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RECONSOLIDATION OF THE SOIL SURFACE AFTER TILLAGE DISCONTINUITY, WITH AND WITHOUT CULTIVATION, RELATED TO EROSION AND ITS PREDICTION WITH RUSLE[1]

E. V. STRECK[2] & N. P. COGO[3]

SUMMARY

Site-specific regression coefficient values are essential for erosion prediction with empirical models. With the objective to investigate the surface-soil-consolidation factor, C_f, linked to the RUSLE's prior-land-use subfactor, PLU, an erosion experiment using simulated rainfall on a 0.075 m m^{-1} slope, sandy loam Paleudult soil, was conducted at the Agriculture Experimental Station of the Federal University of Rio Grande do Sul (EEA/UFRGS), in Eldorado do Sul, State of Rio Grande do Sul, Brazil. Firstly, a row-cropped area was excluded from cultivation (March 1995), the existing crop residue removed from the field, and the soil kept clean-tilled the rest of the year (to get a degraded soil condition for the intended purpose of this research). The soil was then conventional-tilled for the last time (except for a standard plot which was kept continuously clean-tilled for comparison purposes), in January 1996, and the following treatments were established and evaluated for soil reconsolidation and soil erosion until May 1998, on duplicated 3.5 x 11.0 m erosion plots: (a) fresh-tilled soil, continuously in clean-tilled fallow (unit plot); (b) reconsolidating soil without cultivation; and (c) reconsolidating soil with cultivation (a crop sequence of three corn- and two black oats cycles, continuously in no-till, removing the crop residues after each harvest for rainfall application and redistributing them on the site after that). Simulated rainfall was applied with a Swanson's type, rotating-boom rainfall simulator, at 63.5 mm h^{-1} intensity and 90 min duration, six times during the two-and-half years of experimental period (at the beginning of the study and after each crop harvest, with the soil in the unit plot being re-tilled before each rainfall test). The soil-surface-consolidation factor, C_f, was calculated by dividing soil loss values from the reconsolidating soil treatments by the average value from the fresh-tilled soil treatment (unit plot). Non-linear regression was used to fit the $C_f = e^{b.t}$ model through the calculated C_f-data, where t is time in days since last tillage. Values for b were -0.0020 for the

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reconsolidating soil without cultivation and -0.0031 for the one with cultivation, yielding C_f-values equal to 0.16 and 0.06, respectively, after two-and-half years of tillage discontinuation, compared to 1.0 for fresh-tilled soil. These estimated C_f-values correspond, respectively, to soil loss reductions of 84 and 94 %, in relation to soil loss from the fresh-tilled soil, showing that the soil surface reconsolidated intenser with cultivation than without it. Two distinct treatment-inherent soil surface conditions probably influenced the rapid decay-rate of C_f-values in this study, but, as a matter of a fact, they were part of the real environmental field conditions. C_f-factor curves presented in this paper are therefore useful for predicting erosion with RUSLE, but their application is restricted to situations where both soil type and particular soil surface condition are similar to the ones investigate in this study.

Index terms: water erosion, simulated rainfall, soil consolidation, RUSLE equation.

RESUMO: *RECONSOLIDAÇÃO DA SUPERFÍCIE DO SOLO APÓS CESSAMENTO DO PREPARO, NA PRESENÇA E NA AUSÊNCIA DE CULTIVO, RELACIONADA COM A EROSÃO E SUA PREDIÇÃO COM O MODELO "RUSLE"*

Valores locais de coeficientes de regressão são essenciais para predizer a erosão por meio de modelos empíricos. O fator consolidação da superfície do solo, C_f, associado ao subfator uso anterior da terra, PLU, do modelo "RUSLE", foi investigado usando chuva simulada em Argissolo Vermelho distrófico típico, textura franco-arenosa e 0,075 m m^{-1} de declividade, na Estação Experimental Agronômica da Universidade Federal do Rio Grande do Sul (EEA/UFRGS), em Eldorado do Sul (RS). Para começar o estudo, uma área com culturas anuais em fileiras foi retirada do processo de cultivo, em março de 1995, tendo sido progressiva e intencionalmente degradada por meio da remoção dos resíduos culturais e de freqüentes arações e gradagens, o restante do ano. Após o último preparo de solo na área de estudo, em janeiro de 1996, foram estabelecidos, e avaliados para reconsolidação da superfície do solo e erosão do solo, até maio de 1998, sobre pares de parcelas de erosão com dimensões de 3,5 x 11,0 m, os seguintes tratamentos: (a) solo recém-preparado, continuamente em pousio descoberto (parcela unitária); (b) solo em processo de reconsolidação na ausência de cultivo; e (c) solo em processo de reconsolidação na presença de cultivo (três ciclos culturais de milho intercalados com dois ciclos culturais de aveia preta, continuamente em semeadura direta, removendo-se os resíduos culturais após a colheita de cada cultura para aplicação das chuvas e retornando-os posteriormente). As chuvas foram aplicadas com um simulador de chuva de braços rotativos, tipo Swanson, na intensidade de 63,5 mm h^{-1} e duração de 90 min, seis vezes durante os 2,5 anos de período experimental (no início e logo após a colheita de cada cultura, com o solo na parcela unitária sendo repreparado toda vez que um teste de chuva era realizado). O fator consolidação da superfície do solo, C_f, foi derivado dividindo-se os valores de perda de solo observados nos tratamentos de reconsolidação do solo pela perda de solo observada no tratamento com o solo recém-preparado. Empregou-se análise de regressão não-linear para ajustar o modelo $C_f = e^{bt}$ aos dados derivados de C_f, em que t é o número de dias decorrido desde o último preparo do solo. Os valores encontrados de b foram -0,0020 para o tratamento reconsolidação do solo sem cultivo e -0,0031 para o com cultivo, que geram, respectivamente, após 2,5 anos de cessamento do preparo de solo, valores de C_f iguais a 0,16 e 0,06, comparados ao valor 1,0 para o solo recém-preparado. Estes valores estimados de C_f equivalem a reduções de perda de solo de, respectivamente, 84 % e 94 %, em relação à perda verificada no solo recém-preparado, mostrando que o solo reconsolidou mais sua superfície na presença de cultivo do que na sua ausência. Duas condições distintas de superfície do solo, inerentes aos tratamentos de reconsolidação do solo avaliados, provavelmente influenciaram a rápida taxa de declínio dos valores de C_f neste estudo, mas, de qualquer forma, elas eram parte do ambiente real no campo. Assim, as curvas do fator-C_f apresentadas neste estudo são válidas para predizer a erosão hídrica com o modelo "RUSLE", porém seu uso é limitado àquelas situações em que tanto o tipo de solo, quanto sua condição específica de superfície, são similares às estudadas nesta pesquisa.

Termos de indexação: erosão hídrica, chuva simulada, consolidação do solo, equação "RUSLE".

INTRODUCTION

Despite intense research on erosion mechanisms and erosion control techniques, soil degradation by this process is still a problem in many agricultural areas. In addition, erosion products such as sediments and soil-adsorbed and/or runoff-transported chemicals are detrimental to our environment. To impair soil erosion and its deleterious effects on our environment, sound, scientifically-based conservation and management practices must be developed, so that well-planed erosion control programs can successfully be implemented.

A useful tool for making 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 Weltz 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:

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

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 PLU subfactor 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:

$$PLU = C_{f.} \,.\, \exp(-c \,.\, B_u) \qquad (2)$$

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 controling erosion (area depth^{-1} mass^{-1}).

As stated in RUSLE (Renard et al., 1997), C_f expresses the effect of tillage-induced surface density changes on erosion. However, in this definition for C_f, the meaning of the term "surface density changes" is not so clear. Does it refer to the regular bulk density changes in the whole soil mass caused by tillage (for a depth not yet specified), or to any density change, regardless of the depth of the altered soil mass and the place where it may have occurred (in the soil mass, right at the surface of the soil, or both)? Doubtlessly, tillage operations tend to break soil aggregate bonds, causing pronounced density changes in the whole soil mass, which increases the erosion potential. This is reflected in the lower erosion rates of undisturbed soils in rangelands or in no-till systems (Renard et al., 1997). In our interpretation of the soil-surface consolidation factor, C_f, although not explicitly expressed in the RUSLE definition, it expresses the effect on soil erosion not only of surface density changes caused by tillage per se (alterations in the whole soil mass), but also of density changes that might occur right at the surface of the soil, exactly where the physical work of erosion takes place. These can be caused by machinery and/or animal traffic, soil sealing, crust development, and/or biological activity (such as presence of algae), regardless of density changes that might occur in the soil mass beneath the surface. Results in this paper are discussed on this interpretation basis of the consolidation effects on soil erosion.

Wischmeier (1975) found that C_f-values dropped to 0.45 after nine years without tilling the soil, but keping it free of traffic and vegetation, compared to 1.0 for fresh-tilled soil. Similarly, Dissmeyer & Foster (1981) established C_f = 1.0 for a fresh-tilled soil and C_f = 0.45 for a soil undisturbed for seven years, based on an exponential decay-rate of C_f-values. Certainly, the effect of soil-surface consolidation on erosion is highly dependent on both soil type and specific soil surface conditions. Caution is therefore recommended when extrapolating these kind of data.

The main objective of this research was to obtain preliminary regression coefficient values to estimate the surface-soil consolidation factor, C_f, linked of the RUSLES prior-land-use subfactor, PLU, for two distinct soil conditions, namely, reconsolidating soil without cultivation (with no vegetation and no traffic) and reconsolidating soil with cultivation (under vegetation and traffic).

MATERIAL AND METHODS

The field work was carried out at the Agriculture Experimental Station of the Federal University of Rio Grande do Sul (EEA/UFRGS), in Eldorado do Sul (RS), Central Depression region of Rio Grande do Sul State, Brazil. The climate of the region is moist, sub-tropical "Cfa" type, according to Köeppen's classifacation. 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 0.075 m m^{-1} slope-steepness. To begin the study, a row-cropped area was excluded from cultivation (March 1995), the existing crop residue removed from the field, and the soil kept continuously clean-tilled the rest of the year (to get a degraded soil condition for the intended purpose of this research). The soil was then conventional-tilled for the last time (except for a standard plot which was kept continuously clean-tilled for comparison purposes), in January 1996, and the following treatments were established and evaluated for soil reconsolidation and soil erosion until May 1998, on duplicated 3.5 x 11.0 m erosion plots: (a) fresh-tilled soil, continuously in clean-tilled fallow - unit plot); (b) reconsolidating soil without cultivation; and (c) reconsolidating soil with cultivation (a crop sequence of three corn- and two black oats cycles, continuously in no-till, removing the crop residues after each harvest for rainfall application and redistributing them on the site after that). Simulated rainfall was applied with a rotating-boom rainfall simulator (Swanson's type), at 63.5 mm h^{-1} intensity and 90 min duration, six times over the two-and-half years of experimental period (at the beginning of the study and after each crop harvest, with the soil in the unit plot being re-tilled before each rainfall test). Measurements in the soil of the plots, at a soil depth of 0 to 0.075-0.10 m, consisted of organic carbon content, size of water-stable aggregates (MWD - mean weight diameter), and bulk density. Erosion measurements during rainfall application consisted of sediment concentration in runoff, soil loss rate at steady-runoff, total soil loss, steady-runoff rate, total runoff, and D_{50}-index of runoff-transported sediments (size of sediments for which 50 % - in a mass basis, are higher and 50 % are lower than that size). These measurements were accomplished by using the standard procedures described in the literature (Cogo, 1981; Cogo et al., 1983; Cogo et al., 1984; Levien et al., 1990; Streck, 1999). The surface-soil-consolidation factor, C_f, linked to the RUSLE's prior-land-use subfactor, PLU (Renard et al., 1997), was calculated by dividing the soil loss values from the reconsolidating soil treatments by the average value from the fresh-tilled soil treatment (unit plot). Non-linear regression (SAS, 1989) was used to fit the $C_f = e^{b.t}$ model through the calculated C_f-data, where t is time in days since last tillage. The statistical significance for the values of the determination coefficient, r^2, was tested by using probability levels of 1 % (**) and 5 % (*). More details about the procedures used in this study can be found in Streck (1999).

RESULTS AND DISCUSSION

Organic carbon, water-stable aggregates, and bulk density of the soil in the plots

The organic carbon content measured for this soil under native grass was 17.5 g kg^{-1}. When the soil in the experimental area was excluded from cultivation with row crops, in March 1995, the organic carbon content was 13.4 g kg^{-1}, and when the study effectively began, in January 1996, it was about 12.0 g kg^{-1} (Streck, 1999). From this date on organic carbon in the soil always decreased in the reconsolidating soil without cultivation, while in the one with cultivation it decreased up to seven months latter and, then, tended to recompose and stayed at about an equilibrium rate (Figure 1). These results are consistent, since cropping continuously adds biomass to the soil, maintaining its organic matter content better. Results for the continuously fresh-tilled soil (Streck, 1999) showed a behavior similar to the one for the reconsolidating soil without cultivation, except for its lower values. This is because the frequent tillage operations tend to break aggregate bonds, increasing the oxidation rate of organic substances and, thus, decreasing organic carbon in the soil faster (Oades, 1984; Carter, 1992).

Despite the erratic behavior in some of the MWD-values (Figure 2), the size of water-stable aggregates increased with time in the reconsolidating soil with cultivation, while in the one without cultivation it tended to decrease. This certainly was due to the presence and the absence of plants, respectively, in these reconsolidating soil treatments. In the absence of plants, organic carbon tends to decrease with time, and so does soil aggregation, while in the presence of plants just the opposite occurs. The better soil aggregation under cultivation, expressed by the higher MWD-values, compared to no cultivation, is due to the combined effect of plant roots and microbial activity, which improves soil structures (Tisdall & Oades, 1982; Oades, 1984).

Bulk density of the soil increased greatly in the first four months after tillage was discontinued (from

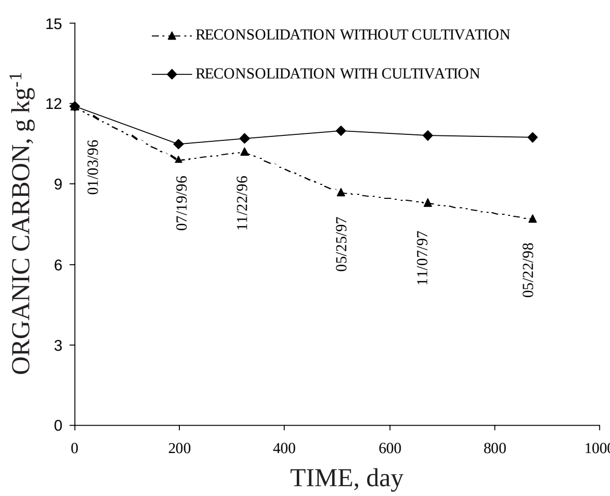

Figure 1. Organic carbon at a soil depth of 0-0.10 m as a function of time in the reconsolidating soil treatments.

1.26 kg dm^{-3} to about 1.55 kg dm^{-3}), regardless of cultivation, tending to level off thereafter (Figure 3). However, bulk density values were always considerably higher with cultivation than withoutit. This probably was caused by the combined effect of machinery traffic, plant root pressure, and soil drying (due to soil-water extraction by plant roots) in the reconsolidating soil with cultivation, which increased soil density (Tisdall & Oades, 1982; Nearing et al., 1988).

Water losses

In essence, total water loss and steady-runoff rates behaved the same in this study, since in all rainfall tests runoff started almost immediately after rainfall began, regardless of treatments. Therefore, only steady-runoff rates are discussed here. Runoff rates were extremely high (about 95 % of the applied rainfall rate) in all rainfall tests, in both reconsolidating soil treatments (Figure 4). This

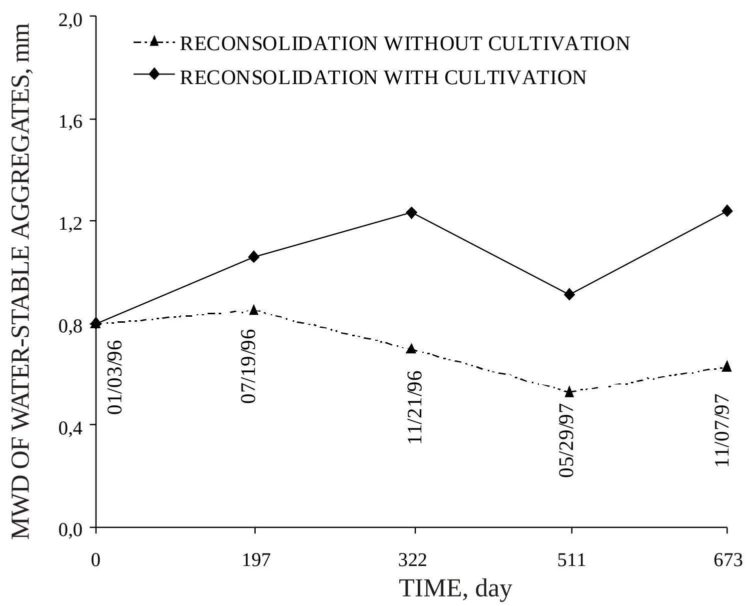

Figure 2. Size of water-stable aggregates (MWD) at a soil depth of 0-0.10 m as a function of time in the reconsolidating soil treatments.

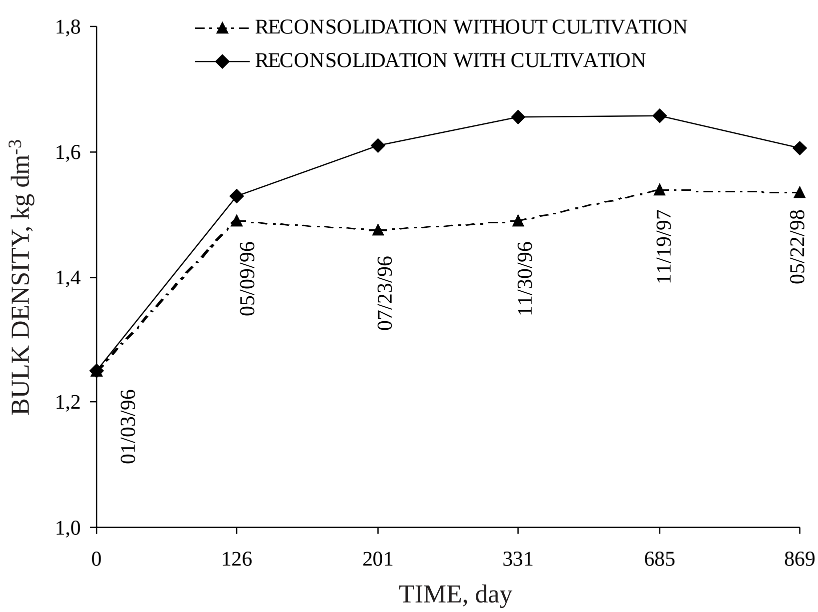

Figure 3. Bulk density at a soil depth of 0-0.075 m as a function of time in the reconsolidating soil treatments.

reveals that, although cultivation improved both organic matter content (Figure 1) and size of water-stable aggregates (Figure 2), compared to no cultivation, it had no effect at all on water infiltration in the soil in this study. There are several reasons for this. First, tillage-induced surface roughness was essentially absent in both reconsolidating soil treatments, providing no surface retention capacity and, thus, minimum soil surface detention capacity to store or, at least, delay rainwater on its surface. Second, in both reconsolidating soil treatments the soil was kept bare for rainfall application, in all rainfall tests (crop residues of the cultivated plots were always previously removed), thus permitting the soil to seal its surface under the direct impact of raindrops (in addition to sealing, crusts developed as time progressed, especially in the soil without cultivation, hindering water infiltration). Third, the progressive reconsolidation of the soil mass due to tillage discontinuity was probably the cause for a smaller volume of aeration-porosity for infiltrating rainwater faster, denoted by the relatively high soil density values in both reconsolidating soil treatments (Figure 3). At this point, it is worth to stress that, as far as infiltration of rainwater into the soil is concerned, physical conditions right at the soil surface prevail over those in the soil mass beneath the surface, regardless of soil cover. Dominant factors controlling water infiltration in the soil are tillage-induced surface roughness and an open soil structure (from the subsurface of the soil up to its surface, which implies absence of compacted layers in the soil, seals, and crusts). Certainly, surface crop residues are essential to maintain such favorable surface conditions for infiltrating water into the soil. However, not seldom, well-covered untilled soils infiltrate less rainwater than do soils with less cover, but tilled to some degree. This is a consequence of the lacking tillage-induced surface roughness and open soil structure in the untilled soils, caused not only by the absence of tillage per se (which would otherwise induce surface roughness), but also by the progressive consolidation of their surfaces with time.

Soil losses

Soil losses by erosion were evaluated by measuring sediment concentration in runoff, soil loss rates at steady-runoff, and total soil loss. The values of these variables behaved essentially the same in each of the reconsolidating soil treatments, showing an exponential decay-rate as a function of time. For this reason, and for practical purposes, only soil loss rates at steady-runoff are discussed here (Figure 5). Erosion rates as a function of time decreased most in the first year after tillage was discontinued, in both reconsolidating soil treatments, afterwards they asymptotically tended to an equilibrium rate. These results are consistent, since most of the settlement in the soil mass occurs soon after the soil has been tilled, denoted by the great increase in soil bulk density values after only three months of tillage discontinuity, in both reconsolidating soil treatments (Figure 3). However, soil loss rates were always considerable higher in the reconsolidating soil without cultivation than they were with cultivation. Some explanations for these facts are given below.

The higher erosion resistance of a soil surface under cultivation, compared to no cultivation, is due to the combined effects of machinery traffic, plant root pressure, soil drying due to soil-water extraction by plant roots, and microbial activity, all of which contribute to a more consolidated soil surface (Nearing et al., 1988; Nearing & West, 1988; Schafer

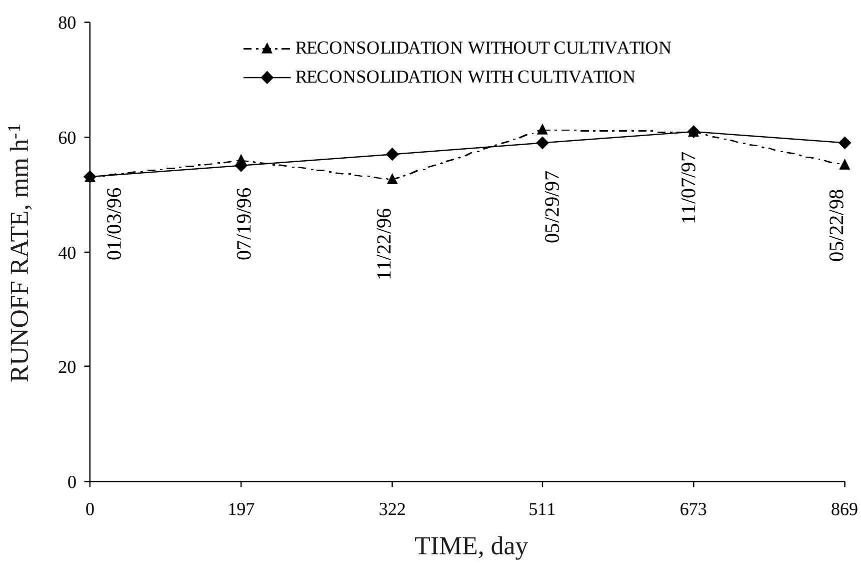

Figure 4. Steady-runoff rate as a function of time in the reconsolidating soil treatments.

et al., 2001). This is confirmed by the higher values of both MWD of water-stable aggregates (Figure 2) and bulk density (Figure 3) for the reconsolidating soil with cultivation, compared to the one without cultivation. For non-cultivated soils, reconsolidation occurs exclusively by gravity, wetting-drying processes, and direct raindrop impact (Allison, 1968; Tisdall & Oades, 1982; Oades, 1984), while for cultivated soils there are the additional, important effects of machinery and plant root pressures, as well as the effect of soil drying due to soil-water extraction by plant roots, all of which contribute to the reconsolidation process of the soil surface. The great reduction in erosion rates with time observed in both reconsolidating soil treatments in this study was probably influenced by two distinct treatment-inherent soil surface conditions. One was an easy visible, dense crust formed at the surface of the uncultivated soil, mingled with green algae naturally arisen in the plot. The other was a barely visible, light to median crust formed at the surface of the cultivated soil, but mingled with small, semi-decomposed pieces of crop residues which could not be removed without disturbing the soil surface (this was wanted). These two distinct, soil surface conditions probably influenced the erosion resistance of the soil in the plots, furthermore the reconsolidation effect of the soil mass per se (caused by tillage discontinuity, machinery traffic, and plant root pressure, this latter restricted to the soil under cultivation), decreasing these soil's erodibility. Despite the small, semi-decomposed pieces of residues intermixed with the light to median crust in the reconsolidating soil with cultivation, the effect of soil consolidation per se on soil erosion was not masked; otherwise, the corresponding curve in figure 5 would not exhibit the exponential decay rate of soil loss values. Even though not explicitly expressed in the definition for the C_f-factor in RUSLE, we interpret the effects of such specific soil surface conditions on erosion as implicit parts of the whole reconsolidation process of the soil surface, for they are part of the reality in the field when the soil is not well-protected by crop residue. We therefore consider our erosion data consistent and applicable to situations where both soil type and particular soil-surface condition are similar to the ones studied in this research.

Size distribution of runoff-transported sediments

The size distribution of the runoff-transported sediments in this study was evaluated by means of the D_{50}-index (Figure 6). Mean values of this index decreased exponentially with time in both reconsolidating soil treatments, but they were always lower with cultivation than withoutit, showing that the surface of the uncultivated soil was less erosion-resistant than that of the cultivated soil. This was due to the higher degree of soil reconsolidation in this latter treatment. The more consolidated the soil surface is, the finer the runoff-transported particles are, because of its more detachment-resistant surface. D_{50}-index values in the these reconsolidating soil treatments are consistent with results for organic carbon, water-stable aggregates, and bulk density previously discussed (Figures 1, 2, and 3). As values for these soil parameters increase, as they did for the cultivated soil, the size of the eroded sediments tends to decrease, because of its more selective, erosion-resistant-surface.

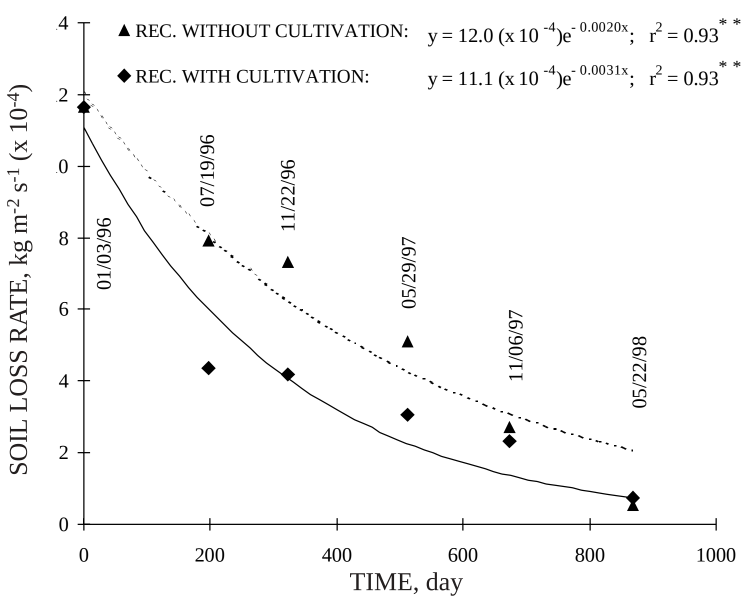

Figure 5. Soil loss rate at steady-runoff as a function of time in the reconsolidating soil treatments.

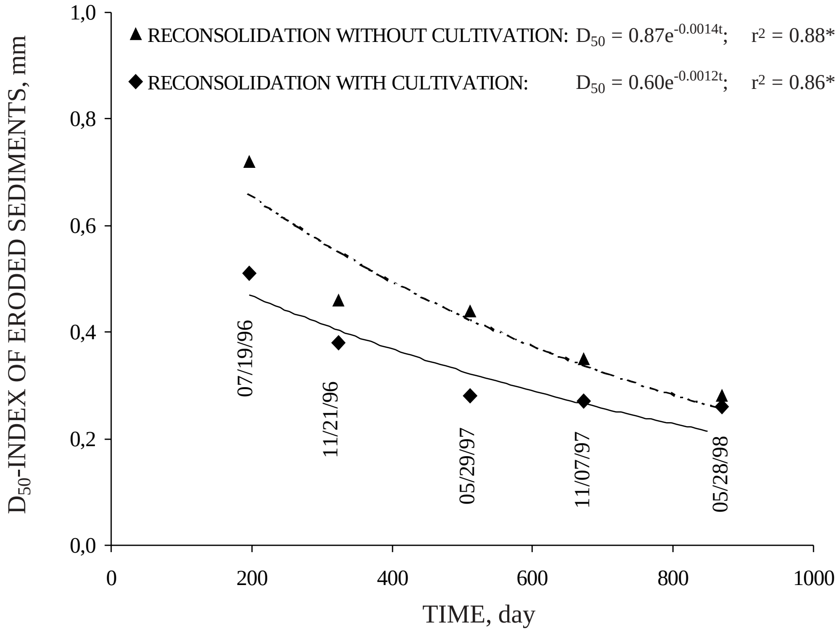

Figure 6. D_{50}-index of eroded sediments during constant discharge as a function of time in the reconsolidating soil treatments.

Surface-soil-consolidation factor

The soil-surface consolidation factor, $C_{f,}$, linked to the RUSLE's prior-land-use subfactor, PLU, was derived using three types of input-data, namely, sediment concentration in steady-runoff, soil loss rate at steady-runoff, and total soil loss. Because exponentially time-decaying C_f-values were about the same, regardless of the type of input-data, a unique regression was run, combining all the data in the same analysis (there were totally eighteen data points in the regression – six from each type of input-data). Results from this unique regression analysis are shown in figure 7 (data points in this figure were omitted for practical purposes only - the reader may refer to figure 5 to have an idea about the scattering of the data around the curve, in this case specifically for the soil loss rate type of input-data; sediment concentration in steady-runoff and total soil loss input-data showed essentially the same pattern of scattering). It is clear from the curves in figure 7 that the soil surface was more reconsolidated in the presence of cultivation than in its absence, as denoted by the lower C_f-values for the first condition. Reasons for this are exactly the same as those already presented when we discussed the decrease in soil loss rates as a function of time in these two reconsolidating soil treatments, since C_f-values are essentially observed erosion rate ratios. What surprised in the data was the great difference between the C_f-values found in this study and those mentioned by Wischmeier (1975) and Dissmeyer & Foster (1981). These authors suggested $C_f = 0.45$ after seven to nine years without disturbing the soil. In our study, C_f-values were equal to 0.06 and 0.16, respectively for with and without cultivation, right after only two-and-half years after tillage had been discontinued. As already discussed, results in this study were probably influenced by two distinct soil surface conditions (a dense crust intermixed with green algae in the uncultivated soil, and a light to median crust mingled with small, semi-decomposed pieces of residue in the cultivated soil), but this was part of the real field conditions under which erosion took place, as mentioned earlier. So, we consider our results correct. On the other hand, C_f-values by Wischmeier (1975) and Dissmeyer & Foster (1981) refer to soils distinctly different from the one used in this research, as well as to not well specified soil-surface conditions, making a straight comparison between their C_f-values and the ones found in our study difficult. Because we have considered our data consistent with the real field occurrences, we judged them applicable to situations where conditions are similar to the ones studied in this research. Anyway, it is clear that much research still has to be done on this subject.

Interrelation of the soil surface-consolidation factor, C_f, with D_{50}-index and bulk density

The relationship between D_{50}-index values of runoff-transported sediments and C_f-factor values is shown in figure 8. D_{50}-index values increased as C_f-factor values increased, in both reconsolidating soil treatments, but apparently with no differences between them. This is because the higher the C_f-factor values are, the less consolidated the soil surface is, and the more easily detached the soil particles become by the erosive agents. These results are consistent with the ones shown in figures 5 and 6, respectively for soil loss rates and D_{50}-index values as a function of time.

The relationship between C_f-factor values and bulk density values is shown in figure 9. Except for the considerable decrease in C_f-factor values from the time the soil was discontinued from tillage (for which C_f = 1.0 and bulk density = 1.24 kg dm^{-3}) to four months later (for which C_f = 0.7 and bulk density = 1.55 kg dm^{-3}), bulk density and C_f-factor values were not well-related in both reconsolidating soil treatments. This probably was because soil density in this study was measured at a depth of 0-0.075 m, while the physical work of erosion takes place right at the soil surface. So, bulk density values for the whole soil mass, as regularly obtained, will not be able to reflect the combined effect of right-at-the soil surface variables which, probably, influences soil erosion greatly, as previously discussed. In situations like this, other physical measures would probably give better results than bulk density per se, perhaps the soil strength right at the surface. Bradford et al. (1987) give a very good insight on this subject. It would be worthwhile to better study these aspects too, as far as RUSLE's soil-surface-consolidation factor, C_f, is concerned.

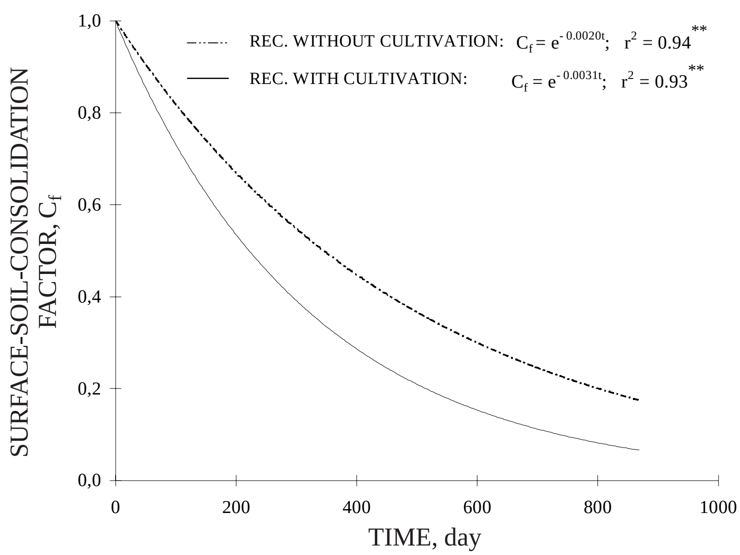

Figure 7. Surface-soil-consolidation factor as a function of time in the reconsolidating soil treatments.

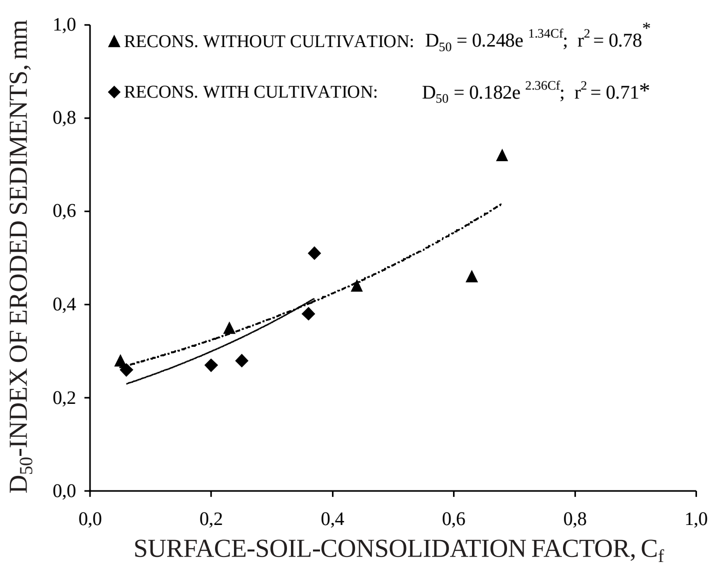

Figure 8. D_{50}-index of eroded sediments during constant discharge as a function of the surface-soil-consolidation factor in the reconsolidating soil treatments.

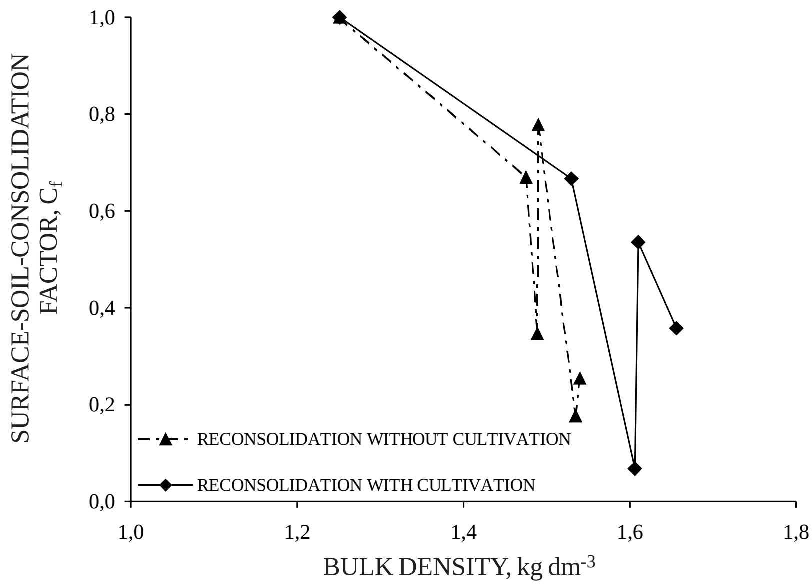

Figure 9. Surface-soil-consolidation factor as a function of bulk density in the reconsolidating soil treatments.

CONCLUSIONS

1. Regardless of cultivation, soil reconsolidation after tillage discontinuity was faster than expected.

2. Soil reconsolidation was higher under cultivation than under no cultivation.

3. Regardless of cultivation, soil reconsolidation after tillage discontinuity greatly decreased soil loss rates by rainfall erosion, whereas runoff rates were not affected and stayed high throughout the whole experimental period.

4. Regardless of cultivation, the surface-soil-consolidation factor, C_f, linked to the RUSLE's prior-land-use subfactor, PLU, in this study exhibited a much sharper exponential decay-rate of values than the ones reported in literature, showing that this erosion-prediction parameter is highly dependent on both soil type and particular soil surface conditions.

5. Curves for the C_f-factor presented in this paper are useful for predicting erosion with RUSLE, but their use is restricted to situations where both soil type and particular soil surface condition are similar to the ones studied in this research; anyway, more research into this subject is necessary.

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