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Article

Oat Straw Mulching Reduces Interril Erosion and Nutrient Losses Caused by Runoff in a Newly Planted Peach Orchard

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Abstract: Soil erosion is one of the major problems in the agricultural areas in the world, and straw mulching is a conservation practice that may reduce soil runoff. How much straw mulching is necessary to reduce soil runoff? The objectives of this study were to quantify and characterize the runoff under different levels of oat straw mulching, as well as to analyze the cost of soil erosion. An experiment was performed in a site with the soil recently tilled for peach orchard implementation. In the ridges in the row of the peach orchard, plots were placed in order to quantify soil and nutrient losses by surface runoff due to interril erosion on the dates 23 August 2015 and 13 March 2016, considering the treatments were composed of different amounts of oat straw mulching (0, 1, 2, 4 and 8 Mg ha^{-1}). The results showed that the use of oat straw mulching decreased soil runoff, especially the doses $\geq$2 Mg ha^{-1}, and the cost to replace the available nutrients P, K, Ca and Mg via mineral fertilizer varies from US$ 75.4 (no mulching) to US$ 2.70 per hectare (8 Mg ha^{-1} oat straw mulching).

Keywords: water erosion; sediment; soil conservation; crop residue; vegetative practices of soil conservation; cost of erosion

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1. Introduction

Soil is the foundation for terrestrial life and the sustainability of humankind. However, this natural resource has become increasingly threatened by excessive tillage, limited crop rotations, poor irrigation management, and contaminants [1]. According to FAO [2], one-third of the world's soil resources have been degraded and the remaining topsoil could become unproductive within 60 years if current rates of degradation continue. Agriculture practices may harm the soil due to compaction, acidification, loss of soil organic matter, and soil erosion. Those changes degrade soil physical properties, increase nutrient loss, and reshape fields, ultimately impacting productivity and environmental outcomes [1].

Soil erosion from agricultural fields is estimated to be currently 10 to 20 times (no-tillage) to more than 100 times (conventional tillage) higher than the soil formation rate, and the current levels of global warming are associated with moderate risks from increased soil erosion [3]. Using simulations carried out from 1901 to 1990, soil erosion at the global scale has been increased during the last century, pointing out Brazil as the region with the largest increase, with human activity being the greatest responsible determinant [4]. Yang et al. [4] highlight that in the 2090s, climate change, mainly induced by rainfall increases, is projected to increase soil erosion by around 9% globally, while land use would change about 5%. Higher global temperatures, as impact of climate changes, intensify the hydrological cycle, resulting in more intense rainfall, which is an important driver of soil erosion [5].

Peach orchard production is of great socio-economic importance in southern Brazil, mainly within the Rio Grande do Sul (RS) State, which is the greatest producer in Brazil, accounting for 60.5% of the total Brazilian peach harvest, and it is mainly cultivated by small farmers, with a total area cultivated of 12,468 hectares [6]. However, orchards represent one of the land-uses for which runoff rates and sediment losses may occur if soil and water conservation practices are not adopted, especially in hill slopes.

Runoff and soil erosion have been reported worldwide and are usually associated with (i) the location on hill slopes and disposition of rows along the slope, which makes runoff and erosion stronger [7], (ii) maintenance of bare soil between rows by mechanical or chemical weeding [8–10], and (iii) intense machinery traffic along fixed paths, which promote soil compaction and reduce soil water holding capacity and water infiltration [11].

Runoff and soil erosion in peach orchards tend to be more intense in the first years after plantation, which can be associated with deep and intensive tillage during orchard installation, disaggregating the soil and exposing it to rainfall. A few studies have reported higher runoff and soil erosion rates due to the orchards' installation practices [9,12,13]. Deep tillage is usually applied to incorporate fertilizer and lime and to improve the soil's physical condition prior to plantation; however, it can also decrease soil aggregate stability [14], increase soil organic matter mineralization [15], and promote soil surface crusting [16], as well as decrease water infiltration, which leads to soil erosion [17].

The physical processes of erosion and the control of those events have been studied across a long time and have been established but soil erosion continues to be the greatest threat to soil health and ecosystem services in many regions of the world, having some controversial points that make the establishment of erosion control measures around the world difficult [18].

The use of cover crops and/or mulching in orchards has the potential to reduce runoff and soil erosion [19]. IPCC [3] references growing green manure and cover crops, crop residue retention, reduced/zero tillage, and maintenance of soil covering through improved grazing management as options to reduce vulnerability to soil erosion and nutrient loss. Mulching and cover crops have been proven to be efficient practices to (1) protect the soil from water droplet impact, (2) enhance aggregate stability, (3) improve soil water infiltration, (4) interrupt runoff pathways, (5) improve nutrient cycling and soil water storage, and (6) reduce soil temperature variation and water loss to evaporation [20,21]. Additionally, higher sediment losses and herbicide residues in runoff water were found in bare soil under avocado (*Persea americana* Mill) hillside orchards [9].

Stark and Thorne [12] argued that peach orchards cannot be maintained over a long time without adequate management practices to maintain soil organic matter and to control soil erosion, suggesting the use of cover crops. A literature review by Wolstenholme et al. [8] has also highlighted the benefits of using mulching in avocado orchards. They found that using mulching and/or cover crops decreased tree stress, improved root growth and health, and improved both fruit size and yield compared to avocado under bare soils. These positive effects of mulching within orchards related in past studies were confirmed recently by some other studies around the world [22–24]. However, there is still a gap in knowledge about the effect of cover crop residue as mulch on the triggering of runoff and soil water erosion in peach orchards in southern Brazil, as well as on the exact amount of mulching, considering this involves costs to the farmers. Furthermore, little information exists about the impact of runoff and soil erosion on environmental health (i.e., water contamination), soil losses and their costs for peach farmers in that region.

Therefore, this study aimed to quantify and characterize (i) the runoff and soil erosion under different levels of oat (*Avena sativa*) straw mulching in a commercial peach orchard; (ii) the cost of soil erosion and runoff during the first year after the peach orchard's installation. We hypothesized that straw mulching would decrease the soil runoff and, consequently, reduce nutrient losses and the production costs in the peach production system in southern Brazil.

2. Materials and Methods

2.1. Experimental Area and Treatments

The experimental area is a 0.7 ha commercial peach orchard (variety "sensação") installed in 2015, with 21% slope located in Pelotas City, "Rio Grande do Sul" State, Brazil

(Latitude 31°34′11,76″ S, Longitude 52°30′16,51″ W, 171 m altitude) (Figure 1). The climate is subtropical humid (Cfa) according to the Köppen's Climate Classification System. The mean annual rainfall is 1367 mm at the Pelotas Agroclimatology Station, in the period 1971–2000 [25]. The mean annual temperature is 17.8 °C, January being the hottest month, at 23.2 °C, and July being the coldest, at 12.3 °C (Figure 2).

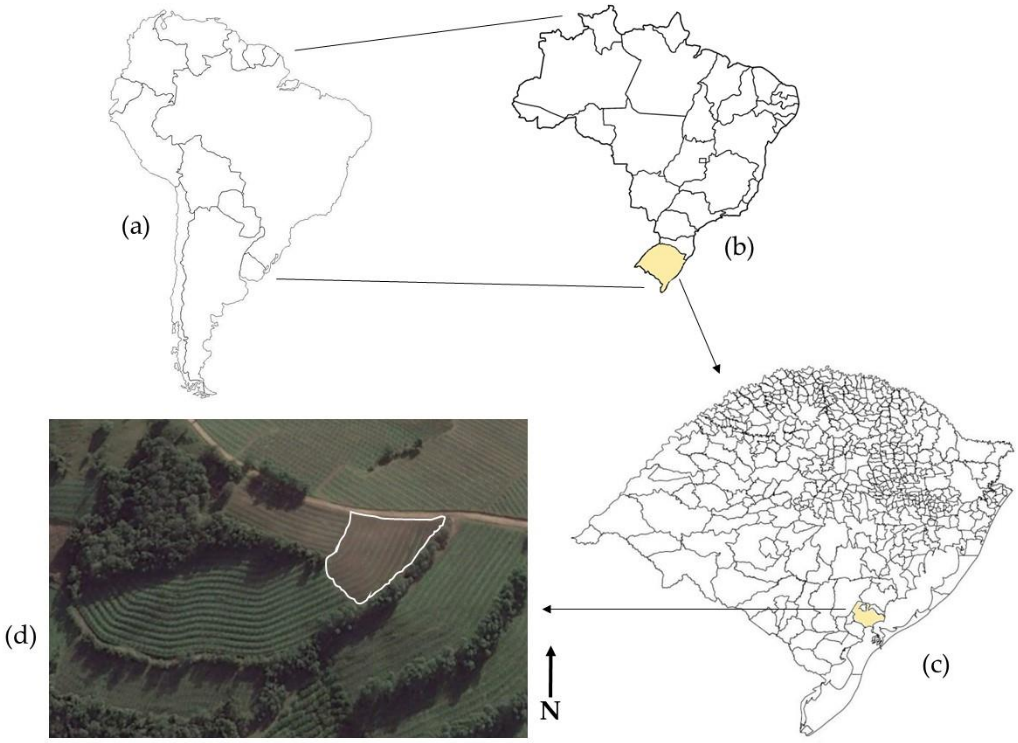


Figure 1. Map from South America (**a**), Brazil and "Rio Grande do Sul" State highlighted (**b**), and "Rio Grande do Sul" State with Pelotas City highlighted (**c**); image from Google Earth with the experimental area surrounded in a white color (**d**). Image of Google Earth dated 7 July 2015.

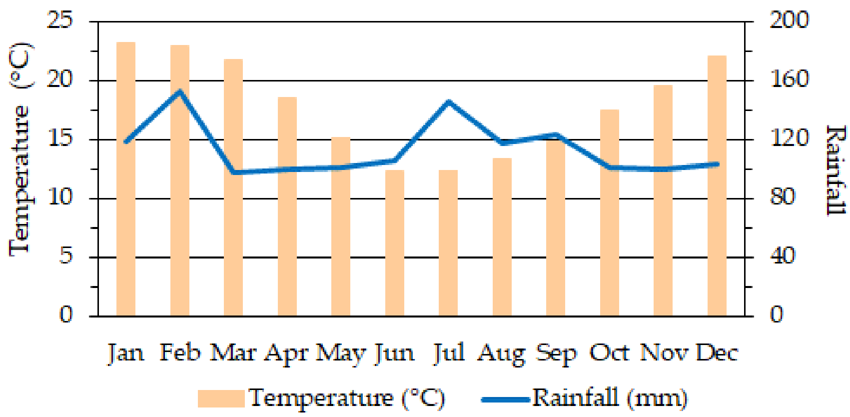


Figure 2. Mean monthly temperature and rainfall of the period 1971–2000. Source: [25].

The soil type at the study region is dominated by Entisols, Mollisols, Ultisols, Inceptisols, Plinthic, Alfisols and Entisols [26] (respectively Neossolos, Chernossolos, Argissolos, Cambissolos, Plintossolos, Planossolos and Gleissolos, accordingly with the Brazilian System of Soil Classification [27]). At the experimental site, the soil was classified as Cambissolo Háplico Tb Distrófico according to the Brazilian System of Soil Classification [27], which corresponds to Inceptisol in Soil Taxonomy [26].

The treatments were composed of different amounts of oat straw (*Avena sativa*) mulching placed on plots with the soil being tilled. The plots were used to measure the soil and nutrient losses by surface runoff.

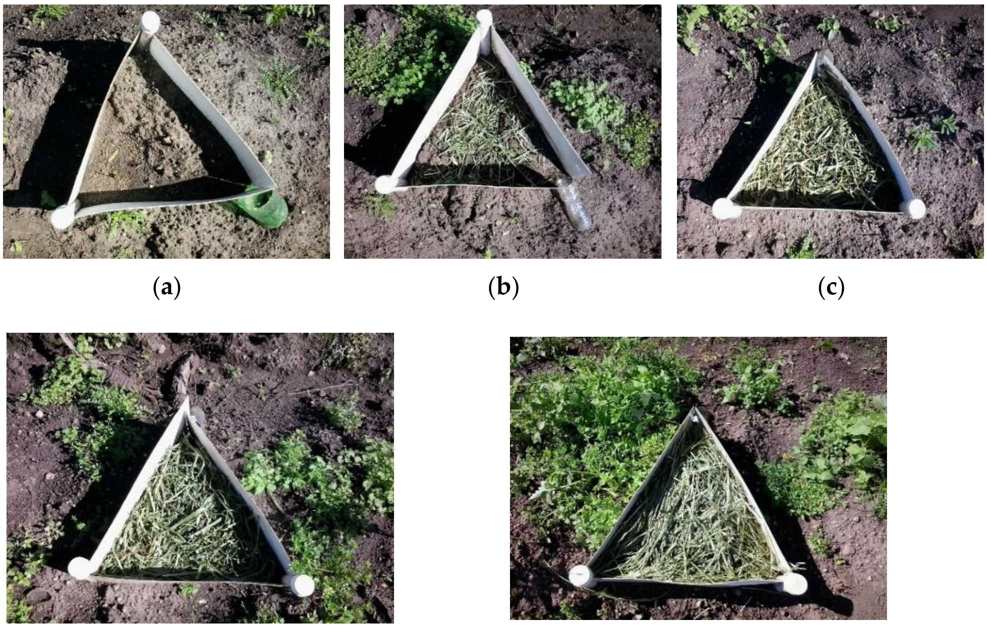
The site was prepared for planting (peach orchard implementation) in June 2015. For instance, the soil was tilled by plowing (approximately 30 cm deep) followed by harrowing. The ridges in the row were made using the soil from the interrow. The height of the ridges was approximately 0.40 m, having the interrow of the orchard as a reference. The distance between plants in the row was 2.5 m, and in the interrow it was 5.0 m. The soil fertility adjustment was realized in the peach orchard implementation.

On 9 July 2015 (i.e., around one month after orchard implementation), in order to quantify soil and nutrient losses by surface runoff due to interril erosion, plots were placed in the ridges (Figure 3). These plots were constructed using polyvinyl chloride (PVC), with strips of 0.5 m length and 0.15 m height, forming a triangle delimiting an area of 0.11 m^2, and were fitted using PVC pipe with a height of 0.25 m. The strips of the plots were linked through slots, to facilitate assembly, disassembly, and transport of such material. A polyethylene terephthalate (PET) bottle was cut in half and placed in the lower edge of the plot to collect the soil loss by surface runoff. In the field, a hole was opened in the ground for fixing the PET bottle, where its border remained close to the ground surface and the PVC strips connected to the border of the PET bottle. The soil loss by runoff in the delimited area (0.11 m^2) was captured in the PET bottle with a capacity of nearly 1.5 L. Plots larger than 0.11 m^2 were not possible to be used because the area of the ridge was smaller to support larger plots. Because of the plots' size and configuration, only interril erosion was possible to measure, as well as the impact and disaggregation of soil as part of erosion process.

Figure 3. Plots to assess the soil losses by surface runoff, installed in the ridge of the peach's orchard row on 23 August 2015, which was date of application of the treatments with different amounts of oat straw (*Avena sativa*) mulching.

Overall, 15 triangular plots (0.11 m^2) were constructed. The soil within each of those plots was covered by different amounts of oat (*Avena sativa*) straw mulching, which represents the treatments: 0 Mg ha^{-1}, 1 Mg ha^{-1}, 2 Mg ha^{-1}, 4 Mg ha^{-1}, 8 Mg ha^{-1} dry biomass (Figure 4). Each treatment had three replicates. The plots were installed on 9 July

2015 and received the treatments with oat straw mulching on 23 August 2015. When the straw mulching of each treatment was totally or almost totally decomposed in the plots, it was replaced along the experiment, avoiding the zero-straw mulching and being possible to evaluate the period of soil cover and decomposition, considering the different amounts of oat straw mulching. Thus, on 8 November 2015 the oat straw mulching was replaced in the treatments 1 and 2 Mg ha^{-1} and, on 13 January 2016, a new replacement of oat straw mulching was realized in all treatments (1 Mg ha^{-1}, 2 Mg ha^{-1}, 4 Mg ha^{-1}, 8 Mg ha^{-1}).



(**a**) (**b**) (**c**)

(**d**) (**e**)

Figure 4. Plots to assess the soil losses by surface runoff, installed in the ridge of the peach's orchard row, covered by different amounts of oat (*Avena sativa*) straw mulching, which represent the treatments: 0 Mg ha^{-1} (**a**), 1 Mg ha^{-1} (**b**), 2 Mg ha^{-1} (**c**), 4 Mg ha^{-1} (**d**), 8 Mg ha^{-1} (**e**) dry biomass. Pictures dated 23 August 2015 (application of the treatments).

The oat straw used as mulching in the plots was collected in a peach orchard next to the studied area and forwarded to the laboratory to dry at a temperature of 65 °C (standard method to quantify dry biomass of plants) and, afterwards, was placed in the plots according to each treatment. In this same orchard, which was twelve years old, in its interrow, oat straw used as mulching was sampled in four random points, in an area of 1 m^2 each one, in its senescence period, to verify the oat straw yield in a management system where it has the objective to protect the soil. The average yield of oat straw was 3 Mg ha^{-1} (dry weight at a temperature of 65 °C). That twelve year-old orchard was chosen because it is next to the studied area and frequently uses oat straw in its interrows.

2.2. Soil Characterization of the Ridges of the Peach Orchard's Row

In order to characterize the soil in the ridges of peach orchard's row (i.e., where the plots for assessment of soil losses by surface runoff were placed), disturbed soil samples were collected within 0 to 0.10 m, 0.10 to 0.20 m and 0.20 to 0.40 m depth. Those samples were analyzed for particle size distribution, dispersible clay in water, particle density, and soil fertility (i.e., pH and soil nutrients). Undisturbed soil samples were also collected in the same depths in metal cylinders of 4.7 cm diameter and 3.0 cm height. These samples were used to evaluate soil porosity, bulk density and saturated hydraulic conductivity.

2.2.1. Soil Chemical Characterization

Disturbed soil samples were also analyzed for pH, organic matter (OM), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), sodium (Na), aluminum (Al) and potential acidity (H + Al), as described by Tedesco et al. [28]. Soil pH was measured using a 1:1 soil-to-water ratio. Through these determinations, the effective cation exchange capacity and that at pH 7.0 (respectively, CECeffective and CECpH7.0), base saturation (V) and aluminum saturation (m) were calculated. The H + Al was determined for the SMP index, while the extractant KCl 1 mol L^{-1} was used to determine Ca, Mg, Mn and Al, and the extractant Mehlich I was used to determine P, K, Na, Zn and Cu. To determine organic matter we used moist digestion.

2.2.2. Soil Physical Characterization

Particle size distribution analysis was performed by the pipette method [29]. The dispersion of the soil samples followed the method described by Suzuki et al. [30], i.e., 20 g of sample, 10 mL of 6% NaOH (chemical dispersant), 50 mL of distilled water and two nylon spheres (each one weighing 3.04 g, diameter of 1.71 cm and density of 1.11 g cm^{-3}) were put in 100 mL glass bottles, which were shacked horizontally at 120 rpm for four hours.

Afterwards, the soil particles were separated into sand (diameter between 2 and 0.053 mm) by sieving, and silt (diameter between 0.053 and 0.002 mm) by calculus between the difference of the sum of sand and clay (diameter < than 0.002 mm), which was determined by pipette. The sand fractions were separated by sieving in very coarse sand (2 to 1 mm), coarse sand (1 to 0.5 mm), medium sand (0.5 to 0.25 mm), fine sand (0.25 to 0.125 mm) and very fine sand (0.125 to 0.053 mm).

The results of the particle size distribution analysis were used for soil textural classification, using the soil texture triangle available from the National Resource Conservation Service/United States Department of Agriculture [31].

Dispersible clay in water was quantified following the same procedure used for total clay evaluation but without using the chemical dispersant.

The calculus of the degree of flocculation (DF, %) followed the Equation (1):

$$DF = [(\text{total clay-dispersible clay in water})/\text{total clay}] \times 100 \quad (1)$$

The particle density was determined by the volumetric balloon method, according to Viana et al. [32].

2.2.3. Soil Porosity, Bulk Density, and Saturated Hydraulic Conductivity

The undisturbed soil samples were saturated through capillarity and balanced on a tension table (at 6 kPa tension) to determine macroporosity (pores > than 50 μm). After that, the samples were oven-dried (105 °C) to determine microporosity (pores < than 50 μm), total porosity and bulk density [33].

Samples with a preserved soil structure were also used to quantify the saturated hydraulic conductivity of the soil, using a permeameter of constant charge, as described by Klute and Dirksen [34]. Before beginning recording the measurements, the samples remained for some minutes with the water passing through the samples, to reach equilibrium and constancy. Three measurements for each sample were realized and we calculated the mean value.

Equation (2) below was used to calculate the saturated hydraulic conductivity:

$$KS = (V \times L)/[A \times t(h + L)] \quad (2)$$

where: KS = saturated hydraulic conductivity, mm h^{-1}; V = volume of water passed through the soil sample, mm^3; L = length of soil sample, mm; A = area of the transversal section of the soil sample, mm^2; t = time of lecture, hours; h = pressure potential (hydraulic charge) in the top of the soil sample, mm.

2.3. Soil and Nutrient Losses by Surface Runoff

In order to quantify the soil loss, the soil runoff plus water accumulated of rain in the PET bottle fixed in the lower edge of each plot was taken after each one of the ten rainfall events, sent to the laboratory and dried at 110 °C. Afterwards, the soil was broken manually and passed through a sieve with 2 mm mesh to separate particles larger and smaller than 2 mm. The total soil loss by surface runoff per hectare was quantified.

Soil runoff was collected 10 times between 23 August 2015 and 13 March 2016. A composite sample of soil with diameter < than 2 mm for each treatment (0 Mg ha^{-1}, 1 Mg ha^{-1}, 2 Mg ha^{-1}, 4 Mg ha^{-1}, 8 Mg ha^{-1} oat straw mulching dry biomass), collected in the ten events, was used to determine the particle size distribution and soil fertility indicators using the same procedures described above. Joining the soil of the 10 events of soil runoff to make a composite sample was necessary due to small amount of soil runoff in each event.

By multiplying the total amount of soil (<2 mm) runoff along the period of evaluation (data presented in Table 4, expressed in kg ha^{-1}), and the nutrient concentration in that soil (data presented in Table 6, expressed in kg dm^{-3}) the available P, K, Ca, and Mg runoff in one hectare (kg ha^{-1}), was calculated.

The cost of soil erosion (from 23 August 2015 to 13 March 2016) was calculated as the cost to replace the amount of soil nutrients (i.e., P, K, Ca and Mg) lost by runoff in one hectare using commercial mineral fertilizers. Specifically, superphosphate triple (41% P_2O_5) was considered for P, potassium chloride (50% K) for K, and dolomitic limestone (32% CaO + 6% MgO) for Ca and Mg replacement. The information about each nutrient concentration in the fertilizer was obtained in the Normative instruction number 39 of the Ministry of State of Agriculture, Livestock and Supply of Brazil [35], and the fertilizer cost was obtained using current market values (Pelotas City, Brazil).

The rainfall for the period of study was obtained from the monthly weather report available at Agrometeorology Laboratory of the Embrapa Temperate Climate (Embrapa/"Laboratório de Agrometeorologia" [36]), with data collected in an automatic weather meteorologic station installed in the Headquarters Weather Station of the Embrapa Temperate Climate/Pelotas City/"Rio Grande do Sul" State, around 14 km away of the experiment.

2.4. Data Analyses

The data were analyzed in terms of relative percentage; an analysis of variance and the Tukey test of means were performed considering 5% significance.

3. Results and Discussion

The ridges of the peach orchard's row where the plots to assess the soil losses by surface runoff were installed present a high soil fertility (Table 1). These results reflect the addition of high doses of chemical fertilizers before the orchard implementation, with high and very high nutrients content in the soil [37].

The soil runoff is basically the surface layer and the knowledge of its nutrient concentration is important to preview the possible environment impacts and economical losses due to soil runoff.

Tables 2 and 3 show the physical characterization of the soil ridges of peach orchard's row where the plots to assess the soil losses by surface runoff were installed. Overall, the soil had low average bulk density (1.12 Mg ha^{-1}), high macro (0.26 m^3 m^{-3}), micro (0.30 m^3 m^{-3}) and total (0.56 m^3 m^{-3}) porosity, and high saturated hydraulic conductivity (197 mm h^{-1}). These results were expected and reflect the short-term loose and disaggregated soil effect of tillage on those soil physical properties and processes. Within this area, deep tillage was performed around 1 month before soil sampling to incorporate fertilizer and to build the ridges where the peach plants were planted. In the short term, tillage can improve soil physical qualities for plant growth, however, this practice can also decrease aggregate stability [14] and promote soil surface crusting, which in turn can reduce the water infiltration rate and promote soil erosion [17]. Indeed, the tilled soil in the experimental area had a high content of dispersible clay in water and a low flocculation degree, suggesting a soil with high level of disaggregation (Table 2). Therefore, these results confirm the high potential of new planted peach orchards for nutrient losses and environmental degradation associated with runoff and interril soil erosion.

Table 1. Soil chemical characterization of the ridges of peach orchard's row where the plots to assess the soil losses by surface runoff were installed.

Soil		Depth, m			
Attribute	**Unit**	**0–0.10**	**0.10–0.20**	**0.20–0.40**	**Mean**
SOM	g kg^{-1}	27.6 (medium)	26.2 (medium)	27.6 (medium)	27.1 (medium)
P-Melich	mg dm^{-3}	108.1 (very high)	155.6 (very high)	202.1 (very high)	155.3 (very high)
Exch. K	mg dm^{-3}	95.0 (high)	128.0 (very high)	143.0 (very high)	122.0 (very high)
Ca	$cmol_c$ dm^{-3}	7.8 (high)	7.9 (high)	7.4 (high)	7.7 (high)
Mg	$cmol_c$ dm^{-3}	2.9 (high)	3.0 (high)	2.7 (high)	2.9 (high)
Na	mg dm^{-3}	11.0	12.0	13.0	12.0
Al	$cmol_c$ dm^{-3}	0.0	0.0	0.0	0.0
H + Al	$cmol_c$ dm^{-3}	2.0	1.6	2.5	2.0
CECeffective	$cmol_c$ dm^{-3}	11.0	11.3	10.5	10.9
CECpH7.0	$cmol_c$ dm^{-3}	13.0 (medium)	12.9 (medium)	13.0 (medium)	13.0 (medium)
pH water		6.4 (high)	6.4 (high)	6.0 (medium)	6.3 (high)
AlS	%	0.0 (very low)	0.0 (very low)	0.0 (very low)	0.0 (very low)
BS	%	85.0 (high)	87.0 (high)	81.0 (high)	84.0 (high)

SOM: soil organic matter; P: phosphorus; Exch. K: exchangeable potassium; Ca: calcium; Mg: magnesium; Na: sodium; Al: aluminum; H + Al: potential acidity; CEC: cation exchange capacity; AlS: aluminum saturation; BS: base saturation. In parentheses is the interpretation of the soil fertility [37].

Table 2. Soil physical and hydraulic characterization of the ridges of the peach orchard's row where the plots to assess the soil losses by surface runoff were installed.

Depth, m	BD, Mg m^{-3}	TP, m^3 m^{-3}	Macro, m^3 m^{-3}	Micro, m^3 m^{-3}	KS, mm h^{-1}	DCA, %	DF, %	PD Mg m^{-3}
0.00–0.10	1.05	0.593	0.259	0.333	142.71	8.94	31.65	2.56
0.10–0.20	1.12	0.538	0.276	0.262	300.58	8.42	31.54	2.52
0.20–0.40	1.20	0.548	0.231	0.318	148.86	8.92	29.04	2.54
Mean	1.12	0.560	0.255	0.304	197.38	8.76	30.74	2.54

BD: bulk density; TP: total porosity; Macro: macroporosity; Micro: microporosity; KS: saturated hydraulic conductivity; DCA: dispersible clay of soil in water; DF: degree of flocculation; PD: particle density.

Table 3. Particle size distribution and textural classification of the ridges of the peach orchard's row where the plots to assess the soil losses by surface runoff were installed.

Depth, m	Sand						Silt	Clay	Textural Classification [31]
	Total	Very Coarse	Coarse	Medium	Fine	Very Fine			
	%								
0–0.10	63.34	11.99	11.44	11.79	16.83	11.30	23.58	13.08	Sandy loam
0.10–0.20	64.10	13.16	11.74	11.31	17.58	10.31	23.60	12.30	Sandy loam
0.20–0.40	63.71	12.41	11.55	11.56	17.70	10.49	23.72	12.57	Sandy loam
Mean	63.72	12.52	11.58	11.55	17.37	10.70	23.63	12.65	

Total sand: particles with diameter between 2 and 0.05 mm; very coarse sand: diameter between 2 and 1 mm; coarse sand: diameter between 1 and 0.5 mm; medium sand: diameter between 0.5 and 0.25 mm; fine sand: diameter between 0.25 and 0.125 mm; very fine sand: diameter between 0.125 and 0.053 mm; silt: diameter between 0.053 and 0.002 mm; clay: diameter < than 0.002 mm.

The degree of flocculation is low (Table 2), and the sand content is a high sandy loam textural class (Table 3), reinforcing the necessity of soil and water conservation practices in that soil. Clay is an important agent of soil aggregation [38–44], therefore, the larger the clay dispersible in water, the larger the possibility to occur water erosion, especially in the topsoil that is more susceptible to the rainfall drop and runoff. The increment of clay dispersible in water decreases water infiltration or water conductivity [45,46] and favors the runoff probably because it closes the pores of soil [47].

It is important to know the relation between the particle size distribution and other soil physical attributes to understand the susceptibility of soil to erosion and sealing of its surface. According to Resende et al. [48], besides particle size distribution [16], other variables should be considered about water erosion: the depth [49], the slope [50–52] and its length [53], the porosity, and others, because they help us to preview the susceptibility to erosion, since water infiltration and storage are related to the variables cited. For example, Suzuki et al. [54] verified that the runoff correlated positively with coarse sand and saturated hydraulic conductivity of soil, while Keesstra et al. [10], using multivariate analysis, observed that vegetation cover, soil moisture and organic matter were negatively correlated with the bulk density, total runoff, runoff coefficient, sediment yield and soil erosion.

Regarding the particle sizes of soil and erosion, sand particles are difficult to be transported because of their size but they are easily detached from the soil mass; although silt soils generally are well aggregated, the aggregates break down easily when wetted, and the particles are easily detached and transported, and the clay particles are difficult to detach but they are transported across larger distances when separated from the soil [38].

The soil runoff in the plots with no straw mulching was larger and differed significantly from the other treatments (Figure 5); besides, according to the increase in the mulching, the soil runoff decreased at most times (Table 4 and Figure 5). This is because the soil is exposed to the rainfall according to the decrease of mulching, which is more susceptible to rainfall drops and splashes. Besides this, the topsoil was tilled to enhance the orchard's performance, breaking the soil aggregates and loosening it. Falling raindrops and running water are the two major agents in water erosion, and both are related to the energy necessary to detach and transport soil particles [38]. However, planting or mulching at the soil's surface intercepts raindrops and slows down runoff [38,49,51,55]. Other practices used together with straw mulching such as the disposal of branches from the yearly pruning on the interrows, harvesting manually, and opting for using a compact tractor contribute to avoiding soil compaction and probably soil erosion [56], as well as the use of terracing [57–60], such as dry-stone wall or earth bank terraces [53], and keyline arrangement [61,62].

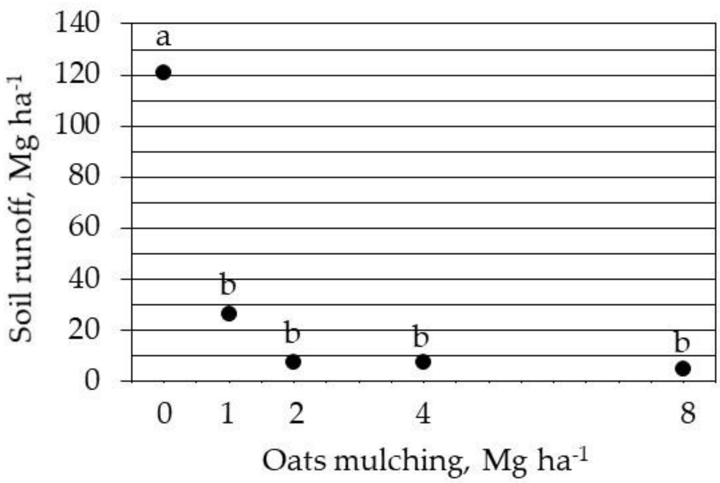


Figure 5. Tendency of total soil losses by surface runoff (particles with diameter < than 2 mm) in the period between 29 August 2015 to 13 March 2016, according to the amount of oat straw mulching in the plots. Total soil losses followed by same letters do not differ statistically from each other by Tukey's test at 5% significance.

Table 4. Soil losses by surface runoff (particles with diameter < than 0.002 mm) (Mg ha^{-1}) and percentage of losses by surface runoff in relation to the treatment without mulching, and rainfall accumulated up until the sampling date.

Sampling	[1] Rainfall	Treatment (Amount of Oat Straw Mulching, Mg ha^{-1})					
Date	Accumulated	0	1	2	4	8	Total
	mm	Mg ha^{-1}					
29 August 2015	110.5	0.86 (100%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.86
7 September 2015	28.9	0.27 (100%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.27
27 September 2015	284.0	11.53 (100%)	3.00 (26%)	1.35 (12%)	0.53 (5%)	1.03 (9%)	17.44
25 October 2015	299.2	18.73 (100%)	4.34 (23%)	2.29 (12%)	1.27 (7%)	0.94 (5%)	27.57
[2] 8 November 2015	42.4	0.00	0.00	0.00	0.00	0.00	0.00
14 November 2015	92.4	8.72 (100%)	2.19 (25%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	10.91
8 December 2015	164.1	7.43 (100%)	2.97 (40%)	0.64 (9%)	0.89 (12%)	0.58 (8%)	12.51
[2] 13 January 2016	251.6	28.90 (100%)	7.12 (25%)	1.78 (6%)	4.86 (17%)	2.34 (8%)	45.00
16 February 2016	180.2	24.11 (100%)	4.81 (20%)	0.80 (3%)	0.00 (0%)	0.00 (0%)	29.72
13 March 2016	188.6	20.39 (100%)	1.83 (9%)	0.70 (3%)	0.00 (0%)	0.00 (0%)	22.92
Total		120.94	26.26	7.56	7.55	4.89	

[1] Source: "Laboratório de Agrometeorologia da Embrapa Clima Temperado" (Agrometeorology Laboratory of the Embrapa Temperate Climate) [36]. [2] On 8 November 2015, the oat straw mulching was replaced in the treatments 1 and 2 Mg ha^{-1} and on 13 January 2016 a new replacement of oat straw mulching was realized in all treatments (0 Mg ha^{-1}, 1 Mg ha^{-1}, 2 Mg ha^{-1}, 4 Mg ha^{-1}, 8 Mg ha^{-1} oat straw mulching dry biomass).

Those values of soil losses are high, because according to FAO [2], rates of tolerable soil loss calculated using soil production rates range from 0.2 to 2.2 Mg ha^{-1} year^{-1} and tolerable rates based on maintenance of crop production range from approximately 1 to 11 Mg ha^{-1} year^{-1}, and these ranges reinforce the need for site-specific studies to evaluate the different sensitivities of soils for the removal of surface soil through erosion.

These results agree with other studies, where the use of cover crops and/or mulching in orchards has the potential to reduce runoff and soil erosion [10,19,63].

In a rainfall simulation experiment using organic mulching in an urban forestry park, the runoff amount and runoff generation rate decreased by 28–83% and 21–83%, respectively, when using 0.25 kg m^{-2} and 0.50 kg m^{-2} of mulching, compared to bare soil [64]. Testing different mulching types of banana (*Musa* sp.) leaves, coconut (*Cocos nucifera*) leaves, and vetiver (*Vetiveria zizanoides*) and various amounts (0 Mg ha^{-1}, 10 Mg ha^{-1}, 20 Mg ha^{-1} and 40 Mg ha^{-1}) in farm fields with an 8% slope after seeding the plots with maize, the banana leaves at 10 Mg ha^{-1} and coconut leaves at 40 Mg ha^{-1} mitigated soil and nutrient erosion to, respectively, 28.9% and 57.3%, contributed to the mechanical barrier provided by the mulches, and also to the reduction of raindrops acting on the soil aggregates [65]. The author [65] verified that mulching also contributed to increasing the infiltration rate, lowering the temperature and, therefore, lowering evaporation.

On 8 November 2015 there was no soil runoff, even with rainfall before this date, corresponding to 14 days after the sampling in October. On this same date (8 November) the oat straw mulching was replaced in the treatments 1 and 2 Mg ha^{-1} because it was totally or almost totally decomposed in the plots, avoiding the zero-straw mulching. The larger soil runoff in the 4 Mg ha^{-1} mulching treatment compared to 2 Mg ha^{-1} mulching treatment, on 8 December and after, may be associated with this replacement of mulching, when the treatment with 4 Mg ha^{-1} mulching could be presenting less mulching than the treatment with 2 Mg ha^{-1} because of its decomposition since the installation of the experiment, considering the replacement of mulching on 8 November 2015 was realized only in the treatments with 1 and 2 Mg ha^{-1}.

On 13 January 2016 a new replacement of oat straw mulching was realized in all treatments. The straw mulching replacement along the experiment was necessary to maintain the same or almost the same cover density during the period, avoiding the zero-straw mulching, and to verify the biomass time of decomposition according to each treatment.

Considering the application of mulching in the treatments on 23 August 2015, the decomposition practically totaled 2 Mg ha^{-1} of oat straw mulching at around 80 days (23 August 2015 to 8 November 2015), while the larger amounts of straw mulching (4 and 8 Mg ha^{-1}) would take more than 140 days (23 August 2015 to 13 January 2016) to totally decompose, taking into account the conditions of the present study. The time of decomposition of the straw mulching is important because the longer it spends on the soil surface, the more soil protection against rainfall it provides. Besides, it was verified in the field that the plots with mulching presented a smaller incidence of spontaneous plants, especially at 4 and 8 Mg ha^{-1}, which was practically null. That is an important finding. In organic tree fruit fields, for example, the farmers have limited options for controlling weeds and furnish nutrients at the appropriate time and adequate amount [66].

Although the soil runoff was statistically the same with straw mulching (1 to 8 Mg ha^{-1}), from 2 Mg ha^{-1} straw mulching there was less soil runoff (Figure 5); it is possible to indicate this value as minimum amount of mulching in the peach orchard or any other condition of soil tilled to reduce soil erosion, but it is important to say that the time spent on decomposition and soil exposure will be greater than with larger amounts of mulching. This value (2 Mg ha^{-1}) is smaller than the 3 Mg ha^{-1} value, representing the average yield of oat straw mulching in its senescence (see Material and methods). In areas where the spontaneous weed is used, it would be interesting to evaluate its straw mulching yield if it is comparable to oat straw.

We verified soil runoff in all plots with different amounts of straw mulching, although with different amounts along the period of study, either because of rainfall intensity (not measured) or when the soil reached its capacity of infiltration. When the soil is exposed, it is more susceptible to rainfall. Then, when mulching or cover crops are used, the rainfall dropping onto the soil and topsoil compaction are decreased, and this reduces flooding speed [49,51,55,67,68]. According to some authors [51,67,68], the speed of the covering of plants is important, because the soil runoff is associated with the time of soil exposure, being susceptible to erosion. Water loss through runoff in Aquic Argiudoll (Luvic Phaeozem) soil was more related to the number of months in the year with the presence of crops than to the soil physical properties related to porosity and water flow [69].

According to Bertoni and Lombardi Neto [70], in Brazil, the soil runoff in agricultural areas is caused especially by water erosion, and this happens generally in the period of soil being tilled to crops' plantation, which is also the case in the present study; the tillage of the soil and implementation of the orchard changed its physical characteristics, and the soil was also exposed to rain and wind.

In general, there was an increase in accumulated rainfall that increased soil runoff (Figure 6). The total rainfall is not the most important variable when soil erosion is evaluated, the most relevant are the rainfall drop, the intensity (volume of rainfall during a certain period), speed and specially volume, duration and time to return the rainfall in the watershed [53,71]. Natural rainfalls larger than 70 mm resulted in similar runoff coefficients in an Aquic Argiudoll (Luvic Phaeozem) soil with a 3.5% slope, in natural plots under monocultures, rotation, pasture, and tilled soil without vegetation, while for intermediate and small rainfalls the runoff coefficients were different [69]. The rainfall in the "Rio Grande do Sul" State is well-distributed along the year, but its volume is different: the mean rainfall in the south is between 1299 mm and 1500 mm, while in the north it is between 1500 mm and 1800 mm [72]. The Pelotas mean annual rainfall is 1367 mm, according to the Pelotas Agroclimatology Station, in the period 1971–2000 [25], lower than the mean of the "Rio Grande do Sul" State.

According to Volk and Cogo [73], the main variables used to determine soil runoff are the rainfall intensity and flooding associated with it [52], the particle size distribution [16] and the degree of consolidation of the soil surface, the type of erosion (sheet, rill or gully), the soil cover [49,51,55], the microrelief or surface roughness resulting from soil tillage and the size and stability of soil aggregates [55].

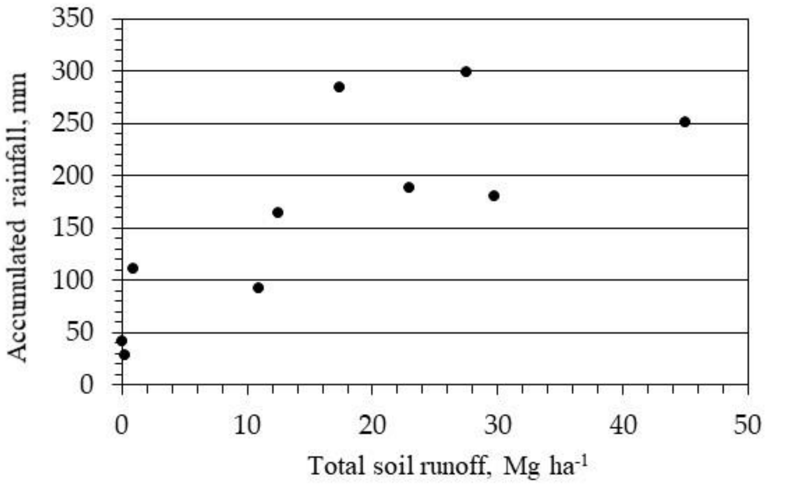


Figure 6. Total soil losses by surface runoff considering the sum of all treatments (amount of oat straw mulching) and accumulated rainfall until each sampling date.

Independent of rainfall intensity, the mulching prevented or reduced the runoff compared to bare soil, and the larger the amount of mulching, the greater the soil protection. In this sense, Suzuki et al. [54] verified less runoff under no tillage compared to conventional tillage.

The textural class of the soil runoff (Table 5) is the same one of the ridges of the peach orchard's row (Table 3). Comparing it with the soil depth 0–0.10 m of the ridges of peach orchard's row, the soil runoff has less clay, fine and very fine sand, and increases in the other particle sizes. Statistically, coarse, medium and fine sand did not differ significantly between treatments.

Table 5. [1] Particle size distribution of the soil runoff in the plots. [2] In parentheses is the percentage of increment or decrease of the particle compared to the soil depth 0–0.10 m (data available in Table 3).

Treatment	Sand						Silt	Clay	Textural Classification
	Total	Very Coarse	Coarse	Medium	Fine	Very Fine			
	%								
0 Mg ha^{-1}	64.07 c (+0.73)	10.98 b (−1.01)	14.78 a (+3.34)	12.90 a (+1.11)	14.70 a (−2.13)	10.70 a (−0.60)	28.29 a (+4.71)	7.65 ab (−5.43)	Sandy Loam
1 Mg ha^{-1}	67.32 bc (+3.98)	18.58 ab (+6.59)	15.97 a (+4.53)	12.30 a (+0.51)	12.77 a (−4.06)	7.70 b (−3.60)	24.04 bc (+0.46)	8.65 a (−4.43)	Sandy Loam
2 Mg ha^{-1}	70.13 ab (+6.79)	15.40 ab (+3.41)	15.53 a (+4.09)	13.33 a (+1.54)	15.47 a (−1.36)	10.40 ab (−0.90)	24.92 b (+1.34)	4.95 c (−8.13)	Sandy Loam
4 Mg ha^{-1}	73.73 a (+10.39)	22.33 a (+10.34)	16.20 a (+4.76)	13.13 a (+1.34)	13.80 a (−3.03)	8.27 ab (−3.03)	21.20 c (−2.38)	5.07 c (−8.01)	Sandy Loam
8 Mg ha^{-1}	67.53 bc (+4.19)	15.47 ab (+3.48)	14.87 a (+3.43)	12.40 a (+0.61)	14.60 a (−2.23)	10.20 ab (−1.10)	26.17 ab (+2.59)	6.30 bc (−6.78)	Sandy Loam

Total sand: particles with diameter between 2 and 0.05 mm; very coarse sand: diameter between 2 and 1 mm; coarse sand: diameter between 1 and 0.5 mm; medium sand: diameter between 0.5 and 0.25 mm; fine sand: diameter between 0.25 and 0.125 mm; very fine sand: diameter between 0.125 and 0.053 mm; silt: diameter between 0.053 and 0.002 mm; clay: diameter < than 0.002 mm. [1] Values obtained from a composite sample of soil runoff in each sampling date. [2] Calculation considering particle size of the soil runoff–particle size of the soil depth 0–0.10 m. Means followed by same letters in each column do not differ statistically from each other by the Tukey's test at 5% significance.

The soil runoff is basically composed of the topsoil of the ridges, generally with a larger amount of organic matter and nutrients (Table 6). In general, comparing with the soil depth 0–0.10 m of the ridges of peach orchard's row, the soil from runoff was more acid and, consequently, with slightly higher Al concentration and Al saturation. In addition, Na and K concentration was higher in the soil runoff than the 0–0.10 m depth.

Table 6. [1] Chemical characterization of the soil runoff in the plots. [2] In parentheses is the percentage of increase or decrease of the chemical element compared to the soil depth 0–0.10 m (data available in the Table 1) and the interpretation of the soil fertility [37].

Soil Attribute	Unit	Treatment (Amount of Oats Mulching)				
		0 Mg ha^{-1}	1 Mg ha^{-1}	2 Mg ha^{-1}	4 Mg ha^{-1}	8 Mg ha^{-1}
SOM	g kg^{-1}	27.6 (0.00/medium)	2.90 (+0.14/medium)	2.49 (−0.27/low)	2.76 (0.00/medium)	2.90 (+0.14/medium)
P-Melich	mg dm^{-3}	70.7 (−37.4/very high)	27.3 (−80.8/high)	146.5 (+38.4/very high)	122.3 (+14.2/very high)	97.0 (−11.1/very high)
Exch. K	mg dm^{-3}	103 (+8/high)	133 (+38/very high)	141 (+46/very high)	154 (+59/very high)	171 (+76/very high)
Ca	cmol$_c$ dm^{-3}	8.5 (+0.7/high)	7.8 (0.0/high)	7.8 (0.0/high)	8.1 (+0.3/high)	7.0 (−0.8/high)
Mg	cmol$_c$ dm^{-3}	2.9 (0.0/high)	2.7 (−0.2/high)	2.7 (−0.2/high)	2.7 (−0.2/high)	2.4 (−0.5/high)
Na	mg dm^{-3}	32 (+21)	32 (+21)	43 (+32)	35 (+24)	35 (+24)
Al	cmol$_c$ dm^{-3}	0.1 (+0.1)	0.1 (+0.1)	0.1 (+0.1)	0.1 (+0.1)	0.1 (+0.1)
H+Al	cmol$_c$ dm^{-3}	2.0 (0.0)	2.5 (+0.5)	2.0 (0.0)	2.0 (0.0)	2.2 (+0.2)
CECeffective	cmol$_c$ dm^{-3}	11.9 (+0.9)	11.1 (+0.1)	11.1 (+0.1)	11.4 (+0.4)	10.1 (−0.9)
CECpH7.0	cmol$_c$ dm^{-3}	13.8 (+0.8/medium)	13.5 (+0.5/medium)	13.0 (0.0/medium)	13.3 (+0.3/medium)	12.2 (−0.8/medium)
pH water 1:1		6.0 (−0.4/medium)	5.7 (−0.7/medium)	6.0 (−0.4/medium)	5.7 (−0.7/medium)	5.7 (−0.7/medium)
AlS	%	0.8 (+0.8/very low)	0.9 (+0.9/very low)	0.9 (+0.9/very low)	0.9 (+0.9/very low)	1.0 (+1.0/low)
BS	%	86 (+1/high)	81 (−4/high)	85 (0/high)	85 (0/high)	82 (−3/high)

SOM: soil organic matter; P: phosphorus; Exch. K: exchangeable potassium; Ca: calcium; Mg: magnesium; Na: sodium; Al: aluminum; H + Al: potential acidity; CEC: cation exchange capacity; AlS: aluminum saturation; BS: base saturation. [1] Values obtained from a composite sample of soil runoff in each sampling date. [2] Calculation considering chemical element of the soil runoff–chemical element of the soil depth 0–0.10 m.

The other variables, such as base saturation and Ca, Mg and organic matter levels (except 0 Mg ha^{-1}) (Table 6), did not present larger differences than 0–0.10 m depth, and may be associated with the lower clay content in the soil runoff (Table 5) compared to the 0–0.10 m depth (Table 3), since the reactivity and cation exchange capacity (CEC) of soil are derived from the clay. Troeh and Thompson [39] cite that the sequence of attractive forces between a cation and a micelle is the following one: $Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH^{4+} > Na^{+}$.

The soil surface has organic matter and nutrients, and in agricultural areas it has seeds, fertilizers and agrochemicals as well, and depending on soil runoff, this material may be carried to down in the relief, and may pollute and degrade soil and rivers, decrease the soil capacity of yield and increase costs of production, because it may be necessary for the addition of more fertilizers and interventions to stop soil erosion. Suzuki et al. [74] verified high concentrations of nutrients in the soil runoff, with the prevalence of silt and clay, in areas under annual crops. This has a strong relation with particle size due to CEC. The cations are adsorbed to the negative charges of the soil, and control the availability of Ca, Mg, K, Na, NH_4 and Al [75].

Along with mulching increments, the available nutrients P, K, Ca and Mg decreased in the soil runoff (Table 7). This was especially true for Ca; it presented expressive losses in surface runoff, followed by Mg, which was associated with the larger amount of these elements in the soil compared to P and K.

Table 7. Available nutrient losses in surface runoff according to their concentration in the soil runoff.

	P	K	Ca	Mg
Treatment	**kg ha^{-1}**			
0 Mg ha^{-1}	8.6	12.5	206.0	42.6
1 Mg ha^{-1}	0.7	3.5	41.0	8.6
2 Mg ha^{-1}	1.1	1.1	11.8	2.5
4 Mg ha^{-1}	0.9	1.2	12.3	2.5
8 Mg ha^{-1}	0.5	0.8	6.9	1.4

P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium.

The losses for erosion are variable but the total number of bases lost in eroded soils may be almost the same number being exported by the harvested plants [39].

The cost to replace lost nutrients (Table 7) via mineral fertilizer (using respectively, superphosphate triple-41% P_2O_5, potassium chloride-50% K, dolomitic limestone-32% CaO + 6% MgO) would be US$ 75.4 per hectare, considering the larger losses for no-mulching (Table 8), and this cost would be reduced to US$ 2.70 per hectare for 8 Mg ha^{-1} oat straw mulching. It is important to highlight that other costs, such as transport and application of the fertilizer, fuel, depreciation, and others, were not considered in this cost, besides the impacts to the environment.

Table 8. Amount of mineral fertilizer necessary to replace the available nutrients lost in surface runoff and the cost of fertilizer, considering the treatments with larger (0 Mg ha^{-1} oat straw mulching) and smaller (8 Mg ha^{-1} oat straw mulching) losses.

	Treatment	
Variables	**0 Mg ha^{-1}**	**8 Mg ha^{-1}**
Superphosphate triple (41% P_2O_5), kg ha^{-1}	9	1
Potassium chloride (50% K), kg ha^{-1}	21	1
Dolomitic limestone (32% CaO + 6 % MgO), kg ha^{-1}	460	15
Cost of Superphosphate triple (US$ 240.00/ton), US$/ha	2.18	0.12
Cost of Potassium chloride (US$ 202.50/ton), US$/ha	4.19	0.28
Cost of Dolomitic limestone (US$ 150.00/ton), US$/ha	69.05	2.30
Total cost with mineral fertilizer, US$/ha	75.4	2.70

The cost of soil erosion varies according to its clay, organic matter, nutrient contents and other characteristics of soil but, due to concentrations in the topsoil layer, a ton of eroded soil may be more fertile and therefore more valuable than a ton of soil [38].

Other studies have showed the cost of soil erosion around the world. For example, Bucur et al. [76] verified mean annual losses of 10.24 kg ha^{-1} N, 0.62 kg ha^{-1} P_2O_5, 1.38 kg ha^{-1} K_2O, 0.66 kg ha^{-1} Ca^{2+}, 0.19 kg ha^{-1} Mg^{2+} and 195.95 kg ha^{-1} humus in a wheat–maize rotation, in a Cambic chernozem of Romania. Those values, however, decreased with the increase in crop rotation (i.e., the inclusion of pea, wheat, alfalfa, and perennial grasses into the cropping system), which protected the soil against erosion.

In vineyard fields in Spain, Martínez-Casasnovas and Ramos [77] verified that soil erosion exported 14.9 kg ha^{-1} of N and 11.5 kg ha^{-1} of total P, which represented 6 and 26.1% of the annual intakes and 2.4 and 1.2% of the annual income from the sale of the grapes, respectively. On the other hand, under the perennial crops of banana or banana-coffee, Onesimus et al. [78] observed a soil loss of, respectively, 38.5, 6.6 and 0.87 Mg ha^{-1} $year^{-1}$, with the replacement of NPK losses, caused by erosion, equaling a cumulative cost of, respectively, US$ 16,663, 4404 and 442 ha^{-1} $year^{-1}$, and the authors also verified that the total cost of replacing nutrients was higher, US$ 15,451 ha^{-1} $year^{-1}$,in areas without conservation practices (terraces), than in areas with terraces, equaling US$ 6,058 ha^{-1} $year^{-1}$.

Asfaw et al. [79] cite for their study that subsidizing fertilizers for the least productive farmers is a way to replace topsoil nutrients lost by soil erosion, but it does not provide cost-effective targeting criteria, being that erosion control practices are more effective in supporting this type of farmer.

The lack of information on erosion requires farmers to adopt soil conservation practices, and not adopting such practices affects farmers and society, since the society will bear the cost of repairing the off-site damage caused by soil erosion [80].

Our results come contribute information about water erosion and soil runoff using conservation practices such as mulching in peach orchards. Especially in the implementation of the orchard, when the soil is tilled, the use of mulching is efficient in reducing soil runoff by interril erosion and consequently the costs of fertilizers exported by runoff.

4. Conclusions

The use of oat straw mulching was efficient to protect the soil from water erosion, especially the doses ≥ 2 Mg ha^{-1}, with considerably decreasing soil runoff by interril erosion from peach orchard.

The straw mulching decomposition time is important to protect soil against rainfall. Eighty days after its addition, 2 Mg ha^{-1} of oat straw mulching was totally decomposed. Meanwhile, the decomposition of the largest added amounts of oat straw mulching (4 and 8 Mg ha^{-1}) took more than 140 days. Furthermore, we visually verified in the field that the plots with straw mulching presented a smaller incidence of spontaneous plants, and was practically null at 4 and 8 Mg ha^{-1} straw mulching.

The textural class of the soil runoff is the same one of the ridges of peach orchard's row (sandy loam) but, with less clay and fine and very fine sand, and with increases in silt, and medium–large–very large sand compared with the topsoil of the ridges of peach orchard's row.

Compared with the topsoil of the ridges of peach orchard's row, the soil runoff is enriched with Na and K, but with more acid and with slightly larger Al concentrations and Al saturations.

With the incremental increase in straw mulching, the available nutrients P, K, Ca and Mg decreased in the soil runoff by interril erosion, and the cost to replace these nutrients via mineral fertilizer (using, respectively, superphosphate triple-41% P_2O_5, potassium chloride-50% K, dolomitic limestone-32% CaO + 6% MgO) is US$ 75.4 per hectare, considering the larger losses for no mulching, and this cost is reduced to US$ 2.70 per hectare for 8 Mg ha^{-1} oat straw mulching. We did not consider other costs such as transport and application of the fertilizer, fuel, and depreciation, nor did we assess the impacts on the environment.

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References

1. Karlen, D.L.; Rice, C.W. Soil degradation: Will humankind ever learn? *Sustainability* **2015**, *7*, 12490–12501. [CrossRef]
2. FAO—Food and Agriculture Organization of the United Nations, 2015. International Year of Soil Conference. 2015. Available online: http://www.fao.org/soils-2015/events/detail/en/c/338738/ (accessed on 30 August 2021).
3. IPCC—Intergovernmental Panel on Climate Change. Climate change and land. An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas Fluxes in Terrestrial Ecosystems. Summary for Policymakers. 2019; 41p. Available online: https://www.ipcc.ch/srccl/ (accessed on 24 August 2021).
4. Yang, D.; Kanae, S.; Oki, T.; Koike, T.; Musiake, K. Global potential soil erosion with reference to land use and climate changes. *Hydrol. Process.* **2003**, *17*, 2913–2928. [CrossRef]

5. Olsson, L.; Barbosa, H.; Bhadwal, S.; Cowie, A.; Delusca, K.; Flores-Renteria, D.; Hermans, K.; Jobbagy, E.; Kurz, W.; Li, D.; et al. Land Degradation. In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*; Shukla, P.R., Skea, J., Buendia, E.C., Masson-Delmotte, V., Pörtner, H.O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., Van Diemen, R., et al., Eds.; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2019; pp. 345–436.
6. IBGE—Instituto Brasileiro de Geografia e Estatística, Diretoria de Pesquisas, Coordenação de Agropecuária, Produção Agrícola Municipal. 2016. Áreas destinada à colheita e colhida, quantidade produzida, rendimento médio e valor da produção de pêssego segundo as grandes regiõ e unidades da federação produtora —Brasil 2016. Available online: https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html?utm_source=landing&utm_medium=explica&utm_campaign=producao_agropecuaria&t=downloads (accessed on 25 August 2021).
7. Jie, Y.; Haijin, Z.; Xiaoan, C.; Le, S. Effects of tillage practices on nutrient loss and soybean growth in red-soil slope farmland. *Int. Soil Water Conserv. Res.* **2013**, *1*, 49–55. [CrossRef]
8. Wolstenholme, B.N.; Moore-Gordon, C.; Ansermino, S.D. Some pros and cons of mulching avocado orchards. *South Afr. Avocado Grow. Assoc. Yearb.* **1996**, *19*, 87–91.
9. Atucha, A.; Merwin, I.A.; Brown, M.G.; Gardiazabal, F.; Mena, F.; Adriazola, C.; Lehmann, J. Soil erosion, runoff and nutrient losses in an avocado (*Persea americana* Mill) hillside orchard under different groundcover management systems. *Plant Soil* **2013**, *368*, 393–406. [CrossRef]
10. Keesstra, S.; Pereira, P.; Novara, A.; Brevik, E.C.; Azorin-Molina, C.; Parras-Alcántara, L.; Jordán, A.; Cerdà, A. Effects of soil management techniques on soil water erosion in apricot orchards. *Sci. Total Environ.* **2016**, *551–552*, 357–366. [CrossRef]
11. Suzuki, L.E.A.S.; Reisser Júnior, C.; Miola, E.C.C.; Rostirolla, P.; Scherer, V.S.; Terra, V.S.S.; Pauletto, E.A. Efeito do manejo e da irrigação localizada sobre os atributos físicos e hídricos de um Argissolo cultivado com pessegueiro. *Pesqui. Agropecuária Gaúcha* **2021**, *27*, 127–147. [CrossRef]
12. Stark, A.L.; Thorne, D.W. Peach orchard soil management studies. Bulletin No. 330, UAES Bulletins. Paper 291. 1948. Available online: https://digitalcommons.usu.edu/uaes_bulletins/291 (accessed on 28 January 2023).
13. Youlton, C.; Espejo, P.; Biggs, J.; Norambuena, M.; Cisternas, M.; Neaman, A.; Salgado, E. Quantification and control of runoff and soil erosion on avocado orchards on ridges along steep-hillslopes. *Cien. Inv. Agr.* **2010**, *37*, 113–123. [CrossRef]
14. Nunes, M.R.; Karlen, D.L.; Moorman, T.B. Tillage intensity effects on soil structure indicators—A US meta-analysis. *Sustainability* **2020**, *12*, 2071. [CrossRef]
15. Nunes, M.R.; Karlen, D.L.; Veum, K.S.; Moorman, T.B.; Cambardella, C.A. Biological soil health indicators respond to tillage intensity: A US meta-analysis. *Geoderma* **2020**, *369*, 114335. [CrossRef]
16. Castilho, S.C.P.; Cooper, M.; Silva, L.F.S. Micromorphometric analysis of porosity changes in the surface crusts of three soils in the Piracicaba region, São Paulo State, Brazil. *Acta Scientiarum. Agron.* **2015**, *37*, 385–395. [CrossRef]
17. Baumhardt, R.L.; Stewart, B.A.; Sainju, U.M. North American soil degradation: Processes, practices, and mitigating strategies. *Sustainability* **2015**, *7*, 2936–2960. [CrossRef]
18. FAO—Food and Agriculture Organization of the United Nations. *Soil Erosion: The Greatest Challenge to Sustainable Soil Management*; FAO: Rome, Italy, 2019; 100p, Available online: http://www.fao.org/3/ca4395en/ca4395en.pdf (accessed on 25 August 2021).
19. Vicente-Vicente, J.L.; Gómez-Muñoz, B.; Hinojosa-Centeno, M.B.; Smith, P.; Garcia-Ruiz, R. Carbon saturation and assessment of soil organic carbon fractions in Mediterranean rainfed olive orchards under plant cover management. *Agric. Ecosyst. Environ.* **2017**, *245*, 135–146. [CrossRef]
20. Walshl, B.D.; Salmins, S.; Buszard, D.J.; Mackenzie, A.F. lmpact of soil management systems on organic dwarf apple orchards and soil aggregate stability, bulk density, temperature and water content. *Can. J. Soil Sci.* **1996**, *76*, 203–209. [CrossRef]
21. Wade, M.K.; Sanchez, P.A. Mulching and green manure applications for continuous crop production in the Amazon basin. *Agron. J.* **1983**, *75*, 39–45. [CrossRef]
22. Liu, Y.; Wang, J.; Liu, D.; Li, Z.; Zhang, G.; Tao, Y.; Xie, J.; Pan, J.; Chen, F. Straw mulching reduces the harmful effects of extreme hydrological and temperature conditions in citrus orchards. *PLoS ONE* **2014**, *9*, e87094. [CrossRef]
23. Lordan, J.; Pascual, M.; Villar, J.M.; Fonseca, F.; Papió, J.; Montilla, V.; Rufat, J. Use of organic mulch to enhance water-use efficiency and peach production under limiting soil conditions in a three-year-old orchard. *Span. J. Agric. Res.* **2015**, *13*, e0904. [CrossRef]
24. Bakshi, P.; Wali, V.K.; Iqbal, M.; Jasrotia, A.; Kour, K.; Ahmed, R.; Bakshi, M. Sustainable fruit production by soil moisture conservation with different mulches: A review. *Afr. J. Agric. Res.* **2015**, *10*, 4718–4729. [CrossRef]
25. EMBRAPA—Empresa Brasileira de Pesquisa Agropecuária. *UFPEL—Universidade Federal de Pelotas. INMET—Instituo Nacional de Meteorologia. Normais Climatológicas Período: 1971/2000 (Mensal/Anual)*. Available online: http://agromet.cpact.embrapa.br/estacao/mensal.html (accessed on 2 June 2020).
26. Soil Survey Staff. *Keys to Soil Taxonomy*, 12th ed.; USDA-Natural Resources Conservation Service: Washington, DC, USA, 2014; 142p. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/taxonomy/?cid=nrcs142p2_053580 (accessed on 8 December 2021).

27. Santos, H.G.; Jacomine, P.K.T.; Anjos, L.H.; Oliveira, V.A.; Lumbreras, J.F.; Coelho, M.R.; Almeida, J.A.; Araujo Filho, J.C.; Oliveira, J.B.; Cunha, T.J.F. *Sistema Brasileiro de Classificação de Solos*; Embrapa: Brasília, Brasil, 2018; Available online: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/199517/1/SiBCS-2018-pdf (accessed on 29 November 2021)ISBN -9788570358004.
28. Tedesco, M.J.; Gianello, C.; Bissani, C.A.; Volkweiss, S.J. *Análises de Solo, Plantas e Outros Materiais*, 2nd ed.; Departamento de Solos, UFRGS: Porto Alegre, Brazil, 1995; 174p, (Boletim Técnico 5).
29. Gee, G.W.; Or, D. Particle-size analysis. In *Methods of Soil Analysis, Part 4: Physical Methods*, 5th ed.; Dane, J.H., Topp, C., Eds.; Soil Science Society of America: Madison, WI, USA, 2002; pp. 255–293.
30. Suzuki, L.E.A.S.; Reichert, J.M.; Albuquerque, J.A.; Reinert, D.J.; Kaiser, D.R. Dispersion and flocculation of Vertisols, Alfisols and Oxisols in Southern Brazil. *Geoderma Reg.* **2015**, *5*, 64–70. [CrossRef]
31. National Resource Conservation Service-NRCS/United States Department of Agriculture-USDA. Soil texture calculator. 2022. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?cid=nrcs142p2_054167 (accessed on 14 October 2022).
32. Viana, J.H.M.; Teixeira, W.G.; Donagemma, G.K. Densidade de partículas. In *Manual de Métodos de Análise de Solo, ver. ampl.*, 3rd ed.; Teixeira, P.C., Donagemma, G.K., Fontana., A., Teixeira, W.G., Eds.; Embrapa: Brasília, Brazil, 2017; pp. 76–81. Available online: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1085209 (accessed on 15 April 2021).
33. Blake, G.R.; Hartge, K.H. Bulk density. In *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*, 2nd ed.; Klute, A., Ed.; American Society of Agronomy, Soil Science Society of America: Madison, WI, USA, 1986; pp. 363–375. [CrossRef]
34. Klute, A.; Dirksen, C. Hydraulic conductivity and diffusivity: Laboratory methods. In *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*; Klute, A., Ed.; American Society of Agronomy, Soil Science Society of America: Madison, WI, USA, 1986; pp. 687–734.
35. BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Instrução normativa nº 39, de 8 de agosto de 2018. Diário Oficial da União—Seção 1, n. 154, p. 19, 10 de agosto de 2018. Available online: https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/36278414/do1-2018-08-10-instrucao-normativa-n-39-de-8-de-agosto-de-2018-36278366 (accessed on 24 August 2021).
36. EMBRAPA—Empresa Brasileira de Pesquisa Agropecuária/Laboratório de Agrometeorologia. Boletim Climatológico Mensal. Available online: http://agromet.cpact.embrapa.br/online/Resumos_Mensais.htm (accessed on 2 July 2020).
37. SBCS—Sociedade Brasileira de Ciência do Solo. NRS—Núcleo Regional Sul. CQFS—Comissão de Química e Fertilidade do Solo. Manual de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina, 2016; 376p. Available online: http://www.sbcs-nrs.org.br/docs/Manual_de_Calagem_e_Adubacao_para_os_Estados_do_RS_e_de_SC-2016.pdf (accessed on 7 August 2022).
38. Troeh, F.R.; Hobbs, J.Á.; Donahue, R.L. *Soil and Water Conservation for Productivity and Environmental Protection*; Prentice-Hall: Hoboken, NJ, USA, 1980; 718p.
39. Troeh, F.R.; Thompson, L.M. *Solos e Fertilidade do Solo*; Dourado Neto, D.D.; Dourado, M.N., Translators; Organização Andrei Editora Ltda: São Paulo, Brazil, 2007.
40. Tombácz, E.; Libor, Z.; Illés, E.; Majzik, A.; Klumpp, E. The role of reactive surface sites and complexation by humic acids in the interaction of clay mineral and iron oxide particles. *Org. Geochem.* **2004**, *35*, 257–267. [CrossRef]
41. Bronick, C.J.; Lal, R. Soil structure and management: A review. *Geoderma* **2005**, *124*, 3–22. [CrossRef]
42. Wagner, S.; Cattle, S.R.; Scholten, T. Soil-aggregate formation as influenced by clay content and organic-matter amendment. *J. Plant Nutr. Soil Sci.* **2007**, *170*, 173–180. [CrossRef]
43. Reichert, J.M.; Norton, L.D.; Favaretto, N.; Huang, C.; Blume, E. Settling velocity, aggregate stability, and interrill erodibility of soils varying in clay mineralogy. *Soil Sci. Soc. Am. J.* **2009**, *73*, 1369–1377. [CrossRef]
44. Totsche, K.U.; Amelung, W.; Gerzabek, M.H.; Guggenberger, G.; Klumpp, E.; Knief, C.; Lehndorff, E.; Mikutta, R.; Peth, S.; Prechtel, A.; et al. Microaggregates in soils. *J. Plant Nutr. Soil Sci.* **2018**, *181*, 104–136. [CrossRef]
45. Igwe, C.A.; Agbatah, C. Clay and silt dispersion in relation to some physicochemical properties of derived savanna soils under two tillage management practices in southeastern Nigeria. *Acta Agric. Scand. Sect. B-Soil Plant Sci.* **2008**, *58*, 17–26. [CrossRef]
46. Parwada, C.; van Tol, J. Soil properties influencing erodibility of soils in the Ntabelanga area, Eastern Cape Province, South Africa. *Acta Agric. Scand. Sect. B-Soil Plant Sci.* **2017**, *67*, 67–76. [CrossRef]
47. Lunardi Neto, A.; Albuquerque, J.A.; De Almeida, J.A.; Mafra, Á.L.; Medeiros, J.C.; Alberton, A. Atributos físicos do solo em área de mineração de carvão influenciados pela correção da acidez, adubação orgânica e revegetação. *Revista Brasileira de Ciência do Solo* **2008**, *32*, 1379–1388. [CrossRef]
48. Resende, M.; Curi, N.; Rezende, S.B.; Corrêa, G.F. *Pedologia: Base Para Distinção de Ambientes*; UFLA: Lavras, Brazil, 2007; 322p.
49. Ramos, M.M.; Díaz, J.D.G.; Rivas, A.I.M.; Gómez, M.U.; Hernández, B.J.V.; García, P.R.; Asencio, C. Factors that influence soil hydric erosion in a temperate forest. *Rev. Mex. Cienc. For.* **2020**, *11*, 51–71. [CrossRef]
50. Farhan, Y.; Zregat, D.; Nawaiseh, S. Assessing the influence of physical factors on spatial soil erosion risk in Northern Jordan. *J. Am. Sci.* **2014**, *10*, 29–39.
51. Holz, D.J.; Williard, K.W.J.; Edwards, P.J.; Schoonover, J.E. Soil Erosion in Humid Regions: A Review. *J. Contemp. Water Res. Educ.* **2015**, *154*, 48–59. [CrossRef]
52. Shojaei, S.; Kalantari, Z.; Rodrigo-Comino, J. Prediction of factors afecting activation of soil erosion by mathematical modeling at pedon scale under laboratory conditions. *Sci. Rep.* **2020**, *10*, 20163. [CrossRef]

53. Pijl, A.; Reuter, L.E.H.; Quarella, E.; Vogel, T.A.; Tarolli, P. GIS-based soil erosion modelling under various steep-slope vineyard practices. *Catena* **2020**, *193*, 104604. [CrossRef]
54. Suzuki, L.E.A.S.; Matieski, T.; Strieder, G.; Pauletto, E.A.; Bordin, S.S.; Lima, L.S.C.; Collares, G.L.; Dai Prá, M. Perdas de solo por erosão hídrica e granulometria do material erodido em propriedades agrícolas. In *X ENES—Encontro Nacional de Engenharia de Sedimentos: Artigos selecionados, Capítulo X*; Poleto, C., Pletsch, A.L., Mello, E.L., Carvalho, N.O., Eds.; ABRH: Porto Alegre, Brazil, 2012; pp. 93–108.
55. Peng, L.; Tang, C.; Zhang, X.; Duan, J.; Yang, L.; Liu, S. Quantifying the effects of root and soil properties on soil detachment capacity in agricultural land use of Southern China. *Forests* **2022**, *13*, 1788. [CrossRef]
56. Ramos, M.F.; Almeida, W.R.S.; Amaral, R.L.; Suzuki, L.E.A.S. Degree of compactness and soil quality of peach orchards with different production ages. *Soil Tillage Res.* **2022**, *219*, 105324. [CrossRef]
57. Socci, P.; Errico, A.; Castelli, G.; Penna, D.; Preti, F. Terracing: From agriculture to multiple ecosystem services. *Oxf. Res. Encycl. Environ. Sci.* **2019**. [CrossRef]
58. Rutebuka, J.; Uwimanzi, A.M.; Nkundwakazi, O.; Kagabo, D.M.; Mbonigaba, J.J.M.; Vermeir, P.; Verdoodt, A. Effectiveness of terracing techniques for controlling soil erosion by water in Rwanda. *J. Environ. Manag.* **2021**, *277*, 111369. [CrossRef]
59. Pijl, A.; Wang, W.; Straffelini, E.; Tarolli, P. Soil and water conservation in terraced and non-terraced cultivations: An extensive comparison of 50 vineyards. *Land Degrad. Dev.* **2022**, *33*, 596–610. [CrossRef]
60. Rodrigo-Comino, J.; Seeger, M.; Iserloh, T.; González, J.M.S.; Ruiz-Sinoga, J.D.; Ries, J.B. Rainfall-simulated quantification of initial soil erosion processes in sloping and poorly maintained terraced vineyards—Key issues for sustainable management systems. *Sci. Total Environ.* **2019**, *660*, 1047–1057. [CrossRef]
61. Al- Siaede, R. Using Landscape analysis techniques to prevent silt accumulation in the reservoir of the Dwerige weir project and developing River basin, Missan, South Eastern IRAQ. *Iraqi J. Sci.* **2022**, *63*, 3031–3039. [CrossRef]
62. Giambastiani, Y.; Biancofiore, G.; Mancini, M.; Di Giorgio, A.; Riccardo Giusti, R.; Cecchi, S.; Gardin, L.; Errico, A. Modelling the effect of keyline practice on soil erosion control. *Land* **2023**, *12*, 100. [CrossRef]
63. González-Rosado, M.; Parras-Alcántara, L.; Aguilera-Huertas, J.; Lozano-García, B. Soil productivity degradation in a long-term eroded olive orchard under semiarid mediterranean conditions. *Agronomy* **2021**, *11*, 812. [CrossRef]
64. Wang, B.; Niu, J.; Berndtsson, R.; Zhang, L.; Chen, X.; Li, X.; Zhu, Z. Efficient organic mulch thickness for soil and water conservation in urban areas. *Sci. Rep.* **2021**, *11*, 6259. [CrossRef]
65. Lalljee, B. Mulching as a mitigation agricultural technology against land degradation in the wake of climate change. *Int. Soil Water Conserv. Res.* **2013**, *1*, 68–74. [CrossRef]
66. Granatstein, D.; Sánchez, E. Research knowledge and needs for orchard floor management in organic tree fruit systems. *Int. J. Fruit Sci.* **2009**, *9*, 257–281. [CrossRef]
67. Dechen, S.L.F.; Lombardi Neto, F.; Castro, O.M. Gramíneas e leguminosas e seus restos culturais no controle da erosão em Latossolo Roxo. *Revista Brasileira de Ciência do Solo* **1981**, *5*, 133–137.
68. Amado, T.J.C.; Matos, A.T.; Torres, L. Flutuação de temperatura e umidade do solo sob preparo convencional e em faixas na cultura da cebola. *Pesqui. Agropecuária Bras.* **1990**, *25*, 625–631.
69. Sasal, M.C.; Castiglioni, M.G.; Wilson, M.G. Effect of crop sequences on soil properties and runoff on natural-rainfall erosion plots under no tillage. *Soil Tillage Res.* **2010**, *108*, 24–29. [CrossRef]
70. Bertoni, J.; Lombardi Neto, F. *Conservação do Solo*; Ícone: São Paulo, Brazil, 1999; 355p.
71. Pruski, F.F. (Ed.) *Conservação de Solo e Água: Práticas Mecânicas para o Controle da Erosão Hídrica*, 2nd ed.; UFV: Viçosa, Brazil, 2009; 279p.
72. Rio Grande do Sul. Atlas Socioeconômico do Rio Grande do Sul. Clima, temperatura e precipitação. 7th ed., 2022. Available online: https://atlassocioeconomico.rs.gov.br/clima-temperatura-e-precipitacao (accessed on 26 December 2022).
73. Volk, L.B.S.; Cogo, N.P. Relações entre tamanho de sedimentos erodidos, velocidade da enxurrada, rugosidade superficial criada pelo preparo e tamanho de agregados em solo submetido a diferentes manejos. *Revista Brasileira Ciência Solo* **2009**, *33*, 1459–1471. [CrossRef]
74. Suzuki, L.E.A.S.; Bordin, S.S.; Matieski, T.; Rostirolla, P.; Strieder, G.; Nunes, M.R. Soil and nutrient losses by runoff from farmlands in Southern Brazil. *Rev. Ciências Agroambientais* **2021**, *19*, 1–15.
75. Ernani, P.R. *Química do Solo e Disponibilidade de Nutrientes*; O Autor: Lages, Brazil, 2008; 230p.
76. Bucur, D.; Jitareanu, G.; Ailincai, C.; Tsadilas, C.; Ailincai, D.; Mercus, A. Influence of soil erosion on water, soil, humus and nutrient losses in different crop systems in the Moldavian Plateau, Romania. *J. Food Agric. Environ.* **2007**, *5*, 261–264.
77. Martínez-Casasnovas, J.A.; Ramos, M.C. The cost of soil erosion in vineyard fields in the Penedès-Anoia Region (NE Spain). *Catena* **2006**, *68*, 194–199. [CrossRef]
78. Onesimus, S.; Kimaro, D.; Kasenge, V.; Isabirye, M.; Makhosi, P. Soil and nutrient losses in banana-based cropping systems of the Mount Elgon hillsides of Uganda: Economic implications. *Int. J. Agric. Sci.* **2012**, *2*, 256–262.

79. Asfawa, S.; Pallante, G.; Palma, A. Distributional impacts of soil erosion on agricultural productivity and welfare in Malawi. *Ecol. Econ.* **2020**, *177*, 106764. [CrossRef]
80. Telles, T.S.; Dechen, S.C.F.; De Souza, L.G.A.; Guimarães, M.F. Valuation and assessment of soil erosion costs. *Scientia Agricola* **2013**, *70*, 209–216. [CrossRef]