Erosion and Soil Productivity Relationships for an Oxisol in the Eastern Plains of Colombia

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Abstract: The impact of erosion on soil productivity was assessed for a Typic Hapludox on the Eastern Plains of Colombia (EPOC). An experiment was initiated in 1997 on a site with a known history of prior erosion in order to determine primarily the effect of differing degrees of soil erosion on the current soil quality status and to assess the impact on soil productivity through its effect on current yield of an upland rice crop (*Oryza sativa*). The results demonstrate that the influence of erosion on crop productivity is complex and simple relationships with changes in soil quality variables and with crop yields may often be confounded by other factors. Yet, EPOC's Oxisols are still shown to be extremely vulnerable to water erosion and illustrate the risk of converting savannas to croplands without appropriate soil management practices.

Keywords: soil erosion, soil productivity

1 Background

The extensive Eastern Plains of Colombia (EPOC) cover 24 million hectares of national territory and represent about 10% of tropical savannas in South America. Most commonly soils of the EPOC are Oxisols, associated locally with acid Inceptisols and Entisols. Oxisols are limited primarily by deficiency of available nutrients, low organic matter, presence of toxic elements such aluminium and water stress during three to four months (Tanaka *et al*., 1984). Erosion is widely perceived as the main driver inducing these changes in soil quality and the primary threat to agricultural sustainability of the EPOC. However, despite these limitations, new technological inputs including crop germplasm tolerant to acid soils have aroused great expectations regarding the agricultural potentiality of the Eastern Plains of Colombia. Consequently, there is an urgent need to get a better understanding of the driving forces behind the soil erosion process and its impact on soil productivity. A crucial question is to identify which, if any, intensive agricultural system can be sustainable and produce a positive economic return to land users in the EPOC.

2 Materials and methods

The study was carried out at La Libertad Research Center of Colombian Corporation for Agricultural Research (CORPOICA). The experimental area is on the High Terrace of the Alluvial Plain of Piedmont of the EPOC, 1 to 4 percent slope, located 25 Km east of Villavicencio Town, in Meta Department (4° 09′ N, 73° 38′ W), at an altitude of 336m above sea level. Soils were classified as loamy skeletal kaolinitic isohyperthermic Typic Hapludox (Soil Survey Staff, 1992) (See Fig. 1).

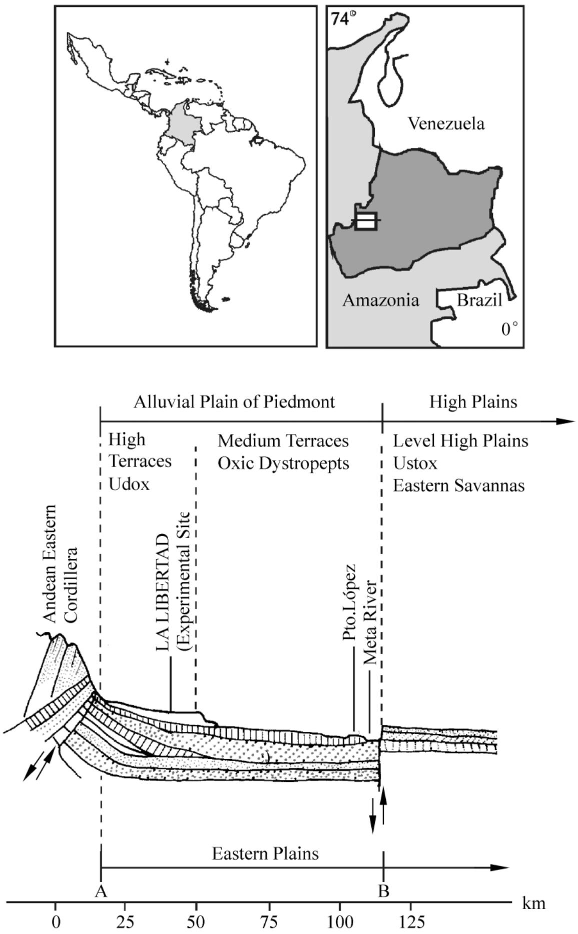

Fig.1 Map of Colombia showing the location of the Eastern Plains, main geomorphological units and major soil orders of the study area

The experimental site had been under a uniform cover of grass with extensive grazing until ten years previously. Following a subsequent long term research trial on soil, water and nutrient losses under contrasting situations of land use and soil management on the current site, four erosion classes were defined

on the basis of monthly records (mean of three replications) (Table 1). Quality of topsoil of the existing run-off plots (3m wide and 10m long) was evaluated. Soil samples were taken at 0-10cm depth for laboratory physical and chemical analyses. Soil physical properties included bulk density (BD), particle density (PD), total porosity (TP), mean weight diameter of water stable aggregate (MWD), and moisture retention (MR). Infiltration rate (IR) and resistance to penetration (RP) were measured directly in the field. A uniform rice crop with low inputs was then planted on all plots and grain yield measured.

Table 1　Erosion classes, prior land use and soil management and accumulated soil losses

Erosion Class	Prior Land use Soil Management	Acummulated Soil Losses Mg • ha^{-1}
Class 1 "nil to very slight erosion"	Secondary savanna (savannized forest) Extensive grazing during last 30 years. Good cover.	2.5
Class 2 "slight erosion"	Secondary savanna. Since 1987 zero grazing pastures (*Brachiaria decumbens*). One year bare-tilled soil and one year fallow.	23.5
Class 3 "moderate erosion"	Secondary savanna. Since 1987 rotational upland rice-soybean based systems. One year bare-tilled soil and one year fallow.	67.5
Class 4 "severe erosion"	Bare-tilled soil over previous 10 years. One year fallow.	401.2

3　Results

BD increased and TP decreased with increasing erosion. Before cropping, MWD was significantly higher in erosion Class 1 than all other erosion classes, but decreased markedly from 5.02mm to 2.17mm after harvesting the rice crop (Table 2). It is clearly evident that the change of land use from secondary savanna to an upland rice crop decreased MWD very rapidly and hence decreased TP. These findings corroborate the hypothesis that bonds of sesquioxides in EPOC's Oxisols are extremely susceptible to destruction by physical impact of raindrops (Goosen, 1971) and this change in soil quality is rapidly operative within season.

Table 2　Impact of erosion on structural soil properties at 0—10 cm depth

EROSION CLASS	Structural soil properties			
	BD Mg • m^{-3}	TP m^{3} • m^{-3}	MWD (mm)	
			Before cropping	After harvesting
Class 1	1.193 c	0.537 a	5.024 a	2.173 a
Class 2	1.295 b	0.497 c	1.669 b	1.669 b
Class 3	1.278 b	0.512 b	1.351 c	1.351 c
Class 4	1.359 a	0.477 d	1.787 b	1.801 b

Values followed by the same letter down the column are not significantly different at $P<0.05$.

There were significant differences between RP in erosion Class 1 and all other erosion classes (Table 3). There were no significant differences between Class 2 and Class 4. In searching for reasons for this anomaly, profile descriptions subsequently revealed that plots of erosion Class 2 were situated over a soil inclusion with high skeletal fraction in the top layer. Field examination of soil morphology revealed the presence of a gravelly layer on these plots. This explains why RP values similar to erosion class 4 were found despite lower erosion and bulk density. The generalized increase of RP with increasing severity of erosion, particularly evident at 3.5cm depth, is thought to be associated with the disruption of soil structure by the continued use of hand tools for seed bed preparation.

Table 3 Impact of erosion on soil resistance to penetration (RP) at three different depths

Erosion Class	Depth (cm)		
	3.5	7.5	10.5
	Resistance (MPa)		
Class 1	0.295 c	1.005 b	1.219 c
Class 2	0.900 a	1.768 a	2.018 a
Class 3	0.703 b	1.175 b	1.544 b
Class 4	1.030 a	1.932 a	2.206 a

V*alues followed by the same letter down the column indicate nonsignificant differences* (P<0.05)

There were significant differences in MR between Class 1 and all other erosion classes at all suctions (Table 4). However, the amount of plant available water (AWC) defined as the difference between 0.03MPa and 1.5MPa volumetric moisture content was not significantly affected by erosion class. The low AWCs and the augmented RP suggest that erosion of EPOC's Oxisols is likely to induce plant water stress by shortening the Least Limiting Water Range (LLWR) (da Silva *et al*., 1994).

Table 4 Impact of erosion on soil moisture retention at 0 to 40 cm depth

EROSION CLASS	Suction (MPa)					
	0.01	0.03	0.1	0.5	1.5	AWC $m^3 \cdot m^{-3}$
	Moisture content %					
Class 1	35.29 a	31.44 a	29.86 a	28.31 a	27.80 a	7.94 a
Class 2	27.83 b	25.35 b	23.38 b	22.29 b	20.78 b	5.92 a
Class 3	26.31 c	24.94 b	23.75 b	22.17 b	21.60 b	4.27 a
Class 4	27.00 bc	25.46 b	24.05 b	22.07 b	21.64 b	5.19 a

Values followed by the same letter down the column indicate nonsignificant differences (P<0.05)

There was no clear effect of erosion on the infiltration constants (Table 5). Class 3 IR was significantly higher than that in all other classes. Erosion Class 4 had the lowest IR of 2.24 $cm \cdot h^{-1}$ which allow to be concluded that water intake decreased somehow in eroded soils and hence may increase the likelihood of erosion-induced water deficit for normal plant growth.

Table 5 Parameters of the Kostiakov equation determined by double-ring infiltrometer test and measured cumulative infiltration (CI)

EROSION CLASS	Constant B	N	R²	IR $Cm \cdot h^{-1}$	CI Cm
Class 1	21.99 b	0.37	0.98**	3.318 b	28.96 b
Class 2	20.99 b	0.38	0.99**	2.899 b	23.12 bc
Class 3	43.60 a	0.36	0.99**	6.236 a	45.29 a
Class 4	26.14 b	0.44	0.98**	2.142 b	18.92 c

Values followed by the same letter down the column indicate nonsignificant differences (P<0.05)

SOM had significant differences between erosion Class 1 and all other erosion classes and decreased from 3.2%, in Class 1 to 1.6% in Class 4.

ER, defined as the ratio between nutrient content in the eroded sediments and nutrients in the original soil (FAO, 1985), for SOM and P had the highest values in the erosion Class 1, which suggests that initial stages of soil erosion may have a dramatic impact on P and SOM, and hence on total N. This effect has been found in other erosion-productivity studies (Tengberg *et al*., 1997).

Table 6 Chemical composition of the original soil (0—10 cm depth) and enrichment ratio, ER$^+$

EROSION CLASS	SOM %	PH-H_2O	P mg • Kg^{-1}	Al	K	Ca	Na	Mg
				Cmol • Kg^{-1}				
				Original soil				
Class 1	3.187 a^{++}	4.56	2.50 c	2.30 a	0.063 b	0.526 d	0.103	0.109 d
Class 2	1.700 c	4.66	30.00 b	1.50 b	0.100 a	0.776 c	0.120	0.230 c
Class 3	1.967 b	4.96	63.00 a	0.36 d	0.126 a	2.55 a	0.110	0.396 a
Class 4	1.567 c	4.76	27.00 b	1.1 c	0.066 b	0.96 b	0.117	0.360 b
				Enrichment ratio (ER)				
Class 1	3.4	1.15§	6.50	0.86	2.26	2.34	1.250	1.120
Class 2	1.21	1.10	2.44	0.19	3.99	1.38	0.680	1.040
Class 3	1.01	1.10	1.47	0.24	3.00	1.77	0.800	1.040
Class 4	0.99	1.00	1.76	0.18	2.56	1.27	0.930	1.190

$^+$ *Composite Values of three replications.*

$^{++}$*Values followed by the same letter down the column are not significantly different at* $P<0.05$.

§ *Relation between pH in the eroded sediments and pH in the original soil.*

Rice grain yields were significantly different between all soil erosion classes (Fig.2). Rice grain yield reduction was 84% for erosion Class 2, 32% for Class 3 and 63% for Class 4 relative to Class 1. At 1.073Mg • ha^{-1} yield was least on the slightly eroded soil (Class 2), which is likely to be associated with the spatial variability of subsurface skeletal material on the experimental site. It is evident that this material inhibited normal rooting and hence decreased yield, because of the lower water and nutrient retention capacity of the soil. It is also evident, therefore, that erosion-induced effects on soil productivity can be compounded when combined with other yield-affecting variables of soil quality. Soil losses, without including erosion Class 2, accounted for 68% of the variation in rice grain yield and can be estimated by the following linear equation:

$$Y = 5.634 - 0.0068X \qquad R^2 = 0.68^* \qquad (n = 9) \qquad (1)$$

Where Y is estimated rice grain yield in Mg.ha^{-1} and X is accumulated soil losses in Mg • ha^{-1}.

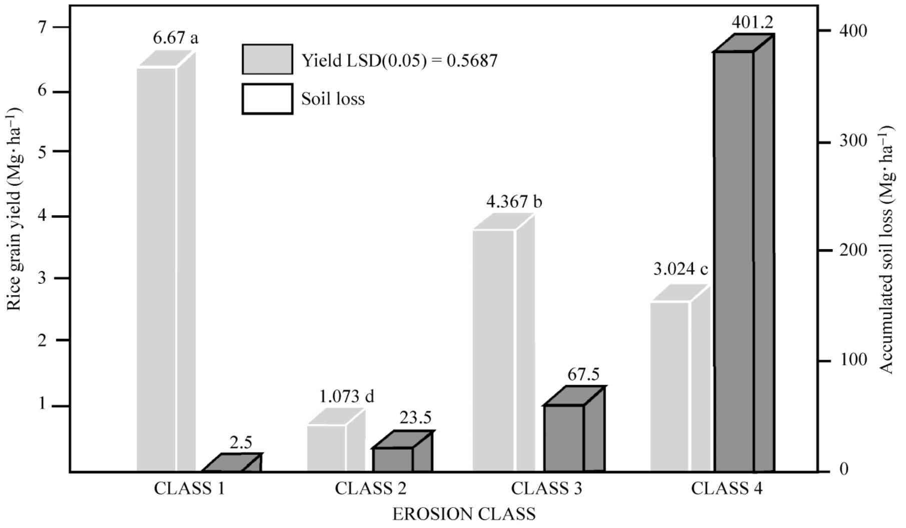

Fig.2 Rice grain yield as a function of accumulated soil losses and erosion class *Values of grain yield followed by the same letter are not significantly different at* $P<0.05$

4 Conclusions

This study shows that Oxisols of the Eastern Plains of Colombia are highly vulnerable to soil erosion. A linear relationship between accumulated soil losses and rice grain yield was found ($R^2 = 0.68$), although as this is based only on nine (3 replications of 3) data points, it is not conclusive as to the precise nature of the relationship. Nevertheless, the results suggest that major erosion-induced losses in soil productivity occur at early stages of soil erosion and are linked to rapid losses of soil organic matter and changes in associated physical properties. Further erosion is unlikely to produce much effect on crop productivity as reported for other South American Oxisols (Tengberg *et al*., 1998). A non-linear exponential relationship may then also be verified at the EPOC site. Residual effects of fertilizers and lime, as suggested by the high levels of P and exchangeable bases in the eroded classes (Table 6), do not compensate for the negative impact of soil losses. The initial soil quality in terms of soil organic matter content and associated soil physical conditions may be more important in acid soils growing crops tolerant to high aluminum saturation.

Thus, strategies for conservation of eastern Colombian savanna soils should address management practices that mitigate the primary driving processes of erosion’s effect on soil productivity. They should not only aim to increase soil fertility through liming and fertilizers, but also to maintain or improve the quality of the soil surface by avoiding rapid decline in soil organic matter. For acid savanna soils following a build-up fertilization program, practices such as crop rotation including improved pastures, green manure, minimum or no tillage, cover crops and mulching are important management tools, to improve and maintain soil fertility and optimum crop production potential (Lopes, 1996). Additional research work is needed under standardized experimental designs in order to dissect the complex interactions between changes in soil quality consequent on erosion, the high spatial variability of these savanna soils, and resultant crop yields that can be gained by current farming practices. Early indications are that strategies that address erosion’s effect on soil quality through maintaining SOM will not only reduce erosion itself but also have a positive economic return for the land user. However, this last assumption needs firm verification before techniques of conservation and amelioration of eroded soils are widely promoted.

References

FAO, 1985. Erosion-induced loss in soil productivity: a research design. Consultants’ Working Paper No.2, Soil Conservation programme, Land and Water Development Division, United Nations Food and Agriculture Organization, Rome.

Lopes, S.A. 1996. Soils under cerrado: A success story in soil management. Better Crops International. **10** (2): 9-15.

Da Silva, A.P., B.D. Kay and E. Perfect.1994. Characteristics of the least limiting water range of soils. Soil Sci. Soc. Am. J. 58:1775-1781

Goosen, D. 1971. Physiography and soils of the Llanos Orientales, *Colombia*. Publications of the International Institute for Aerial Survey and Earth sciences (ITC)- Enschede the Netherlands, Series B Number 64 (chapter 5).p 112-159.199p.

Kutilek, M. and R.D. Nielsen. 1994. Soil Hydrology. Geoecology texbook. Cremlingen-Dested: catena-verl. (catena). Germany.370.p:158-159.

Tanaka, A.; T. Sakuma, N. Okagawa, H. Imai, and S. Ogata. 1984. Agroecological condition of the oxisol-ultisol area of the Amazon river system (report of a preliminary survey). Faculty of Agriculture, Hokkaido University, Sapporo, Ogo, Japan. 101 p.

Tengberg, A.; M.A. Stocking and M. da Veiga. 1997. The impact of erosion on the productivity of a ferralsol and a cambisol in Santa Catarina, Southern Brazil. Soil use and management. 13: 90-96.

Tengberg, A.; M. Stocking S.C.F. Dechen. 1998. Soil erosion and crop productivity research in South America. Advances in GeoEcology **31** (2): 355-362.

Soil Survey Staff. 1992. Keys to soil taxonomy. 5th ed. SMSS Technical Monograph N^o 19. Blacksburg, Virginia: Pocahontas Press, Inc. 556p.