Research Article

Influence of native field management on soil, water erosion and nutrient losses[1]

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ABSTRACT

The native field area in southern Brazil has been reduced due to cultivation, and part of the remainder is traditionally burned and may increase water erosion and soil degradation. In this research, the soil chemical composition and water erosion, under natural rainfall, were evaluated in an Inceptisol, in the south of the Santa Catarina state plateau. The treatments consisted of native field, field mowed and burned once a year, and field cultivated under no-tillage conditions, in plots of 3.5 x 22.1 m and average slope of 10 %. The water erosion was evaluated between November 2016 and September 2018, when there were 61 erosive rainfalls, totaling 1,997 mm and 8,472 MJ mm ha^{-1} h^{-1}. The soil losses were 82 kg ha^{-1} in the cultivated field, 55 kg ha^{-1} in the burned field and 24 kg ha^{-1} in the native field; and the water losses, in relation to the total rainfall, were 2.2 % in the native field and cultivated field and 1.2 % in the burned field.

KEYWORDS: Burned field, no-tillage, soil degradation.

RESUMO

Influência do manejo de campo nativo no solo, erosão hídrica e perdas de nutrientes

A área de campo nativo no Sul do Brasil foi reduzida devido ao cultivo, e parte do remanescente é tradicionalmente queimada, podendo aumentar a erosão hídrica e a degradação do solo. Avaliou-se a composição química do solo e a erosão hídrica, sob chuva natural, em um Cambissolo Húmico, no sul do planalto Catarinense. Os tratamentos consistiram de campo nativo, campo roçado e queimado uma vez ao ano e campo cultivado em condição de semeadura direta, em parcelas de 3,5 x 22,1 m e declividade média de 10 %. A erosão hídrica foi avaliada entre novembro de 2016 e setembro de 2018, quando ocorreram 61 chuvas erosivas, totalizando 1.997 mm e 8.472 MJ mm ha^{-1} h^{-1}. As perdas de solo foram de 82 kg ha^{-1} no campo cultivado, 55 kg ha^{-1} no campo queimado e 24 kg ha^{-1} no campo nativo; e as perdas de água, em relação ao total precipitado, foram de 2,2 % no campo nativo e campo cultivado e de 1,2 % no campo queimado.

PALAVRAS-CHAVE: Campo queimado, plantio direto, degradação do solo.

INTRODUCTION

The native field in southern Brazil contains about 2,200 plant species (Bencke 2009, Boldrini 2009). Burning in native field is practiced in this region to eliminate the remaining dry mass of winter and accelerate the vegetation regrowth in spring (Rheinheimer et al. 2003, Baretta et al. 2005, Boldo et al. 2006).

Fire reduces the soil surface cover, decreasing the dissipation of kinetic energy of raindrops, soil porosity and water infiltration (Hester et al. 1997, Baretta et al. 2005, Ferreira et al. 2008, Bertol et al. 2011, Souza et al. 2017). As a result, losses of soil, water and nutrients due to erosion increase. Burning also mineralizes organic matter (Schacht et al. 1996, Baretta et al. 2005) and NH_4, inorganic P, Na, Ca, Mg and K, making them transportable by runoff (Girardi-Deiro et al. 1994, Rheinheimer et al. 2003, Baretta et al. 2005). These losses impoverish the soil (Heringer et al. 2002, Jacques 2003, Boldo et al. 2006, Bertol et al. 2011) and can contaminate surface waters and other non-aquatic environments (Bertol et al. 2011).

The use of fire in native field is controversial, and studies of its impact on water erosion are scarce. In the last 30 years, the native field area has decreased by 25 % in southern Brazil (Overbeck et al. 2015), mainly due to annual cropping. Fire changes chemical, physical and biological conditions and degrades the soil (Schröder et al. 2002), reducing

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water infiltration and increasing water erosion (Bertol et al. 2004).

In this research, the hypothesis was that burning the field would result in an increase in the losses of soil, water and nutrients by water erosion, in relation to the field converted to agricultural cultivation with annual crops and to the field maintained without anthropic action. Thus, the study aimed to determine the effect of fire on native field, field with annual crops and field maintained without anthropic action, contents of Ca, Mg, P and K in the soil, as well as losses of these nutrients and of soil and water by water erosion, under conditions of natural rainfall.

MATERIAL AND METHODS

The research took place between November 2016 and September 2018, in an experiment that began in 2012, in the south of the highlands of the Santa Catarina state, Brazil (27º49'S, 50º20'W and altitude of 923 m). Therefore, the result of this research constituted a temporal cut of two years within the total period of six years of conduction of the experiment.

The climate in the area is Cfb, according to Köppen (Wrege et al. 2011), with annual rainfall of 1,533 mm and erosivity of 5,033 MJ mm ha^{-1} h^{-1} (Schick et al. 2014a). The soil is an Inceptisol (Santos et al. 2013), or Humic Distrudept (USDA 2014), whose erodibility is 0.0175 Mg ha h ha^{-1} MJ^{-1} mm^{-1} (Schick et al. 2014b), with 443 g kg^{-1} of clay, 402 g kg^{-1} of silt and 155 g kg^{-1} of sand, in the 0-20 cm layer. In this layer, the contents of P and K are, respectively, 2.52 and 115 mg dm^{-3}, those for Ca and Mg are 0.64 and 0.39 $cmol_c$ dm^{-3}, and that for CO is 43 %. The history of implantation and conduction of the experiment before this research can be found in Souza et al. (2017).

Plots of 3.5 x 22.1 m (77.35 m^2 $plot^{-1}$), with the greatest extension in the direction of the slope and average slope of 10 %, delimited on the sides and at the upper end by 2.0 x 0.2 m galvanized sheets, were used. At the lower end of each plot, there was a tank to receive runoff, which was connected by a PVC pipe to a first 750 L sedimentation tank, 6 m below. This tank was connected, through a "Geib" type runoff divider, to a second 750 L storage tank. The "Geib" divider allowed the passage of 1/9 of the runoff from the first to the second tank.

During the research, three treatments were evaluated, with two plots per treatment, distributed entirely at random: native field; burned field; and field converted to agricultural cultivation with annual crops under no-tillage condiction. The native field was permanently maintained without anthropic action and without mowing to control the vegetation since the installation of the experiment. For the burned field, burning has been carried out once a year, in August (the month in which burning takes place in the region), since 2012. The phytomass was cut and burned at two to three days later. In the cultivated field, the crop rotation consisted of soybean (*Glycine max*), turnip (*Raphanus sativus*), black bean (*Phaseolus vulgaris*) and common vetch (*Vicia sativa*) under no-tillage since the experiment was implemented. During the research, soybean was sown in November 2016 (350,000 seeds ha^{-1}), with a "saraquá" or "matraca" type manual seeder and spacing of 0.45 m among rows. The soybean was harvested in April 2017 and the turnip sown by broadcasting in May (30 kg ha^{-1} of seeds). The turnip was managed with manual mowing at the end of October and, in November, the bean was sown with a "saraquá" seeder (300,000 seeds ha^{-1}) and spacing of 0.45 m among rows. The bean was harvested manually in March 2018 and the vetch was sown manually by broadcasting (80 kg ha^{-1} of seeds) in April. The vetch was managed with manual mowing in early September 2018, ending the cultivation phase of the research. The soybean and bean were fertilized with N, P and K (CQFS-RS/SC 2016), and the turnip and vetch were not fertilized. The sequence of crops and managements carried out between 2012 and 2016 are described in Souza et al. (2017).

The soil chemical characterization was carried out after the end of the last agricultural crop (vetch), in September 2018. Soil samples were collected in layers of 0-2.5, 2.5-5, 5-10 and 10-20 cm, at just one point in the central position of each plot, to determine the phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents. The collections were carried out in only one point of each plot because, according to Souza et al. (1997), statistically, it is not necessary to collect soil samples at more than one point in an area of only 77.35 m^2.The samples were air-dried, ground and passed through a 2-mm sieve, in which the extractable P was determined by Mehlich 1 (molecular absorption spectrophotometer in the visible region at 882 *nm*), exchangeable K (flame photometer), Ca and exchangeable Mg (flame atomic absorption spectrophotometer), according to Tedesco et al. (1995).

The procedure for collecting water and sediments resulting from water erosion in the field, processing them in the laboratory and calculating soil and water losses for each erosive natural rainfall followed the methodology described by Bertol et al. (2019). Erosive rainfall was selected according to Wischmeier & Smith (1958). Erosion was evaluated in each erosive natural rainfall to quantify the P, K, Ca and Mg contents. Immediately after being collected, the water samples were filtered through a 0.45 μm cellulose ester membrane and preserved between -1 and -4 ºC until the moment of analysis. The P content was determined according to Murphy & Riley (1962) and the K, Ca and Mg in the water according to Tedesco et al. (1995).

The data, according to the completely randomized design, with two plots per treatment, were submitted to Anova, using the Assistat software (Silva & Azevedo 2018), and, subsequently, the Tukey test was performed ($p < 0.05$). In most situations, there was no statistical difference among the treatments, so the discussion was based on numerical values. In the case of nutrients in the soil and those lost by erosion, the levels were also compared according to the CQFS-RS/SC (2016).

RESULTS AND DISCUSSION

During the research, 61 erosive rainfalls occurred, with a total height of 1,997 mm and EI_{30} of 8,472 MJ mm ha^{-1} h^{-1} (Table 1). The total soil losses were 23.6 kg ha^{-1} for the native field treatment, 54.6 kg ha^{-1} for the burned field and 81.4 kg ha^{-1} for the cultivated field. The lower soil losses in the native field treatment were due to the total absence of anthropic action and permanent soil cover with vegetation. These two aspects were effective in reducing the water erosion, confirming the data obtained at other times in this experiment (Souza et al. 2017), due to the dissipation of the kinetic energy of raindrops and surface runoff (Cogo et al. 2003, Bertol et al. 2011). Bertol et al. (2011) observed lower soil losses in a native field treatment without fire, in relation to the burned field, under a simulated rainfall of 75 mm h^{-1} with duration of 3 hours, for an Oxisol. These authors observed that the burning in the burned field increased the soil losses 8.7 times, in relation to the absence of burning. In the present research, the soil losses were 2.3 times higher in the burned field than in the native field.

The low soil losses observed in the burned field treatment, when compared to the cultivated field (Table 1), is explained by the absence of high volume and intensity rainfall right after the burning, and by the fast regeneration of the vegetation. It is important to point out, however, that the occurrence of rainfall with high erosivity, after burning, can cause severe environmental damage. This is due to the reduction of surface coverage by burning, which can enhance erosion. A single rainfall can result in substantial losses of chemical elements adsorbed to sediments or solubilized in runoff water, contaminating erosion deposit environments (Bellilas & Rodà 1993, Shigaki et al. 2007).

The effect of vegetation burning depends on the intensity of the fire and edaphoclimatic factors. The duration of burning and the temperature of the fire vary greatly and depend on the humidity of the soil and air. Furthermore, the type of vegetation influences the severity of the burning. Thus, the soil losses resulting from erosion after an annual burning depends on the environmental conditions at the time of burning. The sediment production after burning can increase due to the sudden exposure of the soil to rainfall, water repellency or breakdown

Table 1. Height and erosivity of erosive rainfall and soil and water losses (average of two plots) after 23 months of the survey and 61 erosive rainfalls, in native, cultivated and burned field, in an Inceptisol.

Treatment	Height (mm)	Erosivity (R-EI_{30}) (MJ mm ha^{-1} h^{-1})	Soil loss (kg ha^{-1})	Water loss (% of rainfall)
Native field			23.6^{ns}	2.3^{ns}
Cultivated field	1,997	8,472	81.4	2.2
Burned field			54.6	1.2
CV (%)	106	164	62.4	34.4

^{ns} Not significant by the Tukey test ($p < 0.05$); CV: coefficient of variation.

of soil aggregates by heating (Johansen et al. 2001). In native field areas, normally the fire permanence time is short and the burning intensity is low, only reducing the soil cover. Water repellency and other soil changes are uncommon in native field subjected to fire (Johansen et al. 2001). This suggests that, in native field with a predominance of shrub species and in the forest, the soil is more vulnerable to these alterations than in the cultivated field without shrubs and burned annually (Bodí et al. 2012). Thus, the difference in the soil vulnerability between these ecosystems is reflected in water erosion (Bellilas & Rodà 1993, Shigaki et al. 2007, Bertol et al. 2011).

The higher soil losses in the cultivated field (Table 1) are explained, in part, by soil disturbance, although it is low due to the practice of no-tillage. Crop residues and shoots did not always completely and permanently cover the soil. It is necessary to point out that the soil losses in all the treatments were much lower than the annual limit of 9.6 Mg ha^{-1} defined by Bertol & Almeida (2000) for Inceptisol. In adittion, the soil losses in this research were lower than those observed by Souza et al. (2017), in this same experiment. The values observed by these authors were 35, 80 and 34 times greater than those of this research, respectively for cultivated field, burned field and native field. This reiterates the importance of conducting natural rainfall experiments for a long time, since seasonal climate changes, especially rainfall, and soil and vegetation conditions influence soil losses.

The water losses were also low in relation to the rainfall volume and did not differ among the treatments, being 2.3 % in the native field, 2.2 % in the cultivated field and 1.2 % in the burned field (Table 1). Burning in the native field did not increase water losses in relation to the absence of burning, contrary to the expectations. A decreased soil cover by burning reduces infiltration and water retention in the soil (Bertol et al. 2011). The fact that the burning did not increase the water losses in this research was due to the absence of heavy and intense rainfall in the days following the burning. The co-evolution of grassland vegetation with fire allows it to resist burning or rapidly regenerate (Overbeck et al. 2015). Due to this and the absence of a high volume and intensity of rainfall right after burning, erosion was low in the burned field, with no difference in relation to the other treatments. In other studies, burning increased water losses in relation to the absence of burning (Hester et al. 1997, Ferreira et al. 2008).

It is worth mentioning that low water losses were observed in the present study (Table 1). In a study carried out in the initial phase of this experiment, in which the cultivated field treatment was under turnip, bean, vetch and corn crops, Souza et al. (2017) observed water losses 5.9, 13.3 and 4.3 times higher than in this research, respectively for the cultivated field, burned field and native field treatments, under rainfall of 650 mm. It is necessary to consider that the contamination of surface waters, among other environments, is one of the biggest problems arising from the burning of pastures. This contamination is due to nutrients and organic carbon transported by runoff (Ferreira et al. 1997, Ferreira et al. 2008), highlighting the importance of controlling runoff.

The Ca, Mg, P and K contents in the soil at the end of the survey were generally high, with exceptions (Table 2), according to the CQFS-RS/SC (2016). For Ca, the variation was between 3.4 and 5.3 $cmol_c$ dm^{-3}, and, for Mg, between 1.7 and

Table 2. Calcium (Ca), magnesium (Mg), phosphorus (P) and potassium (K) contents in the layers of an Inceptisol, in native field, cultivated field and burned field, determined at the end of the survey, in September 2018 (average of two plots).

Treatment	Ca	Mg	P-Mehlich	K
	$cmol_c$ dm^{-3}		mg dm^{-3}	
0-2.5 cm layer				
Native field	5.3^{ns}	3.0^{ns}	38.9^{ns}	94.5^{ns}
Cultivated field	8.1	4.1	73.5	34.5
Burned field	4.8	2.6	35.4	106.5
CV (%)	14.5	42.8	33.7	30.1
2.5-5 cm layer				
Native field	4.0^{ns}	3.3^{ns}	44.2^{ns}	51.0 ab*
Cultivated field	5.8	3.8	22.7	36.0 b
Burned field	3.9	1.7	48.9	82.0 a
CV (%)	40.8	43.3	24.3	14.9
5-10 cm layer				
Native field	4.3^{ns}	3.4^{ns}	45.4^{ns}	44.0^{ns}
Cultivated field	4.2	4.5	18.3	28.5
Burned field	4.1	1.7	45.5	43.5
CV (%)	51.6	58.0	36.6	28.6
10-20 cm layer				
Native field	4.1^{ns}	4.0^{ns}	48.5 a	20.5^{ns}
Cultivated field	3.4	4.0	15.6 b	72.5
Burned field	4.3	1.7	49.3 a	27.0
CV (%)	56.4	48.9	15.3	96.3

* Averages followed by distinct lowercase letters in the column differ from each other by the Tukey test ($p < 0.05$); ^{ns} not significant; CV: coefficient of variation.

4.5 $cmol_c$ dm^{-3}. The P content varied between 15.6 and 73.5 mg dm^{-3} and that for K between 20.5 and 106.5 mg dm^{-3}, considering the treatments and soil layers. The Ca and Mg values were high, despite the fact that limestone was not applied to the soil. In this research, field burning did not increase the Ca and Mg contents in the soil surface layer, differing from what was found by Rheinheimer et al. (2003). The P and K contents were lower in the cultivated field than in the other treatments, only in the 10-20 cm layer for P and in the 2.5-5 cm layer for K. In the cultivated field, the soil management was no-tillage, with surface fertilization based on P and K once a year, and without tilling the soil. The accumulation of nutrients on the soil surface under no-tillage has already been observed by some authors (Bertol et al. 2007, Gebler et al. 2012). Possible environmental damage can be caused by the eutrophication of water sources due to erosion (Gebler et al. 2012), in addition to economic losses due to the financial value of nutrients (Araújo et al. 2016) and the lost water and soil itself.

The P contents in the native field and burned field were lower in the superficial layer than in the deeper layers (Table 2). In these treatments, there was little change in the P content in depth. In the soil layers, this element ranged from 44.2 to 48.5 mg dm^{-3} in the native field and from 45.5 to 49.3 mg dm^{-3} in the burned field. Differently from what was expected, the field burning during the period of this research did not cause an increase in P in the soil surface layer. In general, after burning, there is an increase in the soil P content (Serrasolsas & Khanna 1995). However, this effect tends to disappear in the medium term, due to the loss of nutrients through runoff (Knicker 2007). In the cultivated field treatment, the P content was high in the surface layer, what is justified by the annual addition of this element to the soil during the fertilization of summer crops.

The potassium (K) content in the soil was higher in the superficial layer than in the others (Table 2). Only in the 2.5-5 cm layer the K content differed statistically. In this layer, the element content was lower in the cultivated field than in the burned field. A similar result was obtained by Rheinheimer et al. (2003), in a study with samples collected immediately before and at 30, 60, 90, 150, 220 and 350 days after burning. The authors found that only the 0-2 cm layer was sensitive to the action of fire, in terms of nutrient content, in which burning increased the K, Ca and Mg contents and soil pH. However, the content of these elements returned to the original values from 90 days after burning.

The average content of soluble Ca in the runoff water (Figure 1a) was 9.7 mg L^{-1} in the native field, 13.4 mg L^{-1} in the cultivated field and 1.5 mg L^{-1} in the burned field, while those for Mg (Figure 1b) were 1.7, 2.8 and 2.2 mg L^{-1} in the respective treatments. For P, the mean values (Figure 1c) in the respective treatments were 0.71, 0.98 and 1.05 mg L^{-1}, and for K (Figure 1d) they were 11.4, 8.7 and 22.7 mg L^{-1} in the respective treatments.

In the burned field treatment, there was an increase of 1.2 times in the Ca content, in relation to the native field (Figure 1a), similarly to what was verified by Bellilas & Rodà (1993), who obtained an increase of 1.4 times in this type of relation. The authors attributed this result to the unburned plant material present on the soil surface, retention of nutrients in the soil and absorption by vegetation after burning, and also the weak rainfall shortly after burning, that did not remove nutrients by water erosion.

The cultivated field treatment showed a Ca content in the runoff water higher than those observed by Bertol et al. (2017), which were 4.9 mg L^{-1} in the autumn/winter and 5.3 mg L^{-1} in the spring/summer, in the same experiment. Wolschick (2018), however, observed a Ca content of 16.6 mg L^{-1} in the runoff water in this same soil, in another experiment under no-tillage. In general, the Ca content was relatively high in the runoff water in the cultivated field, with some values exceeding 40 mg L^{-1} (Figure 1a). Eventually, this could cause disturbances in erosion deposit environments, indicating the need to contain surface runoff in these areas.

The soluble Mg content in the runoff water was 1.3 times higher in the burned field than in the native field (Figure 1b). Bellilas & Rodà (1993) did not observe an increase in the Mg content in the runoff water from burned pasture, when compared to unburned one. In the cultivated field, the content of this element in the runoff water was similar to the value of 2.05 mg L^{-1} verified by Bertol et al. (2017) and that of 3.37 mg L^{-1} observed by Wolschick (2018), in treatments under no-tillage in the same soil. In most erosion events, the Mg content in the surface runoff water was low, with a range of up to 8 mg L^{-1}.

The field burning increased the soluble P content in the runoff water by 1.5 times, when compared to the native field (Figure 1c). Bertol

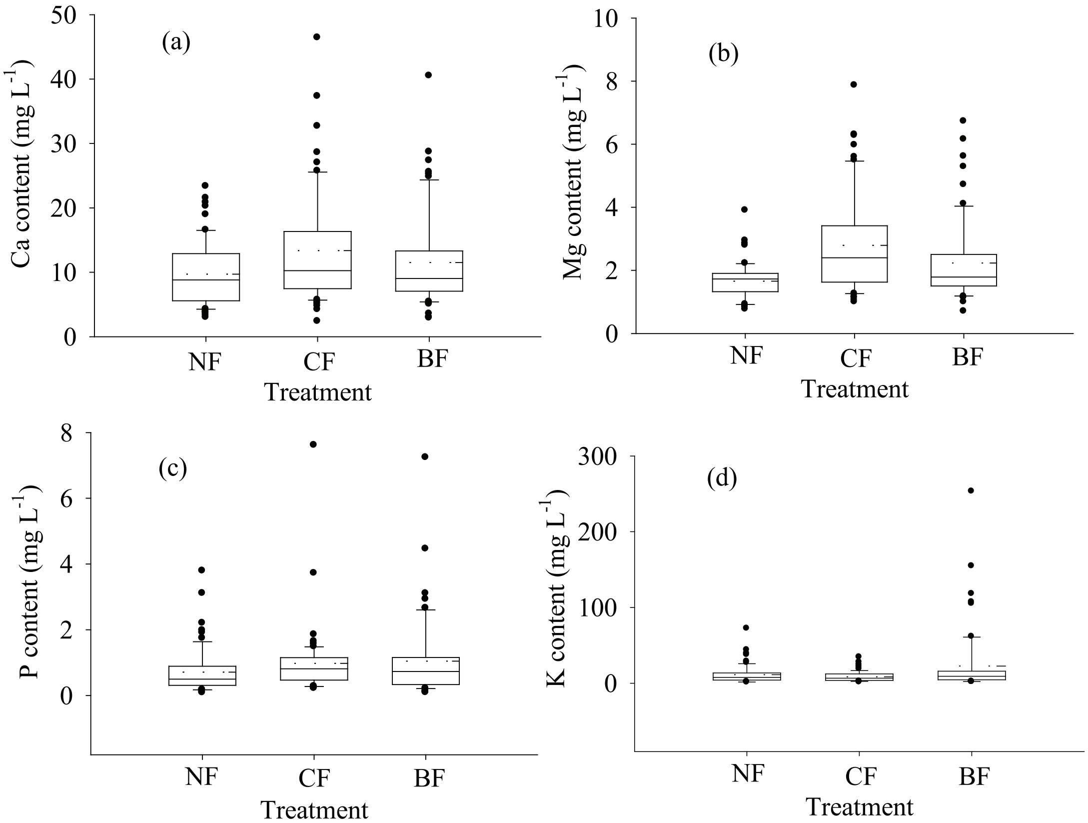

Figure 1. Calcium (Ca; a), magnesium (Mg; b), phosphorus (P; c) and potassium (K; d) contents in the runoff water. NF: native field; CF: cultivated field; BF: burned field, for an Inceptisol.

et al. (2011) observed a P content in the runoff water of 0.020 mg L^{-1} in a native field treatment and 0.640 mg L^{-1} in a burned field treatment, in a study carried out with simulated rain in an Oxisol, with a difference of 32 times between burned and native field. It is important to point out that these P losses reported by Bertol et al. (2011) occurred in a simulated rainfall of 75 mm h^{-1}, lasting three hours and performed immediately after burning. This time is the most critical for nutrient loss by erosion, because the nutrients are newly mineralized by fire and readily available for transport by surface runoff.

In the cultivated field, the P content in the runoff water (Figure 1c) was slightly lower than those of 1.30 mg L^{-1} obtained by Bertol et al. (2017) and 1.5 mg L^{-1} by Wolschick (2018), in a humic Inceptisol under no-tillage. However, the P content in the runoff water was high in the three treatments, and the continued loss of P with this content in the runoff water can cause environmental damage. Vollenweider (1971) suggested 0.01 mg L^{-1} as the critical level of water-soluble P. Thus, if the P content exceeds this value in the water, eutrophication may occur. Surface water eutrophication is one of the main problems caused by the high P content in surface runoff water (Shigaki et al. 2007, Gebler et al. 2012). In certain erosive events, the P content in runoff water reached values close to 8 mg L^{-1}. Based on this, it is important to monitor the transport of nutrients, especially P, and the quality of water sources, with a view to reduce P losses below the critical limit.

Field burning increased twice the K content in the runoff water, when compared to no burning (Figure 1d). Bellilas & Rodà (1993) observed an increase of 4.4 times in the K content in the runoff water in burned pasture, if compared to unburned one. Fire increases the supply of carbonates, basic cations and oxides in the soil (Bodí et al. 2012), and ash also increases the K content in the soil. The K content was 3.81 mg L^{-1} in the native field and 37.11 mg L^{-1} in the burned field (9.7-fold difference), in runoff water under simulated rainfall (Bertol et al. 2011). The authors observed that, in the first moments after the start of the runoff, most of the nutrients were transported, in relation to the whole, and, at the end of three hours of rainfall, the K content in the runoff water was still high (10 mg L^{-1}) in the burned field, evidencing the detrimental effect of field burning on the mineralization of K.

In the runoff water, the K contents were 13.9 and 38.1 mg L^{-1}, respectively in the researches by Bertol et al. (2017) and Wolschick (2018), in cultivation under no-tillage. These values are respectively 1.5 and 4.3 times greater than the K content in the cultivated field in this research (Figure 1d). High levels of K in the runoff water under no-tillage were also observed by Bertol et al. (2003), in an erosion experiment under simulated rainfall in a Haplic Nitosol, and by Barbosa et al. (2009), in an erosion experiment under simulated rainfall in an Inceptisol. K contents in the runoff water greater than 100 mg L^{-1} were observed in this research. High values of K in the runoff water are a reason for concern, especially from the point of view of soil impoverishment at the site of erosion and contamination of environments outside that site.

CONCLUSIONS

1. Soil and water losses due to water erosion under natural rain, and calcium, magnesium, phosphorus and potassium contents in the soil and surface runoff water were not influenced by the management form of the native field, rejecting the research hypothesis that the burning of the field would result in increased losses of soil, water and nutrients by water erosion;
2. The burned field, field with agricultural cultivation in the form of no-tillage and field maintained without anthropic action did not differ among themselves, in terms of soil, water and nutrient losses.

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