cm mesh was set up in a trench dug perpendicular to the slope. For each space in the mesh, the presence or absence of roots was noted. The percentage colonisation of the layers of the soil was calculated as being the percentage of mesh openings with at least one root.

The whole aerial phytomass was collected, weighed and oven dried to assess the production of dry matter (kg dry wt). The hedge was pruned on average twice during each growing season and the production of leaf and branch was measured as was the production of

Maize-bean association (4 clumps) + light mulching

![Diagram](image)

Fig. 3. Layout of the 4 m² scale. The frames were positioned slightly aslant to aid collection of runoff.
weeds after each hoeing and at the end of the season. The crops of corn and beans were harvested and the yield of grain and haulm estimated on the 100 m$^2$ plots.

2.4. Runoff and erosion on the 4 m$^2$ mini-plots

For a more detailed analysis of the effects of exposure and altitude on rainfall on the scale of the watershed, 10 pairs of planted mini-plots of 4 m$^2$ (mulched and unmulched) were set up in various localities of the lower watershed. Each mini-plot was surrounded by a metal frame, with a pipe at the base for collecting solid and liquid runoff. A rain-gauge was placed near each pair of plots (Fig. 3).

Soil and tilling conditions were identical to those of the 100 m$^2$ plots. The liquid and solid runoff was collected in 100 l tanks and measured after each rain. Grain and haulm production was measured at the end of the year. Fisher's test was used for statistical analysis.

3. Results

3.1. Influence of mulching and hedges on erosion from runoff and on dry mechanical erosion

3.1.1. Runoff and erosion studied on the 100 m$^2$ agricultural plots

The rains from 1993 to 1996 were representative of the series 1974–1992 with two normal years (357 mm in 1993 and 425 mm in 1995) and two dry years (160 mm in 1994 and 190 mm in 1996). The aggressiveness index of Wischmeier and Smith (1978) was much lower during the study period ($R = 112$) than during the period prior to the study ($R$ for 1974–1992 = 205).

Calculated over the whole year, runoff (0.3–5%) was very low considering the steepness of the slopes, but it did reach 40% during exceptionally strong rain. It was seen that, over the 4-year study period, for rainfall intensities ($I_{30}$) of less than 40 mm/h and for rainfall $L_p$ not exceeding 40 mm, no runoff occurred.

Table 3 illustrates the efficiency of mulching in preventing runoff and erosion: the losses of soil on the plot prepared in the traditional way (P1) were 160 times greater than those of the mulched plot (P2), while runoff was nine times greater. The soil surface showed marked degradation on the unmulched plot (8–15% of surface crust and 5–10% erosion gouges) compared to the mulched plot (1–2% of surface crust and no gouging from erosion).

The presence of hedges alone (P4) reduced runoff and erosion but much less than light mulching alone (P2) (Table 3). In addition, erosion rills was caused by the ditches filling up and the banks giving way caused concentrated erosive flow in spite of the grassy strip. Digging a ditch in front of the hedge should therefore be reconsidered. A preliminary feasibility study showed that a hedge will grow just as well on the flat, avoiding the formation of rivulets wearing down the bank.

It was the combined effect of mulching and hedges (P3) which gave the best results, reducing runoff and erosion to almost zero (Table 3). A few erosion rills were present downhill of the hedges, but the mulch broke the momentum of the rivulets coming over the bank and prevented the spread of the rills down the whole slope. In addition, the filter/dam effect of the hedge on the accumulation of sediment seemed to be greater in the presence of the light mulch. This role is even more apparent when dry mechanical erosion is considered. The figures for the 2 years 1995–1996 were 8.7 Mg ha$^{-1}$ for P1, 4.0 Mg ha$^{-1}$ for P2, 1.1 Mg ha$^{-1}$ for P3 and 2.5 Mg ha$^{-1}$ for P4.

Table 3

<table>
<thead>
<tr>
<th>Soil losses (Mg ha$^{-1}$) and runoff (as a percentage of the under erosive rainfall) under erosive rains$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total for 1994–1996</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Soil losses (Mg ha$^{-1}$)$^b$</td>
</tr>
<tr>
<td>Runoff (%)$^b$</td>
</tr>
</tbody>
</table>

$^a$ The figures represent the total for the 3 years, 1994–1996. See Table 2 for information of treatments (P1–P5).

$^b$ Tests gave errors from 6 to 10%. These values are considered very acceptable (Roose, 1977).
Table 4  
Effect of mulching on runoff and soil losses on the 4 m² plots in the watershed (Godim, Santiago)

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall H (mm)</th>
<th>I₉₀b</th>
<th>Proportion of runoff (%)</th>
<th>Mean soil losses (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>d.f.ᵇ</td>
<td>Mulch</td>
</tr>
<tr>
<td>21/08/1995</td>
<td>42</td>
<td>28</td>
<td>11</td>
<td>1.08</td>
</tr>
<tr>
<td>05/09/1995</td>
<td>72</td>
<td>47</td>
<td>13</td>
<td>1.57</td>
</tr>
<tr>
<td>13/09/1995</td>
<td>82</td>
<td>66</td>
<td>11</td>
<td>2.78</td>
</tr>
<tr>
<td>30/09/1995</td>
<td>27</td>
<td>16</td>
<td>11</td>
<td>0.22</td>
</tr>
<tr>
<td>22/08/1996</td>
<td>53</td>
<td>42</td>
<td>11</td>
<td>1.07</td>
</tr>
<tr>
<td>08/09/1996</td>
<td>64</td>
<td>47</td>
<td>13</td>
<td>3.03</td>
</tr>
</tbody>
</table>

ᵃ Maximum rain intensity during 30 min.  
ᵇ Degrees of freedom.  
ᶜ Not determined.  
* Significant difference (5%) compared to control.

Apart from the simple mechanical filter action of the base of the hedge, the retention of mulch and soil improves the quality of the earth uphill of the hedge and leads to the slope of the hillside being modified — two elements which are far from negligible in the medium term. This leads to the formation of deeper soil, decrease of runoff and improvement of infiltration, slowed flow and deposition of sediment (Smolikowski, 1997).

3.1.2. Runoff and erosion studied on the 4 m² mini-plots

The results obtained on the 4 m² mini-plots confirm the observations made on the 100 m² plots. The proportion of runoff and the soil losses were always lower on the mulched plots (Table 4). In spite of a very high variability of the results (CV varying between 30 and 115% for runoff and 25–55% for erosion) variance analysis performed on the means for the mini-plots, where runoff was noted showed that the effect of light mulching on runoff and erosion was usually significant at 5% level.

The measurements made on the mini-plots (Fig. 4) showed that both in the presence and the absence of mulch, runoff started to occur with rains of over 25–30 mm. However, as the quantity of rain falling in one shower increased, the difference between the proportions of runoff with mulching and without increased. It is thus concluded that mulching clearly increases infiltration into the regosol decreasing runoff and erosion.

From these data, linear relationships were established between the amount of rain that fell (Lₐ) and the proportion of water running off the surface (Lₑ):

- with mulching: \( Lₐ = 0.04Lₑ - 1.35, R² = 0.80, \) probability = 1.71%, standard error = 0.0102;
- without mulching: \( Lₐ = 0.07Lₑ - 1.62, R² = 0.80, \) probability = 1.62%, standard error = 0.0162.

These results indicate that in spite of a high variability, the effect of mulching on runoff and erosion is clear at either of the scales of observation used. It seems difficult, however, to compare plots of different sizes. This is because the processes of runoff and erosion on the two sizes of plot are not identical (Fig. 5). On the 4 m² plots, runoff was in sheet erosion form and essentially only silt was transported, whereas on the 100 m² plots runoff was predominantly linear (rivulets) causing linear erosion (rills) and, owing to
the effect of the hillside (steepness and length), carried larger elements.

3.2. Consequences on the availability of water for the phytomass: water balance

The method used in this study is based on the evaluation of the ground water balance terms by means of Hillel's equation (Hillel, 1974). The mean water consumption per day (MWCd) of the crop association maize-bean was estimated for certain characteristic periods of maize growth. Overall, regosols have a high storage capacity.

3.2.1. Usable water reserve

The regosols studied had no clogged horizon but a satisfactory total porosity of between 53 and 57% in the surface layers (0–10 cm) and 46–50% in the deeper layers (10–50 cm). However, in spite of a fairly high clay content (Table 1), these soils did not present a water storage capacity of more than 13% (pF 2.5–4.2) theoretically available for the plant at the surface and about 8–10% in the root-containing layers. Their macroporosity was good at the surface and decreased at depth (20 and 15%, respectively). Soil moisture measurements on samples saturated in the laboratory indicated that after a rain shower, the macroporosity of the soil was not saturated.

For the 100 m² plots, the maize-bean root system analysed over three seasons (1994–1996), on the 30th and 60th days after sowing, was very similar from year to year. Fig. 6 showed that the root depths were not significantly affected by the different treatments (maximum depth 60 cm). However, the root density in the first 25 cm of soil was seen to be much greater on the mulched plots (P3 and especially P2). The mulch maintains a much higher water content in the surface layers during the period of active growth (till the start of flowering) enhancing the development of the crop root hairs.

On the 3rd year after planting, the hedge composed of Leucaena and of Poaceae (Vetiveria and Digitaria), showed a very high density of root colonisation down to a depth of 50 cm (over 70% of the volume of the soil was effectively used by the hedge roots) (Fig. 6). Considering the accumulation of roots at this level in the soil (0–60 cm), competition for water and minerals probably occurred between the hedge and the crops next to it. Overall, the water reserve that is available for the crops was fairly low of the order of 60 mm.

3.2.2. Water content of the soil, water storage capacity and its availability for the plant

The measurement of the water content of the soil by reflectometry indicated that the soil water reserves available to the roots were increased by 5–10% on
the plots that had been mulched (P2 and P3) (Fig. 7) with respect to the control plot P1, especially during the phase of active growth and flowering of the maize. This gain can be directly attributed to the improved penetration of rainwater with mulching through reduction of runoff.

In 1996, the reflectometry and water pressure studies showed that there was a higher level of moisture near the hedge than between the hedges. As no runoff was observed during the whole season, this must be the result of improved recovery of the water under the effect of the deep root system of Leucaena, or to a higher storage capacity of the first 40 cm of soil owing to build-up of soil and accumulation of organic matter.

The data recorded showed that the requirements of the plants, even during “good” years were never more than 80% satisfied. During the critical flowering period, even in the so-called “wet” years, only

![Fig. 6. Density of root colonisation versus depth after flowering of the maize (60th day) in 1996, on the regional control plot (P1), the plot with mulch (P2), the plot with mulch and hedges (P3) and under the hedge.](image)

![Fig. 7. Gain in soil moisture in the layer of earth used by maize roots (0-60 cm) on the mulched plots (P2 and P3) with respect to the regional control (P1) in 1995.](image)
Table 5

Yields (kg dry matter ha⁻¹) on 100 m² runoff plots during 1993–1996

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>5449</td>
<td>5428</td>
<td>4979</td>
<td>4251</td>
</tr>
<tr>
<td>Bean</td>
<td>1556</td>
<td>1436</td>
<td>1372</td>
<td>1401</td>
</tr>
<tr>
<td>Total crops</td>
<td>6985</td>
<td>6864</td>
<td>7172b</td>
<td>6423b</td>
</tr>
<tr>
<td>Leircaena</td>
<td>–</td>
<td>–</td>
<td>1973</td>
<td>1904</td>
</tr>
<tr>
<td>Poaceae</td>
<td>–</td>
<td>–</td>
<td>1204</td>
<td>1058</td>
</tr>
<tr>
<td>Total hedges</td>
<td>0</td>
<td>0</td>
<td>3177</td>
<td>2962</td>
</tr>
<tr>
<td>Weeds</td>
<td>331</td>
<td>711</td>
<td>759</td>
<td>514</td>
</tr>
<tr>
<td>Total biomass</td>
<td>7316</td>
<td>7575</td>
<td>10247</td>
<td>9128</td>
</tr>
</tbody>
</table>

a See Table 2 for information of treatments (P1–P4).
b Only the crops surface was considered.

about 63% of the needs were satisfied and in the dry years this already low figure fell to under 30% accounting for the near zero grain production in 1994 and 1996.

3.3. Effect of treatments on biomass production

For the 100 m² plots, the results (Table 5) were all corrected to the same surface area when there were hedges. The total production of the crops (grain + maize–bean haulms) for the 1993–1996 series was similar between plots with mulching (the mean of P2 and P3 was 7.02 Mg dry wt ha⁻¹) and the P1 control (6.99 Mg dry wt ha⁻¹). In other words, mulching did not seem to have a positive effect on crop production. The yields obtained on plot P4 with hedges but no mulching were 8% lower than the control. The proliferation of weeds with mulching was confirmed: weeds competed with crops for water. For all 4 years of observation, the greatest phytomass production was recorded on plots P3 and P4 with their *Leucaena* hedges and Poaceae. With respect to the control plot (P1), the additional yield brought about by the hedges was 25 (mean of plots P4) and 40% when “mulching” was associated with “hedges”. The increased yield presents a further point of interest — it occurred from the very first year the hedges were planted and was particularly noticeable in the dry years (rainfall below 200 mm; 1994, 1996). Plot P2 with just mulch did not present significantly enhanced biomass.

The additional biomass produced in dry years had the added advantage of being available in dry years (i.e., 8 years out of 10) when forage becomes the limiting factor in the production of livestock (cows and goats) in the semi-arid region. Over the whole series of study campaigns, the association of hedges with mulching led to higher production of total biomass confirming the effect of mulching on total production (crops + hedge growth + weeds).

3.4. Overall soil losses (USLE) model

The model of Wischmeier and Smith (1978) was designed to predict sheet erosion on slopes of between 2 and 20%. It was not intended for application to volcanic soils on steep slopes, nor to Sahelian climates where rainfall is exceptional and plays a determinant role.

The graph of annual rainfall (Pan) versus annual aggressivity (Ran) over the period 1974–1996 (Fig. 8) shows a linear relationship where Ran = 0.98 × Pan – 112 (R² of 0.72, probability of 0.01%, standard error of 0.155).

The index of soil erodibility (K) (Wischmeier et al., 1971) determined on the fallow plot (P5) defines the soil as very slightly erodable: K1995 = 0.016 and K1996 = 0.004 (K = 0.012). These erodibility indices should be considered with precaution because the USLE model used (Smolikowski, 1997) was designed to predict sheet erosion in slightly hilly areas, as indicated earlier, while the present study had slopes greater than 40%. Also, erosion by rills predominates and runoff is therefore a much greater source of energy than rain impact (Roose, 1996a). The results of the present study allowed the development of a new model of erosion based on the USLE equation. The model enabled evaluation of erosion risks, but was only applicable to slopes of 45% (SL of 15.8). Using the metric system, and hence a conversion factor of 2.24, the equation for the steep Orgãos hillsides is as follows:

\[ E = R \times K \times SL \times C \times P \]

where \( E \) is the annual erosion in Mg/ha/year, \( Pan \) the yearly rainfall in millimetres, \( K = 0.012 \) (mean for 1994–1996), \( SL = 15.8 \) (from Wischmeier and Smith, 1978), \( C \) the mean cover index (mean for
Fig. 8. Annual rainfall (mm) versus the annual climatic aggressivity index ($R$ index of USLE, Wischmeier and Smith, 1978) for the 1974–1996 series at Alto Figuerinha (18 data points) with respect to the regional control in 1995.

Table 6
Means ($\mu$), standard errors ($\sigma(\Delta)$) and variation coefficients (CV) of simulated results of annual erosion from the rainfall of 1974–1992 with the different types of land treatment

<table>
<thead>
<tr>
<th>Land use treatment</th>
<th>Pan (mm)</th>
<th>Ran (mm)</th>
<th>Soil losses (Mg/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>P1 maize + beans</td>
</tr>
<tr>
<td>Annual mean</td>
<td>308</td>
<td>198</td>
<td>34         ±0</td>
</tr>
<tr>
<td>$\sigma(\Delta)$</td>
<td>162</td>
<td>147</td>
<td>25         0.13</td>
</tr>
<tr>
<td>CV (%)</td>
<td>52</td>
<td>74</td>
<td></td>
</tr>
</tbody>
</table>


Using this model, soil losses for the rainfall series 1974–1992 for each type of land treatment were simulated. The results are presented in Table 6.

The above results give an estimate of the losses of soil from a bare plot over 10 years ($E = 840$ Mg ha$^{-1}$, i.e., 84 mm). The losses from a plot using the traditional system of cultivation would have been 34 mm — already a considerable reduction compared to soil kept bare. By just planting hedges the losses would be reduced to 22 mm and for plots receiving light mulching with or without hedges, the losses would be negligible. The combined use of hedges every 10 m and light mulching at the foot of the hedge would certainly lead to an increase in soil depth over time.

4. Discussion

4.1. Soil losses

Even if the rains on Cabo Verde are a little more aggressive than in other semi-arid areas of the Sudan–Sahel countries, erosion remained similar when comparing results obtained in similar situations ($E_{\text{mean 1994–96}} = 16$ Mg/ha/year). In the Niger, Martin (1995) observed mean annual earth losses for cultivated land of 9 Mg/ha/year the maximum measured reaching 18.5 Mg/ha/year. In Burkina Faso, Roose (1996a, 1977) measured soil losses of 0.2–20 Mg/ha/year under cereals, peanuts and cotton growing on glacis with a slope of less than 3%. In northern Cameroon, Thebe (1987) reported erosion of
between 11 and 21 Mg/ha/year under cultivation. In Cabo Verde, the effect of the slope was compensated by good soil resistance to erosion. It should be noted, however, that the traditional system of agriculture used at Godim does not bring erosion below the acceptable threshold of 12 Mg/ha/year (Lal, 1977). Only anti-erosive practices (mulching and hedges) were able to limit the risks, improve biomass production and enable the depth of soil on the hillsides to increase.

Mannaerts (1986) notes that it is the topographical, soil and climatic conditions acting together which cause the heavy runoff and considerable erosion measured in the overspill of the retaining dykes of the very dry plateau edge areas of Cabo Verde. This was not borne out by the 4 and 100 m² plots on the very steep hillsides of the semi-arid zones (Smolikowski, 1997). Indeed, runoff was relatively infrequent on the cultivated regosols (yearly average runoff = 3.1%). These soils showed a very good resistance to erosion by water (erodibility index very low <0.02) in spite of the aggressivity of the rains which can be high (during a half-hour rainstorm, the intensity can be over 40 mm/h and the monthly aggressivity can reach over 150 international unit). No runoff was noted for showers of less than 40 mm and for an rain intensity during 30 mm (I₃₀) of less than 40 mm/h confirming the high porosity of the soils and their high penetrability. Sheet erosion was rare on the regosols where erosion by rills was greatly predominant. However, under traditional techniques of cultivation, the soil losses on the over 50% slopes were relatively low (about 15 Mg/ha/year) — rocks and resistant soils were found on these hillsides.

This study showed the efficiency of light superficial mulching of regosols with crop waste (1.5 Mg dry wt Mg/ha/year) on the upper sections of very steep hillsides. It keeps the surface of the soil intact, enhancing penetration of water, drastically reducing runoff and almost totally eliminating soil losses. Although the enhancement of penetration was very slight, only reaching 6% in the wettest years and 1% in dry years, it improved water storage in the soil by 5–10%. This improvement of the water storage gives rise to a greater amount of water being available for the plants during the wet periods but this was not the case for the dry periods when runoff hardly occurred at all. The effects of this improvement on root colonisation by the local strains of crop plant were not very strong. Whatever the amount of rain that fell, the root system remained superficial and concentrated in the first 25 cm of the soil.

4.2. Responding to crop requirements

The technique of mulching improved water storage in the soil more than the other treatments during wet years with relatively high runoff. The same did not occur in the dry season. However, considering the daily water consumption of the plant cover, few significant differences were seen, as reported by other authors (Al Darby et al., 1987; Whilhelm et al., 1987). The slight increase measured in water consumption did not affect the yield. The water requirements of the plants were rarely satisfied, even in wet years and the slight gain in water reserves noted on the mulched plot did not enable this deficit to be overcome. Moreover, a chronic water deficit seems to occur in maize during the most crucial phase of growth, i.e., flowering.

Overall, the main effect of mulching seems to have been on the production of weeds. This is the result of several factors including the numbers and the species of weed present. It also depends on the amount of water available at the time when the plants are in flower and on the availability of mineral salts which can also reduce flowering and grain production (Scopel, 1994). Weed production was, however, considered beneficial by the farmers since the weeds were always used as forage for the livestock (Barry et al., 1995).

5. A new soil and water conservation technique for steep slopes in Cabo Verde

The technique of light mulching plus the presence of hedges gave the best results both concerning erosion and total biomass production. The plant matter on the soil surface breaks the momentum of the rivulets of water that burst the bank and prevents the streams from gouging out rills all the way down the slope. This action stresses the importance of the hedge’s function.

Well looked after, the hedge should give better results as successfully done in northern Cameroon (Boli et al., 1993) and in Rwanda (Roosé and Ndayizigiye, 1996). So, it seems preferable firstly to dissipate the energy of the water in the rivulets which arise form the saturation of the surface layers and which flow down the steep upper hillsides, and secondly to improve...
water penetration in the glacies of the lower, less steep (5–25%) hillsides. Surface runoff only occurs on regosols when they are saturated. It was showed that the ground water reserves were very low but could not be improved drastically since penetration of the water is already excellent. It is therefore preferable to let the water continue to flow on the surface but to reduce the speed at which it does so and thus the erosion that it causes. A strip of crop residue resting at the foot of the hedge on the uphill side should give excellent results (Roose and Ndayizigiye, 1996). This would also have the advantage of requiring less plant residue (0.5 Mg ha−1 should be sufficient), reducing tilling time (sowing, hoeing) and the overall cost of farming the land. Hedges, planted at 8–10 m intervals along the contour lines would take up about 10% of the space available and livestock would consume the entire biomass production. These filtering hedges should be combined with an uphill plantation of fruit or forage trees that have lower water requirements (Ziziphus mauritiana, Parkinsonia aculeata) to provide a little litter and Congo pea bushes (lifetime 5 years) in the hedges to make full use of the deep ground water reserves unavailable to the crops (below 80 cm).

6. Conclusions

This study confirms that mulching, possibly associated with the plantation of hedge, reduces runoff and erosion on the steep hillsides of the Cabo Verde mountains. However, the ability to improve the use of the water resources by grain-producing crops in semi-arid regions is questionable. Plant material for mulching was only available and efficient after the wet years. The efficiency is therefore irregular and depends on the abundance of rainfall, weed production and the degree to which plant water and nutrient requirements are met at the critical moment when the crops are in flower.

Hedges of bushes without ditches or banks, planted on the flat and aided by mulching at the foot could contribute to the supply of fodder in the dry season as well as blocking rivulet runoff and erosion. The bushes, such as Congo pea and Leucaena, develop deeper roots than the annuals and continue to give leaf or grain when the maize or beans have been withered for a long time. This suggests that the ground water reserves are not exhausted after the tilled crops are over. The plantation of Leucaena hedges, successfully carried out elsewhere, could therefore be of interest for extensive livestock farming in Cabo Verde. In spite of its potential advantages, the success of this technique will depend on numerous socio-economic factors and its adoption by farmers is far from being a reality: it does require better weed control.

These results can be considered as a reference collection of data and tools for: (1) setting up regional maps of the potential rainfall and agricultural possibilities of an area; (2) considering the effects of the risks of runoff and erosion; (3) helping in establishing programmes for agricultural development in semi-arid mountainous regions, in particular, Cabo Verde.

References


