

SURFACE AND SUBSURFACE DECOMPOSITION OF A DESICCATED GRASS PASTURE BIOMASS RELATED TO EROSION AND ITS PREDICTION WITH RUSLE⁽¹⁾

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SUMMARY

Erosion is deleterious because it reduces the soil's productivity capacity for growing crops and causes sedimentation and water pollution problems. Surface and buried crop residue, as well as live and dead plant roots, play an important role in erosion control. An efficient way to assess the effectiveness of such materials in erosion reduction is by means of decomposition constants as used within the Revised Universal Soil Loss Equation - RUSLE's prior-land-use subfactor - PLU. This was investigated using simulated rainfall on a 0.12 m m⁻¹ slope, sandy loam Paleudult soil, at the Agriculture Experimental Station of the Federal University of Rio Grande do Sul, in Eldorado do Sul, State of Rio Grande do Sul, Brazil. The study area had been covered by native grass pasture for about fifteen years. By the middle of March 1996, the sod was mechanically mowed and the crop residue removed from the field. Late in April 1996, the sod was chemically desiccated with herbicide and, about one month later, the following treatments were established and evaluated for sod biomass decomposition and soil erosion, from June 1996 to May 1998, on duplicated 3.5 x 11.0 m erosion plots: (a) and (b) soil without tillage, with surface residue and dead roots; (c) soil without tillage, with dead roots only; (d) soil tilled conventionally every two-and-half months, with dead roots plus incorporated residue; and (e) soil tilled conventionally every six months, with dead roots plus incorporated residue. Simulated rainfall was applied with a rotating-boom rainfall simulator, at an intensity of 63.5 mm h⁻¹ for 90 min, eight to nine times during the experimental period (about every two-and-half months). Surface and subsurface sod biomass amounts were measured before each rainfall test along with the erosion measurements of runoff rate, sediment concentration in runoff,

⁽¹⁾ Part of second author's Ph.D. thesis, submitted to the Soil Science Graduate Program, Federal University of Rio Grande do Sul – UFRGS. Paper presented at the 10th International Soil Conservation Organization (ISCO) Conference, West Lafayette (IN, USA), May 23-28, 1999. Accomplished with financial support from the CNPq-PRONEX/Soils Project and with scholarships from FAPERGS, PIBIC-CNPq/UFRGS and CNPq. Received for publication in february of 2002, and approved in october of 2002.

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soil loss rate, and total soil loss. Non-linear regression analysis was performed using an exponential and a power model. Surface sod biomass decomposition was better depicted by the exponential model, while subsurface sod biomass was by the power model. Subsurface sod biomass decomposed faster and more than surface sod biomass, with dead roots in untilled soil without residue on the surface decomposing more than dead roots in untilled soil with surface residue. Tillage type and frequency did not appreciably influence subsurface sod biomass decomposition. Soil loss rates increased greatly with both surface sod biomass decomposition and decomposition of subsurface sod biomass in the conventionally tilled soil, but they were minimally affected by subsurface sod biomass decomposition in the untilled soil. Runoff rates were little affected by the studied treatments. Dead roots plus incorporated residues were effective in reducing erosion in the conventionally tilled soil, while consolidation of the soil surface was important in no-till. The residual effect of the turned soil on erosion diminished gradually with time and ceased after two years.

Index terms: water erosion, simulated rainfall, crop biomass decomposition, RUSLE equation.

RESUMO: *DECOMPOSIÇÃO SUPERFICIAL E SUBSUPERFICIAL DA BIOMASSA DE UMA PASTAGEM DE GRAMÍNEAS DESSECADA RELACIONADA COM A EROSÃO E SUA PREDIÇÃO COM O MODELO "RUSLE"*

A erosão reduz a capacidade produtiva do solo para as culturas e causa problemas de sedimentação e poluição da água. Os resíduos culturais superficiais e incorporados ao solo, assim como as raízes vivas e mortas das plantas, são importantes no controle da erosão do solo. Uma forma eficiente de avaliar a eficácia de redução da erosão de tais materiais é por meio de constantes de decomposição como as usadas no subfator uso anterior da terra ("PLU") da Equação Universal de Perda de Solo Revisada ("RUSLE"). Para investigar este assunto, foi utilizada chuva simulada sobre um solo Argissolo Vermelho distrófico típico, textura franco-arenosa, com 0,12 m m⁻¹ de declividade, na Estação Experimental Agronômica da Universidade Federal do Rio Grande do Sul, em Eldorado do Sul (RS). A área experimental encontrava-se na condição de campo nativo com pastagem de gramíneas aproximadamente há quinze anos. Em meados de março de 1996, a pastagem foi roçada mecanicamente e seu resíduo cultural removido da área. Ao final de abril de 1996, a pastagem foi quimicamente dessecada por meio da aplicação de herbicida e, cerca de um mês após, foram estabelecidos e avaliados para decomposição de biomassa vegetal e erosão hídrica do solo, de junho de 1996 a maio de 1998, sobre pares de parcelas de erosão com dimensões de 3,5 x 11,0 m, os seguintes tratamentos: (a) e (b) solo sem preparo, com resíduo superficial e raízes mortas, (c) solo sem preparo, com raízes mortas somente, (d) solo com preparo convencional a cada dois meses e meio, com raízes mortas e resíduo superficial incorporado e (e) solo com preparo convencional a cada seis meses, com raízes mortas e resíduo superficial incorporado. As chuvas foram aplicadas com um simulador de chuva de braços rotativos, na intensidade de 63,5 mm h⁻¹ e duração de 90 min, oito a nove vezes durante o período experimental (aproximadamente a cada dois meses e meio). As quantidades de biomassa superficial e subsuperficial da pastagem nativa dessecada foram avaliadas antes de cada teste de chuva simulada, acompanhadas das medições de erosão relativas à taxa de enxurrada, concentração de sedimentos na enxurrada, taxa de perda de solo e perda total de solo. Análise de regressão não-linear com os dados observados foi efetuada por meio de um modelo exponencial e um modelo potencial. A decomposição da biomassa superficial da pastagem dessecada foi mais bem descrita pelo modelo exponencial, enquanto a da subsuperficial pelo modelo potencial. A biomassa subsuperficial decompôs-se mais rapidamente e em maior quantidade do que a biomassa superficial, com as raízes mortas em solo não preparado e descoberto decompondo-se mais do que as raízes mortas em solo não preparado e coberto. O tipo e a frequência de preparo do solo praticamente não influenciaram na decomposição da biomassa subsuperficial. As taxas de perda de solo aumentaram expressivamente tanto com a decomposição da biomassa vegetal superficial, quanto com a decomposição da biomassa subsuperficial, no solo preparado convencionalmente; todavia, elas foram pouco influenciadas pela

decomposição da biomassa subsuperficial no solo não preparado. As taxas de enxurrada mostraram-se pouco influenciadas pelos tratamentos estudados. As raízes mortas mais o resíduo cultural incorporado foram importantes na redução da erosão no solo preparado convencionalmente, enquanto a consolidação da superfície do solo foi importante no solo não preparado. O efeito residual da pastagem nativa dessecada e incorporada ao solo sobre a erosão diminuiu gradualmente no tempo e cessou após dois anos.

Termos de indexação: erosão hídrica, chuva simulada, decomposição de biomassa vegetal, "RUSLE" equação.

INTRODUCTION

Although much has already been done, soil erosion by rainfall is still a major problem in many agricultural areas, especially in the developing countries of tropical and subtropical regions. In some places, erosion is a problem because of both high soil and water losses, which decrease crop productivity and cause sedimentation and water pollution problems, while in other places erosion is more a problem because of high water-rainfall losses in the form of runoff, which, despite the low load of solids in suspension, also causes serious environmental problems. Potentially hazardous pesticides and nutrients dissolved and transported in the runoff water may impair the quality of surface waters for human and animal consumption, and for irrigation purposes as well. On this background, it is a basic requirement in land management systems to improve soil structure for both a higher resistance against the erosive forces of rainfall and runoff and a better infiltration of rainwater in the soil.

Plant roots and incorporated residues, because of their combined and pronounced effect on soil structure, play an important role in erosion control (Wischmeier, 1973; Wischmeier & Smith, 1978). The effectiveness of such materials in reducing soil erosion in a given climatic region will vary with cropping and management factors, however. Such effectiveness can take two forms. First, roots and residue can control erosion directly by physically binding soil particles together and acting as mechanical barriers to soil and water movement. Second, roots and residue exude binding substances and serve as a food source for microorganisms which produce other organic binding agents. These contribute to an increased soil aggregation and thereby reduce the soil's susceptibility to erosion (Renard et al., 1997).

As we have already stated in another paper in this journal (E.V. Streck & N.P. Cogo - "Reconsolidation of the soil surface after tillage discontinuity, with and without cultivation, related to erosion and its prediction with RUSLE"), also dealing with the RUSLE's prior-land-use (PLU) subfactor, to counteract soil erosion and its deleterious effects on our environment, sound, scientifically-based conservation and management practices must be

developed, so that well-planned erosion control programs can successfully be implemented. The statements which follow in the next two or three paragraphs are mainly the same as those already expressed in the paper we just referred to, but because of their importance for this study, which deals with the same general subject of crop residues and soil erosion, they are repeated below.

A useful tool for conservation plans is the Revised Universal Soil Loss Equation - RUSLE (Renard et al., 1997). This erosion model retains the six factors from the original USLE in Agriculture Handbook Nº 537 (Wischmeier & Smith, 1978) to calculate the average-annual soil loss under given conditions. The technology for evaluation of these factor values has been altered and new data have been added (Renard et al., 1997). The cover and management C-factor in the equation is the one most used to compare the relative impacts of management decisions on conservation plans. However, it is also the most complicated factor for evaluating, since the combined effect of cover and management variables is influenced by numerous significant interrelations (Wischmeier & Smith, 1978; Renard et al., 1997).

According to Wischmeier (1975) and Mutchler et al. (1982), the general impact of cropping and management practices on soil losses can be divided into a series of subfactors. This technique is used within RUSLE with the modifications of Laflen et al. (1985) and Wertz et al. (1987). Based on these authors' new descriptions of cropping and management practices and their influence on soil loss, the necessary soil loss ratios for calculating C-values (Renard et al., 1997) are computed as:

$$SLR = PLU.CC.SC.SR.SM \quad (1)$$

where SLR is the soil loss ratio for given conditions, and the subfactors PLU for prior-land-use, CC for canopy-cover, SC for surface-cover, SR for surface-roughness, and SM for soil-moisture.

The subfactor PLU expresses the influence of subsurface residual effects from previous crops on soil erosion, as well as the effect of previous tillage practices on soil consolidation. The relationship is expressed in the form:

$$PLU = C_f \cdot \exp(-c \cdot B_u) \quad (2)$$

where PLU is the prior-land-use subfactor (ranging from 0 to 1), C_f a surface-soil-consolidation factor, B_u the mass of live and dead roots and buried residues found in the upper 2,5 cm of soil (mass area⁻¹ depth⁻¹), and c a coefficient representing the effectiveness of roots and buried residues in erosion control (area depth⁻¹ mass⁻¹).

The relationship with the B_u variable is expressed as (Stott et al., 1990; Stott, 1991):

$$M_e = M_b \cdot \exp(-a \cdot D) \quad (3)$$

where M_e = residue mass (kg ha⁻¹) at the end of a period, M_b = residue mass (kg ha⁻¹) at the beginning of the period, D = number of days, and

$$a = p \cdot [\text{minimum of } (W, F)] \quad (4)$$

where p = crop residue decomposition constant (taken from RUSLE's CROP database, which shows empirically derived p values varying from 0.015 to 0.025, depending on the crop species; default values in RUSLE's program show the same decay rates for surface and buried residue) and W and F are ratios for rainfall and temperature data, respectively.

In our opinion, critical points in RUSLE for PLU are the equal decay rates for surface and subsurface biomass, as well as the adequacy or not of the unique exponential function used to express such decay rates for the many and varied crop species, under the many and varied environmental conditions. For these reasons, we conducted this research to investigate some of these aspects, for further details, using both surface (crop residue) and subsurface (dead roots only and dead roots plus incorporated residue) biomass of a chemically desiccated grass pasture, two tillage treatments (no-till and two frequencies of conventional tillage), simulated rainfall, non-linear regression analysis, and an exponential and a power model.

MATERIAL AND METHODS

The field experiment was carried out at the Agriculture Experimental Station of the Federal University of Rio Grande do Sul (EEA/UFRGS), in Eldorado do Sul, Central Depression region of Rio Grande do Sul State, Brazil. The climate of the region is moist, sub-tropical "Cfa" type, according to Köppen's classification. The soil used is a Paleudult, sandy loam in texture (600 g kg⁻¹ sand; 230 g kg⁻¹ silt; 170 g kg⁻¹ clay), with 0.12 m m⁻¹ slope-steepness. The experimental area used for this study had been under a native grass pasture (predominantly *Paspalum* spp.) for about fifteen years. By mid-March 1996, the sod was mechanically mowed and the crop residue removed from the field. By the end of April 1996, the sod was chemically desiccated by applying a herbicide and, about one month later,

the following treatments were established and evaluated for sod biomass decomposition and soil erosion, from June 1996 to May 1998, on duplicated 3.5 x 11.0 m erosion plots: (a) and (b) soil without tillage, with surface residue and dead roots, (c) soil without tillage, with dead roots only (surface residue of the killed sod was removed from the plot by hand-hoeing), (d) soil tilled conventionally every two-and-half months, with dead roots plus incorporated residue, and (e) soil tilled conventionally every six months, with dead roots plus incorporated residue. Conventional tillage consisted of one plowing (with a disc plow) and two disking (with a disc harrow) operations. Simulated rainfall was applied with a Swanson's type (Swanson, 1965), rotating-boom rainfall simulator, at an intensity of 63.5 mm h⁻¹ for 90 min, eight to nine times during the experimental period (about every two-and-half months). Biomass measurements of the killed sod consisted of the percentage of soil cover with surface residues (photographic method), surface residue mass (by sampling residue from a 0.25 m² soil area and oven-drying them at 60 °C), dead roots, and dead roots plus incorporated residue mass at soil depths of 0-10 and 10-20 cm (by sampling soil cores with a 3.81 cm diameter probe, immersing the samples in water and carefully hand-disrupting the soil aggregates to separate roots from the soil, using a sieve and washing water). These biomass measurements were accomplished before each rainfall test, along with the erosion measurements for runoff rate, sediment concentration in runoff, soil loss rate, and total soil loss, using the standard procedures for this type of research (Cogo, 1981; Cogo et al., 1983; Cogo et al., 1984; Lopes et al., 1987; Levien et al., 1990; Streck, 1999). A sod-factor, S_f , was obtained by dividing the observed total soil loss from the turned sod treatments measured after each rainfall test (for which buried sod biomass was still measurable) by the observed total soil loss from the same treatments, but with no more buried sod biomass, measured in the rainfall test by the end of the experimental period (when buried biomass was not measurable anymore and, thus, considered zero). Non-linear regression analysis with the observed, non-transformed data (SAS, 1989) was performed using an exponential and a power model.

RESULTS AND DISCUSSION

Exponential versus power model for describing surface and subsurface sod biomass decomposition as a function of time

According to Stott et al. (1990) and Stott (1991), biomass decomposition of a crop residue as a function of time can be described by the exponential $y = ae^{-bx}$ model, where y is the residue mass at the end of a time period, a the mass at the beginning of the

period, x the number of days, and b a coefficient that describes the exponential decomposition rate of surface residue (it depends on residue characteristics and environmental factors as well). This model is used within RUSLE (Renard et al., 1997) when calculating the prior-land-use (PLU) subfactor. Since there were not enough data to justify different values for subsurface decay b values, the default values in RUSLE's program show identical decay rates for surface and buried residues (it is commented, however, that users may change this). Nevertheless, no comments are made in RUSLE on whether this exponential model is or is not the most appropriate one for describing vegetal biomass decomposition for the many and varied crop species, under the many and varied environmental conditions.

In this study, we investigated some of the above aspects for further details by fitting our sod biomass data with both an exponential and a power model, using non-linear regression with non-transformed data. Results are shown in figures 1 through 3 for the studied, desiccated grass pasture biomass (surface biomass and buried biomass at soil depths of 0-10 and 10-20 cm). Based on the coefficient of determination values, r^2 , it became clear that surface biomass decomposition (residue left on the surface of untilled soil - figure 1) was better described by the exponential model, whereas buried biomass decomposition (dead roots and dead roots plus incorporated residues - Figures 2 and 3, respectively) was better described by the power model, regardless of soil depths. Data for dead roots in untilled soil after surface residue removal and for dead roots plus buried residue in the soil tilled conventionally every six months (not shown in this paper) were also better fitted with the power model (Streck, 1999). The exponential model underestimated buried biomass decomposition until about six to seven months after sod desiccation and incorporation in the soil, and overestimated it thereafter. On the other hand, the power model did the opposite except for surface biomass decomposition. These findings indicate that different functions may be required to represent decomposition for different biomass materials which will probably vary according to biomass type, cropping and management practices, and environmental factors.

Surface and subsurface sod biomass decomposition as a function of time

Absolute reduction-values of the sod biomass amount as a function of time were already presented in figures 1 through 3. Based on the best fitting model, it became evident that the type of curve for buried biomass was the same for dead roots only and dead roots plus incorporated residues, regardless of soil depths (Figures 2 and 3). However, the curve was distinctly different from the one for surface biomass reduction (Figure 1). As already mentioned, this indicates that the equal decomposition rates for

surface and subsurface biomass, as shown by the default values in RUSLE's program (Renard et al., 1997), may not be tenable. Nevertheless, a direct comparison of the exponential b values shown in figures 1 through 3 with the pertinent ones shown by the default values in RUSLE's program is not possible. There are two reasons for this. First, one cannot say how much of the differences in these

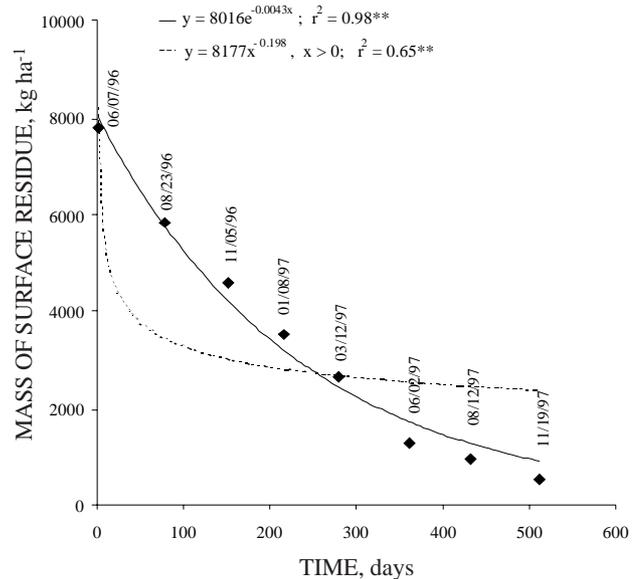


Figure 1. Surface residue mass reduction as a function of time in the untilled soil with residue left on the surface, evaluated by an exponential and a power model.

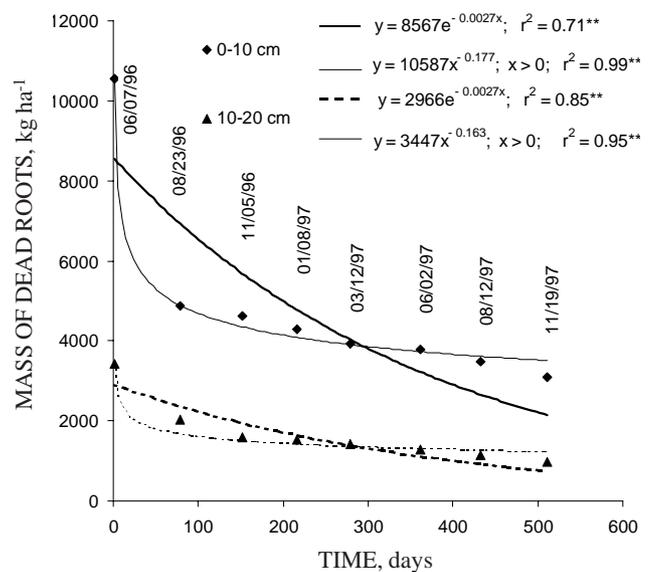


Figure 2. Dead root mass reduction as a function of time in the untilled soil with residue left on the surface, evaluated by an exponential and a power model.

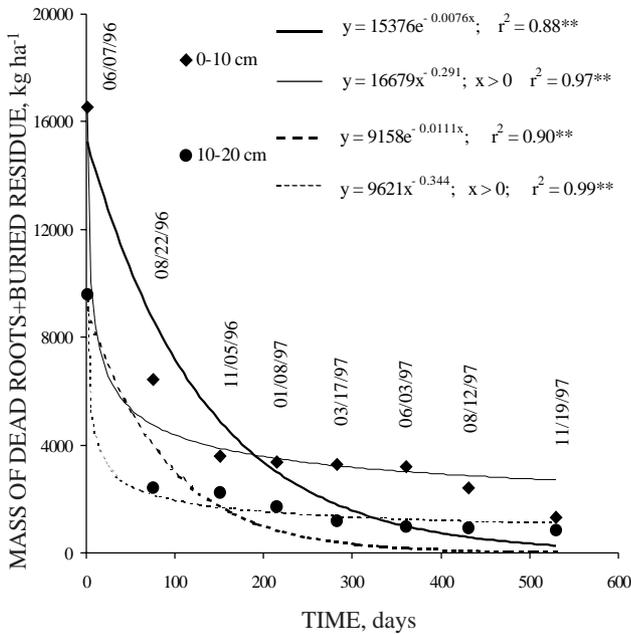


Figure 3. Dead roots plus incorporated residue mass reduction as a function of time in the soil tilled conventionally every 2.5 months, evaluated by an exponential and a power model.

coefficient values is due to differences in the units used for the variables in the regression analysis (SI units in this study and English units in RUSLE) and how much is due to differences in the way the coefficient values were obtained (by field experimentation in this study and by empirical derivation in RUSLE - nevertheless, without a clearer explanation on the procedure used for such a derivation). Second, it is difficult to say how much of the differences in the coefficient values is due to differences in residue characteristics and how much is due to differences in environmental factors, both of which greatly affect vegetal biomass decomposition.

To make differences between biomass type (dead roots and crop residue) and placement (surface and subsurface) in terms of decomposition amounts in this study more evident, absolute values of sod biomass amounts in figures 1 through 3 were converted to relative percent-values and are presented in figure 4 (for a soil depth of 0-10 cm only). It can be seen that buried biomass amounts were rapidly and greatly reduced within three months after the sod desiccation and incorporation in the soil, slightly more in the tilled soil with dead roots plus incorporated residues than in the untilled soil with dead roots, while surface biomass (residue of the killed sod left on the soil surface) relative reduction was slow and gradual over eighteen months after sod desiccation. Based on the results shown in figure 4, relative buried biomass amount reduction within three months after sod desiccation and

incorporation in the soil varied from about 50 to 70 %, while relative surface biomass amount reduction in the same time period was only about 25 %. The increasing order of biomass decomposition amount was: surface residue in untilled soil, dead roots in untilled soil with residue left on the surface, dead roots in untilled soil without surface residue, and dead roots plus incorporated residue in conventionally tilled soil, with no appreciable differences for tillage frequency in the latter condition.

Using the appropriate coefficient values from the equations shown in figure 4, the expected relative sod biomass loss for the above, same order listed treatments are, respectively after 75 and 150 days: 23, 49, 58, 59, and 60 % and 41, 61, 73, 76, and 77 %. Based on these relative values, decomposition amount for the killed-sod biomass can now conversely be ranked as: surface residue in untilled soil less than dead roots in untilled/covered soil less than dead roots in untilled/uncovered soil about equal to dead roots plus incorporated residue in conventionally tilled soil, with no appreciable differences for tillage frequency in the latter condition.

The faster and greater decomposition of subsurface biomass, compared to surface biomass, is probably due to the greater microbial activity in the soil when residue is buried, caused by the closer

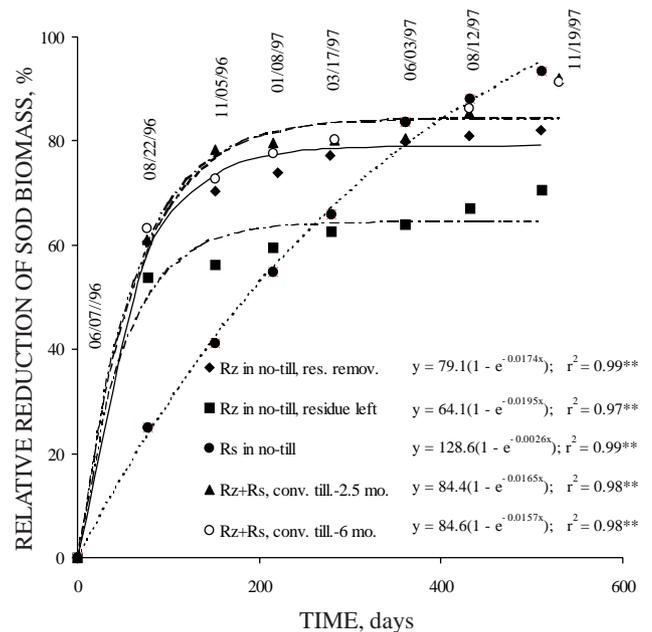


Figure 4. Relative sod biomass amount reduction as a function of time in the studied treatments (Rz = dead roots (0-10 cm); Rz + Rs = dead roots plus incorporated residue (0-10 cm); Rs = surface residue; conv. till.-2.5 or 6 mo. = soil tilled conventionally every to 2.5 or 6 months; res. remov. = residue removed).

contact between soil particles and roots and/or incorporated residue pieces. Also, subsurface biomass is probably less influenced by fluctuations in moisture and temperature than is surface biomass, thus providing a better and steadier environment for microbial decomposition. Other researchers reported similar findings (Brown & Dick, 1970; Parr & Papendick, 1978; Ghidry & Alberts, 1994; Streck, 1999). The greater decomposition of dead roots in untilled soil without surface residue, compared to dead roots in the untilled soil with surface residue, was probably because of higher soil temperatures in the first treatment, which stimulated microbial activity more. Type (no-till and conventional tillage) and frequency (two-and-half months and six months) of tillage did not appreciably influence subsurface biomass decomposition in this study.

The lower relative biomass decomposition amounts observed for buried biomass after about three months after the sod had been killed and incorporated in the soil (Figures 2, 3 and 4) was probably due to the predominance of thicker and older roots at this point of the decomposition process, compared to the ones at the beginning of the decomposition process, when there was a predominance of thinner and younger roots, which are different in terms of chemical composition. Roots and incorporated residue pieces which are thicker and older contain greater amounts of lignin and cellulose and higher values for the C:N ratio than do thinner and younger roots and incorporated residue pieces, and consequently, decompose more slowly (Parr & Papendick, 1978).

Values for the percent ratio of dead root mass in the 10-20 cm to dead root mass in the 0-10 cm soil layer are presented in figure 5. This information can be helpful for estimating root mass at 10-20 cm soil depth, when only root mass of the 0-10 cm soil layer is available, when calculating the prior-land-use (PLU) subfactor with RUSLE's program. This ratio for dead roots in the untilled soils was about constant throughout the experimental period, regardless of soil cover, with an average value in the order of 35%. This value is markedly smaller than the overall 80% value reported in RUSLE (Renard et al., 1997). Probably, root mass ratio values will vary greatly with crop species, tillage methods, and environmental factors. With respect to the ratio values for dead roots plus incorporated residues in the conventionally tilled soil, results in figure 5 show some erratic but different behavior among treatments. For dead roots plus incorporated residue with re-tillage every two-and-half months, ratio values oscillated above and below 50%, probably because of the more frequent tillage operations in this treatment, while for dead roots plus incorporated residue with re-tillage every six months, ratio values tended to increase from about 35% at the beginning to about 60% by the end of

the experiment. This variation in the values of the mass root-ratio for the buried, dead roots plus incorporated residue biomass in the tilled soil, compared to the ratio values for dead roots only biomass in the untilled soils, can be accepted as normal, as far as field conditions are taken into account, for the tillage operations and their inherent, non-uniform resulting soil physical conditions impose a great variability in the data when sampling buried biomass, compared to untilled soils.

Reduction of soil cover by crop residue as a function of time is shown in figure 6 for the untilled soil with residue left on the surface, along with the soil cover by the remaining, exposed dead roots in the untilled soil without surface residue. It can be seen that, for the untilled soil with residue left on the surface, soil cover by residue remained high until about six months after sod desiccation, dropping sharply thereafter (the last data point of soil cover for this treatment was omitted from the regression analysis because it essentially consisted of exposed roots). On the other hand, soil cover by the remaining, exposed dead roots in the untilled soil with out surface residue tended to increase gradually with time. This was because this soil surface was progressively being wore away by the combined action of raindrop impact and flowing water originated from the successive rainfall applications, besides the erosive action of natural rains.

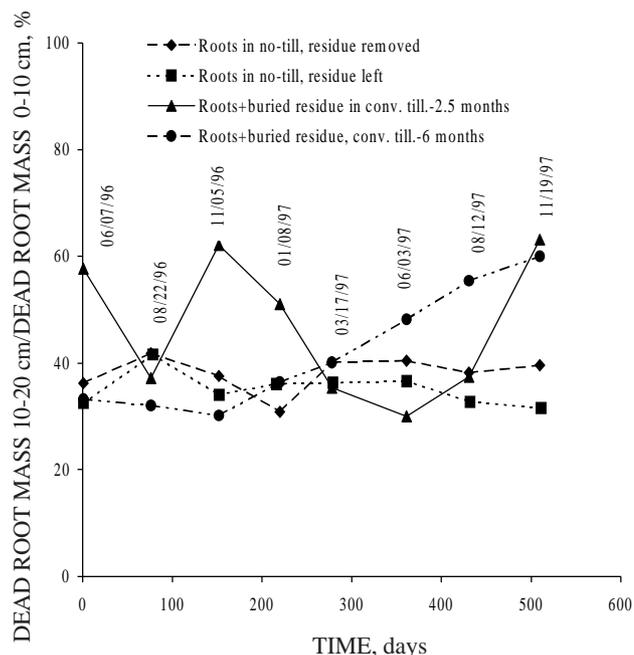


Figure 5. Percent ratio of dead root mass in the 10-20 cm soil layer to dead root mass in the 0-10 cm soil layer as a function of time in the studied treatments (conv. till.-2.5 or 6 mo. = soil tilled conventionally every to 2.5 or 6 months).

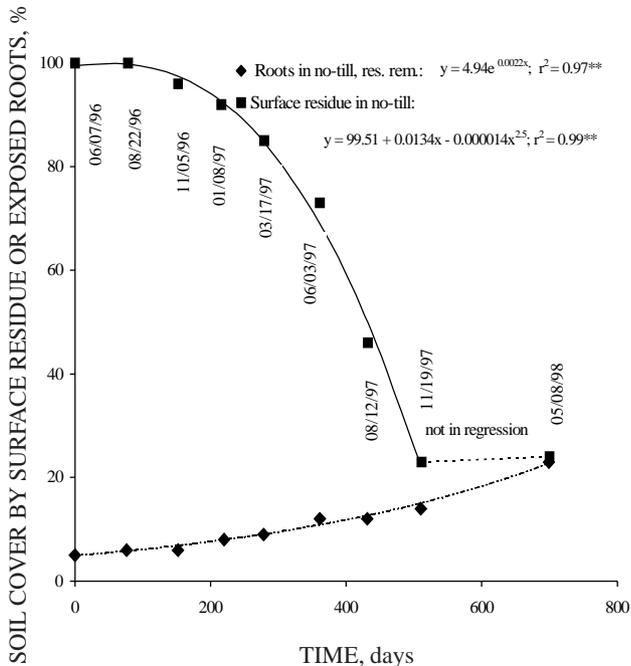


Figure 6. Soil cover by residue in the untilled soil with residue left on the surface or by exposed dead roots in the untilled soil without surface residue as a function of time (res. rem. = residue removed).

Runoff and erosion rates as a function of time

Runoff and erosion rates as a function of time for the studied treatments are shown, respectively, in figure 7 and figures 8 and 9. Runoff rate was the highest and about constant throughout the experimental period for the untilled soil without surface residue, while it was much lower and tended to increase with time in the other treatments (Figure 7), despite of some erratic values. These results can be explained in terms of both surface and subsurface physical soil conditions. For the untilled soil without surface residue, the soil surface was stable with time due to its high degree of consolidation, thus keeping runoff rate about constant, whereas for the untilled soil with residue left on the surface, runoff rate tended to increase with time due to the loss of its surface cover (Figure 6). For the two conventionally tilled soils with mixed, buried biomass (dead roots plus incorporated residue) runoff rates increased with time due to reduction of biomass and the implicit soil structural quality, caused by the successive and frequent tillage operations. Total water losses (not shown in this paper) showed a similar behavior (Streck, 1999).

In relation to soil loss rates (Figure 8), differences between treatments were markedly greater than differences for runoff rates (Figure 7). Soil loss rate was negligible for the untilled soil with residue left on the surface for over a year after the sod

desiccation, and then tended to increase due to the loss of its surface cover (Figure 6). For the untilled soil with out surface residue, erosion rate was greater than that for the previous treatment, but still low when compared to rates for the tilled soils, keeping more or less constant with time. After about one-and-half years, soil loss rates in the two untilled soils became approximately equal, tending to decrease afterwards in the soil which had been permanently bare and to reach equilibrium in the soil which had been protected by surface residue most of the time. These results are consistent as far as physical characteristics and ages of these two eroding soil surfaces are concerned. In relation to the conventionally tilled soils (Figure 8), soil loss rates increased greatly with time in both of them. This was because of the loss in the soil structural quality, as time progressed and with the continued tillage operations, the residual effect of the turned sod on erosion was terminating (Figure 9), thus making soil losses reach equilibrium, but at a high rate (soil loss rate increased from about zero at the beginning to approximately $12 \times 10^{-4} \text{ kg m}^{-2} \text{ s}^{-1}$ by the end of the experiment in both tilled soil treatments).

The residual effect of the turned sod on erosion, as expressed by the derived sod-factor, S_f , shown in figure 9, gradually decreased with time and ceased after about two years of sod desiccation and incorporation in the soil. This is just the same period of time as the one reported by Wischmeier (1973) and Wischmeier & Smith (1978) for the same intended purpose. Similar results (not shown in this paper) for the effect of the turned sod on erosion

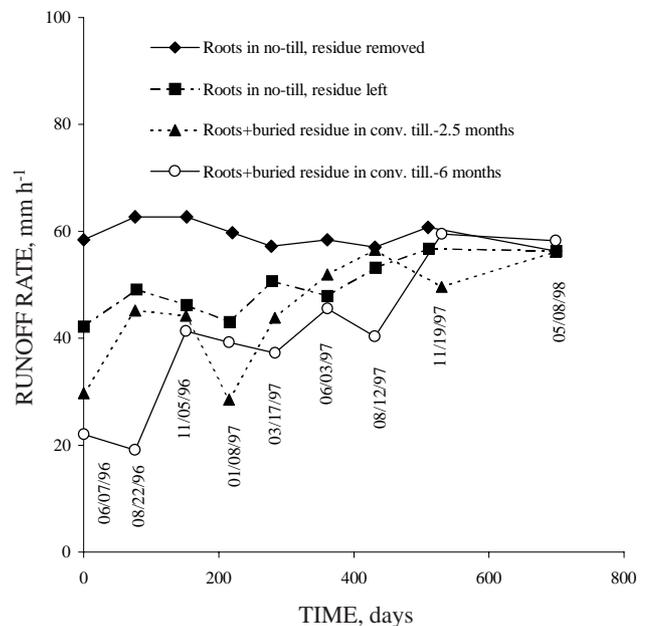


Figure 7. Runoff rate at steady-state as a function of time in the studied treatments (conv. till.-2.5 or 6 months = soil tilled conventionally every 2.5 or 6 months).

were also found when we used the sediment concentration at steady-runoff and the total soil loss data as input-data to verify such a relationship (Streck, 1999).

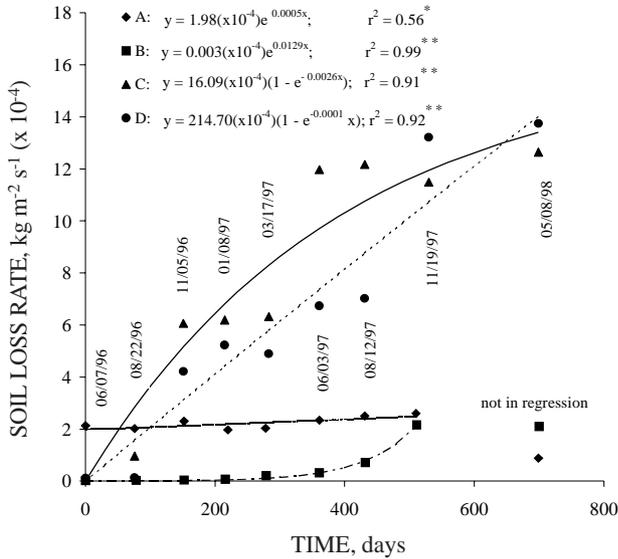


Figure 8. Soil loss rate at steady-runoff as a function of time in the studied treatments (A = no-till, residue removed; B = no-till, residue left; C = dead roots plus incorporated residue, conventional tillage every 2.5 months; D = dead roots plus incorporated residue, conventional tillage every 6 months).

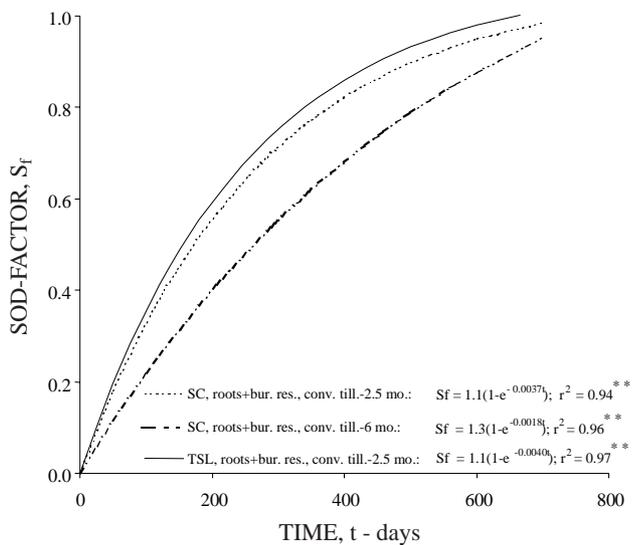


Figure 9. Residual effect of the turned sod on erosion as a function of time, as expressed by a sod-factor, S_f (input data: SC = sediment concentration at steady-runoff and TSL = total soil loss from the conventionally tilled soils; roots+bur. res., conv. till.-2.5 or 6 mo. = roots plus incorporated residue, conventional tillage every 2.5 or 6 months).

Total soil loss as a function of surface and subsurface sod biomass decomposition

Total soil loss as a function of percent of soil cover reduction is shown in figure 10 for the untilled soil with residue left on the surface. Soil loss was low until about 30 % of the residue cover had been reduced (70 % of residue cover still remained over the soil surface), increasing sharply thereafter. This is consistent with other studies (Kramer & Meyer, 1969; Cogo, 1981; Cogo et al., 1984; Norton et al., 1985; Lopes et al., 1987), for the greater the fraction of the soil surface that is directly exposed to rainfall, the greater the amount of soil particles that are detached and transported by the erosive agents.

Total soil loss as a function of relative subsurface biomass reduction for dead roots in the untilled soils, as well as for dead roots plus incorporated residue in the conventionally tilled soils, are shown in figure 11. Relative dead root mass reduction did almost not influence total soil loss at all in the untilled soils, regardless of soil cover. This was because of the crop-residue cover present most of the time in the treatment with residue left on the surface, and because of the high degree of consolidation of the soil surface in the treatment where surface residue had been removed. This latter treatment gave rise to a total soil loss which was considerable greater than that for the first treatment, anyway. These results are consistent with other studies (Dissmeyer & Foster, 1981; Wischmeier, 1975) which have also emphasized the surface resistance of undisturbed soils to erosion, as in pasturelands and no-till systems, caused by soil consolidation. With respect to the mixed, buried biomass (dead roots plus incorporated residues) in

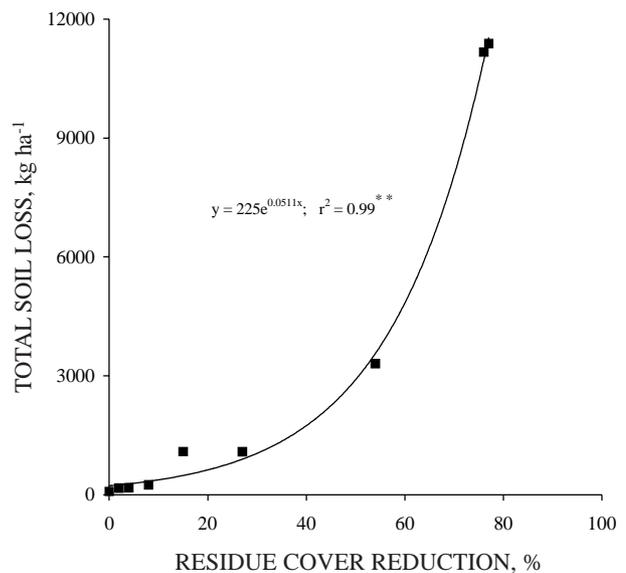


Figure 10. Total soil loss as a function of residue cover reduction in the untilled soil with residue left on the surface.

the conventionally tilled soils, total soil loss was low until about 50 to 60 % of the biomass amounts had been reduced, mainly in the treatment with re-tillage every six months, increasing sharply thereafter. This was because, at that point of buried biomass amount reduction, the soil structure had probably lost most of its original, good quality, for the residual effect of the turned sod on erosion was progressively diminishing with time (Figure 9).

Erosion-reduction effectiveness of the buried sod biomass

Buried biomass is important for erosion control because of its strong influence on soil structure and the inherent physical conditions, especially in relation to organic matter content and soil aggregation. This has to do with two fundamental aspects in the erosion process: (a) easyness by which soil particles are detached by rainfall and runoff, and (b) available infiltration capacity of the soil for rainwater. Knowledge on the erosion-reduction effectiveness of buried biomass is important in RUSLE when calculating the prior-land-use (PLU) subfactor (Renard et al., 1997). Results for such a type of relationship obtained in this study are shown in figure 12 using the killed-sod biomass density data at 0-10 cm soil depth and the sediment concentration data at steady-runoff.

An examination of the results in figure 12 shows that sediment concentration in runoff dropped sharply until the level of about 5,000 to 6,000 kg ha⁻¹ of buried sod biomass was reached, tending to a

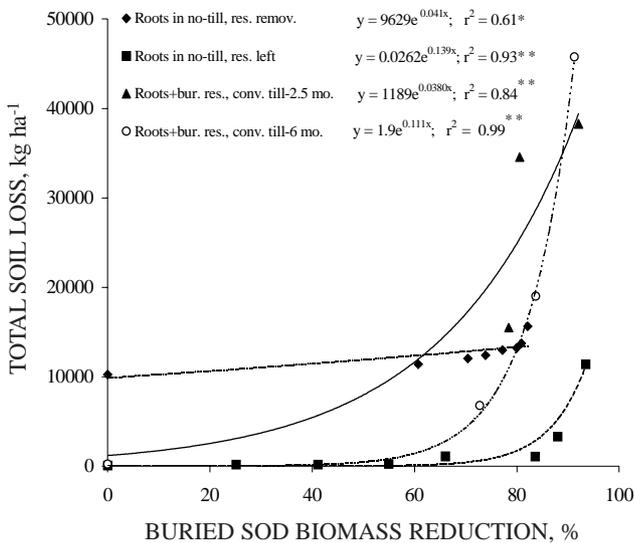


Figure 11. Total soil loss as a function of relative buried sod biomass amount reduction (0-10 cm) in the studied treatments (res. remov. = residue removed; res. left = residue left; roots + bur. res, conv. till.-2.5 or 6 mo. = roots plus incorporated residue, conventional tillage every 2.5 or 6 months).

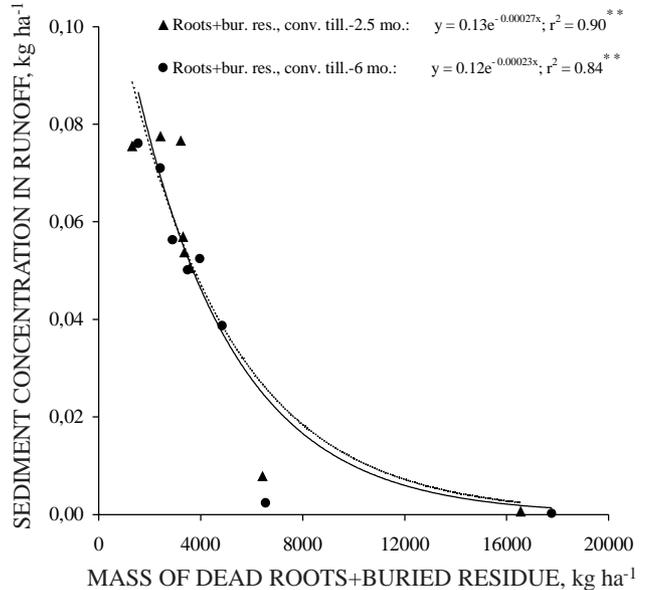


Figure 12. Sediment concentration at steady-runoff reduction as a function of subsurface sod biomass (dead roots plus incorporated residue at 0-10 cm soil depth) in the conventionally tilled soils (roots+bur. res., conv. till.-2.5 or 6 mo. = roots plus incorporated residue, conventional tillage every 2.5 or 6 months).

minimum value thereafter as the buried biomass amounts increased, regardless of tillage frequency, as denoted by the very close regression coefficient-b values (-0.00027 and -0.00023) for these two tilled soil treatments. Caution is recommended for the idea to compare regression-b values in the $y = ae^{-bx}$ model found in this study with the pertinent ones reported in RUSLE (Renard et al., 1997), since they are not directly comparable. There are two reasons for this. First, the units used for the variables in the regression analysis for verifying such a type of relationship are different (SI units in this study and English units in RUSLE). Second, soil depths used for the expression of buried biomass density are also different (0-10 cm in this study, equivalent to 3.937 inches, and the upper inch in RUSLE, equivalent to 2.54 cm). To make regression-b values from figure 12 comparable to the ones reported in RUSLE, simultaneous conversion for units and depth for expression of buried biomass density must firstly be made. This is possible by multiplying regression-b values in figure 12 by the factor 4.4127. After doing so, it will be found that regression-b values in figure 12 become equal to -0.0012 and -0.0010, which are quite close to the ones reported in RUSLE (-0.0018 for rill erosion, -0.0014 for rill-interril erosion, and -0.00081 for interrill erosion), according to Van Liew & Saxton (1993) and Wischmeier & Smith (1978). We judged that the conventionally tilled soil surfaces in the erosion plots we used for verifying such a type of relationship

eroded under the mixed, rill-interril form of erosion during the experimental period. So, results for expressing the erosion-reduction effectiveness of buried biomass found in this study are consistent with the pertinent ones shown in RUSLE (Renard et al., 1997).

CONCLUSIONS

1. Subsurface sod biomass decomposition was better described by the power model, while surface sod biomass was by the exponential model.

2. Subsurface sod biomass decomposed faster and more than surface sod biomass.

3. Dead roots in untilled soil without residue on the surface decomposed more than dead roots in untilled soil with residue on the surface.

4. Type and frequency of tillage did not appreciably influence subsurface sod biomass decomposition.

5. Soil loss rates increased greatly with both surface sod biomass decomposition and decomposition of subsurface sod biomass in the conventionally tilled soil, but they were minimally affected by subsurface sod biomass decomposition in the untilled soil.

6. Runoff rates were little affected by the studied treatments.

7. Subsurface sod biomass was effective in reducing soil loss in the conventionally tilled soil, while consolidation of the soil surface was important in no-till.

8. The residual effect of the turned sod on erosion diminished gradually with time and ceased after two years.

ACKNOWLEDGMENTS

To CNPq-PRONEX/Soils Project and to PIBIC-CNPq/UFRGS, FAPERGS, and CNPq, respectively for the financial support and the scholarships granted to the students who collaborated on this research.

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