USLE C FACTOR DETERMINED BY MULTI-TEMPORAL AVHRR/NOAA-14 DATA

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ABSTRACT

This paper presents a methodology for the integration of AVHRR/NOAA-14 sensor data and USLE (Universal Soil Loss Equation) for identifying soil degradation and mapping erosion risks. The study area was the Piracicaba river watershed (5,457 km^2) located in São Paulo State, Brazil. Thirty percent of the region is covered with sugarcane plantations, which are the raw-material provider both for cane-sugar mills as for carburant-alcohol distilleries. To apply USLE equation, remote sensing and GIS techniques were used. The USLE C factor (use and management) indicates the soil protection provided by the vegetative cover and it changes gradually with the biomass yield. NDVI (Normalised Difference Vegetation Index) was selected to determine C factor since it is commonly used due its high sensitivity in monitoring green biomass. Channels 1 and 2 digital counts from seven AVHRR multi-temporal images from may/1996 to september/1997 were transformed from grey levels to percent of reflectance, since reflectance data are more suitable to get NDVI. Radiometric calibration was applied following the procedures of NOAA/NESDIS (National Environmental Satellite Data and Information Service). Through the NDVI data it was possible to characterise the sugarcane biomass growth and the values of predicting soil losses in a two-harvest period. Five classes of erosion risks were determined: (*Class 1*: 50.6% of sugarcane crop area; *Class 2*: 20.6%; *Class 3*: 24.3%; *Class 4*: 4.1%; *Class 5*: 0.3%). The correlation between erosion risk classes and soil types showed that sugarcane is mostly cultivated on soils with better physical characteristics, preferably on less steep slopes.

RÉSUMÉ

ESTIMATION DU FACTEUR C DE L'EUPS À PARTIR DES DONNÉES MULTI-TEMPORAL DU CAPTEUR AVHRR/NOAA-14

Une méthode d'intégration des données du capteur AVHRR/NOAA à partir de l'EUPS est présenté en visant l'identification de la dégradation du sol et l'estimation des risques d'érosion. La région d'étude a été le bassin de la rivière Piracicaba (5.457km^2) situé dans l'état de São Paulo (Brésil). La canne-à-sucre, qui est utilisé pour la production de l'alcool et du sucre, couvre vers 30% du sol agricole de la région. Le calcul de l'EUPS a été fait en utilisant des méthodes de télédétection et des systèmes d'information geographiques. L'indice C de l'EUPS indique la protection du sol fourni par le couvert vegetal et est proportionnel au developpement de la biomasse verte. Le NDVI a été utilisé pour estimer l'indice C à cause de sa sensibilité au developpement de la biomasse verte. Le NDVI a été calculé en utilisant les données de reflectance obtenues à partir de 7 images du capteur AVHRR/NOAA acquis du Mai 1996 au Septembre 1997. Le NDVI a permit de suivri le developpement de la biomasse de la canne à sucre et d'estimer la perte du sol dans une période équivalent a deux récoltes. Il a été possible d'établir 5 classes de risque d'erosion à partir du couvert du sol par de la canne à sucre: La correlation entre les classes de risque d'erosion et les types de sol de la région a montré que les plantations de la canne à sucre utilisent les sols qui possedent des meilleurs caractéristiques physiques et qui sont situées dans les régions où les pentes sont plus légers.

I. INTRODUCTION

Erosion has been causing severe damages in São Paulo State, Brazil, not only through the crop soils losses, but also in urban areas degradation, where a great amount of public investment is expended every year. Data from Agronomic Institute of Campinas indicate that significant parcel of cultivated land is being affected by erosive processes beyond the natural recovering limits, in such a way that both in short and medium terms, important crop areas will be so degraded that it would take hundreds of years to be spontaneously recovered. Being an intensive agriculture management crop, sugarcane has caused serious problems of soil degradation and in water resources, as outflow reduction, sediment transportation and pesticides contamination.

A better understanding of the soil degradation risks and its geographic distribution, as well as where the degradation processes effectively occur, should be the main concern of researchers, planners, and decision-makers involved with land use policy, in order to establish efficient planning and soil management. Such evaluation is particularly important in the present, due to the fast changing of land use in many parts of the world which is frequently the main factor of soil degradation (Chisci, 1981)

The studied area is particularly important due to its strategic insertion into the MERCOSUL (South Common Market), which was created in 1995 to integrate economically Brazil, Argentina, Paraguay and Uruguay. Paraná, Tietê, Piracicaba, Paraguay and Uruguay rivers compound Paraná River Basin, in a 500 million hectares with a population of 90 million people, taking the greatest and richest parcel of MERCOSUL, being responsible for 13% (10 billion dollars) of total Brazil's exportation figures in 1995. Prognostics for year 2010 indicate that the fluvial transportation will reach 13 million ton (25 billion dollars) since cargo will be mostly originated in the Tietê-Pananá waterway surroundings.

The detection and monitoring of the accelerated soil erosion by means of remote sensing techniques may provide data mostly related to the terrain surface (Pinto, 1991). In view of the above, Cavalli & Lombardi Neto (1996) accomplished soil losses assessment through erosion in part of Piracicaba river watershed to calculate erosion risks under sugarcane plantations using geo-processing and remote sensing techniques. In such a context, the present work characterised soil losses in sugarcane plantations to define mostly the limiting areas where environmental problems might be occurring. In addition, correlation between erosion risk classes and soil types were performed in order to define soil preferences for sugarcane cropping.

2. METHODOLOGY

2.1 Localisation

The area studied has an extension of 5,457 km^2, located among co-ordinates 22°00' to 23°00'S and 47°00' to 48°30'W, corresponding to the lower sector of Piracicaba river watershed at the centre-eastern region of São Paulo State, Brazil (Figure 1), where sugarcane is the main crop, taking some 30% of the area. In fact, sugarcane is planted all over the country, being São Paulo State the main producer, taking an area of 2,856,000 hectares in 1996/97 harvest, representing 60% of sugarcane production, 62% of fuel alcohol and 56% of cane-sugar produced in Brazil.

Figure 1. The study area location

2.2 AVHRR/NOAA-14 images

The polar orbiting environmental satellites operated by National Oceanic and Atmospheric Administration (NOAA) carries the Advanced Very High Resolution Radiometer (AVHRR) a multi-spectral scanner that collect images covering a 2,700-km swath on Earth with a spatial resolution of 1 km^2.

Two satellites (12 and 14) operates in sun synchronous orbits, at an 850-km height. Each one performs a mission around the Earth in 24 hours, crossing a place at the same time every day. This research used data from satellite 14, because it crosses the study area around 14:30 local time, thus providing excellent data for vegetation studies. AVHRR images are adequate for vegetation distribution studies and seasonal changing at regional and continental scale, as it follows: a) its 2,700-km swath covers Brazilian territory with some few images; b) daily AVHRR data coverage provides significant image collection to observe seasonal changes or cloud-free targets.

where ρ_1 and ρ_2 correspond to reflectance values of visible band (AVHRR 1) and near-infrared (AVHRR 2) respectively.

2.5 The Universal Soil Loss Equation (USLE)

Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) was used to evaluate actual land degradation of Piracicaba river watershed; it resulted in maps presenting the current erosion and the natural erosion potential aspects. The USLE equation is

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (2)$$

where
A = computed soil loss per unit area (t/ha/year);
R = erosivity (rainfall erosive power) (MJ.mm/ha.h);
K = erodibility (soil susceptibility to erosion) (t.h/MJ.mm);
L = slope-length factor is the ratio of soil loss from a field slope length to that from a 25m length under identical conditions;
S = slope-steepness factor is the ratio of soil loss from a field slope gradient to that from a 9-percent slope under identical conditions;
C = cover and management factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow;
P = support practice factor is the ratio of soil loss with a support practice to that with straight-row farming up and down the slope.

Factors R, K, L and S are dependant of natural conditions and the factors C and P are related to land use and management.

2.5.1 Land Use and Management (C Factor). C Factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Bertoni & Lombardi Neto, 1990). The canopy protection of crops depends on the type of vegetation, the stand, the quality of growth, and also on the different months and seasons. As a consequence, the value of C also varies and measures the combined effect of crop and management practices. Protection provided by vegetation cover. As vegetation cover protects soil gradually during its phenological cycle, its common to divide the crop year in 5 (five) cropstage periods, for which vegetation cover effects are considered uniform within each period as follows:

- Period **D** – soil preparation: from tillage until stalk planting;
- Period **1** – planting: from planting until 1 month after period D;
- Period **2** – establishment: from end of period 1 until 2 months after planting;
- Period **3** – development and maturing crop: from 2 months after planting until crop harvest:
- Period **4** – residue: from harvest to plowing.

2.5.2 Soil Loss Ratio. Soil loss ratio (SLR) must be computed for each of the five cropstage periods and for each crop, under several conditions (crop sequence, fertility level, yield, crop stubble). These parameters were derived using Bertoni & Lombardi Neto (1990) methodology, using data already established by Agronomic Institute of Campinas (IAC) for São Paulo State. The linear correlation between soil-loss ratio values (Y) and sugarcane's age (days after planting) can be written as

$$Y - 0.241 - 0.0005227X \qquad (3)$$

where X is the age in days, with a correlation coefficient (r^2) = 0.99

2.5.3 Rainfall Erosion Index (EI). Rainfall erosion index was derived from the percentage of rain effectively dropped in the test area (Santana Farm). As a result, C Factor was derived from the soil loss ratio multiplied by the percentage of annual erosion-index distribution both in each period limited by AVHRR image taking.

2.5.4. Field control. To achieve the necessary correlation between field data and NDVI data determined from AVHRR images, a test area with 900 hectares was established as "ground truth" (Santana Farm), compound by 104 sugarcane plots. Seven images of the area were created in which sugarcane's age data (days after planting) were attributed to plots. Sugarcane's age corresponded to AVHRR images acquisition dates (05/29/96; 06/15/96; 07/23/96; 11/27/96;

Studies on vegetation coverage through remote sensing may conveniently use spectral-radiance data. Since pigments absorption and water content are highly correlated, only two spectral range from the electromagnetic radiation have been used to infer vegetation's biophysical properties. These wavelengths are the visible upper portion (0.6μm to 0.7μm) and the near-infrared (0.75μm to 1.1μm). Values measured by the AVHRR sensor in those two regions may be combined to normalise solar irradiance. The combination of visible and near-IR wavelengths generate vegetation indexes as Normalised Difference Vegetation Index (Tucker & Sellers, 1986). In the present work, the digital counts of AVHRR-1 and AVHRR-2 channels were used. They were selected from the images covering the whole São Paulo State territory, which were necessary for providing adequate ground locations for geo-referencing procedures.

Radiometric calibration was performed following the convention adopted by National Environmental Satellite Data and Information Service (NESDIS) according to Mitchell (1997) for transformation of digital counts from AVHRR channels 1 and 2 into reflectance values.

By using a two-phase geo-referencing process, it was possible to accomplish an adequate precision level for the AVHRR images: First, images were coursed geo-referenced in a general level, by using visible ground points located on the big dams existent all over São Paulo State territory. Next, with the aid of points selected on local hydrographical net, geo-referencing was refined to reach an inside-one-pixel precision level (Figure 2).

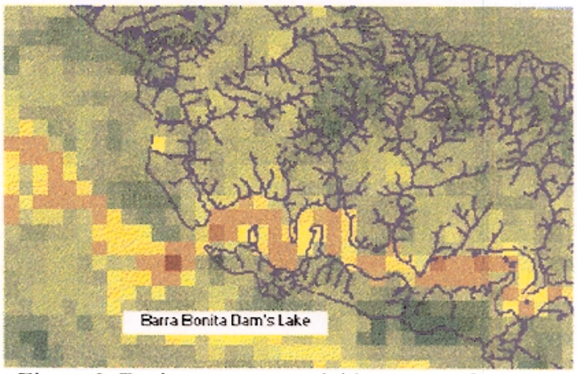


Figure 2. Drainage map overlaid on geo-referenced AVHRR images.

2.4 Normalised Difference Vegetation Index (NDVI)

The reflectance values are indicated for deriving NDVI because they are more sensible than the digital numbers (grey level). In addition, reflectance figured out in percentage values normalises data from images taken in different time and situations, what allow a better comparison among them. That is the case of the present study where NDVI images of different times and harvests are compared (Figure 3).

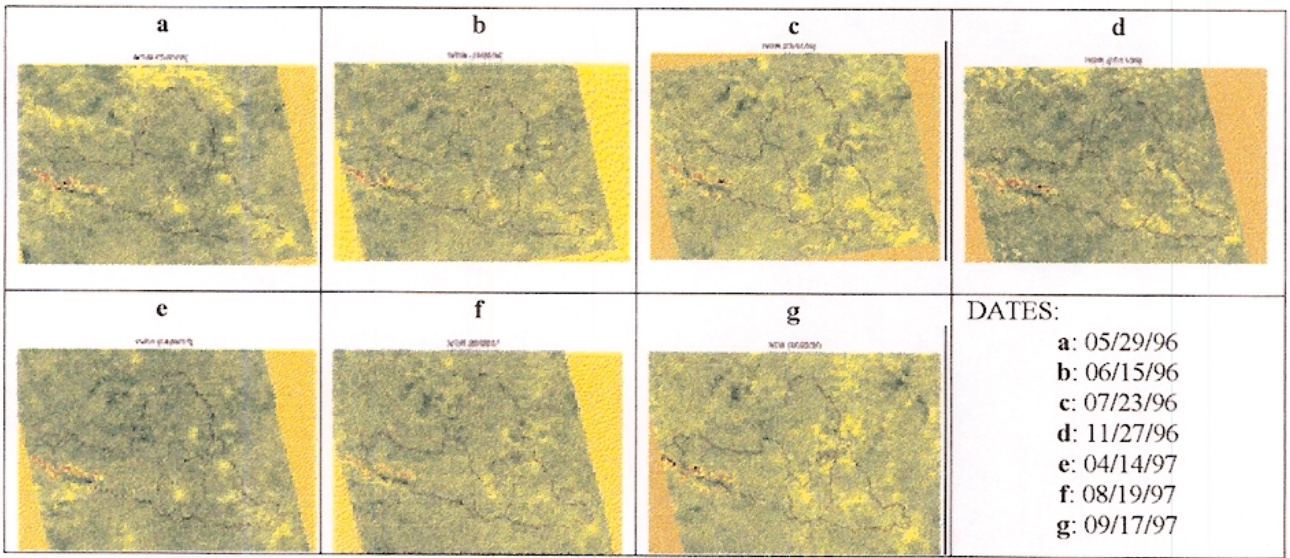


Figure 3. NOAA/AVHRR-14 showing NDVI's images changes in Piracicaba River watershed

Normalised Difference Vegetation Indices (NDVI) were derived from seven AVHRR images though algorithms existent in the Geographic Information System (GIS) compound of algebraic operations applied to channels 1 and 2 of the selected images, as follows:

$$NDVI = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \qquad (1)$$

04/14/97; 08/19/97 and 09/17/97). Through the equation (3), each plot assumed soil loss ratio values (Figure 4). Since SLR and NDVI are time related, a correlation between them was established, aiming to find a proper equation to determine SLR in the AVRRR/NOAA images which allowed to reach C Factor values.

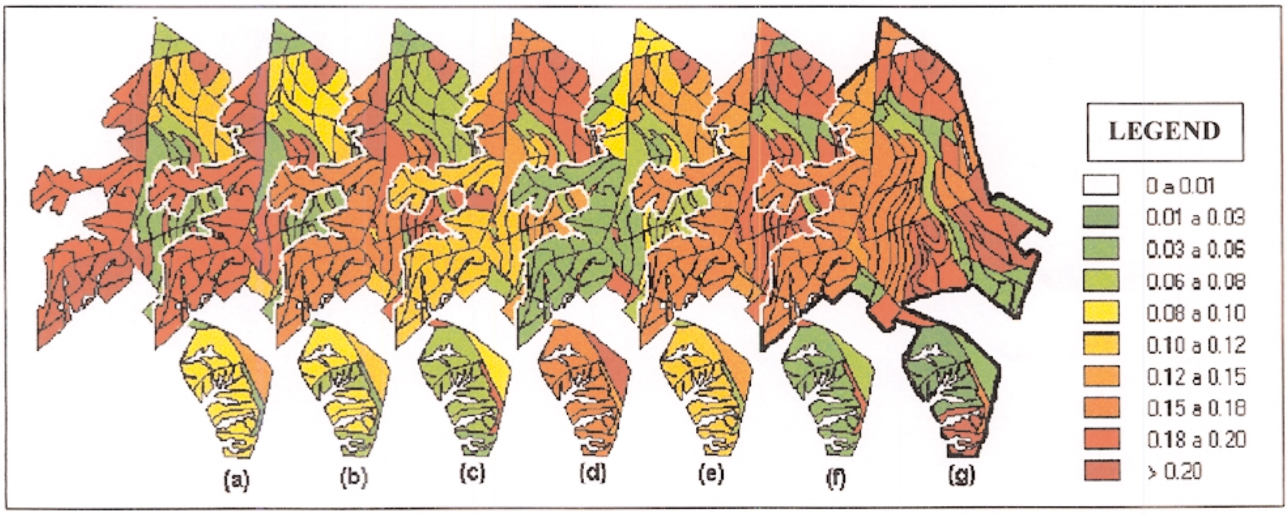


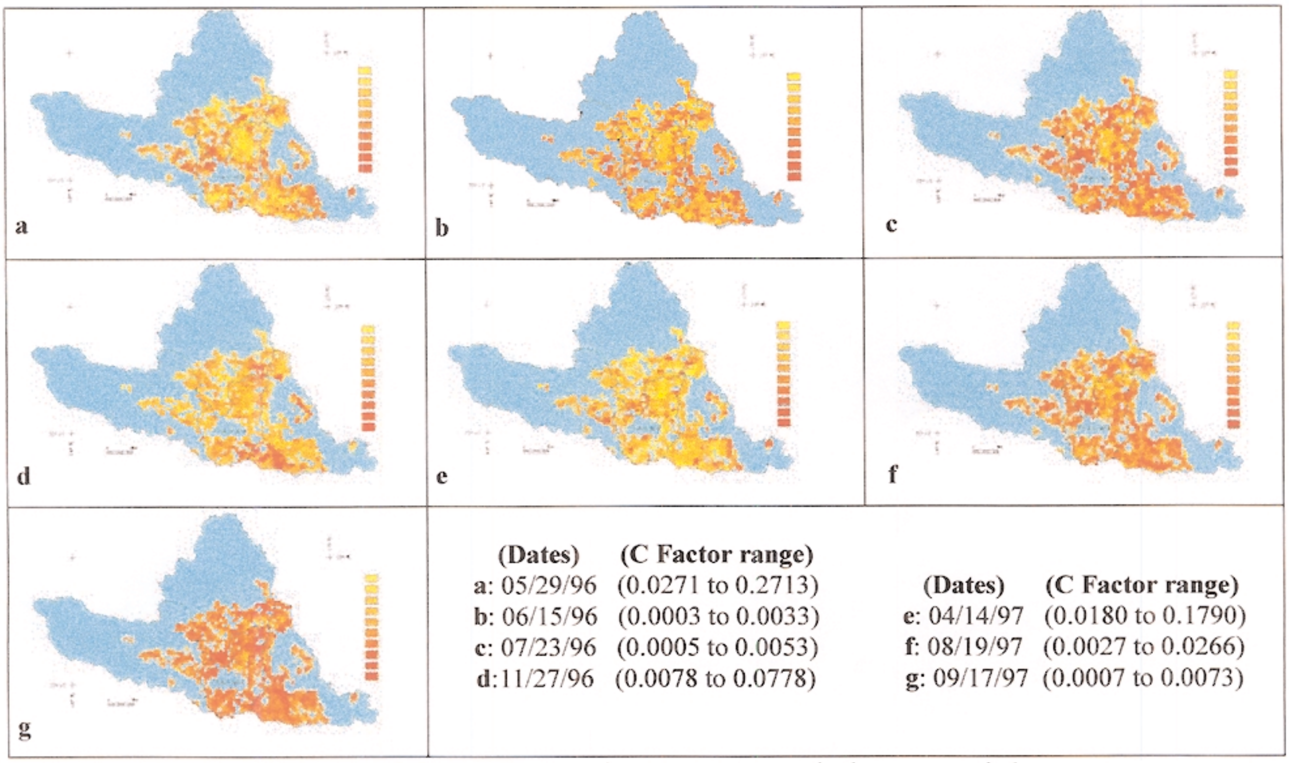
Figure 4. Santana Farm: sugarcane plots with soil loss equation values in the dates of AVHRR images taking.

After being geo-referenced, those seven ground images were overlaid on the AVHRR images, so that the sugarcane plots SLR values could be correlated with the medium NDVI corresponding values, resulting in a new adjustment equation:

$$Y = 0.346 - 0.553X \quad (4)$$

where Y represents the SLR and X represents NDVI, with a correlation coefficient (r^2) = 0.71

Figure 5 shows seven layers for USLE calculation. They were obtained according to the following procedure:



(Dates)	(C Factor range)
a: 05/29/96	(0.0271 to 0.2713)
b: 06/15/96	(0.0003 to 0.0033)
c: 07/23/96	(0.0005 to 0.0053)
d: 11/27/96	(0.0078 to 0.0778)

(Dates)	(C Factor range)
e: 04/14/97	(0.0180 to 0.1790)
f: 08/19/97	(0.0027 to 0.0266)
g: 09/17/97	(0.0007 to 0.0073)

Figure 5: C Factor classes under sugarcane crops in the seven periods

2.6. Erosion risk

The expression soil loss tolerance is used to point out the maximum soil erosion intensity in ton/ha/year, which will allow the economical maintenance of a high level of productivity indefinitely. In São Paulo State, tolerance ranges from 4.5 to 15.0 t/ha/year being a function of soil characteristics (Bertoni & Lombardi Neto, 1990). Deep, medium texture, well drained soils present higher tolerance values. On the other hand, shallow, superficial horizon soils present lower ones.

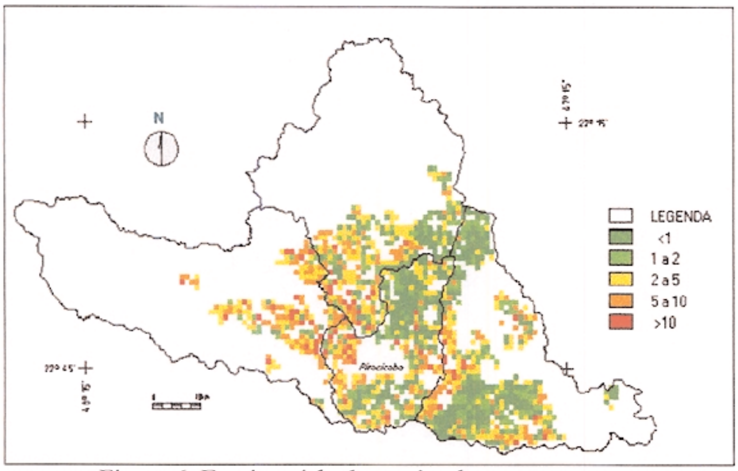


Figure 6. Erosion-risk classes in the sugarcane area

The expected soil loss intensity may be compared with the soil loss tolerance in a given area, what makes possible to combine planting and management practices to be adopted where the soil loss is lower than tolerance values, thus providing a satisfactory condition of soil erosion control.

To each elapsed period between the image dates, the erosion risk was derived overlaying (dividing) the expected soil loss (USLE's "A" value) layer by soil tolerance layer. Those maps were reclassified resulting in 5 (five) erosion risk classes: **class 1**, less than one time the soil loss tolerance; **class 2**, 1 to 2 times the tolerance; **class 3**, 2 to 5 times the tolerance; **class 4**, 5 to 10 times the tolerance; **class 5**, more than 10 times the tolerance. Figure 6 shows risk classes in annual values.

2.6 Distribution of soils in the erosion risk classes

Since soil characteristics are determining parameters to management techniques, a cross classification was performed to compare the map of soils occurring under sugarcane crops with the erosion-risk-classes map resulting in a new layer for analysis (Figure 7). Data showed that the major soil occurrence were: the LEa3 (Rhodic Ferralsol) with 16,14%; the PV1 (Haplic Acrisol) with 15.3%; the association LRd1+LRe1 (Rhodic Ferralsol) with 10.69% and the PVa4 (Haplic Acrisol) with 9.86%. These figures show clearly the sugarcane preferences for fertile soils with better physical characteristics.

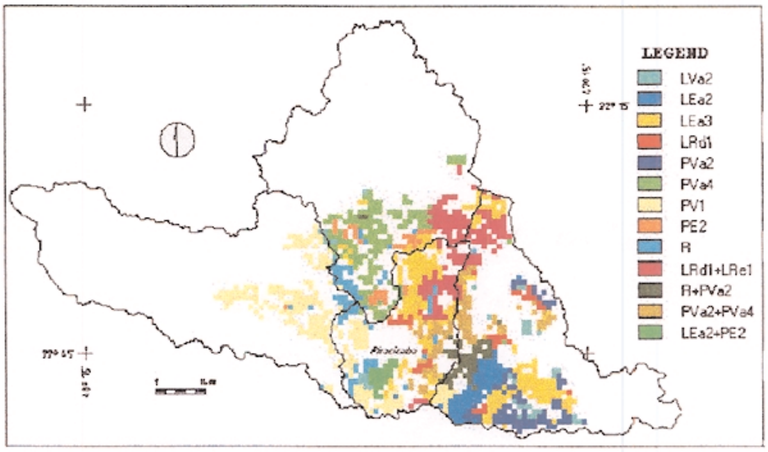


Figure 7. Soils under sugarcane crops.

3. RESULTS

To determine the temporal variation of NDVI values on sugarcane plantations in the different images dates, a transect was overlapped on the seven NDVI images, obtaining values of the same pixels in all images.

Figure 8 exemplifies sugarcane's NDVI values in the periods surveyed. In May, 1996, by the beginning of the harvest, NDVI values are still high on account of the big amount of green biomass still existent in the plots. As harvest proceeds, NDVI values decreases until the end of harvest period (November). Its important to consider that such decrease is not bigger due to the ratoons growth, what compensate the soil exposition effect and thus mitigating NDVI decline. In April, 1997, sugarcane crop stands in the top of their phenological development, right before the harvest beginning. In this stage, the green biomass NDVI shows its maximum value. The harvest cycle repeats and the vegetation indices start growing once again.

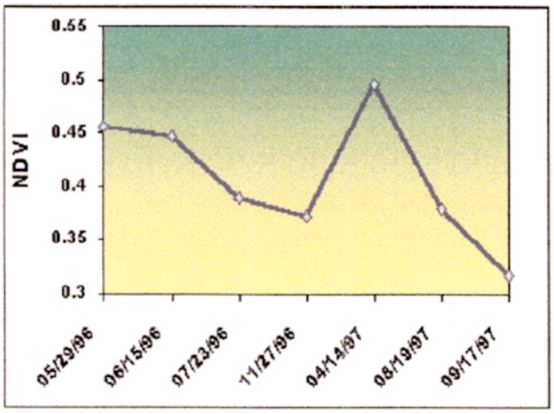


Figure 8. NDVI temporal variation in sugarcane crop

Table 1 presents the erosion risk classes in the studied sugarcane area and shows average values for the whole period of the research (07/01/95 to 09/17/97) as follows: 50.6% of total area are included in class 1 (soil-loss values are smaller than tolerance ones), which means that the area do not present problems of environmental impacts caused by erosion; erosion risk classes 4 and 5 presented an area of 4.4% where soil losses bigger than 5 times the soil loss tolerance values occurred, probably causing environment impacts by erosion. Since the erosion control mitigation costs for such areas are frequently quite expensive, it would be advisable to recommend the substitution of sugarcane crop for more adequate land use. In general sense, sugarcane may be considered among the crops able to cause least environmental impact through erosion. As a glasslike plant, its hairy root system provides a kind of protection net avoiding runoff damages.

Besides, the huge amount of leaves rapidly cover the soil, promoting an efficient protection against rain drops impacts on the terrain. Probably, the environmental impacts caused by sugarcane is mostly due to monoculture, since the exaggerated concentration of continuous crops strengthens the impacts. Yet, when the land is massive used, basic principles of soil natural drainage and gallery vegetation protection are disregarded, which concurs to soil degradation. Table 2 shows Rhodic soils occupy the lower erosion-risk classes, highly concentrated in class 1 (under the tolerance level).

Period	**Erosion risk classes**				
	1	**2**	**3**	**4**	**5**
	%	%	%	%	%
07/01/95 to 05/29/96	51.38	19.66	23.24	5.10	0.62
05/29/96 to 06/15/96	100.0	0.00	0.00	0.00	0.00
06/15/96 to 07/23/96	100.0	0.00	0.00	0.00	0.00
07/23/96 to 11/27/96	94.55	4.69	0.76	0.00	0.00
11/27/96 to 04/14/97	67.24	20.48	11.45	0.76	0.07
04/14/97 to 08/19/97	99.45	0.55	0.00	0.00	0.00
08/19/97 to 09/17/97	100.0	0.00	0.00	0.00	0.00
Total Period (average)					
07/01/95 to 09/17/97	50.62	20.62	24.34	4.14	0.28

Table 1. Erosion risk classes for sugarcane crop occurring between the image taking

Soil types		**Erosion risk classes**				
		1	**2**	**3**	**4**	**5**
(Brazilian)	*(FAO)*	%	%	%	%	%
LVa2	Haplic Ferralsol	76.19	19.05	4.76	0.00	0.00
LEa2	Rhodic Ferralsol	94.37	5.63	0.00	0.00	0.00
LEa3	Rhodic Ferralsol	86.32	11.97	1.71	0.00	0.00
LRd1	Rhodic Ferralsol	89.74	10.26	0.00	0.00	0.00
PVa2	Haplic Nitrisol	26.19	22.62	47.62	3.57	0.00
PVa4	Haplic Acrisol	37.06	33.57	25.87	3.50	0.00
PV1	Haplic Acrisol	13.90	24.66	50.22	10.76	0.45
PE	Rhodic Ferralsol	12.50	37.50	42.50	7.50	0.00
R	Lithic Leptosol	15.00	20.00	48.75	15.00	1.25
LRd1+Lre1	Rhodic Ferralsol	92.90	7.10	0.00	0.00	0.00
R+PVa2	L. Leptosol + H. Nitrisol	13.73	19.61	50.98	11.76	3.92
PVa2+PVa4	H. Acrisol + H. Nitrisol	21.28	32.98	42.55	3.19	0.00
Lea2+PE2	Rhodic Ferralsol	56.25	34.38	9.38	0.00	0.00
Others		53.09	24.07	20.37	2.47	0.00

Table 2. Distribution of soil types by erosion-risk classes in sugarcane crops.

Differently, the order changes in Haplic soils, which occupy the higher erosion-risk classes, concentrating on levels 2 and 3, but not reaching the critical level (5). Such evidences were expected since Rhodic soils occur in soft relief and Haplic soils occur most of time in steeper sites. Data showed that 42 to 50% of these soils are concentrated in class 3, indicating they might be subject to soil erosion problems. In such cases, they should need different management routines to be applied to the various erosion levels affecting them.

5. CONCLUSIONS

- The use of analytic methods derived from remote sensing products acquired from AVHRR/NOAA-14 sensor, together with geoprocessing and geographic information systems techniques allowed to obtaining data with enough sensibility to characterise soil degradation through rainfall erosion.
- Normalised Difference Vegetation Index (NDVI) allowed to observe the vegetative cycle of sugarcane crop during practically two harvest periods (1995/96 and 1996/97) since NDVI data measured in a 16-months series represent the behaviour of vegetation cover biomass on Piracicaba river watershed for that period.
- USLE and NDVI data processing with the aid of statistical procedure to achieve regression analysis, allowed to establish a methodology for integrate AVHRR/NOAA-14 digital images in the soil degradation studies at regional levels. Furthermore, it was possible to determine C Factor values from spectral reflectance data for application in Universal Soil Loss Equation.
- The data obtained allow a better planning for sugarcane crop in the region, avoiding possible environmental impact problems and keeping the sustainability for the crop. That is particularly important since the region is critical concerning to quality and quantity of water supply both for human and industrial consumption.

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