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Comparison of Three Water Erosion Prediction Methods (^{137}Cs, WEPP, USLE) in South-East Brazilian Sugarcane Production

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Key words: Erosion prediction, ^{137}Cs, WEPP, USLE, sugarcane, Brazil.

Abstract

Soil erosion is the main degradation process in tropical agroecosystems. Soil erosion rates should be considered in land evaluation and conservation planning assessment. The methods available for erosion prediction are not sufficiently calibrated or validated for tropical soils, climates and crops. Thus, differences in estimated soil erosion values may be expected, even if considering the same input data. Three soil erosion estimation methods (USLE, WEPP and ^{137}Cs) were applied to the same watershed cultivated with sugarcane in Southeastern Brazil (near Piracicaba S 22°38'54" and W 47°45'40"). The absolute erosion rate values and the differences in the spatial distribution were evaluated. The overall results suggested that there are important differences in soil loss estimated by the three methods. The differences occurred in both, mean values and geographic locations. The sequence of mean soil loss values was USLE>>^{137}Cs>WEPP and standard deviation values USLE>WEPP>^{137}Cs, indicating that USLE predicted the highest erosion values and spread out over the widest range. The poor geographical coincidence of the results is evidence that the values resulting from none calibrated soil erosion methods should be considered only as qualitative indications. The method selection should consider overall site variability in relation to known sensitive method factors.

1 Introduction

In tropical agroecosystems, soil erosion is usually considered as the main land degradation process, especially if land use is intense (LAL, 1990). Soil erosion can reduce crop

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productivity, either due to soil degradation or nutrient depletion (Larson et al 1990). Therefore, soil erosion rates are usually part of the information to be considered for land evaluation under tropical conditions. Soil conservation planning, land use technology impact assessment and the evaluation of the sustainability of agriculture are examples of issues that require erosion estimations (Pimentel et al 1995; Clark et al 1985).

Soil erosion evaluations in large scales, for example in a watershed, can not be based on direct measurements due to methodological restrictions (Lal, 1988) and an excessively high temporal variability (Edwards & Owens, 1991). Direct measurements would undertake complex and costly methods resulting in senseless or not representative values. Therefore, under these conditions, soil erosion is usually estimated. If, instead of qualitative erosion risk determination, quantitative predictions are desired, these estimations have to be based on models or on direct assessment as through ^{137}Cs fallout redistribution analysis.

The Universal Soil Loss Equation or USLE (Wischmeier & Smith, 1978) is the most comprehensive statistic soil erosion prediction method. Most of the subsequent statistic based soil erosion prediction methods are based on or have components of USLE (Renard & Mausbach, 1990; Foster, 1982). However, sedimentation can not be estimated with USLE. The Water Erosion Prediction Project or WEPP (Flanagan & Nearing, 1995) is conceptually different because it is a process based soil erosion prediction method and estimates sedimentation as well. The ^{137}Cs fallout redistribution analysis estimates erosion directly, based on soil ^{137}Cs activity. This method is sensitive not only to soil material redistribution via soil erosion but to other pathways such as tillage, scraping and road construction (Ritchie & McHenry, 1990; Walling & Quine 1993).

All three methods have been validated under specific experimental conditions, usually compared to measured erosion data resulting of natural or simulated rainfall (Wischmeier & Smith, 1978; Lane et al 1992; Ritchie & McHenry, 1990). Each of the methods is based on different theoretical assumptions, and in part estimates different parameters (USLE estimates soil erosion rates, WEPP and ^{137}Cs estimate erosion and deposition rates). The equation parameters for USLE and WEPP as well as the statistical procedures to convert ^{137}Cs activity in erosion rates, were determined in temperate environments, mostly in North America and Europe, under completely different soil, climate, management and fallout conditions from the tropical regions.

Probably, bias imposed on methods result from both, differences in theoretical assumptions and exogenous fundamental database, when applied to tropical conditions. These bias may yield differences in estimations, even considering the same input data. The analysis of these differences, in magnitude and geographic location is a step forward to learn about method performance. The definition of specific conditions where the results from one or other erosion prediction method may be more reliable also depends on comparative studies.

The objective of this study was to determine differences in soil erosion prediction patterns from ^{137}Cs fallout redistribution analysis, USLE and WEPP in a watershed intensively cultivated with sugarcane in Brazil, conditions under which none of these models were developed or validated.

1 Material and Methods

The study area is a 6 ha part of the Ceveiro watershed (2,200 ha) located at the Southeastern part of Brazil (Piracicaba) with central coordinates of S 22°38'54" and W 47°45'40". Climate, according to Koeppen's classification is Cwa (Humid subtropical with a dry winter and less than 30 mm rain in the driest month, the temperature in the hottest month is beyond 22°C and in the coldest below 18°C). The S-shaped slope profiles have a mean slope value of 16 % (80 % of the computed slope values were between 5 and 25 %). The soil, an Arenic Paleudult (Soil Survey Staff, 1990), has a surface layer with 70 % sand decreasing to 50 % in the subsurface Bt horizon. Local and overall land use is primary intensive sugarcane production (4.8 ha or 80 % at the site and 50 % regionally). In the central part of the area an abandoned pasture (1.2 ha) is acting as a buffer strip (Figure 1). Past soil erosion is evident by a mosaic of colors at the surface extending from gray colors at the top slope positions characterizing the original surface horizon to strong yellow colors form the Bt horizon, originally at the depth of 1.0 m, at the mid slope. At the end of the slopes and under pasture, a deep surface unstructured sandy horizon, indicating recent depositions, dominates. Ephem-

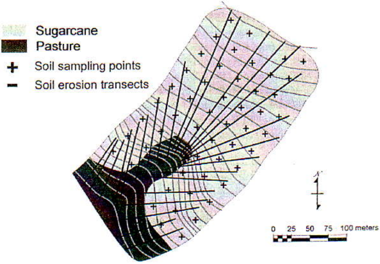

Figure 1: Site location, soil sampling points and soil erosion estimation transects

eral gullies are currently manifested at the end part of the slopes. Earth roads, made of soil material taken out of the site, were build around the area to allow mechanical sugarcane harvesting and transportation.

The ^{137}Cs methodology was applied according to Walling & Quine (1993). Samples were collected down to the depth of 0.8 m, in order to include all ^{137}Cs present in the soil profiles, on 6 transects with a distance of approximately 30 m between sampling positions (Figure 1). The ^{137}Cs determination was performed on a Gamma spectrometry equipment (detector model GEM-20180P, Pop Top EG & G ORTEC, associated to a multi-channel analyzer; 1.0 liter Marinelli Beakers with counting time of 20 to 24 hours). The conversion of ^{137}Cs inventories (Bq m^{-2}) into soil redistribution (Mg ha^{-1} year^{-1}) was calculated by a proportional model as described by Walling & He (1997).

Slope information for USLE and WEPP were extracted from a topographic contour map scale 1:10,000 with an original vertical resolution of 5 m, interpolated to 2 m vertical resolution using GIS triangulation tools. Twenty five soil erosion estimation transects, following the natural surface runoff outflow, were defined for USLE and WEPP calculations. The USLE was applied progressively to the intersections of the contour lines with each one of the 25 erosion estimation transects (Figure 1). For each intersection segment the USLE slope component LS was calculated according to Foster & Wischmeier (1974). For WEPP, the altitude Z values were converted in relative slope values using an interface program for building the slope input files. Local climatic data from daily 30 years records were used to calculate USLE and WEPP climate inputs. The USLE R factor was estimated as 6,235 MJ mm ha^{-1} h^{-1} using the procedures described by Lombardi & Mondenhauer (1980). The climate input file for WEPP was generated using CLIGEN ver. 4.3. (Nicks et al 1995) running a 98 year simulation. Soil erodibility for USLE (K factor) was based on equations suggested by Denardin (1990) and computed from analytical results determined from soil samples collected at the same positions as for ^{137}Cs activity measurements, resulting in a value of 0.0285 Mg h MJ^{-1} mm^{-1}. The same procedure was used for WEPP, computing the soil input file based on the internal equations of WEPP version 99.5. Management files for sugarcane and pasture for WEPP were computed using the 99.5 version shell. The cover and management factor (C) and support practice factor (P) values for USLE were based on the suggested values from De Maria et al (1994). The combined C times P values were CP = 0.1533 for sugarcane and CP = 0.0080 for pasture.

The GIS procedures were carried out by means of *TNTmips* (Micro Images®) version 6.2. After soil erosion determination, the values representing the sampling points for ^{137}Cs analysis and the intersections of the altitude contour lines with the 25 transects established by means of USLE and WEPP hillslope version 99.5, were georeferenced using an interface program and imported for the interpolation calculations into the GIS. The interpolation procedure to transform the data to raster format (1.0 x 1.0 m pixel or 354 lines x 348 columns) was the same for all three methods which was squared inverse distance linear interpolation. The differences or residues for all model combination

(^{137}Cs minus USLE, ^{137}Cs minus WEPP and USLE minus WEPP) were calculated by subtraction of individual pixel values. General statistic mean, standard deviation, minimum and maximum values from soil loss and subtracted amounts were calculated based on the complete set of interpolated values. To allow a geographic representation of the results in form of maps, the values were grouped in intervals as shown in Table 2.

None of the adopted methods were calibrated or validated under the tillage, soil and climatic conditions of the investigated watershed and there were no experimental soil loss data available. This scenario (i.e. lack of method calibration or experimental soil loss data) can be considered as typical for land use planning under tropical conditions (GRAAFF, 1996)

2 Results and Discussion

Table 1 shows general statistic results of each soil erosion prediction method and the differences (subtractions) between them. Table 2 shows the soil erosion and method subtraction erosion rate classes percentages. The maps with soil loss and subtraction values divided in classes are presented in Figure 2.

The overall results suggest that there are important differences in soil loss estimation for the three methods. The differences occurred in both, mean values and geographic performance. Basic methods assumptions could be associated to the different soil erosion estimations patterns. General statements on methods applicability were suggested. A detailed discussion on specific aspects of the method performance and differences follows.

Table 1: General statistics and erosion/deposition frequencies

Method	Minimum	Maximum	Mean	Standard Deviation	Erosion or (+)	Deposition or (-)
	Mg ha^{-1} year^{-1}				%	
	Predicted soil erosion					
^{137}Cs	-86	59	28	16	93.4	6.6
USLE	0	435	52	39	100.0	0.0
WEPP	-831	146	13	20	83.7	16.3
	Difference between methods					
^{137}CS-USLE	-405	53	-24	41	30.9	69.1
^{137}CS-WEPP	-120	860	16	26	76.8	23.2
USLE-WEPP	-6	831	39	36	99.6	0.4

Table 2: Estimated soil erosion classes and method differences class frequencies

Method	**Class in Mg ha^{-1} year^{-1} (%)**								
	>90	60 to 90	30 to 60	15 to 30	0 to15	0 to –15	-15 to -30	-30 to -60	< -60
^{137}Cs	0	0	57	26	10	5	1	1	0
USLE	13	24	28	19	16	0	0	0	0
WEPP	0	0	6	48	29	10	4	2	1

	Class in Mg ha^{-1} year^{-1} (%)						
	>36	36 to 12	12 to 6	6 to -6	-6 to -12	-12 to -36	<-36
^{137}Cs-USLE	3	18	5	9	5	26	34
^{137}CS-WEPP	20	33	15	16	6	8	2
USLE-WEPP	44	32	10	14	0	0	0

The sequence of mean soil loss values was USLE>>^{137}Cs>WEPP and standard deviation values USLE>WEPP>^{137}Cs, indicating that USLE predicted the highest erosion values and spread out over the widest range. The USLE has a very high sensitivity in relation to the topographic factor LS (Risse et al 1993). Over predicted USLE soil loss estimations as compared to experimental plot values were described by Tomás & Coutinho (1994) in Portugal. USLE statistic database, used to develop the equation parameters, was based on uniform small plots (≈ 22 m long and ≈ 3 m wide) under single management experimental conditions. In these plots none or little deposition is expected as compared to real longer complex slopes and management situations. The lack in considering sedimentation and the heritage of the experimental conditions of USLE development were the reasons Johnson (1988) pointed out to explain over-prediction in relation to ^{137}Cs. The conditions under which this study was conducted are coincident with what has been described by Johnson (1988) for USLE soil loss over predictions i.e. long and complex slopes under different management practices. The average slope length from the 25 soil erosion estimation transects (Figure 1) was 129 m (6 times longer than the USLE standard experimental plots) with a minimum value of 78 m and maximum of 219 m. Higher soil loss estimations for RUSLE or Revised Universal Soil Loss Equation, Renard et al (1997) as compared to WEPP were attributed to a lower sensitivity to crop related parameters and higher sensitivity to topographic factors in RUSLE (Nearing et al 1990). A contrasting land use and management pattern with an abrupt boundary between intensively cultivated sugarcane and an abandoned pasture over steep, long and complex S-shaped slopes are favorable conditions for over estimations, or at least, higher erosion rate estimations for the USLE as compared to WEPP or ^{137}Cs. This performance is directly linked and heritage from the experimental conditions under which USLE was developed, its sensitivity in relation to topographic and management factors and the lack of sedimentation prediction.

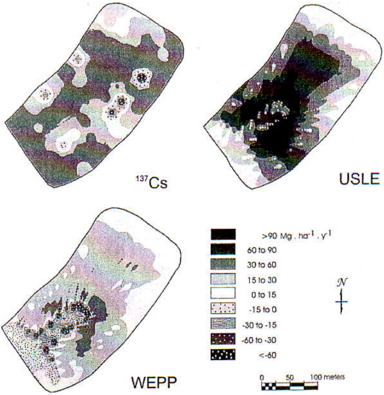

Figure 2: Geographical distribution of absolute soil erosion estimated by three methods.

The influence of the erosion rate estimation method in relation to land use planning decisions was significant. Considering 12 Mg ha^{-1} year^{-1} as normally accepted soil loss tolerance value (McCormack et al, 1982) the mean values would define the area as acceptable in relation to erosion rates by WEPP (≈ 1 time soil loss tolerance), ≈ 2 times tolerable erosion rates with ^{137}Cs and ≈ 4 times by USLE. An area with a soil surface color mosaic showing layers that were one meter deep in the original soil profile, sediments overall spread out at the lower slopes and frequent ephemeral gullies, is far of being considered as acceptable in relation to erosion following the common sense. It is not advisable to rely on quantitative results when working with erosion prediction methods under no calibrated situations, once it is not possible to guarantee accuracy based on experimental results. External standards for acceptable or tolerable soil erosion rates, in this case, may conduct to untrue or far from common sense judgments. The unclear or different problem perception of the farmer in relation to a land use planning decision is a main reason for technology none adoption (Fujisaka, 1994). The tolerable value, under these conditions, should be internal and based on common problem perceptions or other indicators such as productivity decline, silting and water pollution or availability. Absolute quantitative soil loss tolerance values, as suggested by Grossman & Berdanier, (1982), should be substituted by time functions with present time erosion rate equal to the estimated soil rates (Sparovek & De Jong van Lier, 1997). The present time erosion rate, independent to its absolute value or estimation method, would be reduced as a function of time, according to the recognition of erosion related problems and its rehabilitation or reversion and following an executable conservation land use and management strategy. Following this proposal, the relative geographical distribution pattern becomes more important than the absolute values yielded from the erosion estimation methods.

WEPP estimated a continuous deposition area located at the final 1/3 of the transects, coincident with the transition of sugarcane to pasture and with lower slope values. The largest depositions, in this case, were found close after the crop transition (range of < -60 Mg $ha^{-1}year^{-1}$), and deposition rates in the range of 0 to -15 Mg $ha^{-1}year^{-1}$ at the end ¼ transects (Figure 2). The high sensitivity of WEPP to crop parameters and the great differences from sugarcane in relation to pasture for soil cover distribution, surface roughness and tillage (Nearing et al 1990) are the reasons for WEPP reaction to a crop shift. USLE performance at the same boundary had a less significant soil erosion rate reduction, because of the higher sensitivity to slope factors and the none consideration of sedimentation (Risse et al 1993; Wischmeier & Smith, 1978). The geographic distribution of soil erosion values estimated by ^{137}Cs (Figure 2) did not follow the classical and expected trend shown by WEPP and USLE. The common sense would expect increasing erosion rates from up to down slope and deposition (or soil erosion reduction) at the end slope where a pasture buffer strip arises on a smoother landscape position, exactly as shown in figure 2 for WEPP and USLE. The ^{137}Cs redistribution analysis method is, although, sensitive to other soil transport mechanisms e.g. road construction or maintenance, surface leveling after gully formation and downhill plowing (Ritchie & McHenry 1990). All these operations presently occur in the area and can be considered as routine procedures under intensive sugarcane cultivation, consequently undertaken in the area for the last 25 years. The indication of depositions side by side of very high erosion rates at the upper slope, as shown in figure 2 for ^{137}Cs, can not be explained by soil erosion basic concepts or process theory. Although, these patterns can easily be understood by considering that exactly at this position a main earth road was build for sugarcane transportation and that for leveling a road soil material had to be scraped from one place (high soil erosion values) to another (deposition). Other soil material movements may explain the distribution patterns overall the area (gully leveling, secondary road construction) but this information can not easily be assessed or retrieved after 25 years of commercial sugarcane production. Probably, this human material redistribution has not exported soil out of the area thus it should not, in theory, influence average erosion rate values. The intermediate performance of ^{137}Cs in predicting average soil erosion rates as compared to USLE (foreseen over prediction) and WEPP (high sensitivity to none calibrated crop parameters) may not be completely casual.

The sequence of absolute (modulus) mean method differences was USLE-WEPP>> ^{137}Cs-USLE>^{137}Cs-WEPP. Positive values were observed by USLE-WEPP and ^{137}Cs-WEPP and negative values by Cs-USLE (Table 1). USLE estimated higher soil erosion values in 69 % of the area as compared to ^{137}Cs and 99.6 % in relation to WEPP. ^{137}Cs estimations were higher than WEPP in 23 % of the area. The difference class from 6 to -6 Mg ha^{-1} year^{-1}, which would yield the same interpretation in relation to soil loss tolerance considering 12 Mg ha^{-1} year^{-1} as a standard, ranged from only 9 % of the area by ^{137}Cs-USLE up to the maximum, but still low, value of 16 % by ^{137}Cs-WEPP. The differences between ^{137}Cs and WEPP and ^{137}Cs and USLE followed a random or trend less pattern (Figure 3). The differences between USLE and WEPP (Figure 3) show a clear trend, increasing from the upper slope until reaching the maximum values of > 36 Mg ha^{-1} year^{-1} from the ½ slope on. The greater sensitivity to slope parameters in relation to WEPP and a great sensitivity of WEPP to crop related factors and its sediment deposition estimations can be clearly associated to these differences. Probably, if

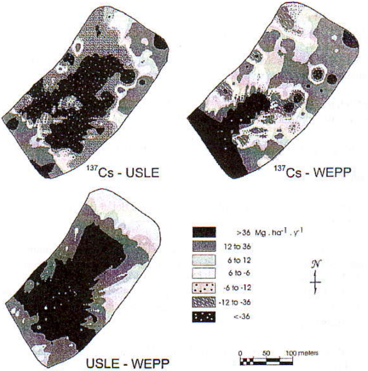

Figure 3: Geographical distribution of differerences between soil erosion estimation methods

an internal relative soil loss tolerance value would be adopted, a similar interpretation of erosion impacts would be achieved by WEPP and USLE at the upper slope and WEPP would attenuate erosion impacts at the mid and end slopes.

The poor geographical coincidence is another evidence that the values resulting from none calibrated soil erosion methods should be considered as qualitative indications and that the target erosion rate value has to be internally determined. In this case, the coherent geographic distribution, the local variability in relation to known sensitive method factors, the kind of output needed and the available database should be the key issues to select methods.

3 Conclusion

The basic assumptions of the erosion prediction method had a significant influence on both, mean erosion or deposition rates and geographic distribution patterns.

The election of the method to predict erosion can influence significantly the final interpretation of erosion associated impacts.

The method selection should consider overall site variability in relation to known sensitive method factors.

Vergleich dreier Methoden (^{137}Cs, WEPP, USLE) zur Schätzung der Wassererosion im Zuckerrohranbau Südostbrasiliens

Schlagwörter: Erosionsschätzung, ^{137}Cs, WEPP, USLE, Zuckerrohranbau

Zusammenfassung

Erosion ist der bedeutendste Faktor für den Verlust an Bodenfruchtbarkeit in tropischen Agrarökosystemen.

Kennwerte für Erosion und Erosionsanfälligkeit sind daher wichtige Grundlagen für die Planung und Bewertung von Bodenschutzmassnahmen. Ein besonderes Problem hierbei ist jedoch, dass die derzeit gebräuchlichen Methoden zur Erosionsschätzung nicht oder nur unzureichend für tropische Klimaten und Anbaubedingungen kalibriert und überprüft sind. Daher sind mit unterschiedlichen Schätzungsmethoden, auch unter sonst gleichen Bedingungen und Eingangsdaten, unterschiedliche Ergebnisse zu erwarten.

Drei Methoden zur Erosionsschätzung (USLE (Universal Soil Loss Equation), WEPP (Water Erosion Prediction Program), ^{137}Cs (Radionuklidverteilung)) wurden auf ein Wassereinzugsgebiet im Südwesten Brasiliens (nahe Piracicaba, S 22°38'54" und W 47°45'40") angewendet. Die absoluten Erosionswerte sowie deren räumliche Verteilung

wurden bestimmt. Generell zeigten sich dabei große Unterschiede sowohl in den absoluten Werten als auch in deren Verteilung. Die Reihenfolge der von den Methoden bestimmten absoluten Erosionswerte war USLE>>^{137}Cs>WEPP, die der Standardabweichungen USLE>WEPP>^{137}Cs. Demnach lagen die mit USLE geschätzten Erosionswerte am höchsten bei gleichzeitig größter Varianz. Die nur geringe geographische Übereinstimmung der vorhergesagten Erosionsereignisse implizieren weiterhin, dass die Ergebnisse nicht kalibrierter Erosionsmodelle allenfalls als qualitative Indikatoren geeignet sind. Bei der Auswahl einer Methode zur Erosionsschätzung sind demnach landschaftstypische Merkmale und methodenspezifische Parameter aufeinander abzustimmen.

5 References

1 Clark E. H., Haverkamp, J. A. and Chapman, W., 1985, *Eroding Soils. The off-farm impacts.* Washington, D.C., The Conservation Foundation. p. 1-252.

2 De Maria, I.C., Lombardi Neto, F., Dechen, S.C. F. and Castro, O. M. de., 1994, Fator C da Equação Universal de Perdas de Solo (EUPS) para a cultura de cana-de-açúcar. In: Resumos da X Reunião Brasileira de Manejo e Conservação do Solo e da Água, Florianópolis, 1994. Summaries. Florianópolis, p.148-149.

3 Denardin, J.E. 1990. Erodibilidade do solo estimada por meio de parâmetros físicos e químicos. Doctoral thesis University of São Paulo, Piracicaba, Brazil.

4 Edwards, W.M. and Owens, L.B., 1991, Large storm effects on total soil erosion. *J. Soil and Water Conservation* 46, 75-78

5 Flanagan, D.C. and Nearing, M.A (eds.), 1995, USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation. West Lafayette: NSERL Report No. 10, 1995.

6 Foster G. R., 1982, 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.

7 Foster, G.R. and Wischmeier, W.H., 1974, Evaluating irregular slopes for soil loss prediction. *Transations of American Society Agricultural Engineering* 17, 305-309.

8 Fujisaka, S., 1994, Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agric. Syst.* 46, 409-425.

9 Graaff, J. de, 1996, The price of soil erosion, an econimic evaluation of siol conservation and watershed development. Ph.D Thesis, Wageningen. 300 pg.

10 Grossman, R.B. and Berdanier, C.R., 1982, Erosion tolerance for cropland: application of the soil survey data base. In Determinants of erosion tolerance. *American Society of Agronomy*, 113-130.

11 Johnson, R.R., 1988, Putting soil movement into perspective. *J. Prod. Agric.* 1,5-12.

12 Lal, R., 1988, Soil erosion by wind and water: Problems and prospects. In: Lal, R. Soil erosion research methods. Wageningen, HL, SWCS.

13 Lal, R., 1990, Soil erosion and land degradation: the global risks. *Advances in Soil Science* 7, 129-172.

14 Lane, L.J., Renard, K.G., Foster, G.R. and Laflen, J.M., 1992, Development and application of modern soil erosion prediction technology. *Australian Journal of Soil Research* 30, 893-912.

15 Larson, W. E., Foster, G. R., Allmaras, R. R. and Smith, C.M., (Ed.), 1990, Proceedings of soil erosion and productivity workshop. Minessota, 142p.

16 Lombardi Neto, F. and Moldenhauer, W.C., 1980, Erosividade da chuva: sua distribuição e relação com perdas de solo em Campinas, SP. In: Encontro Nacional de Pesquisa sobre Conservação do Solo, 3. Recife.

17 McCormack, D.E., Young, K.K. and Kimberlin, L.W., 1982, Current criteria for determining soil loss tolerance. In Determinants of soil loss tolerance. *American Society Agronomy* 95-111.

18 Nearing, M.A., Deer-Ascough, L., and Laflen, J.M., 1990, Sensitivity analysis of the WEPP hilslope profile erosion model. *Transactions of the ASAE* 33, 839-849.

19 Nicks, A.D., Lane, L.J., and Gander, G.A., 1995, Weather Generator. In: Flanagan, D.C., Nearing, M.A. (Ed.) USDA-Water Erosion Prediction Project: Hillslope profile and watershed model documentation. West Lafayette: USDA-ARS-MWA-SWCS, p.2.1-2.22.

20 Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R., 1995, Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117-1123.

21 Renard, K.G. and Mausbach, M.J., 1990, Tools for conservation. In: Larson, W.E., Foster, G.R., Allmaras, R.R., Smith, C.M. (Ed.) Proceedings of Soil Erosion and Productivity Workshop. Minnesota: University of Minnesota, p 55-64.

22 Renard, K.G., Foster, G.R, Weesies, D.K. and Toder, D.C. (Coord.), 1997, Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agricultural handbook 703, 404 p.

23 Risse, L.M., Nearing, M.A., Nicks, A.D., and Laflen, J.M., 1993, Error assessment in the Universal Soil Loss Equation. *Soil Sci. Soc. Am. J.* 57, 825-833.

24 Ritchie, J.C. and McHenry, J.R., 1990, Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review. *Journal of Environmental Quality* 19, 215-233.

25 Soil Survey Staff, 1990, Keys to Soil Taxonomy, fourth edition. SMSS technical monograph No. 6, Blacksburg, Virginia.

26 Sparovek, G. and De Jong van Lier, Q., 1997, Definition of tolerable soil erosion values. *Rev. bras. Ci. Solo* 21, 467-471.

27 Tomás, P.P. and Coutinho, M.A., 1994, Comparison of observed and computed soil loss, using the USLE In: RICKSON, R.J., ed. Conserving Soil Resources - European Perspectives. Cambridge, Silsoe College, Cranfield University, UK. 161-177.

28 Walling, D.E. and He, Q., 1997, Models for converting ^{137}Cs measurements to estimates of soil redistribution rates on cultivated and uncultivated soils. A contribution to the IAEA Coordinated Research Programmes on Soil Erosion (D1.50.05) and Sedimentation (F3.10.01). University of Exeter, Exeter, UK, 29pp.

29 Walling, D.E. and Quine, T.A., 1993, Use of Caesium-137 as a tracer of erosion and sedimentation: Handbook for the application of the Caesium-137 technique. UK Overseas Development Administration Research Scheme R4579. Department of Geography, University of Exeter. 196pp.

30 Wischmeier, W.H. and Smith, D.D., 1978, Predicting rainfall erosion losses - a guide to conservation planning. Washington, D.C. Agricultural Handbook 537. USDA. 58pp.