THE LIFE-TIME CONCEPT AS A TOOL FOR EROSION TOLERANCE DEFINITION [1]

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ABSTRACT: By definition, erosion tolerance should consider the conservation of the soil as a natural resource essential for crop production. Erosion rates greater than soil renewal will cause soil depth loss. A minimum soil depth was defined as the depth in which the inputs (fertilizers, crop residues) and management technology (irrigation, improved genetic crop quality) were insufficient to prevent economic productivity loss. Thus, erosion rates greater than soil formation are acceptable only during the time in which the soil does not reach the minimum depth. We have defined this time period as life-time. The life-time concept was applied to the Ceveiro watershed (1,945 ha) located in a sugarcane growing region in the Southeast of Brazil. Erosion rates were estimated with the Universal Soil Loss Equation and soil depths were measured by field surveys. Depth change and life-time calculations, considering a soil formation rate of 0.2 mm y^{-1}, and assuming the present scenario of land use and a minimum soil depth of 1.0 m were made using the Geographic Information System. Land use represented 1,319 ha (68%) of sugarcane, 346 ha (18%) of forests and 278 ha (14%) of pasture. The area in which soil erosion was less than soil formation (not associated to long term impacts) represented 475 ha (24%), which included the total forest areas and 48% of pastures. The total sugarcane area had erosion rates greater than soil formation. The area with erosion rates greater than soil formation rates and soil depth less than 1.0 m, which resulted in a life-time equal to zero (soil erosion impacts are presently irreversible) was 832 ha (42%). This area was composed of 702 ha of sugarcane and 130 ha of pastures. The remaining area (erosion greater than formation and soil depth > 1.0 m) represented 638 ha (32%), which was composed of 620 ha of sugarcane and 18 ha of pasture. The half-lifetime for the watershed was estimated as 350 yr. The life-time concept was effective to evaluate the extreme soil degradation risk of the Ceveiro watershed in an integral and reliable form.
Key Words: Erosion tolerance, life-time

O CONCEITO DE TEMPO-DE-VIDA COMO FERRAMENTA PARA A DEFINIÇÃO DA TOLERÂNCIA DE PERDA DE TERRA POR EROSÃO

RESUMO: Por definição, a tolerância de perda de terra por erosão deve considerar a preservação do solo como um recurso natural essencial para a produção das culturas. Taxas de erosão do solo superiores a sua renovação ocasionam diminuição da sua espessura. Uma espessura mínima foi definida como sendo a espessura abaixo da qual os insumos (fertilizantes, resíduos de culturas) e a tecnologia de manejo (irrigação, culturas geneticamente melhoradas) são insuficientes para manter economicamente a produtividade. Assim, taxas de erosão maiores do que a formação podem ser aceitas somente durante o tempo no qual não foi atingida a espessura mínima. Este período foi definido como tempo-de-vida. O conceito de tempo-de-vida foi aplicado na bacia do Ceveiro (1.945 ha), localizada em Piracicaba no sudeste do Brasil. O cálculo do tempo de vida foi realizado usando Sistema de Informações Geográficas. Para isto foram utilizadas estimativas das taxas de erosão pela Equação Universal de Perda de Solo e das profundidades do solo obtidas em levantamento de campo. Foram consideradas ainda uma taxa de formação de 0,2 mm ano^{-1}, uma profundidade mínima do solo de 1,0m, e o cenário atual de uso da terra. O uso da terra se distribui em 1.319 ha (68%) de cana-de-açúcar, 346 ha (18%) de florestas e 278 ha (14%) de pastagens. A área na qual a erosão foi menor do que a formação (área não associada a impactos irreversíveis) representou 475 ha (24%). Esta área inclui o total de florestas, 48% das pastagens e nenhuma área de cana-de-açúcar. A área com taxas de erosão maiores do que a formação e profundidade do solo menor que 1,0 m, representou 832 ha (42%), nos quais o tempo de-vida é igual a zero (impactos irreversíveis da erosão no tempo atual). O uso da terra nesta situação se compõe de 702 ha de cana-de-açúcar e 130 ha de pastagens. Para a área restante de 638 ha (32% da bacia) onde a erosão é maior do que formação e profundidade do solo é maior do que 1,0 m, foi estimado o tempo necessário para que 50%da área

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atingisse a profundidade mínima do solo. Este tempo, definido como meia-vida, foi estimado em 350 anos, sendo que nesta situação se enquadram 620 ha de cana-de-açúcar e 15 ha de pastagem. O conceito de tempo-de-vida mostrou-se eficiente na avaliação de maneira integral e confiável do risco extremo de degradação da Microbacia Hidrográfica do Ceveiro.
Descritores: Tolerância de perda de terra por erosão, tempo-de-vida

INTRODUCTION

Soil is an essential natural resource, which is available in limited quantities. Soil functions are mianly in crop production and as a filtering agent indispensable for the maintenance of water quality. In tropical agroecosystems, soil erosion is the main land degradation process, especially if land use is intense (Lal, 1990). Soil erosion can reduce crop productivity, due either to soil degradation or nutrient depletion (Larson *et al.*, 1990). Soil erosion is also an environmental hazard. In this case, the impacts are called off-farm, while silting and pollution of water resources are the major consequences (Clark, *et al.*, 1985).

Erosion limits have to be defined in order to keep these impacts at acceptable levels. An important step forward on this issue was made when Stamey & Smith (1964) suggested a model emphasizing several points involved in the determination of erosion tolerance, including the concepts of permanent preservation and soil improvement as a natural resource. This considers the assumption that if any soil property is available in excess at present or in the predictable future, it is tolerable to use the excess. According to these definitions, erosion tolerance, defined in terms of fixed values, can only be accepted if it is less than soil formation. If soil erosion is greater than formation, soil depth loss will occur and will not allow the permanent preservation of the soil as a natural resource.

The objective of this study was the development of the life-time concept as a tool for the definition of erosion tolerance. The applicability of this concept was evaluated at the watershed scale (Ceveiro watershed Piracicaba, Brazil), considered the most effective scale to treat problems related to erosion impacts and control (Moldan & Cerny, 1994).

MATERIALS AND METHODS

Erosion impacts on soil preservation as a resource for crop production was considered in this evaluation. Erosion environmental impacts were not contemplated because of the lack of quantitative data applicable to the study area.

Erosion effects on crop productivity can often be decreased by productivity increase factors (Olson *et al.*, 1994), such as high fertilizer inputs, more suitable management technology and improvements in genetic crop quality. In an erosion simulation experiment, Sparovek (1991) demonstrated a fast crop productivity restoration under high-input agriculture for an oxisol, even after the complete removal of the topsoil (45 cm). Thus, under the Ceveiros watershed conditions, i.e. high input irrigated sugarcane production, it is expected that even high present erosion rates will not be associated with an immediate productivity reduction. Although high erosion rates do not assure the permanent preservation of the soil as a natural resource, once soil depth loss occurs and a minimum soil depth will be reached or the entire soil will be removed.

In order to assess long-term soil degradation, some definitions were established. Minimum soil depth was defined as the depth at which the productivity increase factors (fertilizer, irrigation, crop management, improvement of genetic crop quality) are not sufficient to prevent economic productivity loss. In similar conditions as in the Ceveiro watershed (under intense natural erosion and high input agriculture) Salviano (1996) could identify direct impacts of soil erosion on crop productivity only after the remaining soil was less than 0.8 m. Skidmore (1982) used a similar definition for minimum soil depth and suggested the depth of 0.5 m. Thus, erosion rates greater than soil formation are acceptable only during the time soil does not reach the minimum depth. After that almost irreversible productivity loss will occur, i.e. the available technology will not be sufficient to counterbalance the erosion impacts and soil preservation. This time was defined as life-time. When the life-time is reached, soil erosion tolerance must be equal to or less than soil formation rates.

The life-time concept was applied to the Ceveiro watershed (1,945 ha) located in a sugarcane growing region near Piracicaba, in the

Southeast of Brazil. Due to its proximity to industry and the possibility of irrigation with industrial residues (vinasse), the pressure of occupation with sugarcane has been great and the management intense. Degradation due to soil erosion was clearly visible through the intense silting of water reservoirs and a high frequency of gullies.

For the life-time calculations, minimum soil depth of 1.0 m was considered and soil formation, according to Friend (1992), was assumed to be 0.2 mm y^{-1}. Soil erosion rates in the present scenario of land use were estimated using the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) and the Geographic Information System (GIS) following the procedures described by Ranieri (1996).

Soil depths were measured by field surveys and were defined for the soil map units. The soil types classified according to the Brazilian Soil Classification System, its depths and occurrence are shown in TABLE 1.

TABLE 1 - Soil types, occurrence and depths in the Ceveiro Watershed.

Soil Type	Depth (m)	Occurrence (ha)
Litossolos	0.5	45.62
Podzólico pouco profundo, Solos Hidromórficos, Solos Aluviais	1.0	14.39
Cambissolos	1.5	3.75
Podzólicos Vermelho-Amarelo, Terra Roxa Estruturada Podzólica	2.0	7.83
Podzólicos Vermelho-Amarelos, Terra Roxa Estruturada	2.5	16.5
Podzólicos Vermelho-Amarelos, Podzólico Vermelho-Escuro	3.0	9.96

The life-time calculations assumed that the present scenario that is, the management and conservation practices and crops would continue into the future.

The selected C factors from the USLE for the different land use types and its occurrence are shown in TABLE 2.

TABLE 2 - Land use types and occurrence and Universal Soil Loss Equation C factor in the Ceveiro Watershed

Land use type	C factor	Occurrence (%)
Sugarcane	0.11	66.3
Pasture	0.008	13.9
Annual Crops	0.55	0.2
Forests	0.0001	17.3
Other uses		2.3

RESULTS AND DISCUSSION

Land use type, soil depth, erosion rate and half-time distribution were calculated (Figures 1a, 1b, 1c and 1d).

The area in which soil erosion was less than soil formation represented 475 ha (24% of the total). According to the definitions, in these areas the minimum soil depth will never be reached (soil depth is increasing), and the preservation of the soil as a natural resource is assured. These areas included the total forests and 48% of the pastures. They were concentrated along the flood plains (Figure 1d), presented low erosion rates (Figure 1c) and were not necessarily associated to deeper soils (Figure 1b). Flood plains also trap sediments originating from soil erosion (Foster, 1982).

Sediment tapping, a soil depth increase process, is not considered in this paper but will also contribute to the prevention of soil depth loss. The pressure of occupation with low-lying sugarcane (flood plain positions) was low due to management restrictions. The presence of forests and pastures was another factor that contributed to the preservation of these areas.
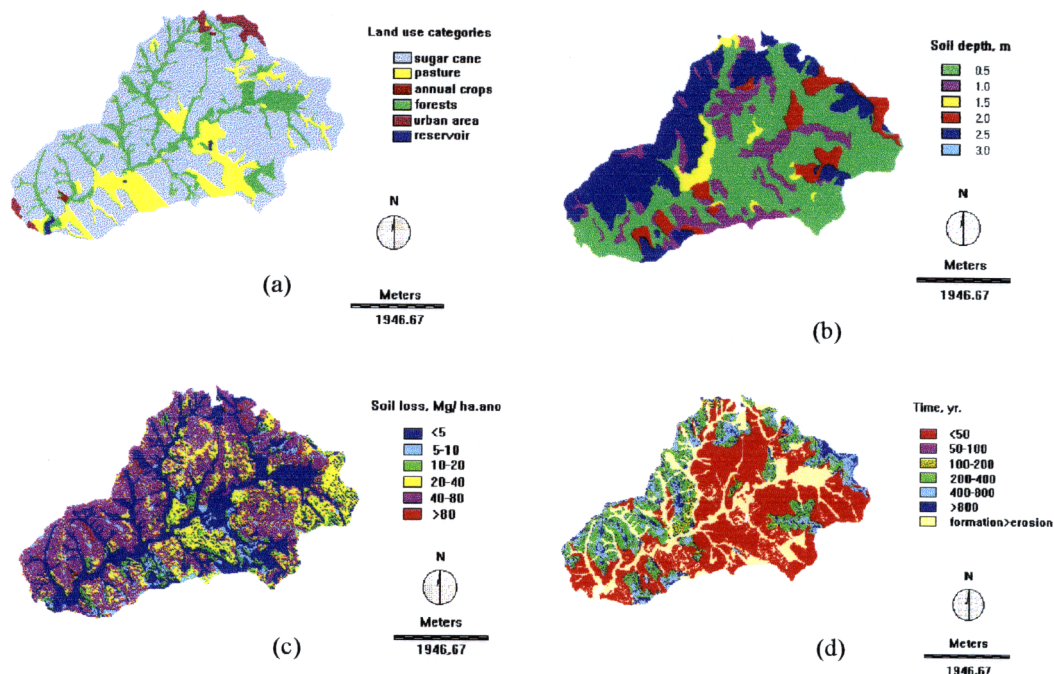
Figure 1 - (a) Land use type, (b) soil depth, (c) erosion rates and (d) half-time distribution in the Ceveiro Watershed.

The total sugarcane area had erosion rates greater than soil formation rates, consequently soil depth loss will occur. Thus, in these areas, the minimum soil depth has already been (life-time = 0) or will be (life-time > 0) reached. The area of sugarcane with life-time equal to zero (soil depth < 1.0 m and erosion > formation) was 702 ha (36%) and areas with positive values for life-time were 617 ha (31%). The relation between the relative area for the entire watershed and the land use types and the life-time is shown in Figure 2. Conceptually, zero life-time indicates that irreversible productivity loss is occurring at present time. The positive half-time values denote areas in which the productivity increase factors have counterbalanced erosion impacts on economic productivity loss at the present time, but soil is not preserved as a natural resource. The large relative area with life-time equal to zero and a final value of 1.0 indicated that sugarcane is the major land use conflict in this area. According to

the shape of the curve (Figure 2), the present situation could be sustained for a period of 100 years before significant increase in relative area were observed. The presence of sugarcane in soils with high erosion susceptibility regionally affects 30% of these lands (Sparovek & Lepsch, 1995). From the total pasture area of 278 ha (14%), 133 ha demonstrated soil formation rates greater than soil erosion and 130 ha had life-time equal to zero. The remaining 15 ha presented positive half-time values. These data and the shape of the curve (Figure 2), indicated that the relative where erosion impacted productivity was great, but no significant increase can be expected for the future.

The whole watershed presented a bias similar to that observed for sugarcane, its major land use. The relative area with life-time equal to zero was 0.43, which increased to a maximum of 0.76. Therefore. only 24% of the soils are preserved as natural resource. The half-life-time for the watershed (the time needed for 50% of the

area with erosion greater than soil formation to reach the minimum soil depth) was 350 years. The present irreversible degradation should remain stable for approximately 100 years, after

which, the relative area at the minimum soil depth will increase significantly and erosion tolerance will need to decrease in order to assure productivity preservation.
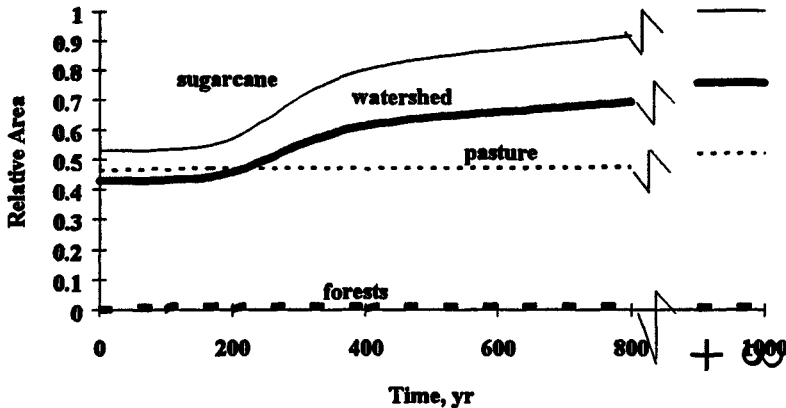

Figure 2 - Relative area for the whole watershed and the associated land use types in relation to the life-time in the Ceveiro Watershed.

The life-time concept allowed a precise definition of erosion tolerance, while indicating land use conflicts, emphasized the need and time of interference according to the land use type. The long-term consequences of current management technologies and land use types, defined mostly by economical conditions, could be identified as well as its sustainability. The life-time concept allowed a low subjective land evaluation procedure (Diepen *et al.*, 1991), treated soil information quantitatively (Bouma, 1989) and was compatible with GIS resulted more reliable results.

CONCLUSIONS

Irreversible impacts on crop productivity due to soil erosion constitutes a serious problem in the Ceveiro watershed, and this is associated with intensive cultivation of sugarcane. The present situation can be sustained for approximately 100 years, after which land degradation will increase significantly. The life-time concept allowed reliable evaluation of the impact of soil erosion on crop productivity.

REFERENCES

BOUMA, J. Using soil survey data for quantitative land evaluation. In: STEWART, B. A., ed. Advances in Soil Science, Springer-Verlag New York Inc., v.9. p.177-213, 1989.

CLARK, E.H.; HAVERKAMP, J.A; CHAPMAN, W. Eroding Soils. The off-farm impacts. Washington, D.C., The Conservation Foundation. p.1-252, 1985.

DIEPEN, C.A.; KEULEN, H.; WOLF, J.; BERKHOUT, J.A.A. Land evaluation: from intuition to quantification. Advances. in Soil Science, v.15, p.139-204, 1991.

FOSTER G.R. Modeling the erosion process. In: HAAN, C.T; JOHNSON, H.P.; BRAKENSIEK, D.L., eds. Hydrologic modeling of small watersheds. St. Joseph: ASAE, p.294-380, 1982.

FRIEND, J.A. Achieving soil sustainability. Journal of Soil and Water Conservation, v.47, p.156-157, 1992.

LAL; R. Soil erosion and land degradation: the global risks. Advances in Soil Science, v.7, p.129-172, 1990.

LARSON, W.E.; FOSTER, G.R.; ALMARAS, R.R.; SMITH, C.M., eds. **Proceedings of soil erosion and productivity workshop.** Minessota, 142p., 1990.

MOLDAN, B.; CERNY, J. **Biogeochemistry of small catchments. A tool for environmental research.** Chichester: John Wiley & Sons. p.1-419, 1994.

OLSON, K.R.; LAL, R.; NORTON, L.D. Evaluation of the methods to study soil erosion-productivity relationships. **Journal of the Soil and Water Cons.** v.49, p.586-590, 1994.

RANIERI, S.B.L. Avaliação de métodos e escalas de trabalho para determinação de risco de erosão em bacia hidrográfica utilizando SIG. São Carlos, SP, 1996. 128p. (Dissertação) Mestrado - Escola de Engenharia de São Carlos, Universidade de São Paulo.

SALVIANO, A.A.C. Relações entre atributos de solo e produtividade da *Crotalaria juncea* em área erodida. Piracicaba, SP, 1996. 92p. (Tese) Doutorado - Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo.

SKIDMORE, E.L. Soil-loss tolerance. In: American Society of Agronomy. **Determinants of soil loss tolerance.** p.87-93, 1982.

SPAROVEK, G.; TERAMOTO, E.R.; TORETA, D.M.; ROCHELE, T.C.P.; SHAYER, E.P.M. Erosão simulada e a produtividade da cultura do milho. **Revista Brasileira de Ciência do Solo,** v.15, p.363-368, 1991.

SPAROVEK, G; LEPSCH, I.F. Diagnóstico de uso e aptidão das terras agrícolas de Piracicaba. In: TAUK-TORNISIETO, S.M.; GOBBI, N.; FORESTI, C.; LIMA, S.T. DE. **Análise ambiental: estratégias e ações.** São Paulo: Queiroz, p. 273-9, 1995.

STAMEY, W. L.; SMITH, R. M. A conservation definition of erosion tolerance. **Soil Science,** Baltimore, v.97, p.183-6, 1964.

WISCHMEIER, W. H.; SMITH, D. D. **Predicting rainfall erosion losses -A guide to conservation planning.** U.S. Department of Agriculture, Sci. and Educ. Admin., Agriculture Handbook., 537, 1978.