Water erosion at different slope lengths

Erosão hídrica em diferentes comprimentos de declive

Erosión hídrica en diferentes longitudes de talud

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ABSTRACT
Water erosion is strongly influenced by slope length (Sl), among other factors. The objective of this work was to quantify the water losses (WL) and soil losses (SL) in different Sl, in a Haplic Distrudept. These losses were determined during one year in uncultivated and uncovered soil (BS) and then in soil cultivated in the form of no-tillage (NT) during three cropping cycles, under natural rainfall conditions. The treatments, with one repetition, consisted of the Sl of 11 m, 22 m, 33 m, and 44 m with 8% slope. In the 1st cycle, black oat (Avena strigosa) + forage radish (Raphanus sativus) + common vetch (Vicia sativa) was cultivated, in the 2nd cycle, single black bean (Phaseolus vulgaris) and in the 3rd cycle, single black oat. With the increase of Sl in the interval from 11 to 44 m, the WL and SL increased, and the SL increased with the increase of the WL. WL and SL were explained by Sl in 79% and 99%, respectively, and SL were explained in 76% by WL. The y = a + bx model was fitted to the data (p<0.01). soil crop for one year in the form of NT reduced WL by 30% and SL by 99% compared to the losses that occurred in the condition in which the soil was under BS. The WL varied less than the SL, in the range from 11 to 44 m of slope.

Keywords: soil erosion, soil crop, bare soil, soil loss, water loss.

RESUMO
A erosão hídrica é fortemente influenciada pelo comprimento de declive (Cd), dentre outros fatores. Com este trabalho objetivou-se quantificar as perdas de água (PA) e perdas de solo (PS) em diferentes Cd, num Cambissolo Húmico. Essas perdas foram determinadas durante um ano em solo sem cultivo e descoberto (SC) e na sequência em solo cultivado na forma de semeadura direta (SD) durante três ciclos de cultivo, em condição de chuva natural. Os tratamentos, com uma repetição, constituíram-se nos Cd de 11 m, 22 m, 33 m e 44 m com 8% de declividade. No 1º ciclo cultivou-se um consórcio aveia preta (Avena strigosa) + nabo forrageiro (Raphanus sativus) + ervilhaca comum (Vicia sativa), no 2º ciclo o feijão preto (Phaseolus vulgaris) solteiro e no 3º ciclo a aveia preta solteira. Com o aumento de Cd no intervalo de 11 a 44 m aumentaram as PA e PS, e as PS aumentaram com o aumento das PA. As PA e PS foram explicadas pelo Cd respectivamente em 79% e 99% e as PS foram explicadas em 76% pelas PA. O modelo y = a + bx foi ajustado aos dados (p<0,01). O cultivo do solo por um ano na forma de SD diminuiu as PA em 30% e as PS em 99% em comparação com as perdas ocorridas na condição em que o solo se encontrava sob SC. As PA variaram menos que as PS, no intervalo de 11 a 44 m de declive.

Palavras-chave: erosão do solo, cultivado do solo, solo descoberto, perda solo, perda água.

RESUMEN
La erosión hídrica está fuertemente influenciada por la longitud de la pendiente (SI), entre otros factores. El objetivo de este trabajo fue cuantificar las pérdidas de agua (WL) y de suelo (SL) en diferentes SI, en un Haplic Distrudept. Estas pérdidas se determinaron durante un año en suelo no cultivado y descubierto (BS) y luego en suelo cultivado en forma de siembra directa (NT)
durante tres ciclos de cultivo, en condiciones naturales de precipitación. Los tratamientos, con una repetición, consistieron en SI de 11 m, 22 m, 33 m y 44 m con pendiente del 8%. En el 1er ciclo, se cultivó avena negra (Avena strigosa) + rábano forrajero (Raphanus sativus) + veza común (Vicia sativa), en el 2º ciclo, solo judía negra (Phaseolus vulgaris) y en el 3er ciclo, solo avena negra. Con el aumento de SI en el intervalo de 11 a 44 m, aumentaron el WL y el SL, y el SL aumentó con el aumento del WL. El WL y el SL se explicaron por SI en un 79% y un 99%, respectivamente, y el SL se explicó en un 76% por WL. El modelo y = a + bx se ajustó a los datos (p<0,01). El cultivo del suelo durante un año en forma de NT redujo el WL en un 30% y el SL en un 99% en comparación con las pérdidas que se produjeron en la condición en la que el suelo estaba bajo BS. El WL varió menos que el SL, en el rango de 11 a 44 m de pendiente.

**Palabras clave:** erosión del suelo, cultivo del suelo, suelo desnudo, pérdida de suelo, pérdida de agua.

1 INTRODUCTION

The water erosion in agricultural areas is one of the main environmental problems even in no-tillage conditions, responsible for soil degradation caused by crop in relief inadequate condition. Among the factors that affect water erosion, soil management is the most important, especially due to the effect of soil cover by cultural residues and the absence of soil preparation (Carvalho et al., 2009; Schick et al., 2017). The relief also is of considerable importance, specially the slope length (Foster et al., 1982). The increase in slope length is reflected in the increase in volume and velocity of the runoff (Bagarello and Ferro, 2010; Barbosa et al., 2012; Bagio et al., 2017).

The sustainment of no-tillage (NT) depends on the soil minimum revolvement and the maintenance of soil surface cover with cultural residues. Soil coverage by crop residues dissipates rain energy, which is the main agent that disintegrates soil without surface cover (Foster et al., 1982). It does not have the same efficiency in the dissipation of runoff energy in the NT (Bertol et al., 1997) especially in conditions of long slope lengths (Bertol et al., 1997; Barbosa et al., 2012). These authors verified significant increases in soil loss (SL) over long slope lengths compared to short slopes under simulated rainfall conditions. However, in the condition of sufficient dry mass (DM) of residues on the soil, the SL are expressively lower in NT than in conventional tillage (CT) and, especially, lower than the SL in uncultivated and bare soil (BS) (Rodrigues, 2017).
Water losses (WL) in general are less influenced than SL, regardless of the type of soil management (Bagarello and Ferro, 2010; Silva and De Maria, 2011). This happens because the soil has a low limit of water infiltration, depending on its characteristics and a high limit of SL by erosion (Pinheiro et al., 2009), according with Wischmeier and Smith (1978). This occurs especially in erosion events caused by high volume rains that soak the soil.

The influence of the NT on the control of the SL and WL by erosion depends on the length of the slope, among other factors, as verified by Foster et al. (1982), Bertol et al. (1997) and Barbosa et al. (2012). With the increasing length, the water has an increased chance of infiltrating into the soil (Bertol et al., 2015). As the slope length increases, cultural residues retain mainly the coarse sediments in the NT. Thus, the size and the load of suspended sediments in the runoff decrease with the increase in surface residues. Therefore, the increase of the SL with the increase of slope length in NT does not follow the potency model proposed by Wischmeier and Smith (1978) for the CT.

The WL were smaller at slope lengths up to 75 m than at shorter lengths and no sediment yield was detected at the various lengths in NT in which the slope was 3%, in Oxisol soil under natural rainfall conditions (Silva and De Maria, 2011). Also in natural rainfall condition, but in BS, the SL did not vary with the length of the slope between 0.25 and 44 m with a slope of 3% in Italia (Bagarello and Ferro, 2010). But, in one year at 8% slope, the SL increased in the range of lengths between 11 and 44 m (Bagio et al., 2017).

The advance of the knowledge frontier in Brazil on this subject depends, therefore, on the quantification of the SL and WL in several lengths of slope wit intermediate slope (8%), in condition of NT in rotation crop system. This will set the critical slope length (Foster et al., 1982) as to the ability of the NT to control erosion under specific conditions. This knowledge should substantiate the planning of conservationist practices in the south of Brazil in NT, depending on the SL and WL occurring at a certain length of slope in natural rainfall condition.

For this study, the following hypotheses were formulated: the SL increase with increasing slope length and decrease from the condition of bare soil to that of soil cultivated in NT; and the SL vary less than the WL, both between slope lengths and between crops. The objective of this research was to quantify the water erosion in a slope with slope lengths of 11 m, 22 m, 33 m and 44 m, in soil cultivated in NT condition, and to compare with the erosion that occurred in the soil without cultivation in a previous period. Specifically, it was aimed to quantify the SL and WL in
the four slope lengths, to relate the SL and WL to the slope length, and to relate the SL with the EI30 index of rainfall and with the WL, and these with the height of the rains. The SL and WL data obtained in this research in soil condition with cultivation were compared to data obtained a year earlier by Bagio et al. (2017) in bare and uncultivated soil condition, with the objective to establish a timeline and verify the influence of soil cultivation on water erosion.

2 MATERIAL AND METHODS

The research was carried out in an experiment that had been installed by Bagio et al. (2017), located in the Plateau South Catarinense inserted in the biome Mata Atlântica, between 27° 49' S and 50° 20' W, at 923 m of altitude, in natural rainfall condition. The climate is of type Cfb according to the classification of Köeppen (Alvares et al., 2013) with average annual rainfall of 1,533 mm and average annual erosivity of 5,033 MJ mm ha⁻¹ h⁻¹ (Schick et al., 2014a). The soil is a Inceptisol, classified according to Santos et al. (2018), or, Haplic Distrudept according to Soil Survey Staff (2014), with clayey texture, whose erodibility is of 0.0175 t ha h ha⁻¹ MJ⁻¹ mm⁻¹ (Schick et al., 2014b). In the 0-0.02 m layer, soil present soil density of 1.2 kg dm⁻³, macroporosity of 20%, total porosity of 60%, phosphorus of 25.3 mg dm⁻³, potassium of 141 mg dm⁻³ and total organic C of 2.4%. The soil management history in the experiment up to the moment of starting the present research, are in Bagio et al. (2017).

The plot had dimensions of 2 m of width and different lengths of slope, depending on the treatment, installed with the length in the direction of the slope. The plot was delimited by 2 x 0.2 m galvanized sheets at the sides and at the upper end of the slope and, at its lower end, it was delimited by a gutter to receive the eroded material from within the plot; the gutter was connected by a pipe to a sedimentation tank situated 6 m below with sufficient capacity to store the runoff of each plot, as described in Bagio et al. (2017).

The four treatments, in two field replicates each, consisted of slope length, as follows. T1: 11 m (22 m²) with mean slope of 0.084 m m⁻¹. T2: 22 m (44 m²) with mean slope of 0.082 m m⁻¹. T3: 33 m (66 m²) with mean slope of 0.077 m m⁻¹. T4: 44 m (88 m²) with mean slope of 0.076 m m⁻¹. In the first year, the soil was kept uncultivated and uncovered (Figure 1), and in this condition, water and soil losses from water erosion were determined by Bagio (2016). In the second year the soil was cultivated in the NT condition, as follows (Figure 2).
In the second year the soil was cultivated in the NT condition, as follows (Figure 2). Intercropping of oats (*Avena strigosa*) + forage turnip (*Raphanus sativus*) + common vetch (*Vicia sativa*) in the 1st crop, single beans (*Phaseolus vulgaris*) in the 2nd crop, and oats in the third crop. In the first crop, the sowing of the intercropping was carried out, with 120 kg ha$^{-1}$ of oat seeds + 40 kg ha$^{-1}$ of vetch + 5 kg ha$^{-1}$ of turnip, manually by broadcast. On the same day 2 t ha$^{-1}$ of limestone + 300 kg ha$^{-1}$ of fertilizer in the formulation 5-3-15 of N + P$_2$O$_5$ + K$_2$O were applied. Everything was manually incorporated with hoe, in the depth of 5 cm. At the time of oat grain filling the plants were cut with manual brushcutter and the crop residue evenly distributed over the soil.

In the second crop, the beans were sown with a manual seeder, 15 seeds per meter distributed in holes, a spacing of 0.45 m between rows and 0.2 m between holes, four lines per plot in the direction of the slope (greater length). The fertilization was done by broadcast with 200 kg ha$^{-1}$ of triple superphosphate + 145 kg ha$^{-1}$ of potassium chloride, and, before flowering, 68 kg ha$^{-1}$ of urea were applied. At the end the manual harvesting was carried out and the cultural residues were distributed evenly over the soil.

In the third crop, the oats were sown. A hundred and fifty kg ha$^{-1}$ of seeds were manually distributed by broadcast and incorporated using a hoe, without fertilization. The oats were cut
and the crop residue evenly distributed over the soil. At the end of each of the three crops the soil cover was 100%.

Figure 2. Aerial view of the experimental area, with detail for the spatial distribution of the plots with the respective treatments in no-tillage crop system and general view of the for-sedimentation tank for runoff collection (b).

The dry mass (DM) of the aerial part of the crops was determined in the final phase of the cycle of the intercropping and the oats, and after harvest in the case of the beans. The mass was collected at a point every 11 m of distance in each plot, that is, at one point in the length of 11 m, in two points in the 22 m, three points in the 33 m and four points in the length of 44 m, calculating the average whenever the number of points was greater than one. The gathering was done using a square of 0.36 m² (0.6 m x 0.6 m). The mass was weighed, dried at 45°C until constant mass was obtained and again weighed.

The procedure of volume measurement and collection of samples of the runoff from the storage and processing boxes of samples in the laboratory, for further determination of SL and WL by erosion, in each erosive rainfall was carried out. From the samples of flash flood, the sediment concentration in the flash flood was determined and the mass of the sediments in it was
calculated. The product of the flash flood height in the boxes, multiplied by their area resulted in the flash flood volume and, with this, the SL and WL were calculated. These procedures were performed as described in Bagio et al. (2017). The SL and WL data obtained in this research in soil condition with cultivation were compared to data obtained a year earlier (Bagio et al., 2017) in uncultivated soil condition and bare soil (BS).

During the research with soil crop there were 49 erosive rains. Rainfall distribution was recorded using pluviograms (model IH-01-01), with a recording amplitude of 10 mm of precipitation and increment of 0.2 mm, recording time of 24 hours and unit of 10 minutes, activated by a mechanical pluviograph installed 600 m from the experimental area. The rainfall erosivity was calculated according to Wischmeier and Smith (1978). The EI$_{30}$ index resulted from the product of the total kinetic energy of the rain (E) by its maximum intensity in 30 minutes (I$_{30}$). The SL were adjusted to the slope of 0.09 m m$^{-1}$, considered standard for the Universal Soil Loss Equation (USLE), using a S-factor procedure according to Wischmeier and Smith (1978), due to the slope variation of each plot in relation to the standard.

The SL and WL are respectively related to EI$_{30}$ and RH, with the objective of decreasing the influence of soil water content on water erosion. Thus, the SL values were divided by the EI$_{30}$ values and the WL values were divided by the RH of the rains. With this procedure, high erosivity rains resulted in relatively high soil loss fraction and high-volume rains resulted in relatively high-water loss fraction. The inverse effect was verified in cases of occurrence of low erosivity and low volume rains.

The plots were distributed in a completely randomized design, with two plots per treatment. Data from SL and WL were submitted to the normality test, followed by analysis of variance and, when the means differed, were compared by the Tuckey test ($p\leq0.05$) with the statistical program ASSISTAT 7.7 Beta (Silva and Azevedo, 2016). The $y = a + bx$ model was fitted to the relationship between SL data and EI$_{30}$ rainfall index data, and between WL and RH data. This model was also adjusted to the relationship between the SL/EI$_{30}$ ratio and the WL/RH ratio.
RESULTS AND DISCUSSION

The dry mass (DM) of the aerial part of the cropped plants was high in the total of the three crop cycles (intercropping of oat + turnip + vetch, beans and oats), whose yield, 17.9 t ha\(^{-1}\) in the average of treatments (Table 1). In the intercropping and in the oats the DM was 7 t ha\(^{-1}\) in each crop, while in the beans it was 3.8 t ha\(^{-1}\), in the average of the treatments (data not shown). The total DM in these crops was higher than that normally found in agricultural areas, influenced by the high production of oats and crotalaria. The DM of oats was superior to that found by Giacomini et al. (2003), which was 4.6 t ha\(^{-1}\). The residues were kept on the soil surface and provided 100% coverage in all treatments, since the 1st crop.

Table 1. Dry mass of aerial part of the crops in with crop soil period one year during current research, in different slope length treatments (average of the replicates)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Slope length</th>
<th>Dry mass t ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1º crop (consortium of the oat + turnip + vetch) + 2º crop (beans) + 3º crop (oat)</td>
<td>m</td>
<td>17.9ab</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>16.8b</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>18.5a</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>18.4a</td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>17.9</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>17.9</td>
</tr>
<tr>
<td>CV (%)</td>
<td></td>
<td>2.2</td>
</tr>
</tbody>
</table>

Averages followed by the same lowercase letters in the column do not differ from one another by the t test (p<0.05). CV: coefficient of variation. Source: Armbrust Rodrigues (2017).

During the research period with soil crop, the total rainfall height (RH) was 1,782 mm in 49 rainfall events (Table 2), with EI\(_{30}\) of 5,503 MJ mm ha\(^{-1}\) h\(^{-1}\) year\(^{-1}\) (Table 3). In the work of Bagio et al. (2017) performed a year earlier, in bare soil (BS) without soil crop, the RH was 1,349 mm in 41 rainfal events, with EI\(_{30}\) of 6,067 MJ mm ha\(^{-1}\) h\(^{-1}\) year\(^{-1}\) at this same place. Thus, during the period this research, the number of erosive rains was 20% higher than that verified by Bagio (2016), the RH was 32% higher and the EI\(_{30}\) 9% lower.

The values of water loss (WL) in this study decreased 44% in relation to the research of Bagio et al. (2017), in the average of the treatments, despite the RH having increased by 32% (Table 2). The fact that the area was kept uncultivated and BS in the previous research and was...
cultivated in NT condition in the present research, justifies this reduction in WL, despite the fact that the RH higher than in the studies of the aforementioned authors. In the NT, the WL normally are reduced by 30%, on average, compared to the BS, according to data obtained by Schick et al. (2017).

Table 2. Rainfall and water losses in bare soil without crop period one year during (Bagio et al., 2017), and in with crop soil period one year during current research, in different slope length treatments (average of the replicates)

<table>
<thead>
<tr>
<th>Slope length</th>
<th>Without crop</th>
<th>With crop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall</td>
<td>Water loss</td>
<td>Rainfall</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>11</td>
<td>392bA</td>
<td>168cB</td>
<td>560</td>
</tr>
<tr>
<td>22</td>
<td>410bA</td>
<td>218bB</td>
<td>628</td>
</tr>
<tr>
<td>33</td>
<td>1,349</td>
<td>1,782</td>
<td>3,130</td>
</tr>
<tr>
<td>44</td>
<td>568aA</td>
<td>328aB</td>
<td>896</td>
</tr>
<tr>
<td>Average</td>
<td>484</td>
<td>270</td>
<td>754</td>
</tr>
<tr>
<td>CV (%)</td>
<td>32</td>
<td>2.3</td>
<td></td>
</tr>
</tbody>
</table>

Averages followed by the same lowercase letters in the column do not differ from one another by the t test (p<0.05). SD: standard deviation. CV: coefficient of variation.

Table 3. Rainfall erosivity (EI30) and soil losses in bare soil without crop period one year during (Bagio et al., 2017), and in with crop soil period one year during current research, in different slope length treatments (average of the replicates)

<table>
<thead>
<tr>
<th>Slope length</th>
<th>Without crop</th>
<th>With crop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EI30 Soil loss</td>
<td>EI30 Soil loss</td>
<td>EI30 Soil loss</td>
</tr>
<tr>
<td></td>
<td>MJ mm ha⁻¹ h⁻¹ Kg</td>
<td>MJ mm ha⁻¹ h⁻¹ Kg</td>
<td>MJ mm ha⁻¹ h⁻¹ Kg</td>
</tr>
<tr>
<td>11</td>
<td>360d</td>
<td>3.7c</td>
<td>363.7</td>
</tr>
<tr>
<td>22</td>
<td>820bc</td>
<td>4.7c</td>
<td>824.7</td>
</tr>
<tr>
<td>33</td>
<td>6,066</td>
<td>5,503</td>
<td>11,569</td>
</tr>
<tr>
<td>44</td>
<td>1,930a</td>
<td>12.5a</td>
<td>1,942.5</td>
</tr>
<tr>
<td>Average</td>
<td>1,108</td>
<td>7.0</td>
<td>1,114.5</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

Averages followed by the same lowercase letters in the column do not differ from one another by the t test (p<0.05). SD: standard deviation. CV: coefficient of variation.

The WL increased by 1.6 and 2.1 times in the average slope lengths of 44 m and 33 mm, in relation respectively to the 22 m and 11 m lengths, in crop soil period (Table 2). In the without crop period, this difference was respectively 1.4 and 1.5 times. The increase in slope length leads to increased runoff volume and velocity (Foster et al., 1982), regardless of the form of soil management (Schick et al., 2017).
The WL of 218 mm year\(^{-1}\) (Table 2) in the slope length of 22 m of present study were 79% higher than the WL of 122 mm year\(^{-1}\) verified by Schick \textit{et al.} (2017) in this same soil also in NT condition with the same slope length. This difference occurred first because of the greater RH occurred in the present study in relation to the work of those authors. Second, because this research was conducted for only one year, while in those authors' research it was conducted for 24 years. Third, in the present research the plots presented a width of 2 m (44 m\(^2\)) while, in the research of Schick \textit{et al.} (2017) they were 3.5 m wide (77 m\(^2\)). The time of conduction of a research like this influences the physical stabilization of the soil and the soil water infiltration, especially in this type of soil management (NT), according to Andrade \textit{et al.} (2010).

The soil loss (SL) values were low (Table 3) compared to those obtained in the previous period by Bagio \textit{et al.} (2017). This was due to the change in soil management that went from uncultivated and BS to cultivated soil in the NT condition. The SL in this study decreased 99% in relation to the research of Bagio \textit{et al.} (2017), in the average of the treatments, despite the EI\(_30\) having decreased only by 9%. This expressive difference confirm the efficacy of NT in decreasing the SL in comparison to the absence of cultivation, as verified by Schick \textit{et al.} (2017). In absolute values, the total SL involving the two researches were low, less than 2 tons, explained mainly by the low losses occurred in the NT phase. Partly, this occurred because the plot width was only 2 m. This plots resulted in areas of 22 m\(^2\), 44 m\(^2\), 66 m\(^2\) and 88 m\(^2\), respectively for 11 m, 22 m, 33 m and 44 m slope length treatments. This aspect should be considered when analyzing these data, since, under agricultural conditions the erosion contribution area is substantially larger.

The SL increased by 74% in the slope length of 44 mm to related the slope length 33 m, and 71% of slope length 33 m related to average of the slope length 22 and 11 m, in with crop soil period (Table 3). In BS without crop period, this difference was respectively 46% and 124%. The increase in slope length leads to increased runoff volume and velocity, according to Foster \textit{et al.} (1982), regardless of the form of soil management (Schick \textit{et al.}, 2017).

There was a tendency to accelerate the rate of increase in soil erosion with the increase in slope length between 11 m and 44 m, both in the absence and in the presence of soil cultivation (Table 4). The reason between WL and RH (WL/RH) increased with the increase of slope length in BS treatments, and in the three cultivation cycles with some exceptions. In BS, the increase in the WR/RH reason was 45% between 11 m and 44 m of slope length. In cultivated soil this
increase was 2.1 times in the first cultivation cycle, 10% in the second cycle and 89% in the third cultivation. This increase was 88% in the average of the cultivation cycles. The increase of the WL with the increase of slope length is normal, due to the normal accumulation of water in longer slopes compared to the shorter ones (Barbosa et al., 2012; Bagio et al., 2017), regardless of RH and of soil management. The positive effect of cultivation in reducing WL, after a period in which the soil remained in bare fallow, is notorious. In this period, the permanence of NT over time as a form of soil management provides favorable conditions to increase the infiltration of water in the soil and decrease the surface runoff (Schick et al., 2017).

Table 4. Rain height (RH), water losses (WL), WL/RH ration values, rainfall erosivity (EI30), soil losses (SL), and SL/EI30 ration values, in bare soil without crop period one year during (Bagio et al., 2017), and in with crop soil period current research one year during, in different slope length treatments (Sle) (average of the replicates)

<table>
<thead>
<tr>
<th>Management</th>
<th>Sle</th>
<th>RH</th>
<th>WL</th>
<th>WL/RH</th>
<th>EI30</th>
<th>SL</th>
<th>SL/EI30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without crop period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>392</td>
<td>0.291</td>
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The increase of slope length resulted in an increase in the reason between SL and EI$_{30}$ of the rainfall (SL/R) in BS, and in the three cultivation cycles with exceptions, whose values were higher in the 1st crop compared to the two final ones (Table 4). The increase in SL/EI$_{30}$ reason with increasing slope length is normal due to the increase in volume and velocity of the runoff on longer slopes compared to the shorter slopes (Foster et al., 1982; Barbosa et al., 2012; Bagio et al., 2017). In BS, the increase in the SL/EI$_{30}$ reason was 5.4 times between 11 m and 44 m of slope length. In cultivated soil this increase was 3.7 times in the first cultivation cycle, 67% in the second cycle and 4.7 times in the third cultivation. This increase was 3.6 times in the average of the cultivation cycles. The positive effect of cultivation in reducing water erosion, after a period in which the soil remained in bare fallow, is notorious, especially in reducing soil losses. In this period, the permanence of the NT over time as a form of soil management provides favorable surface conditions to protect the soil from the erosive energy of the rainfall and of the runoff, thus reducing erosion (Silva and De Maria, 2011; Schick et al., 2017).

The reason of the SL/R means the SL occurrence per unit of rainfall erosivity. In the case of bre soil this relation is equivalent to the soil erodibility (K factor of the Universal Soil Loss Equation - USLE), according to Wischmeier e Smith (1978). The K factor of the Haplic Distrudept studied in the research is 0.0175 t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$ (Schick et al., 2014b).

The SL of 820 kg (Table 4) occurred in 22 m slope length (44 m$^2$) treatment of the BS (Bagio et al., 2017). This means that the SL/EI$_{30}$ reason was 0.13518 t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$. This SL is equivalent to 186.4 t ha$^{-1}$. This means that K factor of 0.0307 t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$, and resulting in a 75% increase of the K factor compared to that determined by Schick et al. (2014b) in the BS. In soil crop, the SL of the 1.57 kg in the average of 22 m slope length three treatments. This means that the SL/EI$_{30}$ reason was 0.00063 t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$, and resulting in a 96% decrease of the K factor compared to that determined by Schick et al. (2014b). This is considered as an important modification in the resistance of this Haplic Distrudept to erosion determined by soil cultivate in the NT form in relation to the condition in which the soil is kept uncultivated and uncovered.

The slope length significantly influenced the WL/RH reason ($p <0.1$), in an lineal and positive relation way (Figure 3). Was observed that with the increase from 11 m to 44 m in the slope length the WL/RH reason increased 65%, agreeing with Bagio et al. (2017). This differed from what was found by Bagarello and Ferro (2010) in slope length between 0.15 m and 44 m,
and also by Silva and De Maria (2011) in length between 25 m and 75 m. Thus, the generally positive energetic effect caused by the relief effect that accumulates a water depth on the soil surface as the slope length increases was confirmed in this work. This observation reinforces the need to adopt conservationist practices of a mechanical character to dissipate the energy of the runoff, as recommended by Foster et al. (1982). According to these authors, the increase in volume and velocity of the runoff along the slope can remove the cultural residues and cause increased water erosion in NT condition.

Figure 3. Relationship between the ration of water loss by runoff (WL) and rainfall height (RH) and the slope length (Sl), considering the average values of uncultivated soil and of the three cultivation cycles and of replicates.

The lineal model adjusted significantly ($P<0.1$) to the SL/EI$_{30}$ reason and slope length, in an lineal and positive relation way (Figure 4). The relationship between SL and EI$_{30}$ index was almost perfect, meaning that the EI$_{30}$ explained the SL almost completely. This fact is unusual in the case of the NT management system. In this case, the relationship between SL and EI$_{30}$ is normally low because the soil cover by crop residues completely dissipates the erosive energy of
rain. It also partially dissipates the erosive energy of the runoff, according to Foster et al. (1982). Was observed that with the increase from 11 m to 44 m in the slope length the SL/EI_{30} reason increased 5.3 times, agreeing with Bagio et al. (2017) and Schick et al. (2017). According to these authors, EI_{30} normally explains the SL in a significant way. The erosive energy of the runoff, determined by the shear stress of the runoff, can erode the soil in case of BS and NT soil cultivate (Foster et al., 1982).

Figure 4. Relationship between the ratio of soil loss (SL) by erosion and erosivity index (EI_{30}) and the slope length (Sl), considering the average values of uncultivated soil and of the three cultivation cycle.

![Graph showing the relationship between soil loss (SL) and slope length (Sl)](image)

The WL explained 76% of the SL through the relationship between the fractions resulting from the WL/RH and SL/EI_{30} reason (Figure 5). Normally the linear model y=a+bx adjusts to these two variables (Silva and De Maria, 2011; Barbosa et al., 2012; Schick et al., 2014b; Dechen et al., 2015). In the research condition where the soil was managed in the form of BS initiality and in the form NT afterning, the SL increased more than the WL. This occurred especially in
longer slopes where the energy of the runoff increased exponentially, according to Foster et al. (1982). Even so, the linear model fit the data.

Figure 5. Relationship between the ratio of soil loss (SL) by erosion and erosivity index (EI30) and the ratio of water loss by runoff (WL) and rainfall height (RH), considering the average values of uncultivated soil and of the three cultivation cycles and of replicates.

![Graph showing the relationship between soil loss and water loss](image)

\[
\frac{SL}{EI_{30}} = -0.0451 + 0.4906 \frac{WL}{RH}
\]

\[R^2 = 0.755**\]


4 CONCLUSIONS

The increase in slope length has an important effect on the increase of water erosion in cultivated area in the form of no-tillage in the range between 11 m and 44 m. With the increase of slope length in the interval from 11 to 44 m, the water loss and soil loss increase, and the soil loss increase with the increase of the water loss. Water loss and soil loss were explained by slope length in 79% and 99%, respectively, and soil loss were explained in 76% by water loss. The y
a + bx model was fitted to the data (p<0.01). Soil crop for one year in the form of no-tillage reduced water loss by 30% and soil loss by 99% compared to the losses that occurred in the condition in which the soil was under bared soil. The water loss varied less than the soil loss, in the range from 11 to 44 m of slope.

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REFERENCES


