Erosion Control and Prediction in Cassava Based Cropping Systems in the Southern Andean Region of Colombia

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1 Introduction

The Andean region of Colombia, covering about one third of the country, is home to about 15% of the total population and to 50% of the rural population. Due to the utilization of most fertile and flat areas for production of sugar and other crops destined for industrial use or exportation, food crops are grown basically in the Andean hillsides. About 85% of the bean, 70% of the hard maize, 80% of the wheat, 80% of the cassava and 90% of the potato production takes place in this region (Howeler, 1984). Considering the high importance of the Andean hillsides for the national food production, it is alarming that 84% of the area are affected by erosion, with close to 40% considered as being between moderate and extreme. According to the Instituto Geografico Agustin Codazzi (IGAC, 1988) the annual area lost in Colombia due to land degradation lies between 170,000 and 200,000 ha. Recent analyses of satellite imagery and field surveys performed in 1999—2000 showed that 80% of the Colombian territory is considered to be affected by erosion (Ministerio del Medio Ambiente, 2000). Taking into account this alarming situation the University of Hohenheim started in 1987, together with the Centro International de Agricultura Tropical's (CIAT) cassava program, an erosion research project with the purpose of adaptation and application of the Universal Soil Loss Equation (USLE) to the local circumstances, to study various cassava based cropping systems concerning their effectiveness with regard to erosion control and income generation, to propagate conservation measures and provide the local farming community with technical advice as well as improved germplasm.

2 Material and methods

The Universal Soil Loss Equation was developed by Wischmeier and Smith (1978) to provide farmers and conservation planners with a tool to consider necessary measures for erosion prevention under the specific circumstances at a given location. Long-term average soil losses can be estimated by means of the USLE, consisting of six factors as shown in Equation 1, of which only R and K have units, the others are dimensionless:

$$A=RKLSCP \tag{1}$$

where A is soil loss amount in $t \cdot ha^{-1}$ for a given time period, commonly a year or a cropping season. *R* is the climate factor in $MJ \cdot mm \cdot ha^{-1}\ h^{-1}$, *K* expresses the soil erodibility in $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$, *LS* are the slope length and slope angle factors, C is the crop management factor and P includes the protection measures.

The R factor being defined as the sum of the products of all erosive rainfall event's total kinetic energy and the maximum intensity sustained for 30 minutes (EI_{30}). All rainfall events with more than 12.7 mm rainfall amount or more than 6.5 mm falling within 15 minutes are considered erosive.

The *K* Factor can be derived by two methods: establishing soil losses from USLE standard plots and then dividing by the *R*-Factor value for the corresponding time period or using a nomograph developed by Wischmeier and Smith (1978). Earlier research at Quilichao and Mondomo trial sites had shown that the nomograph was not applicable to the soil types treated in this work (Reining, 1992; Ruppenthal, 1995).

As the USLE is based upon climate, soil and cropping system data from the USA doubts have been raised about its application to tropical environments. Especially the use of the climate factor EI_{30} and its energy-intensity relationship term for use under different climatic conditions has been questioned (Morgan, 1995; Hudson, 1995; Arnoldus, 1977).

Trials were established at two sites in the Cauca department of Colombia. Santander de Quilichao, located at 3° 6' N, 76° 31' W, at 990 m a.m.s.l., with an average annual precipitation of 1,789 mm and an average temperature of 23.7°C. Mondomo lies about 20 km to the south at 2° 53' N, 76° 35' W at an altitude of 1,450 m a.m.s.l.. Average precipitation is 2,133 mm per year and the average temperature 18.2°C. Soils at both sites belong to the inceptisols, the one at Quilichao was classified as an *oxic Dystropept* and the one at Mondomo as an *oxic Humitropept*. Both soils are characterized by a high infiltration capacity, a low pH and generally low fertility.

Erosion plots were established at both sites on slopes between 7 and 20% with eight treatments with three repetitions in Quilichao and two in Mondomo. The eight treatments during the research phase reported here were:(1) USLE standard plots, kept under permanent bare fallow; (2) cassava based conventional rotation with chicken manure; (3) continuous sole cassava; (4) cassava based rotation with minimum tillage and mulch; (5) cassava based rotation with two years of antecedent bush fallow; (6) cassava based rotation with vetiver barriers; (7) cassava based rotation with legume strips (*Phaseolus vulgaris* L. and *Vigna unguiculata* L. Walp); and (8) cassava based rotation with two years of antecedent improved fallow (*Brachiaria decumbens* Stapf and *Centrosema macrocarpum* Benth).

The USLE standard plots were 22 m long and 11 m wide, while all other treatments had plots of 16 m by 8 m. Runoff and eroded soil from the plots were collected from Eternit® canals at the end of each plot and measured after each event. Rainfall amount as well as intensity were recorded with automatic recording raingauges (Hellmann, Model 1509-20, Lamprecht, Göttingen, Germany). A Distromet disdrometer (Joss-Waldvogel Model RD69, Distromet Ltd., Zürich, Switzerland) was used for the drop size distributions and kinetic energy measurements.

Additionally, long-term rainfall intensity data from four meteorological stations were analyzed and included in the study. These stations were ran by the Colombian Coffee Producer’s research center (CENICAFE), two of them from the Cauca and two in the Valle del Cauca Departments These additional data sets from the southern parts of the Cauca department allowed a more detailed analysis of the region climate’s erosivity. 43 years of rainfall intensity data were analyzed for the station El Tambo (2º 25' N 76º 45' W; 1,700 m a.m.s.l.) and 32 years for the station La Florida (2º 27' N 76º 35 W; 1,800 m a.m.s.l.). El Tambo lies 75 km southwest from Quilichao, whereas La Florida lies 64 km to the southwest, close to the department’s capital Popayan. The El Tambo rainfall records comprised the period between 1956 and 1998 and were analyzed according to the USLE criteria. The data were received in analog 5-minute rainfall intensity format, digitized and *R*-Factor values calculated according to the USLE methodology. The EI_{30} values for 1,800 erosive rainfall events were calculated. The La Florida station contributed 32 years of rainfall recordings and a total of 1,485 erosive rainfall events. Furthermore, data from the two nearest stations of CENICAFE in the Valle del Cauca department were examined. The results from the station Trujillo lying 130 km northwest from Quilichao in the Western Cordillera (4º 10' N 76º 21 W; 1,380 m a.m.s.l.) based on 26 years of rainfall were very similar to those from the Cauca department stations. The Restrepo station (3º 49' N 76º 31' W; 1,360 m a.m.s.l.) lying at 100 km northwest of Quilichao in the Western Cordillera showed very low R-Factor values and had the lowest average annual rainfall amount of 1,100 mm.

All statistical analysis were performed with SAS (SAS, 2001). Analyses of variance were used to test for differences between treatments concerning soil losses and yields.

3 Results

3.1 Rainfall erosivity

During five rainy seasons from 1993 till 1998 18,000 one minute increments of drop size distributions were recorded with the disdrometer. From these measurements the local energy-intensity relationship was derived by means of nonlinear regression. It was best expressed by Equation 2:

$$E_L = 9.52 + (11.04 \ \log(I)) \ \ (r^2 = 0.96) \tag{2}$$

where E_L is energy load in J • m^{-2} • mm^{-1} and I is rainfall intensity in mm h^{-1}.

Statistical analysis showed no significant differences between energy loads of rainfall events calculated according to the equation above and the energy intensity equation used in the USLE.

Annual *R* factor values were calculated for both sites covering a time span of eight years and correlated with annual soil loss amounts from the bare fallow plots. A highly significant linear relationship between the *R*-Factor and annual soil loss amount was found for the period from 1990 till 1998 at both trial sites as shown in Table 1. The correlation coefficient for the relation from Quilichao was higher as compared to Mondomo. However when the outlier year 1997 was eliminated for Mondomo, 1997 having shown an extremely low annual soil loss in relation to the *R*-Factor value, the correlation coefficient was improved considerably.

Table 1 Equation parameters for linear regressions between soil loss and *R*-Factor for the period 1990 till 1998 for Quilichao and Mondomo

		Intercept	Slope	r^2
Quilichao	90—98	–84.65	0.0281	0.85
Mondomo	90—98	–21.85	0.0127	0.76
Mondomo	90—98 without 97	–11.56	0.0123	0.89

As calculation of reliable average *R*-factor values is time consuming and requires long-term rainfall intensity records, which are difficult to obtain for wider areas, especially in developing countries, alternative methods of obtaining reliable R-factor values were evaluated.

R-factor values were calculated from over 140 years of rainfall intensity data from six meteorological stations in the Cauca and Valle del Cauca departments. A modified Fournier index (Eq. 3),

$$R_c = \frac{p^2}{p_i} \tag{3}$$

where R_c is the rainfall coefficient for a given month, p the average monthly rainfall amount in mm and p_i the average annual precipitation in mm, was applied to these data and found to precisely derive annual *R*-factor values from average monthly rainfall amounts, which are available for a far greater number of locations (Carvalho *et al*., 1991).

Two regression types were evaluated, linear and power. The power type was slightly superior for all stations except Mondomo and Restrepo (Table 2). The Restrepo station showed the lowest regression coefficients. When November was eliminated from the regression, the r^2 improved to 0.84 (linear) and 0.85 (power). November had a very low *R*-Factor value as compared to the average monthly rainfall amount and resulting p^2/p_i index.

Table 2 Results for application of the modified Fournier index to calculate average monthly *R*-Factor values

Meteorological station	Linear regression	r^2	Power regression	r^2
Quilichao	y=40.41 (p^2/p_i)+291.4	0.93	y=201.93 $(p^2/p_i)^{0.5811}$	0.95
Mondomo	y=49.62 (p^2/p_i)+307.9	0.92	y=259.02 $(p^2/p_i)^{0.5174}$	0.88
El Tambo	y=23.52 (p^2/p_i)+236.8	0.93	y=126.16 $(p^2/p_i)^{0.6086}$	0.95
La Florida	y=25.41 (p^2/p_i)+264.1	0.96	y=161.0 $(p^2/p_i)^{0.5520}$	0.99
Trujillo	y=41.11 (p^2/p_i)+266.8	0.94	y=188.55 $(p^2/p_i)^{0.5784}$	0.96
Restrepo	y=19.36 (p^2/p_i)+70.99	0.76	y=58.38 $(p^2/p_i)^{0.6721}$	0.76

Source of data for station El Tambo to Restrepo: 5 minute rainfall intensity data received from CENICAFE

3.2 Soil erodibility

Soil loss amounts under bare fallow conditions were high, during the whole 12-yr-period total soil loss for Quilichao was 1,840 t • ha^{-1} and 2,380 t • ha^{-1} in Mondomo. Considering the bulk density of close to one this would imply losses of more than 18 cm and 23 cm of the top soil. Average annual *K*-factor values for Mondomo and Quilichao were 0.011 and 0.017 t • h • MJ^{-1} • mm^{-1} respectively, being considered as low according to Foster *et al*. (1981). The low erodibility is due to the high structural stability and infiltration capacity of the soils found at Quilichao and Mondomo. However, erosion risk in the area is high due to the high erosivity of the climate.

The highest soil loss amounts recorded for single years were 445 t • ha^{-1} at Mondomo and 310 t • ha^{-1} at Quilichao. Average annual soil loss amounts for the whole period from 1987 till 1998 were 185 t • ha^{-1} for Quilichao and 238 t • ha^{-1} for Mondomo.

3.3 Susceptibility of the evaluated cropping systems to erosion

Soil losses under cropped conditions were considerably lower as compared to the bare fallow conditions. Table 3 presents the total LS-corrected soil loss amounts of Quilichao and Mondomo for the research period June 1994 till July 1997, which included the following rotation scheme: cassava, two periods of maize, cassava and during the last cropped period, cowpea at Quilichao and phaseolus beans at Mondomo. At Quilichao the highest soil loss amount was measured for the sole continuous cassava treatment with 16 t • ha^{-1}. Soil losses from this treatment were significantly higher as compared to all other cropped treatments except the bush fallow treatment (15.6 t • ha^{-1}). The other five cropped treatments did not differ significantly although soil losses from the minimum tillage and grass barrier treatments were very low and between five and six times lower as compared to the farmer rotation and legume strips treatments. Considering results from Mondomo showed that as at Quilichao the sole continuous cassava treatment produced by far the highest soil loss with 30.1 t • ha^{-1}. It was significantly higher as compared to all other cropped treatments. The second highest soil losses of 17.3 t • ha^{-1} were recorded for the legume strips treatment being significantly higher than all other treatments except the sole cassava treatment.

Table 3 LS-corrected soil loss amounts from cropped treatments for the period June 1994 till July 1997 recorded at Quilichao and Mondomo and annual soil loss amounts calculated from these data for average field sizes for both sites

Treatments	Quilichao LS-corr. soil loss (t • ha^{-1})	Quilichao average field annual soil loss (t • ha^{-1})	Mondomo LS-corr. soil loss (t • ha^{-1})	Mondomo average field annual soil loss (t • ha^{-1})
Farmer rotation	5.8 b	14.5	1.6 c	4.1
Sole cassava	16.0 a	40.4	30.1 a	75.8
Minimum tillage	1.1 b	2.7	0.5 c	1.3
Bush fallow	15.6 a	39.2	5.9 c	14.8
Grass barrier	0.9 b	2.2	0.6 c	1.5
Legume strips	4.6 b	11.7	17.3 b	43.5
Improved fallow	2.6 b	6.6	1.9 c	4.7

Means with different letters along the same column are significantly different ($p<0.05$)

Annual averages presented in columns three and five were calculated from the values presented in the columns two and four and multiplied with 7.55 according to the USLE LS-methodology.

The data shown in columns 2 and four of Table 3 were converted according to the USLE LS methodology and represent field conditions with the dimensions 22 by 11 m and a slope gradient of 9%.

Considering the real soil loss amounts would imply little changes of values at Quilichao and up to 2.7 times higher values at Mondomo due to its steeper slopes. According to Amezquita (2001), Ruppenthal (1996) and Reining (1992) the soil loss tolerance levels were estimated as being between 2 t • ha^{-1} and 4 t • ha^{-1} at Quilichao and between 1 t • ha^{-1} and 2 t • ha^{-1} at Mondomo, these low estimates principally due to the low soil formation rate and the poor parent material of the soils. Most farmers in the research area use hillsides with far steeper slopes and with a higher degree of degradation. A study in the micro watershed El Pital, located adjacent to the Mondomo trial site, reported that of the total area of 1,245 ha 83% was on slopes with a gradient between 12% and 50%, while 16% of the area was between 50% and 75% of slope gradient. Only 0.4% of the total area was qualified as being adequate for cultivation of annual crops due to quality and stability of the soil, although even these slopes had gradients between 25% and 50% (FIDAR, 1999). Taking this situation into account a more representative field size for the actual situation in the Cauca department with the dimensions 50 m slope length and 25% slope was assumed. These values imply that considering Quilichao and Mondomo soil conditions and the steeper slopes encountered on most farmers lands all treatments except the minimum tillage and grass barrier treatments have to be considered as not being sustainable.

3.4 Productivity of the cassava based cropping systems

A very important factor of adoption of soil conservation measures by the farmers is the productivity. If a production system produces lower yields on the short term as compared to the traditional ones acceptance will be very low. When comparing the two conservation treatments, minimum tillage and grass barriers, with the continuously sole cropped cassava treatment, used by the majority of the small scale cassava farmers in the Cauca department, no significant differences concerning yield performance were detected for both trial sites during most cropping periods. During one cassava cropping period the minimum tillage treatment reached a significantly higher yield at Quilichao, while the grass barrier treatment produced a significantly higher yield during a phaseolus bean cropping phase at Mondomo. The performance of the grass barrier treatment are notable considering that the grass barrier treatments production area is 12.5% less compared to all treatments except the legumes strips treatment.

The highest yield levels of all treatments were achieved by the farmer rotation treatment, however there were no significant differences between this treatment and the minimum tillage treatment at Mondomo and Quilichao. Whereas there where no significant differences between yields from the farmer rotation treatment and the grass barrier treatment at Mondomo, the grass barrier treatment showed significantly lower yields during all but one cropping period at Quilichao.

In view of the reduced fallow duration periods in the Cauca departments hillsides (Ashby, 1985) the improved fallow treatment proved to be a good alternative considering fodder production and general crop yields. However, it should not be used on slopes with more than 25%, as soil losses would be to high to be sustainable over longer periods.

3.5 Soil fertility losses

Organic matter, one of the key reactive fractions of a soil, can be selectively removed by erosion (Lal, 1999; Lowery *et al.*, 1999). It is highly important as a bonding agent for soil aggregates and, thus, also influences infiltration and water transport as well as water holding capacity. The erodibility of a soil depends on its organic matter content as it enhances the stability of surface soil aggregates, thus diminishing possible crust formation and surface sealing, as well as increasing water infiltration. Further beneficial effects are the improved plant availability of macro and micro-nutrients as well as a higher adsorption and exchange capacity for both (Stott *et al.*, 1999). Organic matter declined by 40.5% within nine years in the bare fallow plots at Quilichao (Figure 1). After these plots were abandoned due to complete loss of the top soil, the newly established bare fallow plots lost 27.6% of organic matter within eight years. At Mondomo the losses amounted to 52% within 12 years. The cropped treatments showed no clear tendencies except the continuously sole cropped cassava, where 22.4% were lost within eight years at Quilichao and 25.7% at Mondomo within the same period of time.

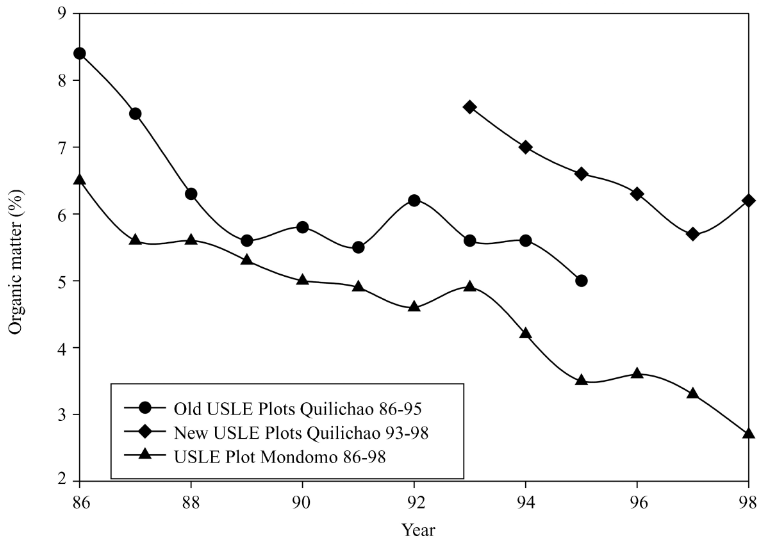

Fig. 1 Development of organic matter in the topsoil of bare fallow plots for the time period 1986 till 1998 at Quilichao and Mondomo. Experiments at the Quilichao site were continued and showed a further decrease of soil organic matter to 5.5% in 2001

3.6 Discussion and Conclusions

The analysis of the rainfall intensity data together with the established energy-intensity relationship indicated that it should be possible to apply the *R*-factor of the USLE to the research regions climate. This was confirmed by the highly significant linear relationship between annual eroded soil amounts and annual *R*-factor values. Based upon these findings, *R*-factor values already calculated in the Colombian Andean region can be used to evaluate the erosive potential of specific sites. For those areas where no intensity data are available, the modified Fournier-index is considered as sufficiently reliable to estimate *R*-factor values from long-term monthly rainfall data, which are available for a wider range of sites.

Although the soil erodibility values of the two soil types examined in the present work are considered as low, basically due to the high structural stability and extreme infiltration capacity, the high soil loss amounts induced by the high erosivity of the climate from the bare fallow plots and the continuously sole cropped cassava show the high necessity of implementing protective measures. As 77% of the Cauca departments soils belong to the inceptisols the *K*-Factor values derived should be applicable to erosion prediction with the USLE to a greater part of the department.

The evaluation of the soil conservation and productive performance showed that the traditionally used cassava based cropping systems, especially the continuously sole cropped cassava, should be replaced by more sustainable and economically interesting cropping systems. An important point when introducing these systems is to combine the conservation measures with further income generation for the farmers, to give them an incentive to implement these measures. This approach was quite successful in the Watershed El Pital, lying adjacent to the Mondomo trial site, where a cooperative of women planted 25 km of lemon grass (*Cymbopogon nardus*) barriers with the dual purpose of soil conservation and the later extraction of essential oils, which were sold to the perfume industry and used to manufacture soap and other consumer goods. The integration of the farmers into the evaluation process of soil conservation measures is crucial for acceptance and thus the successful implementation of any kind of soil conservation.

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