Comissão 3.3 - Manejo e conservação do solo e da água

SOIL, WATER AND NUTRIENT LOSSES BY INTERRILL EROSION FROM GREEN CANE CULTIVATION(1)

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SUMMARY

Interrill erosion occurs by the particle breakdown caused by raindrop impact, by particle transport in surface runoff, by dragging and suspension of particles disaggregated from the soil surface, thus removing organic matter and nutrients that are essential for agricultural production. Crop residues on the soil surface modify the characteristics of the runoff generated by rainfall and the consequent particle breakdown and sediment transport resulting from erosion. The objective of this study was to determine the minimum amount of mulch that must be maintained on the soil surface of a sugarcane plantation to reduce the soil, water and nutrient losses by decreasing interrill erosion. The study was conducted in Pradópolis, São Paulo State, in 0.5 x 1.0 m plots of an Oxisol, testing five treatments in four replications. The application rates were based on the crop residue production of the area of 1.4 kg m^{-2} (T1- no cane trash; T2-25 % of the cane trash; T3- 50 % trash; T4-75 % trash; T5-100 % sugarcane residues on the surface), and simulated rainfall was applied at an intensity of 65 mm h^{-1} for 60 min. Runoff samples were collected in plastic containers and soon after taken to the laboratory to quantify the losses of soil, water and nutrients. To minimize soil loss by interrill erosion, 75 % of the cane mulch must be maintained on the soil, to control water loss 50 % must be maintained and 25 % trash controls organic matter and nutrient losses. This information can contribute to optimize the use of this resource for soil conservation on the one hand and the production of clean energy in sugar and alcohol industries on the other.

Index terms: surface runoff, cane trash, rain simulation.

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RESUMO: *PERDAS DE SOLO, ÁGUA E NUTRIENTES POR EROSÃO EM ENTRESSULCOS EM ÁREA SOB CULTIVO DE CANA CRUA*

A erosão em entressulcos acontece devido à desagregação originada pelo impacto das gotas de chuva pelo transporte por meio do escoamento superficial, por arraste e suspensão das partículas superficiais do solo desagregadas, onde se encontram a matéria orgânica e os nutrientes fundamentais para a produção agrícola. A presença de resíduos vegetais sobre a superfície do solo altera as características do escoamento superficial gerado pela chuva e a consequente desagregação e transporte de sedimentos resultantes do processo erosivo. O objetivo deste trabalho foi determinar a quantidade mínima de palha a ser mantida na superfície do solo, em área cultivada com cana-de-açúcar, para proporcionar menores perdas de solo, água e nutrientes pela redução da erosão em entressulcos. O estudo foi realizado no município de Pradópolis-SP em um Latossolo Vermelho distrófico, em parcelas experimentais de 0,5 por 1,0 m de comprimento, e constituiu-se de cinco tratamentos com quatro repetições; a dose de aplicação de resíduos teve como base a produção de palha da área local de 1,4 kg m^{-2} *(T1-sem palha; T2-25 % de palha; T3-50 % de palha; T4-75 % de palha; e T5-100 % de palha de cana-de-açúcar em superfície), sendo aplicada uma chuva simulada com intensidade de 65 mm h*$^{-1}$ *durante 60 min. Foram coletadas amostras de enxurrada em recipientes plásticos, as quais, em seguida, foram levadas para laboratório para quantificar a perda de solo, de água e de nutrientes. A fim de minimizar a perda de solo por erosão em entressulcos, devem ser mantidos 75 % de cobertura com palha de cana-de-açúcar, 50 % de cobertura para perda de água e 25 % de cobertura para perda de matéria orgânica e nutrientes, o que possibilita otimizar o uso desse recurso tanto para a conservação do solo como para a produção de energia limpa em indústrias sucroalcooleiras.*

Termos de indexação: escoamento superficial, palha de cana-de-açúcar, simulação de chuva.

INTRODUCTION

In the system of mechanized sugarcane harvesting without burning, the leaf blades and sheaths, shoots, as well as a variable amount of stem pieces are cut, ground and distributed over the soil surface, forming a layer of plant waste called trash or mulch. The amount of trash collected from cane plantations without burning varies from 10 to 30 Mg ha^{-1} (Trivelin et al., 1995). The maintenance of the mulch layer in the system can benefit the soil significantly, minimize the problem of air pollution and probably reduce the use of mineral fertilizers, as well as soil, water and nutrient losses (Souza et al., 2005). Therefore, it is essential to determine how much trash can be removed from sugarcane plantations for power generation, so as not to trigger or accelerate the process of erosion, which is one of the driving degradation forces in agricultural areas.

Soil degradation must be considered one of the most serious environmental problems. Among the problems of degradation, water erosion particularly affects the productive capacity of soils and can be initiated and accelerated by inadequate management practices (Carvalho et al., 2002). The different management forms may significantly affect the runoff/flow characteristics on the soil surface, by changes in surface roughness, as well as variations in soil structure, aggregate stability, organic matter content, and by increased total porosity of the tilled layers (Cassol & Lima, 2003; Carvalho et al., 2009).

Erosion is a surface phenomenon that occurs by the physical process of disintegration, transport and deposition of soil particles caused by rainwater and runoff, and is influenced by anthropogenic action. Among the types of water erosion, interrill erosion can be considered the most harmful for carrying off topsoil, which contains the essential elements for crop development (Cogo et al., 2003; Nunes & Cassol, 2008). In the case of interrill erosion, the impact of raindrops is the factor responsible for the disaggregation of the soil particle mass and can break down large amounts of particles by the kinetic energy of the droplets, which exert pressure and shear forces at the point of impact (Cassol & Lima, 2003; Cassol et al., 2004).

Soil covers of crop residues, including sugarcane trash, reduce erosion by dissipating the kinetic energy of raindrops on the surface, decreasing the flow velocity and increasing the depth of the water layer in the surface soil (Martins Filho et al., 2009). In other words, the cover reduces the capacity of runoff of disaggregating and transporting soil particles and forms a network, comparable with a filter, which induces the deposition of particles, especially of the larger ones, carried by the runoff. On the other hand, if the soil cover is removed, e.g., by burning, the soil is freely exposed to rain impact and runoff, and consequently, more susceptible to erosion.

In view of the search for new alternatives for cleaner and environmentally less harmful energy production and by the fiscal incentives of the government, the sugarcane mills in São Paulo state began to produce clean energy. By this process the cane trash formerly left on the soil after mechanical harvesting was removed from the plantations. However, the withdrawal of a certain quantity of trash can be harmful for the environment, facilitating the erosion process by exposing the soil to rainfall. Thus, it is necessary to assess the amount of sugarcane trash that should be maintained on the soil surface of sugarcane plantations, to prevent significant soil, water and nutrient losses by erosion.

This study aimed to determine the minimum amount of trash that must be maintained on the soil surface in sugarcane plantations to reduce soil, water and nutrient losses by minimizing interrill erosion.

MATERIAL AND METHODS

The study was conducted in an area of the São Martinho mill, in the county of Pradópolis, São Paulo State (lat 21^o 18’ 67” South, long 48^o 11’ 38” West; 630 m asl). The climate is mesothermal with a dry winter (Cwa), according to Köppen´s climate classification, and the regional average rainfall is 1,400 mm, at an average intensity of 70.4 mm h^{-1}. The topography is gently sloping, with slopes of 0.05 m m^{-1}; the soil was classified as dystrophic red Oxisol (Latossolo Vermelho distrófico) clayey (Table 1). The area has a use history of more than 20 consecutive years of sugarcane cultivation, with mechanical harvesting in the last 10 years. Thus, the vegetation cover at the time of this study consisted of sugarcane residues that had been left on the surface after the mechanical harvesting of sugarcane in the fifth ratoon cut.

The management used for planting was reduced tillage after destroying the stubble by mechanical elimination, uprooting and chopping the sugarcane stumps. This process caused soil mobilization in the sugarcane rows, since the mechanical destruction ripples the row, making the further use of an offset disk harrow necessary, to minimize the elevation of the soil in the row and prevent the occurrence of soil pulverization in the following operation. Then the total area was subsoiled. Prior to rainfall simulation, 80 m^3 vinasse was applied as well as 550 kg ha^{-1} granular NPK (5-25-25) fertilizer in the furrow.

To simulate rainfall, plots (width 0.50 m, length 1.00 m, 0.50 m^2) were framed with metal sheets (height 0.30 m, of which 0.05 m in and 0.25 m above the ground) along the sides and at the top, and by metal drain channels in the lower parts, The rain collectors (width 0.50 m) converge towards a side exit (diameter 0.065 m). Runoff samples were collected from the channels to quantify the soil and water losses.

The experiment was conducted with five treatments and four replications, based on different amounts of cane trash on the ground (0, 25, 50, 75, and 100 %). The trash was distributed homogeneously on the plots. The cover percentage was determined based on the trash dry weight and measured on a graded ruler of 0.50 m, according to the method described by Adams & Arkin (1977). The application rate was based on the dry matter of the sugarcane trash produced on an area of 1.4 kg m^2. Consequently, the trash quantities for the treatments with 25, 50, 75, and 100 % trash cover corresponded to 0.175, 0.350, 0.520, and 0.700 kg/plot, respectively. In the treatment without cover, the trash was removed from the soil surface.

Table 1. Soil chemical and particle size properties in the 0.00–0.20 m layer

pH	OM	P	K	Ca	Mg	Al	H + Al	SB	CEC	V	Sand	Clay	Silt
	g dm^{-3}	mg dm^{-3}				mmol$_c$ dm^{-3}				%		g kg^{-1}	
4.7	19.4	21.6	1.2	18.4	5.2	1.2	36.2	24.8	60.9	40.5	344	525	132

OM: organic matter, SB: sum of bases, CEC: cation exchange capacity, V: base saturation.

The experiment was conducted in October 2009. Twenty plots were subjected to simulated rain at an average intensity of 65 mm h^{-1} (I) for 60 min. The rainfall was simulated using Veejet-nozzles 80100 installed on a Swanson-type rotating boom simulator, previously calibrated and leveled on the terrain, as described by Swanson (1965), in a circular area (diameter 50 m) to quantify the eroded material. Thirty-six rain gauges were lined up in slope direction within the area of the rain simulator, as described by Martins Filho et al. (2004), to determine the rainfall intensity produced by the simulator on the experimental plots.

The 240 runoff samples containing soil sediment were collected in 1 L plastic containers in the 20 randomly distributed plots under the rainfall simulator, at intervals of 5 min during 60 min of rain. Immediately after collection, the containers were sealed and taken to the laboratory to quantify the sediment concentration and solution volume and determine the rates of soil and water loss. After weighing, 5.0 mL of aluminum sulfate and 5 % PA K was added to the pots, for particle settling for 24 h, then the supernatant was sucked off and the pots dried at 65 °C and weighed to determine the dry soil. The sediment concentration was calculated (in kg L^{-1}) using the relationship between the dry soil mass and the mass of water-sediment mixture.

The rates of soil disaggregation (*Di*) were determined by the following expression:

$$D_i = \frac{m_s}{tA} \quad (1)$$

where m_s: mass of disaggregated soil (kg); t: sampling time (s) and A: plot area (m^2).

The soil losses were determined as:

$$SL = \frac{\sum_{i=1}^{n}(Q_i C_i t)}{A} \quad (2)$$

where SL is the total interrill soil loss (kg m^{-2}); Q is the flow rate (L s^{-1}); C is the sediment concentration (kg L^{-1}); t is the interval between samplings (300 s); A is the plot area (m^2); and n is the total number of samples.

The effect of sugarcane trash covering the soil surface, the sub-factor C_{iII}, was determined by equation (3):

$$C_{iII} = D_i \;/\; (K_i\, I\, R\, S_f) \quad (3)$$

where D_i is the average rate of interrill erosion, observed in plots with soil cover, obtained in the last 15 min of runoff sampling; I is the rainfall intensity, mm or m s^{-1}; and R is the runoff rate, in m s^{-1}. The D_i values obtained in plots without trash cover, in the minutes of runoff sampling, were used to determine the interrill erodibility (K_i). The slope factor (S_f) was determined as cited by Liebenow et al. (1990), using equation (4):

$$S_f = 1.05 - 0.85e^{-4\text{sen}\theta} \quad (4)$$

where e is the base of natural logarithms and θ the slope angle in degrees.

In the chemical and sediment analyses, the concentrations of Ca, Mg, K, and P extracted by ion exchange resin were determined (Raij et al., 2001). Organic carbon was determined following the method described in Embrapa (1997). The pH was determined potentiometrically, in 0.01 mol L^{-1} $CaCl_2$.

The results were subjected to analysis of variance in a randomized design and the means compared, using the Duncan test at 5 %. Analysis of linear and nonlinear regression between quantitative data were performed.

RESULTS AND DISCUSSION

The soil cover had a significant beneficial effect on soil loss, expressed in kg m^{-2} (Figure 1). As the vegetation cover was increased, an exponential decrease of soil loss was observed. In the treatment with 50 % trash on the ground, the soil erosion loss was reduced by 85 % compared with the bare soil treatment. The results were similar to those of Cantalice et al. (2009). Bezerra & Cantalice (2006) concluded that sugarcane residues in direct contact with the ground increased the hydraulic roughness, delaying the onset of runoff, subsequently increasing the water infiltration rate into the soil as well as reducing soil loss caused by interrill erosion.

When leaving 75 % of the cane residue as ground cover, the results remained unchanged in terms of soil loss by interrill erosion (Figure 1), i.e, independent of the amount of trash maintained on the soil surface, the loss was never zero. This agreed with the finding of Martins Filho et al. (2009), who stated that sub-factors relating the soil cover of plots with 100 % trash coverage had an average subfactor C_{iII} of 0.11, indicating that erosion occurs even under complete cover. Braida & Cassol (1999) related erosion with the type and amount of vegetation, and found that interrill erosion decreased exponentially with increasing crop residue soil cover. In the plots with 100 % coverage, interrill erosion was reduced by 92 % compared to the bare ground.

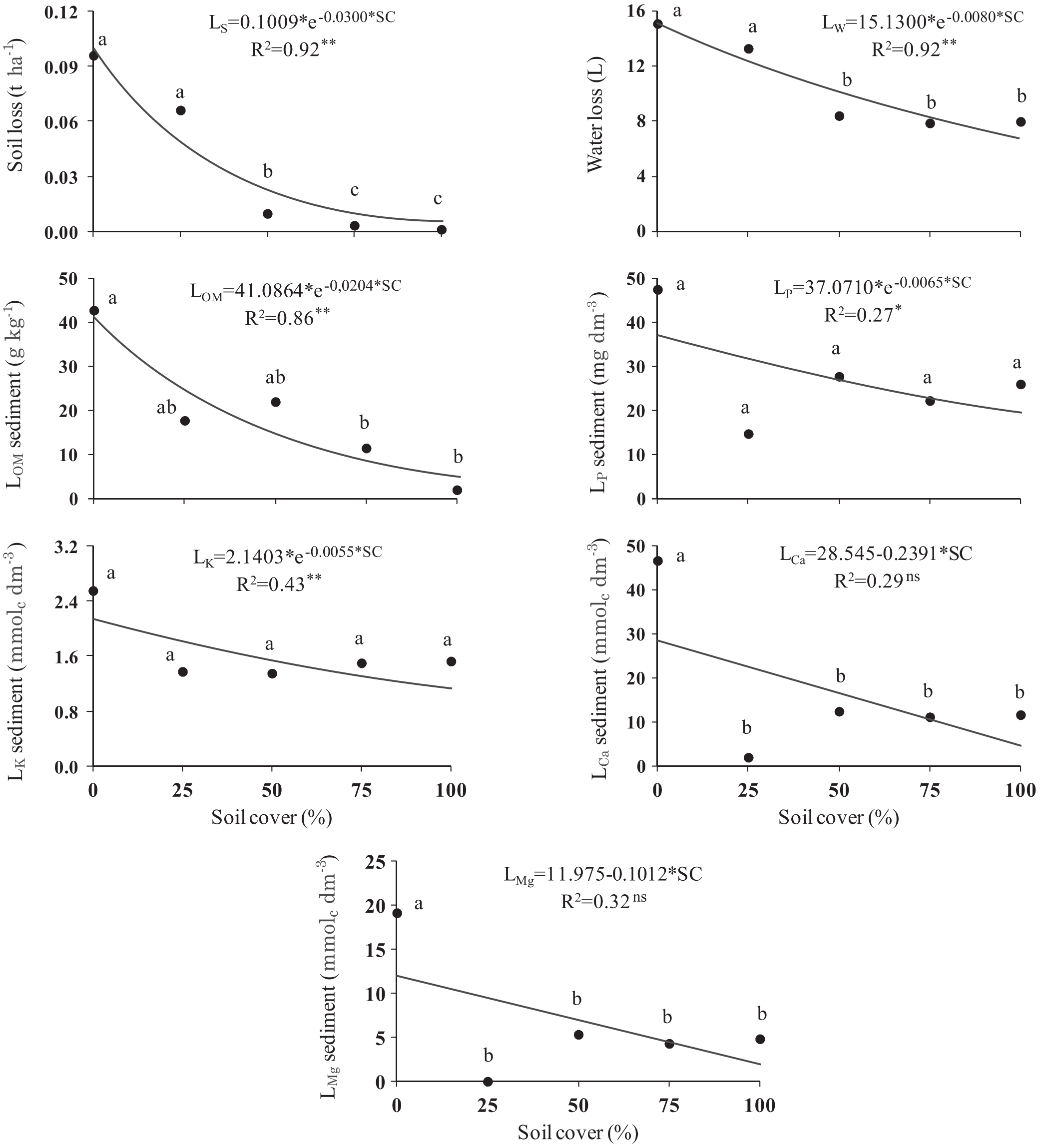

Figure 1. Soil losses (L_S), water (L_W), organic matter (L_{OM}) and nutrients (L_P, L_K, L_{Ca} and L_{Mg}) by interrill erosion from plots with different amounts of cane trash on the soil surface (0, 25, 50, 75, and 100 %) under the rain event studied. Averages of the same treatment followed by the same letter differed by the Duncan test ($p < 0.05$).

Water loss was reduced exponentially with the increase of mulching and behaved similarly to soil loss, mainly in the plots with a cane trash cover equal to and greater than 50 % (Figure 1). On the other hand, water losses are generally less affected by different trash amounts than soil loss, thereby reducing the loss by 47 % compared with the plots covered with 100 % or without trash, confirming the results obtained by Bertol et al. (1997). With the application of 0.80 kg m^{-2} (100 % residues) of corn and wheat straw on the soil surface, Braida & Cassol (1999) found a mean reduction of 34 % in total water loss and a 50 % reduction in the average rate of water loss compared to the bare ground.

Of the nutrients studied, the concentrations in the sediment were highest for P (Figure 1), decreasing exponentially with increasing soil cover. These results are consistent with Schick et al. (2000), who concluded that due to the fact that the element P is adsorbed to soil colloids, the transport is most intense in the clay fractions, resulting in greater losses with sediment runoff. Hernani et al. (1999), studying different systems of soil management and nutrient and organic matter losses by erosion, observed a high P concentration in the sediment due to its specific adsorption and low solubility.

Higher concentrations in the sediment were observed for Ca than for Mg, and the trash treatments differed from the bare soil treatment for both nutrients (Figure 1). This confirms results obtained by Martin Filho et al. (2009), who observed that increasing the sugarcane cover mulch on an Argisol significantly reduced Ca and Mg losses. The nutrient concentrations in water and sediment varied with their soil concentration, as can be observed by the initial nutrient concentrations in the area (Table 1).

The loss of organic matter increazsed exponentially when the ground cover was reduced (Figure 1), because the colloidal fraction and organic matter are the first constituents removed by erosion, in view of their low density (Seganfredo et al., 1997; Schick et al., 2000). Martins Filho et al. (2009), studied soil and nutrient erosion losses from a sugarcane area and found greater losses of organic matter from plots with bare soil, while on the plots where differentiated trash amounts were maintained the organic material losses were significantly reduced.

The P loss in runoff from all plots was high, including the plot with 100 % sugarcane trash (26 mg dm^{-3}), since according to Yoo et al. (1988), when the P concentration in the runoff solution is greater than 0.02 mg dm^{-3}, the processes of eutrophication in lakes and reservoirs may be accelerated, which can contaminate water resources (Figure 1). According to Levine & Schindler (1989), N and P are the nutrients most commonly associated with eutrophication, where P is the limiting factor, since many blue-green algae are capable of using atmospheric N_2. Thus, intensive fertilization in areas without proper soil management, where the P concentration would rise above this critical threshold in the case of laminar flow, can lead to eutrophication.

The loss of K was exponentially reduced with increasing soil cover, but less pronounced than of soil and water (Figure 1). The K loss from plots with maintenance of 100 % trash was similar to that from plots with 25 % trash amount, showing that fertilization in sugarcane areas requires particular attention, especially in areas treated with vinasse, which is also associated to the high mobility of K in the soil. Martins Filho et al. (2009) studied the soil and nutrient losses by erosion from an Alfisol with sugarcane trash, and found that P and K were the elements with highest losses. Another problem is the application form of these nutrients to crops, because if lime and fertilizer are applied to the surface and not incorporated into the soil, especially if rainfalls cause laminar erosion some days after the application of these products, this may result in severe problems with the surface water quality in watersheds that receive these nutrients.

The level of enrichment of the eroded sediment is calculated as the relationship between the concentration of organic matter and nutrients in the sediment and the original soil. A level of sediment enrichment greater than 1 means that the sediment is enriched with organic material or soil nutrients (Hernani et al., 1999; Silva et al., 2005). Under most conditions, the eroded sediment was enriched for all treatments compared with the original soil, with the exception of some treatments for Ca, Mg, and organic matter (Table 2). This result agrees with Silva et al. (2005), in an analysis of the trend of enrichment rates in sediment from a Cambisol, who found no such enrichment in the sediment, while in sediments from an Oxisol, enrichment was confirmed for all nutrients.

Calcium-enriched sediment was observed from bare plots, and in the case of Mg from plots with 0, 25 and 50 % trash cover (Table 2). These elements, especially Ca, are adsorbed to the soil colloids, facilitating their transport into the sediment (Bertol, 1994). The sediment enrichment rate was highest for Ca and Mg from the bare soil plots; according to Bertol et al. (2004) this can be explained by the fact that Ca and Mg are divalent cations, less prone to leaching, which leads to an adsorption to the soil with higher energy than of some monovalent cations. According to Schick et al. (2000), while Ca and Mg are added to the soil in relatively large

Table 2. Enrichment rate of sediment (ER) by organic matter (OM) and nutrients

Cover	OM	P	K	Ca	Mg
%					
0	2.208 a	2.197 a	2.214 a	2.535 a	3.678 a
25	1.136 ab	1.283 a	1.172 a	0.676 b	1.024 b
50	0.917 ab	0.682 a	1.194 a	1.060 b	1.560 b
75	0.594 b	1.029 a	1.302 a	0.607 b	0.827 b
100	0.503 b	1.203 a	1.324 a	0.634 b	0.928 b

Means followed by the same letter in a column do not differ statistically from each other by the Duncan test at 5 %. OM: organic matter, P: phosphorus K: potassium, Ca: calcium, Mg: magnesium.

amounts at liming, the removal of these elements by erosion tends to accelerate the soil acidification.

The enrichment rate of P and K in the eroded sediment did not differ significantly (Table 2). This corroborated results of Langdale et al. (1985), who studied crop rotation in conservation and conventional soil tillage, and found that in the latter, the majority of P lost was adsorbed to runoff sediments. In conservation tillage, the sediment loss was lower, so the total P loss by water erosion was significantly lower than from conventional tillage systems. For K, Silva et al. (2005) claimed that a preferred transport route of K is by water runoff.

The low mobility of P in the soil profile and the reduction in erosion losses in areas with ground cover increases the levels of available P over time in the soil surface layer (Figure 1). Phosphorus accumulation in the topsoil was observed by Rheinheimer et al. (2003) in no-tillage. Similar results were observed by Martins Filho et al. (2009), who evaluated soil and nutrient losses by erosion from an Alfisol with sugarcane trash, where the P concentration in the eroded sediment was only lower in the plot with 100 % trash cover, differing significantly from the other trash rates applied to the soil surface.

It was confirmed that the soil management of sugarcane areas with trash mulch maintenance on the soil surface effectively controls interrill erosion. Therefore, the system of mechanical sugarcane harvesting, which allows the maintenance of trash on the soil surface, reduces the losses of organic matter and nutrients in the sediment (Martins Filho et al., 2009). However, the loss of nutrients and/or chemicals in the runoff can be high in conservation systems (Thompson et al., 2001) especially when lime and fertilizer are applied to the surface and not incorporated into the soil, and particularly if floods occur some days after the application of the products.

CONCLUSION

A sugarcane trash cover of 75 % must be maintained on the ground to minimize soil loss by interrill erosion, a 50 % cover to minimize water loss and 25 % cover to reduce organic matter and nutrient losses, making it possible to optimize the use of cane trash for both soil conservation and for the production of clean energy in sugar and alcohol industries.

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