MAURITIUS RESEARCH COUNCIL

MEASUREMENT OF SOIL EROSION AND VALIDATION OF THE REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE) UNDER LOCAL CONDITIONS

Final Report

June 2003

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APPENDIX D
(Form 1050)

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MAURITIUS RESEARCH COUNCIL
FINAL REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Type the name of the MRC Scheme under which grant is made
   Unsolicited Research Grant Scheme

2. Award Dates From: **July 2000** To: **June 2003 (May 2006)**

3. Organisation and Address
   Mauritius Sugar Industry Research Institute (MSIRI)
   Réduit

   Team members**: D Ah Koon, F Ismael, R Ng Cheong & M Rughoo**

4. Award Number: **MRC/RUN - 008**

5. Project Title
   Measurement of Soil Erosion and Validation of the
   Revised Universal Soil Loss Equation (RUSLE) under local conditions

Mauritius Research Council

PART II – SUMMARY OF COMPLETED PROJECT

Soil erosion is a dynamic and natural process where soil exists in its natural environment under native vegetation; but man's activities can accelerate the process which will result in severe soil losses. Erosion by water involves the processes of detachment, transport, and deposition of soil particles. The erosion rate for a given site depends on the combination of several physical and management variables and can be predicted using models, e.g. the Revised Universal Soil Loss Equation (RUSLE), which would include factors such as rainfall-runoff erosivity, soil erodibility, slope length, slope steepness, cover-management and support practices.

A project was initiated in 2001 to study and measure soil erosion in five major soil groups of Mauritius and to validate the RUSLE under the local conditions. Two erosion plots, one with bare soil and the other planted with sugar cane, were established at five sites, namely Bel Ombre, Sans Souci, Le Val, St Félix and Etoile with soil groups of L, F, B, S and H respectively. For each plot, collecting devices for the bed-load, i.e. sediment moved along the soil surface, and the suspended load, i.e. sediment moved in suspension within run-off water, were installed as well as a pluviometer. All data were recorded through loggers operating with batteries and a solar panel.

The main findings of this project have been:

- Soil erosion varied significantly across sites and year. Highest soil loss (bare plots) was recorded at Bel Ombre and was followed by Sans Souci, Le Val, St Félix and Etoile with a mean of 37.6, 14.3, 9.5, 4.1 and 0.5 t ha^{-1} yr^{-1} respectively. Irrespective of year, the worst erosion measured from the bare plots was at Bel Ombre where an annual soil loss of 59 t ha^{-1} was recorded during the period July 2004 and June 2005. The proportion of soil erosion associated to 'cyclonic' events was found, on average, to vary between 45% and 68% depending on sites.

- The most important factors influencing erosion in the bare plots were soil erodibility and rainfall erosivity. Soil erodibility factors (K) were calculated for the five sites; a mean K factor of 0.14, 0.05, 0.08, 0.03 and 0.01 was obtained for Bel Ombre, Sans Souci, Le Val, St Félix and Etoile respectively. These values may be used for soil loss prediction for other sites with similar soil groups.

- The use of a rainfall simulator to determine the soil erodibility (K) factor was found inappropriate although it showed differences among the soil groups tested.

- Rainfall erosivity factor (R) has been found to vary across sites due to different energy values obtained from rainfall intensity and amount; Bel Ombre and Sans Souci have an erosivity factor of approximately 250, Le Val and St Félix of about 150, and Etoile with 41. In absence of good correlations between indices calculated for each site and their rainfall characteristics and altitude, etc., an R-value of 300 may be used to predict soil erosion in other parts of the island.

- Sugar cane reduced soil erosion by 80% to 99% depending on cane varieties and their stage of growth. Cane variety of the type R 570 was found to be more effective than varieties such as M 3035/66 because of a better canopy closure and amount of trash cover in ratoons.

- The RUSLE (RUSLE1) has been updated to give rise to RUSLE2 during the implementation of this project; the new version, RUSLE2, considers other factors and is based on daily computation compared to monthly data in the previous model. The validation of the RUSLE2, with the data available, may be considered as a future exercise, together with compilation of meteorological data for classifying different zones of the island into areas with varying (high, medium, low) rainfall erosivity indices.

- The main factors of the USLE, i.e. soil erodibility (K), rainfall erosivity (R) and crop-management (C) for sugar cane have been determined. The values obtained for these factors may explain the high amount of sediment load in some of our rivers and deposition in certain lagoons after a heavy rainfall event.

- With the rapid change in land use pattern, including replacement or abandonment of sugar cane cultivation, the outcome of this study highlights the need for an integrated national project to minimise soil erosion for ecological and environmental reasons, and for the sustainability of our agricultural lands. The benefits of such a project will be of invaluable importance to the national economy, particularly the tourism industry which is developing around some of the high erosion 'risk' areas.

PART III – TECHNICAL INFORMATION

1. INTRODUCTION

Soil erosion by water is a natural and dynamic process; the loss of soil is, however, influenced greatly by human activities through soil management/cultural practices. Every year, after heavy rainfalls or during cyclonic periods, our rivers are muddy indicating that significant amount of sediment is being moved from the arable land. It is deposited in non-agricultural areas or downstream and in the lagoons. If the soil loss is greater than the rate of soil formation, the fertility of the soil is affected, thus impairing the sustainability of our agriculture. The sediment load may carry pesticide residues and fertilizers; deposition of sediments may also jeopardise other economic sectors, e.g. tourism with sedimentation of the lagoons.

Soil erosion from sugar cane fields, representing more than 80% of our arable land, is considered to have been efficiently controlled due to the perennial characteristics of the crop and the agronomic practices adopted for its cultivation. However, several changes in the management of the crop have been introduced during the last decades with fields being ploughed more intensively and frequently, longer cane rows are used to increase field machine efficiencies and soil surface derocked. With the reduction in sugar prices, some sloping lands will be no longer cultivated and land use will shift to other crops or activities. To prevent soil losses through erosion, the different processes involved should be understood and the impact of the different associated factors or variables quantified in order to introduce proper soil conservation measures. Factors affecting erosion include climate, soil properties, topography, soil surface conditions and human activities.

The soil loss equation

Rainfall-induced soil erosion is basically a two-phase process. The first phase consists of detachment of individual soil particles from the soil mass while in the second phase the detached particles are transported by running water. When sufficient energy is no longer available to transport the particles, then a third phase comes into operation, namely, the deposition of the particles. Rain splash is the most important detaching agent. When raindrops strike the surface of a bare soil, the soil particles get detached and are then dispersed over several centimeters. Running water and wind also contribute to the detachment process. The loosened soil is then easily carried away by surface flow, if any, thereby causing soil loss. The erosion rate at a given site will depend on the combined effects of many physical and management variables.

The USLE/RUSLE is the most widely used erosion model for agricultural land (Renard *et al*., 1997). The empirical Universal Soil Loss Equation (USLE), a simplified expression of a complex set of interacting variables, has been developed and described in handbooks by Wischmeier and Smith (1965, 1978). It computes the average annual erosion expected on field slopes as

A = R x K x L x S x C x P

where

A Computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R (e.g. t $ha^{-1}yr^{-1}$).

R Rainfall-runoff erosivity factor - the rainfall erosion index.

K Soil erodibility factor – the soil-loss rate per erosion index for a specified soil as measured on a standard plot, which is defined as a 72.6 ft (22.1 m) length of uniform 9% slope in continuous clean-tilled fallow.

L Length factor – a ratio which compares the soil loss with that from a field of specified length of 22.1 m.

S Slope steepness factor – a ratio which compares the soil loss with that from a field of specified slope (9% slope).

C Cover or cropping-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P Conservation or support practice factor – the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope.

The USLE which was developed to predict soil erosion by water and tested successfully in many countries, has been revised twice. The Revised-USLE (RUSLE1) was disseminated by the U S Department of Agriculture (USDA) – Agricultural Research Service (ARS) and USDA-National Resources Conservation Service (NCRS) in 1992 and, as from January 2005, a new version (RUSLE2) is available from the USDA-ARS website (ARS, 2005). The USLE computed soil loss by the equation A = RKLSCP, where an average annual value was calculated for each factor. With the exception of the interaction between the R factor and the C factor, no interaction between the other

USLE factors was considered. The temporal scale used in computing the C factor was a crop stage period over which cover-management conditions were assumed to be an average value for that period. RUSLE1 considered additional interactions between the K and R factors and a partial interaction between P and R. Also, the temporal time scale used in RUSLE1 was half month, or less if an operation occurred within a half month. This approach allowed a 'paper version' of RUSLE1 to be used.

However, while the mathematical techniques used in USLE and RUSLE1 were powerful and allowed paper versions, they were mathematically inaccurate in several situations. The proper mathematical procedure is to compute a daily value for each factor, compute a daily soil loss value, and add up the individual daily values to obtain a final value for the rotation. RUSLE2 uses this mathematical procedure, which is a major improvement from both the USLE and RUSLE1 (NCRS, 2002). Although RUSLE2 computes an average annual value for the standard USLE/RUSLE1 factors, those values are not used to compute soil loss. In fact, multiplication of those values, as was done in the USLE and RUSLE1, will not give the same RUSLE2 soil loss value.

Irrespective of the differences between the two versions, the erosion model remains a very useful tool to predict the average soil erosion for various combinations of cropping systems, management techniques, and erosion control practices on any particular site. The predicted value may be compared with the 'soil-loss tolerance' which is the maximum rate of soil erosion that can occur and will still sustain a viable crop productivity. The soil-loss tolerance value is related to the original depth of topsoil and rate of soil formation. Comparison between the predicted and the soil-loss tolerance values will provide guidelines for the adoption of erosion control practices within specified limits.

With the exception of the MSIRI/ACIAR/QDNRM project at Valetta, no scientific study on soil erosion in Mauritius has been undertaken or reported. The main objective of the Valetta project was to study the movement of agrochemicals from sugar cane fields and the data recorded has permitted the computation of some soil loss values for that site. As climate, soil type, topography, and other management practices vary across the island, data from Valetta should not be extrapolated island-wide and this is why an erosion model would be of major importance. The RUSLE may be a very useful tool but needs to be validated after all the factors involved have been studied and quantified under local conditions. A validated model (RUSLE) or alternative model can be used:

- To predict soil losses for different sites with different agronomic practices or land uses, e.g. soil tillage practices, date of planting, length of cane rows, alternative crops, etc.
- To design conservation measures where soil loss exceeds soil loss tolerance value.
- In farm planning, to decide on length x slope of fields or type of conservation measures to minimise soil loss.
- To establish erosion risks areas (erosion risk maps) and provide guidelines to minimise soil loss and pollution.
- To predict and use soil loss values in Environment Impact Assessments (EIA).
- To indicate the need for any legislation concerning soil conservation.

This project which has been partly funded by the Mauritius Research Council under the 'Unsolicited Research Grant Scheme' was initiated by the MSIRI in 2000 and had a multi-disciplinary approach through collaboration among several research departments. The main objectives of this project were:

- to measure soil loss in the five major soil groups where erosion is known to occur
- to estimate values of the different parameters influencing soil erosion (e.g. soil erodibility and erosivity factors) under local conditions and validation of the RUSLE
- to study soil erosion from sugar cane fields

The results of this research study will pave the way for the soils in Mauritius to be managed on a sound scientific basis; reduction of soil erosion will definitely contribute to a more sustainable agriculture and a safer environment as stipulated by the **Environment Protection Act 1991**:

To provide for the protection and management of the environmental assets of Mauritius so that their capacity to sustain the society and its development remains unimpaired and to foster harmony between quality of life, environmental protection and sustainable development for the present and future generations; more specifically to provide for the legal framework and the mechanism to protect the natural environment, to plan for environmental management and to coordinate the inter-relations of environmental policies and enforcement provisions necessary for the protection of human health and the environment of Mauritius.

2. MATERIALS AND METHODS

Soil erosion is expressed as the amount (t ha^{-1} yr^{-1}) of soil loss from a standard plot, which is defined as a 72.6 ft (22.1 m) length of uniform 9% slope in continuous clean-tilled fallow. Using erosion plots with such length and slope, and maintaining standardised cover-management and conservation-support practice factors, the number of variables in the RUSLE to estimate annual soil loss would then be reduced to only two factors, namely soil erodibility (K factor) and rainfall erosivity (R factor). Using this approach, erosion or runoff plots were established in the field to determine the effects of different agroclimatic and management practices on the rates of runoff and soil loss from the five major soil groups in Mauritius. At each site, two erosion plots were established: one plot was left bare while the other was planted with sugar cane.

2.1 SOIL GROUPS AND SITE IDENTIFICATION

2.1.1 Soil groups of Mauritius

In the 1:100 000 Soil Map of Mauritius (Parish and Feillafé, 1965), the soils of the island are divided into 13 soil groups. The most important ones in terms of area under cane fall under the Latosol and Latosolic classification. The Latosols, which are relatively old soils and have low stone contents, are represented by three great soil groups, namely Low Humic Latosol (L), Humic Latosol (H) and Humic Ferruginous Latosol (F). The Latosolic order is represented by two great soil groups, namely the Latosolic Reddish Prairie (P) and the Latosolic Brown Forest (B) soils. These are young soils and have high stone contents.

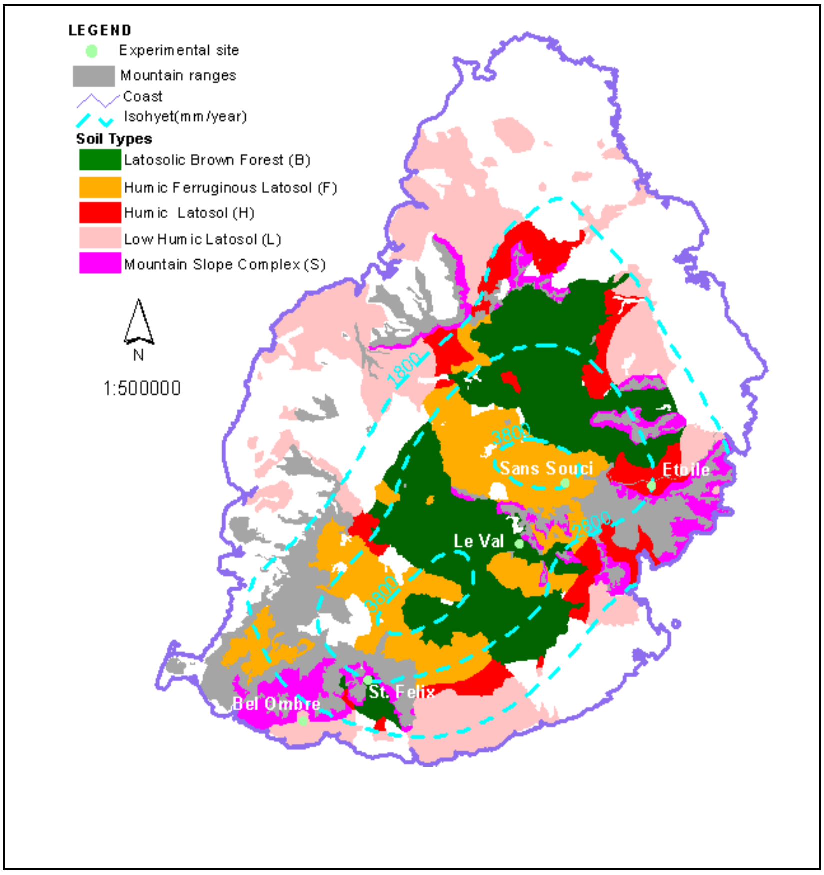
The L, H and F soil groups cover 16.4%, 5.2% and 11.4% of the total area of the island respectively while the P and B soils cover 19.9% and 16.5%. Of these five main soil groups, the P soil is the only one to occur mainly in the sub-humid zone and with little risk for soil erosion. The other four groups can be found in the humid to super-humid zone and are therefore in the higher erosion risk area, even though a fair proportion of the L soil is also found in the sub-humid zone.

The remaining eight soil groups of Mauritius are classified as Grey Hydromorphic, Dark Magnesium Clay, Low Humic Gley, Ground Water Laterite, Mountain Slope Complex, Alluvial Soil, Regosol and Lithosol. Of these, the one that is deemed most at risk to erosion is the Mountain Slope Complex (S), which occurs on the mountain slopes as its name indicates.

2.1.2 Site identification

Five sites were identified with respect to soil types and slopes at Bel Ombre, Le Val, Sans Souci, St Félix and Etoile (Table 1/Fig 1).

Fig 1. Sites for erosion plots and their soil groups



As the soil had to be recently ploughed, the fields were chosen where cane was being planted at time of project implementation. Table 1 summarizes the characteristics which are pertinent at the five sites.

Table 1. Characteristics of the five sites

Site	Soil group*	Altitude (m)	Average annual rainfall (mm)	Cane variety planted	Date of planting
Bel Ombre	L2	59	1800	R 570	7.8.2000
Etoile	H2	170	3100	M 3035/66	13.4.2001
Le Val	B2	324	3225	M 52/78	9.3.2000
St Félix	S/B1	198	2500	R 570	8.8.2000
Sans Souci	F1	315	3800	M 3035/66	15.8.2000

* Source: Parish and Feillafé (1965)

2.2 ESTABLISHMENT OF EROSION PLOTS AND MEASURING DEVICES

2.2.1 Topographic survey of each site

At each site, the two erosion plots, each 22.1 m long x 10 m wide with a linear slope of about 9%, were chosen through two surveys. The first one consisted of surveying (GPS surveying equipment) the block or part of the field; the data was used to generate a digital terrain model (DTM) of the site for identification of areas with the required size and slope (9%). The second survey consisted of staking-out and cross-checking slopes at the identified points in the field; the equipment used for this purpose was an Abney level (Fig 2).

Fig 2. Staking-out erosion plots and checking for slope

2.2.2 Demarcation of erosion plots

At each site, the experimental area comprised of 2 plots of 221 m^2 each. Each plot was isolated from the other and also from the remainder of the field by galvanized metal sheets 400 mm wide, driven below ground such that 200 mm protruded above the soil surface (Fig 3). The aim was to divert unwanted surface flows away from the experimental plots.

Fig 3. Isolating erosion plots with metal sheets

2.2.3 Sediment/water collecting troughs

At the lower end of each plot, metallic troughs, 8.70 m long x 400 mm wide x 220 mm deep were installed to collect all water and soil moving from the surface of the plot. These troughs, made locally using galvanized metal sheets had metal covers to prevent water from splashing directly into the troughs. The slope of the troughs was set at approximately 1%. During erosion events, the coarser fraction of the sediment, known as bed load, deposited in the troughs.

2.2.4 Collecting pit/Excavation pit

Water flowing from the troughs contained suspended sediments. Flow-measuring devices were installed in pits of size 1.2 m x 1.8 m x 1.8 m dug at the distal end of the troughs. These pits were walled by concrete blocks and were designed to house the separators, tipping buckets and so on (Fig 4). An outlet was also created to evacuate excess water in high rainfall events.

Fig 4. Construction of pit for installing collecting devices

2.2.5 Water (suspended load) measuring device

A metal separator was placed at the end of each collecting trough to divert water into the tipping bucket (Fig 5). Each pit was equipped with one manifold (a flow-controlling device), one tipping bucket of 7 L capacity and a container fitted with a splitter (a plastic pipe with several 3-mm wide slots) to collect about 15 mL of water at each tip of the bucket. The number of tips and thus volume of water (runoff) is obtained by placing switches on the tipping buckets and recording them through a Boss-logger.

Fig 5. Tipping bucket showing one tip

2.2.6 Rainfall data recorder

As rainfall intensity is a very important parameter for erosion assessment, a tipping-bucket type rain-gauge (pluviometer) was fixed at each site on a metal pole approximately 4 m high (Fig 6). The data from the pluviometers were recorded on the Boss-logger placed in a metal box at the base of the pole.

Fig 6. Pluviometer mounted on 4 m pole at Etoile

2.2.7 Data-loggers and energy supply

Boss-loggers and solar panels were imported from Australia to be installed at each site. The solar panels for recharging the batteries *in situ* were installed at the top of the pole next to the pluviometer whereas the battery and logger were housed in a metal box for their safety. The data from the two tipping buckets (one bare and one cane plots) and the pluviometer stored in the Boss-logger were downloaded regularly on a portable computer (Palmtop – Hewlett Packard 200LX) (Fig 7).

Fig 7. Palmtop connected to Boss-logger for downloading data

2.3 DATA COLLECTION AND PROCESSING

Apart from the data downloaded from the Boss-logger (number of tips from the pluviometer and from two tipping buckets), the soil collected in the troughs was weighed in the field and sampled for dry weight estimation of the bed load by oven drying (Fig 8). The suspended load from the water samples was calculated after evaporation of the water. The total amount of water flowing from each plot (surface runoff) was obtained from the number of tips recorded on the logger.

Data recording was carried out on a regular basis (fortnightly), the frequency being higher during the rainy season. After each major event, e.g. cyclone, the sites were visited and data recorded as soon as possible.

Fig 8. Collecting eroded soil from troughs

As the RUSLE is an annual soil loss model and the rainy season in Mauritius starts in December and ends in May, all data were compiled over a 12-month period, starting 1 July and ending 30 June of the following year. Data were collected at the five sites during four years (1 July 2001-30 June 2005); collection of data was extended for a further one-year period (ending June 2006) at three sites (Bel Ombre, Sans Souci and Le Val).

2.4 MANAGEMENT OF EROSION PLOTS

One plot at each site was planted with sugar cane using standard cultural practices and according to specifications of the RUSLE. The erosion plots, including bare plots were kept weed-free throughout the study period by regular application of pre- and post-em herbicides. The cane plots were harvested in accordance with the maturation of the cane variety grown. Post-harvest trash management consisted of lining trash on alternate interrows. No cultivation or mechanical weeding was practiced in the cane plots after planting.

2.5 DETERMINATION OF SOIL ERODIBILTY THROUGH RAINFALL SIMULATION

In addition to the five pairs of erosion plots, a rainfall simulator was used to study soil erosion parameters under controlled conditions at Bel Ombre, Sans Souci and Le Val; the main objective was to investigate the possibility of using the simulator to determine the soil erodibility factor.

The simulator was installed in the bare plot at each site (Fig 9); it was mounted to 'spray' two plots (two replicates) measuring 2.1 m x 0.8 m each with the longer side placed in the direction of the slope (9%). Four rainfall intensities were simulated at Bel Ombre and Sans Souci whereas, at Le Val, only three intensities were tested. Each simulated event lasted 30 minutes. The runoff and soil loss were collected in bowls and sieved to measure the bed load; the remaining suspension was thereafter sub-sampled for determination of the suspended load.

Fig 9. Rainfall simulator used to measure soil loss from bare plot

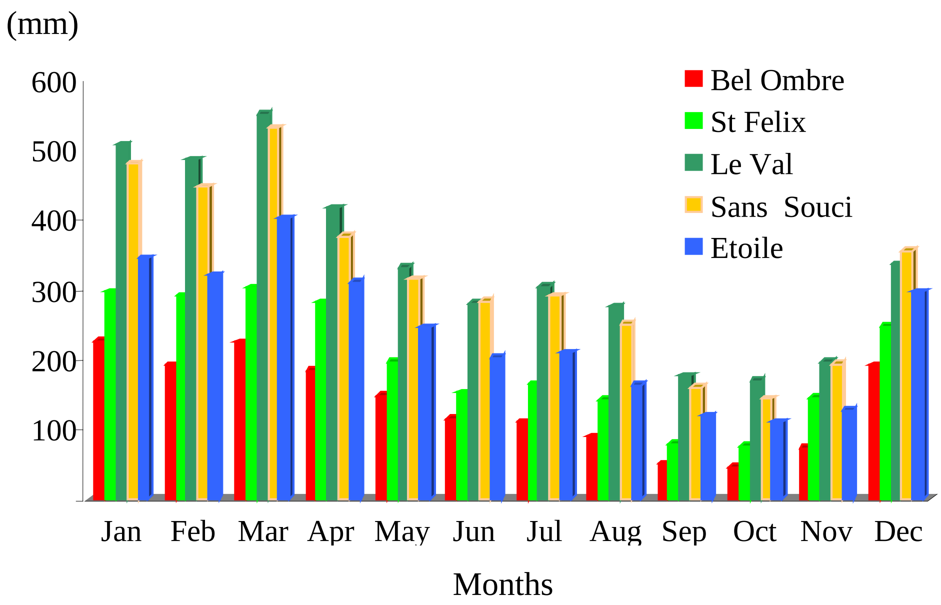
3. RESULTS AND DISCUSSION

3.1 RAINFALL AND RUNOFF

3.1.1 Rainfall distribution

Irrespective of sites, the period December to May receives the highest amount of rainfall (Fig 10). In fact, approximately 70% of the annual rainfall is recorded during that period.

Fig 10. Mean monthly rainfall distribution (mm) at the five sites (1951-1980)

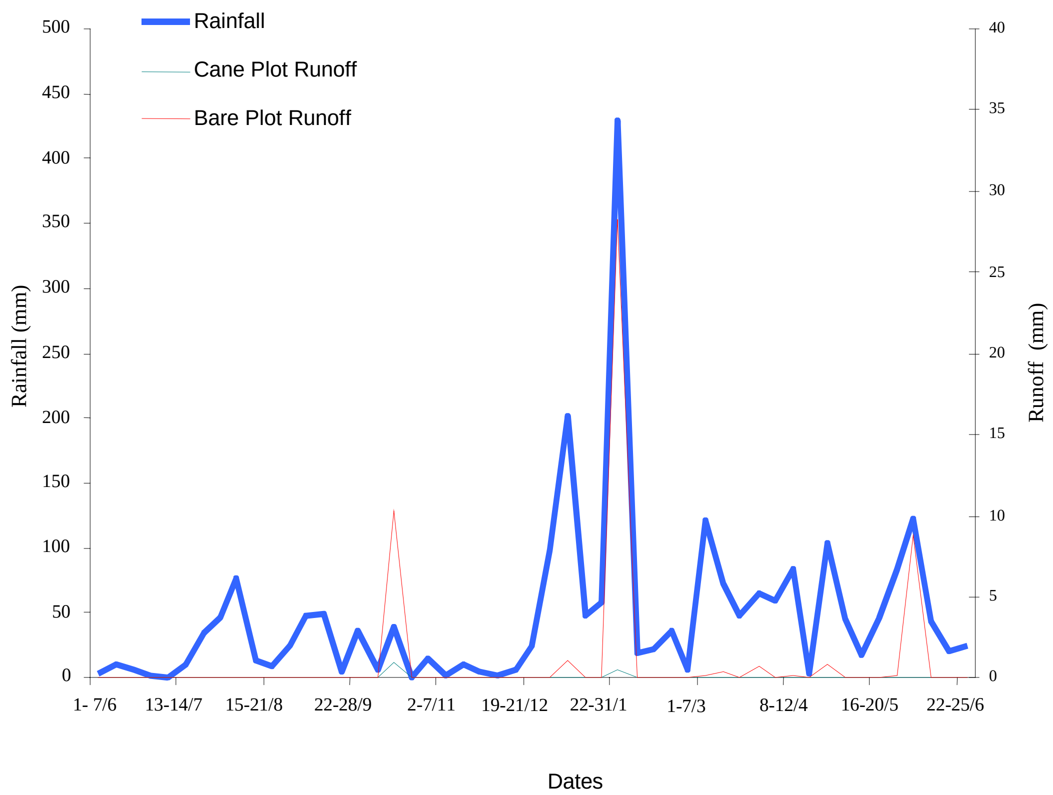


Source: Padya, B M (1984)

3.1.2 Peak runoff

In general, peak runoffs in the erosion plots occurred during the high rainfall periods; a few runoff events were also recorded in June/July at Bel Ombre, Sans-Souci and Le Val. The runoffs were also found to peak out during cyclonic events, e.g. at Bel Ombre, a maximum runoff was associated with cyclone Dina on 20 to 22 January 2002 (Fig 11).

Fig. 11 Rainfall and Runoff at Bel Ombre

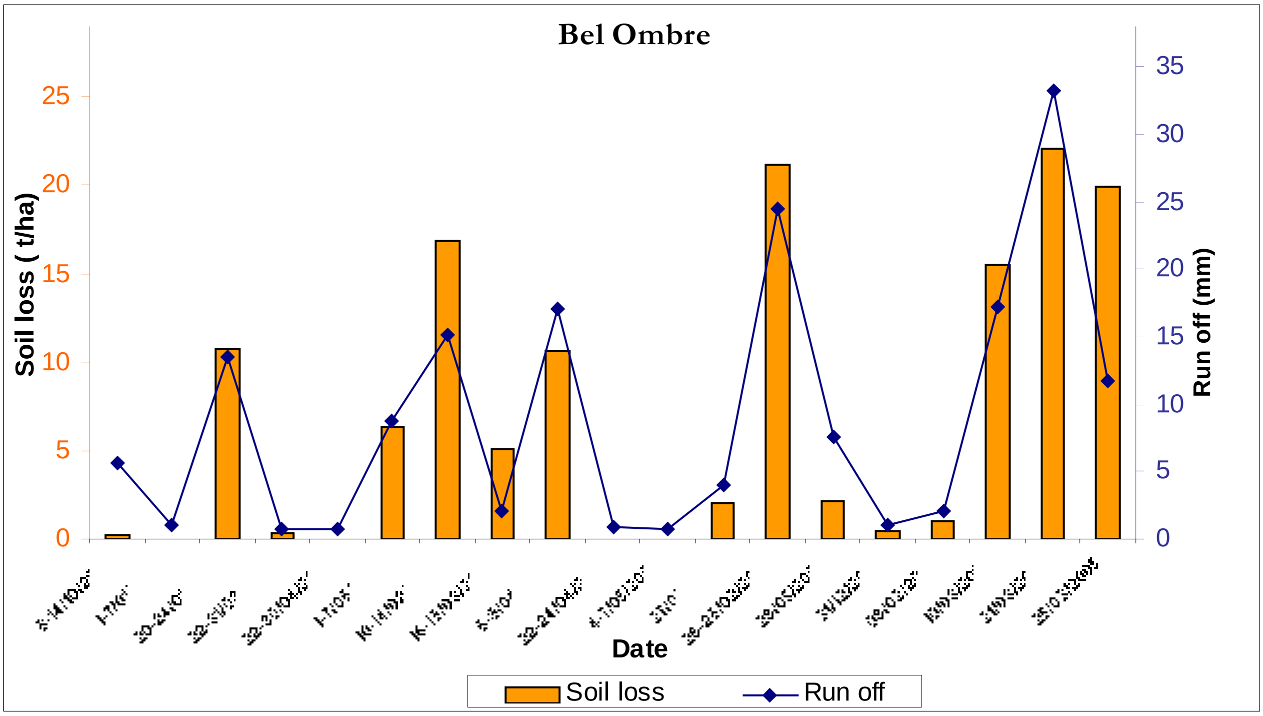


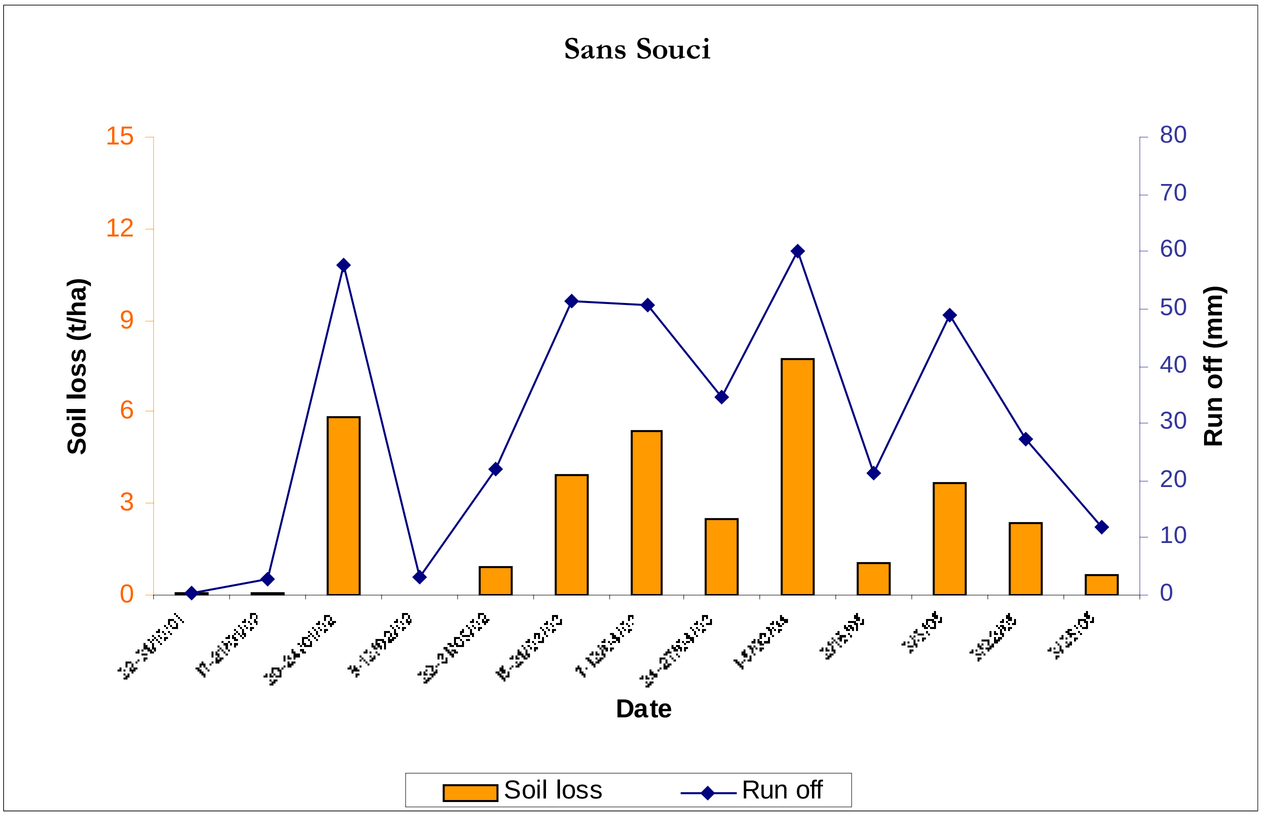
Measurements have also confirmed that runoff was dependent on the soil humidity keeping the soil almost saturated and infiltration at its lowest rate.

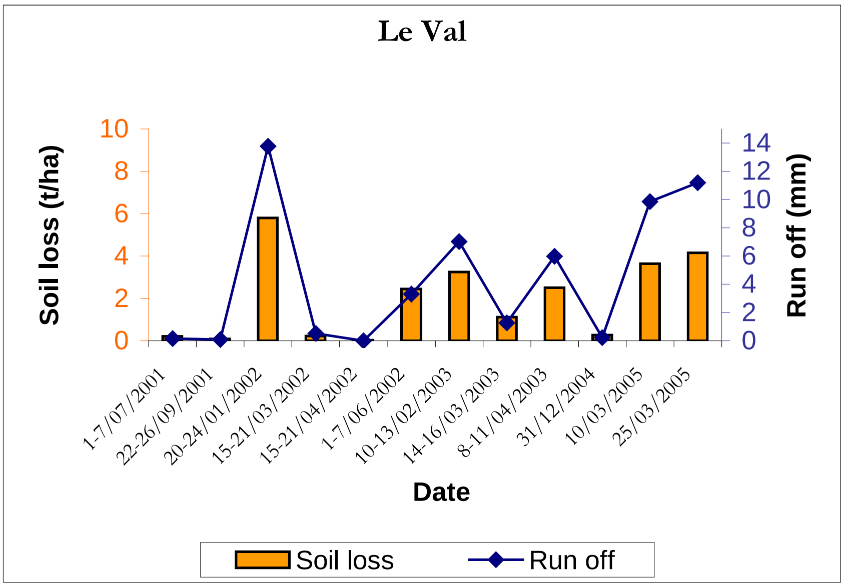
3.1.3 Runoff v/s Erosion

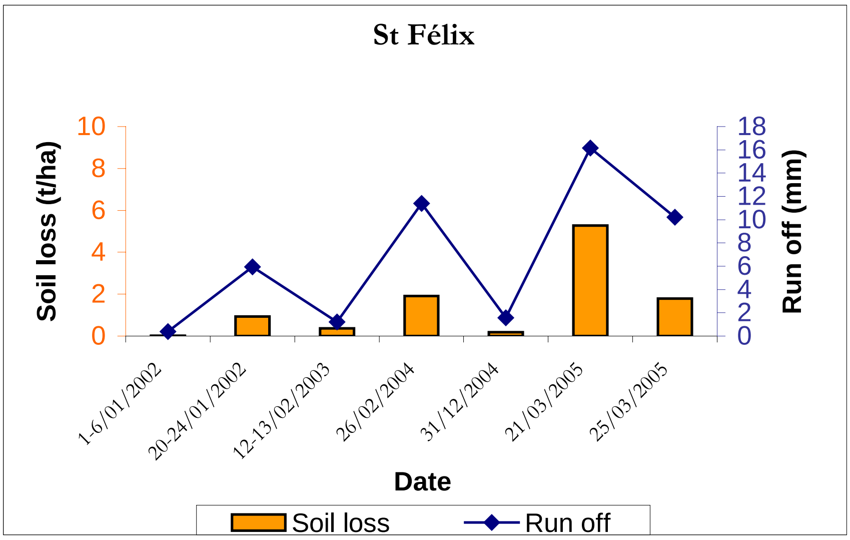
At all sites, erosion was found to be closely associated with runoff (Fig 12). The amount of soil carried was found to increase with bigger runoffs, a linear regression with r^2 of 81.8%, 89.6%, 96.1% and 85.4% being observed between soil loss and runoff at Bel Ombre, Sans Souci, Le Val and St Félix, respectively.

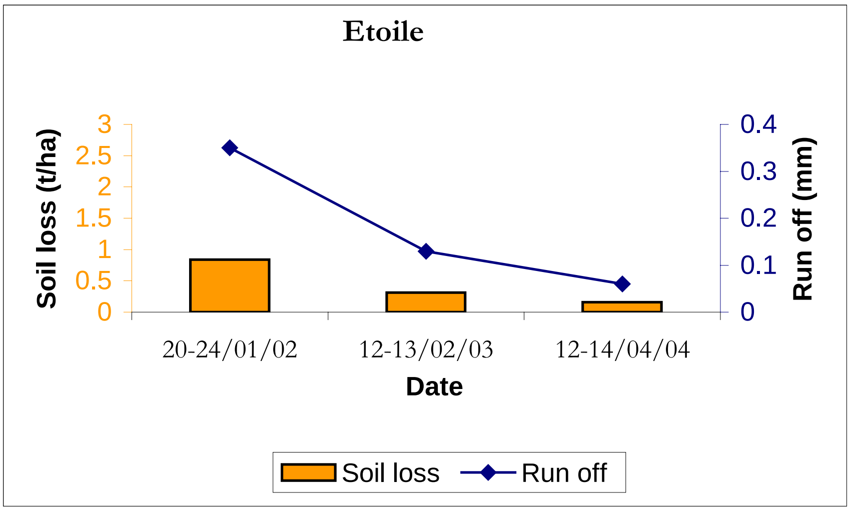
Fig 12. Runoffs and soil loss at Bel Ombre, Sans Souci, Le Val, St Félix and Etoile






Le Val
Soil loss (t/ha)
Run off (mm)
10
8
6
4
2
0
14
12
10
8
6
4
2
0
1-7/07/2001
22-26/09/2001
20-24/01/2002
15-21/03/2002
15-21/04/2002
1-7/06/2002
10-13/02/2003
14-16/03/2003
8-11/04/2003
31/12/2004
10/03/2005
25/03/2005
Date
Soil loss
Run off


St Félix
Soil loss (t/ha)
Run off (mm)
10
8
6
4
2
0
18
16
14
12
10
8
6
4
2
0
1-6/01/2002
20-24/01/2002
12-13/02/2003
26/02/2004
31/12/2004
21/03/2005
25/03/2005
Date
Soil loss
Run off


Etoile
Soil loss (t/ha)
Run off (mm)
3
2.5
2
1.5
1
0.5
0
0.4
0.3
0.2
0.1
0
20-24/01/02
12-13/02/03
12-14/04/04
Date
Soil loss
Run off

3.2 SOIL LOSS

3.2.1 Major erosion events

The number of events when soil loss was recorded in the troughs or as suspended load varied across sites; a significantly higher number of events occurred at Bel Ombre, Sans Souci and Le Val compared to the two other sites (Table 2). These differences could not be explained by the rainfall factor alone as St Félix and Etoile received more rainfall than Bel Ombre.

Table 2. Number of major (soil erosion) events at the five sites

Periods	Number of events				
	Bel Ombre	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	6	6	6	2	1
July 2002-June 2003	5	5	5	2	1
July 2003-June 2004	4	3	3	2	2
July 2004-June 2005	5	6	3	4	-
July 2005-June 2006	3	3	3	-	-

During the five years of study, eight events were linked with tropical depressions/cyclones (Table 3). Four of them, namely Dina, Gerry, Hennie and Diva, caused significant amount of soil loss at all sites.

Table 3. Cyclonic events causing soil loss at the different sites

Cyclone	Date	Bel Ombre	Sans Souci	Le Val	St Félix	Etoile
Cyprien	1–2 Jan 2002	*	*	-	*	-
Dina	17-24 Jan 2002	*	*	*	*	*
Ikala	25–29 Mar 2002	*	-	-	-	-
Gerry	8-15 Feb 2003	*	*	*	*	*
Kalunde	8-16 Mar 2003	*	*	*	-	-
Manou	3-10 May 2003	*	*	*	-	-
Darius	2 Jan 2004	-	*	*	-	-
Hennie	24 Mar 2005	*	*	*	*	-
Diva	3-5 Mar 2006	*	*	*	N/A	N/A

* soil loss

3.2.2 Soil loss from bare plot

The annual soil loss registered from the bare plot at the five sites is given in Table 4; no data was recorded at Etoile and St Félix after June 2004 and June 2005 respectively as the functioning loggers and pluviometers have been moved to the other sites where erosion was more important. The soil loss varied both across the years and sites; over the five-year period, Bel Ombre with a mean erosion rate of 37.6 t ha^{-1} yr^{-1} recorded the highest soil erosion followed by Sans Souci, Le Val, St Félix and Etoile. At the latter site, soil erosion did not exceed 0.8 t ha^{-1} yr^{-1}.

Table 4. Annual soil loss from bare plots

	Soil loss (t ha^{-1} yr^{-1})				
Periods	**Bel Ombre**	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	17.7	6.9	8.8	0.9	0.8
July 2002-June 2003	32.7	22.0	7.8	0.4	0.3
July 2003-June 2004	41.2	15.9	8.4	6.5	0.4
July 2004-June 2005	59.2	12.5	8.1	8.8	-
July 2005-June 2006	37.1	3.0*	14.5	-	-
Mean	37.6	14.3**	9.5	4.1	0.5

* Soil loss relatively low as weeds were present during major event
** Mean of four years (2002 – 2005)

The total erosion (Table 4) consists of soil loss as bed load and suspended load. The amount as suspended load was found to be relatively low at the three sites with the higher erosion rates (Table 5). At St Félix and Etoile, where erosion was low, the relative proportion of suspended load was more important.

Table 5. Amount of soil erosion (% of total soil loss) as suspended load

	Suspended load (%)				
Periods	**Bel Ombre**	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	4.1	5.3	2.1	69.4	4.5
July 2002-June 2003	0.6	1.4	1.5	8.1	3.2
July 2003-June 2004	0.2	1.4	1.3	0.2	100
July 2004-June 2005	0.4	0.6	0.6	0.3	-
Mean	1.3	2.2	1.4	19.5	35.9

The proportion of soil erosion associated with 'cyclonic' events was found, on average, to vary between 45% and 68% depending on sites (Table 6). Within the same cyclonic events, the amount of rainfall was found to vary across sites; e.g. the lower rainfall recorded during passage of cyclone Darius at Bel Ombre in January 2004 explains the relatively lower soil erosion associated with that event.

Table 6. Amount of soil erosion (% of total loss) associated with 'cyclonic' events

Periods	Soil loss (%)				
	Bel Ombre	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	61.0	84.5	65.8	98.2	100
July 2002-June 2003	51.8	46.5	41.9	94.5	100
July 2003-June 2004	4.9	15.8	40.9	0	0
July 2004-June 2005	71.3	24.1	51.2	80.9	-
July 2005-June 2006	38.4	73.9	44.3	-	-

3.2.3 Soil loss from cane plot

Erosion from the cane plots was recorded simultaneously as in the bare plots at each site. The highest soil loss from the cane plot was recorded at Sans Souci; i.e. 4.9 t ha^{-1} during 2002-2003 and 2004-2005 periods. In general, soil loss from the cane plots was significantly reduced compared to the bare plot; the presence of cane decreased erosion by 80% to 99% (Table 7). The relative percentage of soil loss from the cane plots was higher at Sans Souci and Etoile.

Table 7. Soil loss from the cane plot at 5 sites

Periods	Annual soil loss (t ha^{-1})				
	Bel Ombre	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	1.9	1.0	0.9	0.1	0.2
July 2002-June 2003	2.5	4.9	2.5	0.1	0.1
July 2003-June 2004	3.6	1.1	0.8	0.1	0.02
July 2004-June 2005	0.4	4.9	0.3	0.0	-
July 2005-June 2006	0.0	0.4	0.9	-	-
Mean	**1.7**	**2.5**	**1.1**	**0.1**	**0.1**
% of bare plots	4.5	20.5	11.4	1.3	14.8

3.3 EROSIVITY OF RAINFALL

Rainfall is the major climatic variable affecting runoff and transport of sediments. Erosion by rainfall impacting on the original soil is called detachment while that of the deposited layer is referred to as re-detachment. Detachment and re-detachment depend on the rainfall intensity (Hairsine and Rose, 1991). The rates of entrainment and re-entrainment depend on the sheer stresses exerted by overland flow on the soil surface, which is the source power for flow-driven erosion processes and is called stream power by Bagnold (1977). The amount and intensity of rainfall will affect the rate of soil detachment and hence the quantity of soil to be moved by the flowing water (runoff).

The potential ability of a rainfall to cause erosion is defined as its erosivity. Erosivity is a measure of the forces actually applied to the soil by the erosive agents of raindrop impact, water drops falling from plant canopy, and surface runoff. Erosivity has two components; the inherent erosivity determined by the rainfall at a location and the infiltration of the soil based on inherent soil properties. The other component of erosivity is that which management can change such as the infiltration rate.

Erosivity is expressed as an index based on its kinetic energy (KE). The erosivity of a rainstorm is a function of its intensity and duration.

According to Wischmeier and Smith (1978),

$$KE = 11.87 + 8.73 \log_{10} I$$

where KE is the kinetic energy ($J/m^2/mm$) and I is the rainfall intensity (mm/hr)

Wischmeier and Smith (1978) found that soil loss could be related to a compound index of kinetic energy and the maximum 30-minute rainfall intensity, which is known as the EI_{30} erosivity index.

From the rainfall data recorded during each storm, the R factor for that event was calculated by converting the amount and rainfall intensity into energy values. The various R factors from individual storms were then summed to give an annual value (July to June) for each site (Table 8). The mean erosivity index for Bel Ombre was found to be higher than the other sites. The relatively lower erosivity index for Sans Souci compared to Bel Ombre may be explained by the higher rainfall intensities (e.g. I_{30}) recorded during individual events at the latter site although the total rainfall at Sans

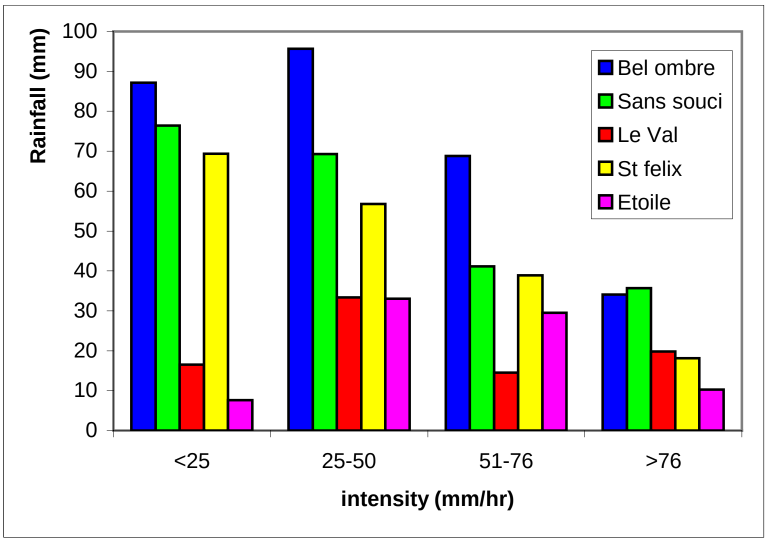
Souci was higher. Likewise, the index at Le Val has been influenced by a relatively lower intensity and number of events per year.

Table 8. Erosivity indices calculated from energy values of rainfall during events

	Erosivity index				
Periods	**Bel Ombre**	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	328	245	73	143	73
July 2002-June 2003	253	552	250	71	22
July 2003-June 2004	265	131	103	176	29
July 2004-June 2005	263	51	71	255	-
Mean	277	245	124	161	41

The much lower indices (Table 8) for St Félix compared to Bel Ombre and for Etoile in comparison with Sans Souci, locations which are only a few kilometres apart, may be explained by the difference in number of events (soil loss recorded) and in the amount of rainfall during each event. This may be illustrated from data recorded between July 2001 and June 2002, when the amount of rain falling during storms, irrespective of intensity were found to be highest at Bel Ombre followed by Sans Souci, St Félix, Le Val and Etoile (Fig 13). These results showed that the total rainfall during events were higher at Bel Ombre than St Félix although the mean annual rainfall is lower at the former site. Similarly, Sans Souci recorded more than twice the amount of rainfall associated with erosion events than Etoile.

Fig 13. Rainfall intensity and amount for the period July 2001 to June 2002



All rainfalls are not erosive; Hudson (1992) considered rainfall with intensity 25 mm per hour as a practical threshold separating erosive and non-erosive rain. However, within an individual erosive event, lower intensities should also be considered as it may contribute to runoff. In this study, as only rainfall events causing detachment and transportation were considered, the lower intensities within those events were included in the estimation of R factor.

Although the R factor in the RUSLE1 is the sum of erosivity indices of erosive events over a one-year period, the mean erosivity indices recorded during cyclonic events were 56% to 230% higher than for non-cyclonic ones (Table 9). The high erosivity indices during cyclonic events caused more erosion irrespective of sites; during 2001 – 2002, cyclone Dina with erosivity indices of 159, 189, 62, 136 and 73 caused 10.8, 5.8, 5.8, 0.9 and 0.8 t ha^{-1} of soil loss at Bel Ombre, Sans Souci, Le Val, St Félix and Etoile respectively. Likewise, for the period 2002 – 2003, soil loss associated with cyclone Gerry was 16.9, 10.2, 3.3, 0.4 and 0.3 t ha^{-1} for erosivity indices of 113, 258, 117, 62 and 22 at Bel Ombre, Sans Souci, Le Val, St Félix and Etoile, respectively. The relative differences among sites may be associated with other variables in the bare plots.

Table 9. Influence of cyclones on erosivity index

Site	Erosivity index	
	Non cyclonic	**Cyclonic**
Bel Ombre	47.4	74.0
Sans Souci	34.9	81.9
Le Val	21.6	47.5
St Félix	47.1	90.6
Etoile	14.4	47.5

3.4 SOIL ERODIBILITY

The resistance of the soil to both detachment and transport is defined as its erodibility. Although soil resistance to erosion depends partly on topographic position, slope steepness and cultural practices, e.g. tillage, the properties of soil are the important determinants. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic matter and mineral contents.

3.4.1 Estimation of soil erodibility

The soil erodibility of a site may be estimated by using a nomograph developed by Wishmeier and Smith (1978). Soil properties used in the nomograph include amount (%) of silt and sand, % organic matter, soil structure and soil permeability. From soil analysis data available for each site, an estimate of the erodibility was obtained from the nomograph. The estimated K factor for the different sites was found to vary from a highest value at Le Val to the lowest one at Bel Ombre (Table 10). As the maximum soil organic matter in the nomograph is 4%, an accurate estimate was only possible for Bel Ombre, the erodibility values for the other sites have in all likelihood been over-estimated as their organic matter content was higher than 4%.

Table 10. Soil properties and soil erodibility estimated from nomograph

Sites	% Clay	% Silt	% Sand	% O.M	Estimated K
Bel Ombre	77.4	15.6	7.0	4.0	0.10
Sans Souci	29.7	32.4	37.9	6.9	0.21
Le Val	21.7	42.5	35.8	13.0	0.26
St Félix	35.1	37.2	27.7	11.0	0.16
Etoile	35.0	36.9	28.1	6.3	0.18

3.4.2 Calculated soil erodibility

From the RUSLE1, the soil erodibility for the bare erosion plots would be:

$$K = A/R$$

Where A = Annual soil loss and R = rainfall erosivity

From soil loss data and the rainfall erosivity values at the each site, a soil erodibility (K) value was calculated for each year (Table 11). The results showed that the K value varied across the years at all sites except at Etoile. This may be explained by the fact that the K is not a pure measure of soil erodibility as an intrinsic soil property. The K values also encompass erosivity effects created by how soil properties affect runoff. This is considered in the RUSLE2 where variation in K is not only site dependent, but is also affected by the sequence of monthly temperature and precipitation at the location.

Table 11. Soil erodibility (K) calculated from soil loss and rainfall erosivity values

Periods	Erodibility factor				
	Bel Ombre	Sans Souci	Le Val	St Félix	Etoile
July 2001-June 2002	0.05	0.03	0.12	0.01	0.01
July 2002-June 2003	0.13	0.04	0.03	0.01	0.01
July 2003-June 2004	0.16	0.12	0.08	0.04	0.01
July 2004-June 2005	0.23	0.24	0.11	0.03	-
Mean (weighted)	0.14	0.05	0.08	0.03	0.01

The mean (weighted) K value of Bel Ombre was found to be quite similar to that estimated from the nomograph. The calculated mean K values for the other sites were found to be significantly lower to their respective values estimated from the nomograph. These differences may be partly explained by the lower organic matter values (maximum 4%) used by nomograph for the estimation.

Although the soil at Sans Souci was found to be less erodible than at Le Val due to its lower silt and higher clay fractions, the annual soil loss was higher at that site as a result of the higher rainfall erosivity. Likewise, soil erodibility values at St Félix and Etoile were found to be very low. The presence of rock fragments or rocks, a common feature in B and P soils, on the soil surface, e.g. at St Félix, may have influenced the K factor. However, the effects of rock fragments on the soil surface are computed in the cover-management factor.

3.5 COVER-MANAGEMENT FACTOR (C)

Soil erosion also depends on ground cover. The presence of a vegetative cover or mulch helps to reduce erosion by intercepting incoming raindrops and thus absorbing their kinetic energy. This results in a reduction of the energy available for the detachment of soil particles. Soil erodibility concerns both overland flow and the detachment of soil material. During an event, the rainfall supplies the erosive agent (water), but the soil determines how much overland flow actually occurs. The erosive power of overland flow is largely influenced by the relief of the terrain when bare and by ground cover whenever vegetation is present. The presence of mulch confers the added benefit of reducing the velocity of runoff water, its entrainment capacity and hence, it favours a re-deposition of eroded sediment.

Mathematically, if the LS and P factors are assumed to be equal to 1, the cover-management factor C in the RUSLE1 may be expressed as

$$C = A/RK$$

From the soil loss data recorded in the cane plots at each site (Table 7) and their respective R and K factors (calculated from the bare plot data), the C factor was found to vary between 0.01 and 0.39 (Table 12).

Table 12. Cover-management factor (C) for sugar cane at five sites

	Cover-management factor				
Periods	**Bel Ombre**	**Sans Souci**	**Le Val**	**St Félix**	**Etoile**
July 2001-June 2002	0.11	0.14	0.10	0.09	0.29
July 2002-June 2003	0.07	0.22	0.31	0.26	0.35
July 2003-June 2004	0.09	0.07	0.10	0.01	0.06
July 2004-June 2005	0.01	0.39	0.03	0.00	-
Mean	0.07	0.21	0.14	0.09	0.23

The mean values of the C factor at Bel Ombre and St Félix were comparable and this could be due to the same cane variety, R 570, being grown at the two sites. Likewise, cane variety M 3035/66 had the same effect at Sans Souci and Etoile. Both cane varieties being harvested late in the season, their respective growth stages at the time of an erosive event should have been similar. However, significant differences were noted in the C values of R 570 and M 3035/66, and this could be attributed to their morphological and agronomic characteristics. M 3035/66 produces fewer stalks per unit area than R 570 and has a more ‘open’ canopy, thus allowing more raindrops to reach the soil surface. Furthermore, as R 570 produces more biomass than M 3035/66, more trash is left after harvest as ground cover (trash lined on alternate interrows). The latter would be an important component of the C factor for sugar cane. The RUSLE 2 considers all factors which include canopy, ground cover, surface roughness, below ground biomass, soil consolidation and antecedent soil moisture. Changes in trash management after harvest, i.e. adoption of a total blanket (green cane trash blanketing) would further influence the C factor. Variety M 52/78 which was grown at Le Val had an intermediate value of C although it produces a biomass comparable to

R 570; but being harvested very early in the harvest season the trash on the ground decays earlier and thus increases surface runoff.

The C factor, irrespective of cane variety, is influenced by the stage of cane growth at the time of an erosive event. This may be illustrated at Bel Ombre where a C factor of 0.11 was observed in 2001-2002 as a result of the major events occurring during January. In contrast, for the period 2004-2005 when the major events were recorded in March, the C factor was reduced to 0.01, the cane being at a more advanced stage of growth.

3.6 SOIL EROSION FROM RAINFALL SIMULATOR STUDY

The rainfall intensities simulated varied between 50 and 200 mm hr^{-1}. Soil loss, irrespective of site and rainfall intensity, was found to be relatively low and therefore prone to large errors (Table 13). In general, the data confirmed that the soil at Bel Ombre was more susceptible to erosion and was followed by Le Val and Sans Souci. Although this trend is similar to that of K values calculated for these three sites in section 3.4.2 (Table 11), the estimated K values derived from the simulated rainfall intensities were very low. These low values could be explained by the fact that the test was carried out after the rainy season when the soil surface was consolidated, with mainly

Table 13. Soil loss under rainfall simulated conditions

Site	Intensity mm hr^{-1}	Soil loss t ha^{-1}
Bel Ombre	59.1	0.4
	104.2	3.1
	158.7	1.7
	195.4	1.8
Sans Souci	96.4	0.4
	166.2	0.6
	185.7	1.3
	203.7	0.5
Le Val	57.9	0.1
	155.7	1.5
	193.8	1.7

large aggregates present (Fig 14); hence little amount of sediment could be displaced. The very low soil erodibility values estimated from data obtained with the rainfall simulator could also be due to a lower erosivity of water droplets compared to natural rainfall. Furthermore, wind velocity may also influence the energy associated with a normal rainfall. All these facts suggest that a rainfall simulator should not be used for estimating the soil erodibility factor (K) if the soil and climatic conditions are not conducive to erosion.

Fig 14. Consolidated soil surface at time of tests with rainfall simulator at Le Val (top) and Sans Souci (bottom)

4. GENERAL DISCUSSIONS AND CONCLUSIONS

Scientifically gathered data that showed the extent of erosion in Mauritius was lacking. This study has filled that gap by showing that the annual soil loss varied significantly across sites and between years; soil loss, irrespective of year, was highest at Bel Ombre, followed by Sans Souci, Le Val, St Félix and Etoile. The highest erosion measured from the bare plots during this study was at Bel Ombre where an annual soil loss of 59 t ha^{-1} was recorded during the period July 2004 and June 2005. The tolerable soil loss limit depends on the rate of soil formation and age of soil; the limit set in the United States is 11.2 t ha^{-1} yr^{-1} (Hudson, 1992). This study has provided evidence that if soils, particularly those of the L, F and B soil groups, are exposed or managed incorrectly, the severe erosion that will occur will exceed the tolerable soil loss. Sustainable production from our agricultural land, therefore, requires appropriate cultural practices and better land management.

Both factors responsible for erosion in the bare plots, i.e. rainfall erosivity and soil erodibility, were site-specific. As the erosivity factor depends on the total amount and intensity of rainfall during each storm causing detachment and transportation, it varies significantly across sites; even though those sites are located a few kilometres apart. Nevertheless, sites may be regrouped into three categories with respect to their erosivity index; namely high (Bel Ombre and Sans Souci), medium (Le Val and St Félix) and low (Etoile) erosivity areas. In the absence of a correlation between erosivity indices obtained for the five sites and other factors such as their total annual rainfall and altitude, R-values for sites other than those studied can only be estimated. Furthermore, as no rainfall intensity data or variations between different national meteorological stations across the island are available, soil loss may only be predicted for other sites in Mauritius by using a mean value of R = 300, a value which will include cyclonic events and is close to the worst-case scenario.

Soil erodibility was the most determinant factor influencing erosion. The use of the nomogragh developed by USDA was found to be inappropriate under Mauritian conditions. Calculated soil erodibility factors varied significantly among sites, e.g. the K factor at Bel Ombre was 14- and five-fold that at Etoile and St Félix, respectively. These differences were mainly associated with the silt and organic matter content of the soil and the presence of rock fragments or gravels on the soil surface. Although, the physical and mineral composition of soils may vary slightly within the same soil group as stated by Parish and Feillafé (1965), soil erodibility factors of 0.14, 0.05, 0.08, 0.03 and 0.01 may be used for soil loss prediction in the L, F, B, S and H soil groups, respectively.

Soil erodibility could not be determined using rainfall simulation as the K values would be systematically underestimated. However, differences between the soil groups studied confirm the results obtained under natural rainfall conditions, at least with respect to their relative values. Determining K values using the rainfall simulator can only be attempted when climatic and soil surface conditions are appropriate, and the simulation must be repeated at different periods of the year.

Sugar cane provides good ground cover particularly during peak period of erosive events; soil erosion will be reduced by 80% to 99% depending on cane varieties and their stage of growth. Cane variety such as R 570 has a lower C value than variety such as M 3035/66 because of a better canopy closure, and amount of trash cover in ratoons. Planting cane at closer spacings will further improve the canopy closure and hence reduce soil erosion. This study has shown that sugar cane has a C factor between 0.07 and 0.23 which is lower than for crops such as pine-apple with C of the order of 0.2 to 0.5 (FAO, 2001) and palmito which are being planted on sloping lands as alternate to sugar cane. If sugar cane is to be replaced by another crop, the necessary appropriate agronomic practices should be adopted to ensure enough ground cover during periods when erosive events occur.

One of the objectives of this study was to validate the RUSLE1. In this context, several parameters required in RUSLE1 were found to differ significantly under local conditions. The new version of the RUSLE (RUSLE2) released in 2005 requires databases of climate, crop (vegetative growth and residue), field operations with respect to the soil, crop and residues and these databases are available only for the conditions in the United States. As the RUSLE2 requires a daily computation instead of a monthly one as for the RUSLE1, the modification and validation exercise could not be undertaken within the time frame and scope of the present project. The validation of the RUSLE2, with the data available, may instead be considered for a future exercise which can include compilation of meteorological data for classifying different zones of the island into areas with varying (high, medium, low) rainfall erosivity indices. The main factors of the USLE, i.e. soil erodibility (K), rainfall erosivity (R) and a cover-management factor (C) for sugar cane have on the other hand, already been determined. These factors may be used to predict or compare soil erosion in different localities of Mauritius having different land uses.

The results from this study also explain the large amount of sediment (suspended load) that is observed in some of our rivers and lagoons after heavy rainfall or cyclonic events. The erosion rates for the different sites are based on a 9% slope over a length of 22.1 m. Extrapolation of our results to erosion occurring from fields or areas with steeper slope (with or without sugar cane) will show a significant increase in soil loss; e.g. for a bare field of 50 m long and 20% slope in the area of Bel Ombre, soil loss will increase five-fold. This means that even with the presence of sugar cane, soil loss of 8.5 t ha^{-1} yr^{-1} or more can be expected in these regions where cane is often planted on slopes higher than 20%. Erosion in the southwest, around the Bel Ombre area, in fact regularly deposits sediments in the lagoons around Rivière des Gallets (Ilot Sancho), Bel Ombre and Macondé (Fig 15); the soil is lost not only from sugar cane fields but also from field roads, non-cropped land, river banks and so on. Replacement of sugar cane in this area will require scientifically designed conservation measures and a choice of crops that avoid excessive sediment deposition in those lagoons which would jeopardise the tourist industry developing in that region.

Fig 15. Sediment deposited around Ilot Sancho (left) and Macondé (right)

Likewise, the high sediment load in Grand River South East (GRSE) is due to erosion occurring in the Sans Souci area. The erosion in the Sans Souci area is partly due to cultivation of cane variety M 3035/66 which offers a less effective cover-management. Furthermore, other crops are being grown along the banks of GRSE without proper conservation measures. Deposition in the sea in other areas (Fig 16) is also influenced by the fact that the rivers originate from the high rainfall areas where the soils are relatively more erodible, and where inadequate conservation or support practices are adopted.

Fig 16. Rivers with high amount of sediment after major events

Research on soil erosion has previously been undertaken only in the high rainfall area at Valetta as part of the MSIRI/ACIAR/QDNRM project on '*Measurement and prediction of agrochemical movement in tropical sugar production*'. This project which lasted from 1997 to 2001 had shown that up to 10.8 tonnes of the F soil from Valetta could be eroded annually if the soil surface is left unprotected (Ng Cheong *et al*., 2004). The presence of the sugar cane crop reduced this value to some 2.0 tonnes and a complete ground cover provided by trash blanketing further reduced this value by half. It was concluded from the study that the current cultural practices associated with sugar cane cultivation were adequate to ensure its sustainability in the super humid environment.

With the rapid change in land use, including replacement or abandonment of sugar cane cultivation, this study highlights the need for an integrated national project to minimise soil erosion for ecological, environmental and sustainability of our agricultural lands. This project should include the identification of erosion risk areas, the design and recommendation of proper cover-management and of conservation practices, the review of existing legislations and the training of all stakeholders so as to produce a Master Plan for soil erosion control in Mauritius. The MSIRI, with the know-how gained from the collaborative project with ACIAR/QDNR on movement of agrochemicals and from this current study, has the expertise and capability to undertake this project (if funding is available). The benefits of such a project will be of invaluable importance to the national economy, particularly to the tourism industry.

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