sustainability

MDPI

Article

Mulch and Grass Cover Unevenly Halt Runoff Initiation and Sediment Detachment during the Growing Season of Hazelnut (*Corylus avellana* L.) in Croatia

Manuel Matisic [1], Marko Reljic [2], Ivan Dugan [1], Paulo Pereira [3], Vilim Filipovic [2,4], Lana Filipovic [2], Vedran Krevh [2] and Igor Bogunovic [1,*]

[1] Department of General Agronomy, Division for Agroecology, Faculty of Agriculture, University of Zagreb, 10000 Zagreb, Croatia; mmatisic@agr.hr (M.M.); idugan@agr.hr (I.D.)
[2] Department of Soil Amelioration, Division for Agroecology, Faculty of Agriculture, University of Zagreb, 10000 Zagreb, Croatia; mreljic@agr.hr (M.R.); v.filipovic@uq.edu.au (V.F.); lfilipovic@agr.hr (L.F.); vkrevh@agr.hr (V.K.)
[3] Environmental Management Laboratory, Mykolas Romeris University, LT-08303 Vilnius, Lithuania; paulo@mruni.eu
[4] School of Agriculture and Food Sustainability, The University of Queensland, St Lucia, QLD 4072, Australia
* Correspondence: ibogunovic@agr.hr

Abstract: Hazelnut orchards are popular for cropping on sloped sites, which are often highly erodible. This study aimed to assess the impact of soil management and season in a hazelnut orchard on soil properties and hydrological response. Three treatments (Tilled, Straw, and Grass) were established in Munije (Croatia) on Stagnosol. In Spring, Summer, and Fall, a rainfall simulation was performed (intensity of 58 mm h^{-1} for 30 min). Results reveal higher water stable aggregate values were observed for the Straw treatment in all seasons. Higher soil organic matter (SOM) content was noticed for the Grass treatment in all seasons, while lower values were recorded for the Tilled treatment. Sediment loss in Summer was up to 650% and 1300% higher for the Tilled treatment compared with the Straw and Grass treatments. This study strengthens the comprehension of utilizing a permanent ground cover in hazelnut orchards as a sustainable practice, contributing to the mitigation of soil erosion processes and the improvement of soil properties. The Straw treatment is a viable option since it increases soil stability and SOM, consequently preventing high soil erosion.

Keywords: ground cover; rainfall simulation; hydrological response; permanent plantation; soil management

check for updates

Citation: Matisic, M.; Reljic, M.; Dugan, I.; Pereira, P.; Filipovic, V.; Filipovic, L.; Krevh, V.; Bogunovic, I. Mulch and Grass Cover Unevenly Halt Runoff Initiation and Sediment Detachment during the Growing Season of Hazelnut (*Corylus avellana* L.) in Croatia. *Sustainability* **2023**, *15*, 15200. https://doi.org/10.3390/su152115200

Academic Editor: Teodor Rusu

Received: 13 September 2023
Revised: 14 October 2023
Accepted: 21 October 2023
Published: 24 October 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Soil represents an essential resource to all terrestrial life through numerous functions and ecosystem services [1]. The most crucial role of the soil in ecosystems is food production [2]. In addition, soil regulates and filtrates water, regulates climate, remediates contaminants, controls flooding, erosion, and pests, increases biodiversity, and ensures energy supply [3,4]. Since the human population is growing continuously, so is the need for greater food production. Intensive agricultural production helps to ensure food security. However, it can cause soil degradation [5], i.e., soil/water pollution, soil erosion, loss of organic matter and nutrients, crust formation, soil compaction, salinization and acidification, loss of biodiversity, and greenhouse gas emissions. Soil degradation represents a severe global problem [6], which covers up to 30 percent of the global land area and exposes more than 3 billion people to declining ecosystem services [7]. Establishing soil conservation measures is essential [8,9] to halt and reverse the negative impacts of conventional practices.

Soil erosion by water is the most widespread physical soil degradation process, which covers more than 56% of the total degraded land caused by human activity [10]. Typically,

soil water erosion appears on sloped areas, primarily vineyards and orchards [11]. Agriculture activities like conventional tillage, continuous machinery trafficking, or agrochemicals are the main drivers of soil erosion by water [12,13]. Intensive tillage and the removal of surface cover leads to direct exposure of the soil to external factors and decreases the soil organic matter (SOM). Low SOM content usually deteriorates soils' physical, chemical, and hydraulic properties and increases vulnerability to erosion [14–16], often causing on-site and off-site problems [17,18]. Some on-site problems are reduced soil effective depth, organic matter and nutrient loss, low yield, and poor soil structure [19]. In contrast, flooding and water and soil pollution represent off-site problems on a larger scale [20]. In the long term, degraded areas are abandoned. Therefore, it is crucial to adopt climate and soil-friendly practices to ensure farmers' productivity and income and to mitigate soil erosion and degradation.

Proper soil management, establishment of plant cover, use of different mulches, and reduced machinery trafficking (combined operations) significantly affect soil properties and soil erosion [17,21–23]. In the previous literature, soil water erosion has been measured in various permanent plantations: vineyards, olives, avocados, citrus, almonds, and figs [24–28], while research performed in hazelnut plantations was only recently conducted by Telak et al. [29]. Based on the mentioned research [29], it is not possible to determine a realistic erosion rate through the hazelnut vegetation season, since the study was performed only on one occasion. Furthermore, the research was conducted in one location, so more comparison information must be provided. The European hazelnut (*Corylus avellana* L.) is an important crop in Croatia and worldwide [30], and the areas under cultivation constantly increase over the years. Data from 2021 show that the harvested area in Croatia during the 20 years grew from 147 to 6.710 ha and globally from 506.283 to 1.051.684 ha [31]. Hazelnuts usually cover sloping terrain and require more intensive agrotechnical and pomo-technical care during cultivation, including pruning, multiple plant protection applications, several weed management interventions, and harvest, making it a culture suitable for high soil erosion rates [29].

In this research, three different types of soil management were observed. Tillage is the most common practice used in permanent plantations and a known accelerator of soil erosion, while permanent grass cover and straw mulch are two soil conservation measures. Furthermore, this research is carried out over three seasons to determine which treatment can mitigate the adverse effects of intensive management on soil properties and erosion during the hazelnut growing season. Usually, measurements during several seasons in rainfall simulation experiments are missing [11,17,23,24,29] and are often identified as a study limitation, supporting present work as novel and justified. We hypothesize that soil tillage will degrade soil physical properties and enhance the overland flow, while permanent grass cover conserves the soil and water and enhances structure stabilization. Moreover, the straw treatments with surface cover will mitigate the soil erosion but will have lower soil quality in addition to grass treatment. This research aims to expand knowledge about soil erosion in hazelnut plantations and find an adequate measure for its mitigation with a favorable long-term impact on soil properties and hazelnut plantations. Moreover, there are three specific objectives of this paper: (1) to evaluate the impact of various management practices in hazelnut orchards on soil properties, considering different seasons; (2) to identify the most effective sustainable soil management practice for permanent plantation; and (3) to establish a relationship between the soil properties and hydrological response.

2. Materials and Methods

2.1. Study Area and Climate

The study was carried out in central Croatia (Munije: 45°68′ N; 17°29′ E, 296 m a.s.l) in a hazelnut orchard (Figure 1) at an average elevation of 185 m a.s.l and an average slope of 10%. The orchard was planted with a spacing of 5 m between rows and 4 m within rows. The landscape of the studied area was dominantly hilly. The parent material is loess, while the

soil is classified as Stagnosol [32]. According to Köppen climate classification, the climate is moderate continental with a Cfwbx description. The annual precipitation (2020) was 856.6 mm (Figure 2), ranging from a minimum of 11.9 mm (April) to a maximum of 158.1 mm (October). The mean annual temperature for 2020 was 12.1 °C, where January is the coldest (0.7 °C) and August is the warmest (22.3 °C) [33]. Cropland is the dominant land use in this region. However, vineyards and orchards cover the slopes in the study area.

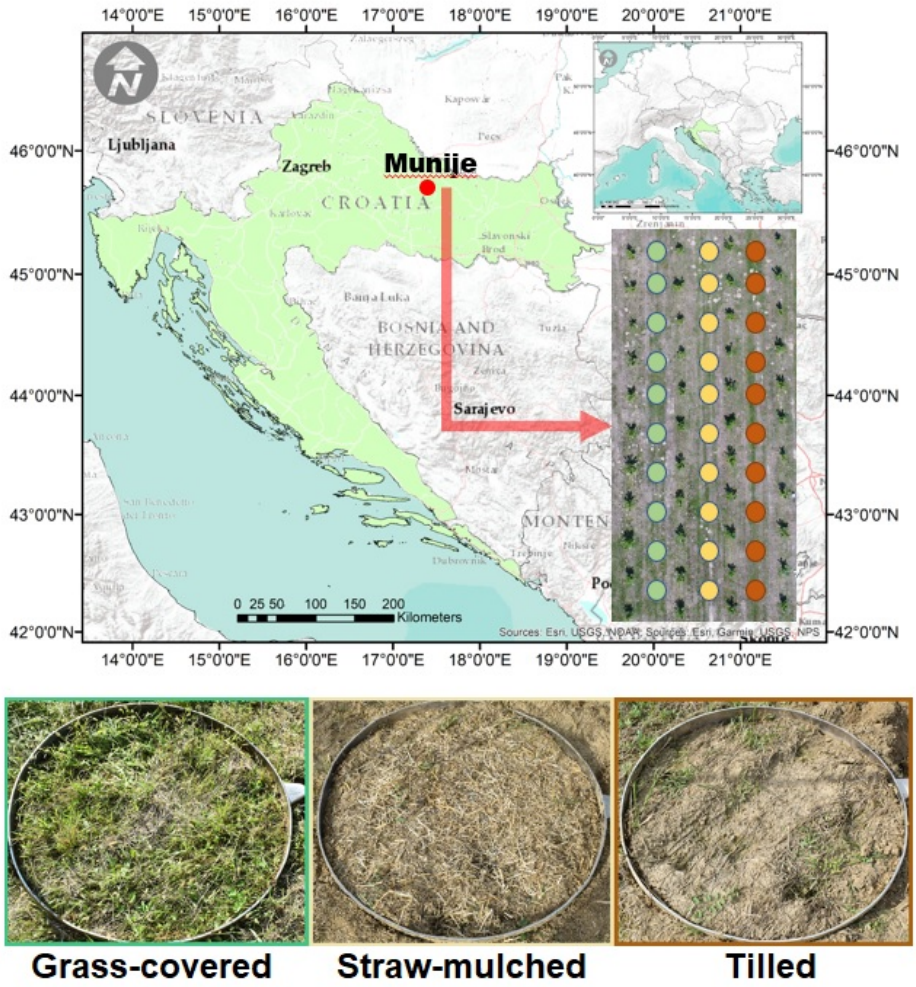


Figure 1. Study site and treatments. Green, yellow and red dots indicate positions of rainfall simulations for grass covered, straw-mulched and tilled plots, respectively.

2.2. Fieldwork

Three different treatments were studied at the location: grass-covered hazelnut orchard (Grass)—natural grass cover; tilled hazelnut orchard (Tilled)—tillage was conducted four times during the experiment (with the use of rotary tiller); and Straw mulched hazelnut orchard (Straw)—Straw was applied every time before the rainfall experiment was conducted at a dosage of 2.5 t ha^{-1}. The grass-covered treatment was mowed five times per year. Each treatment represents an interrow with a length of 40 m. Ten plots were selected for each treatment to conduct the rainfall simulation experiment and to sample the soil using core and additional undisturbed samples. A paired plot strategy was used to ensure similar geomorphological conditions. Ten rainfall simulations with a ring-to-ring distance of approximately 3 m were performed in every treatment. Rainfall simulation experiments were carried out during Spring, Summer, and Fall. In total, 90 rainfall simulation experiments were carried out (3 seasons × 3 treatments × 10 repetitions). Over each plot, a rainfall simulator (UGT Rainmaker, Müncheberg, Germany) [34] was placed to ensure a rainfall at 58 mm h^{-1}

for 30 min. Each plot was enclosed by a metal ring (1 m diameter; 0.785 m^2). Before each simulation started, soil core samples (0–10 cm) and undisturbed soil samples (0–10 cm) were collected near the metal ring to determine soil properties. After the rainfall simulation started, the plastic canisters were connected to the faucet on the metal ring to catch the overland flow. Time to ponding (TP) and time to runoff (TR) were measured with a chronometer (CASIO HS-6-1EF chronometer, Tokyo, Japan) during the simulation.

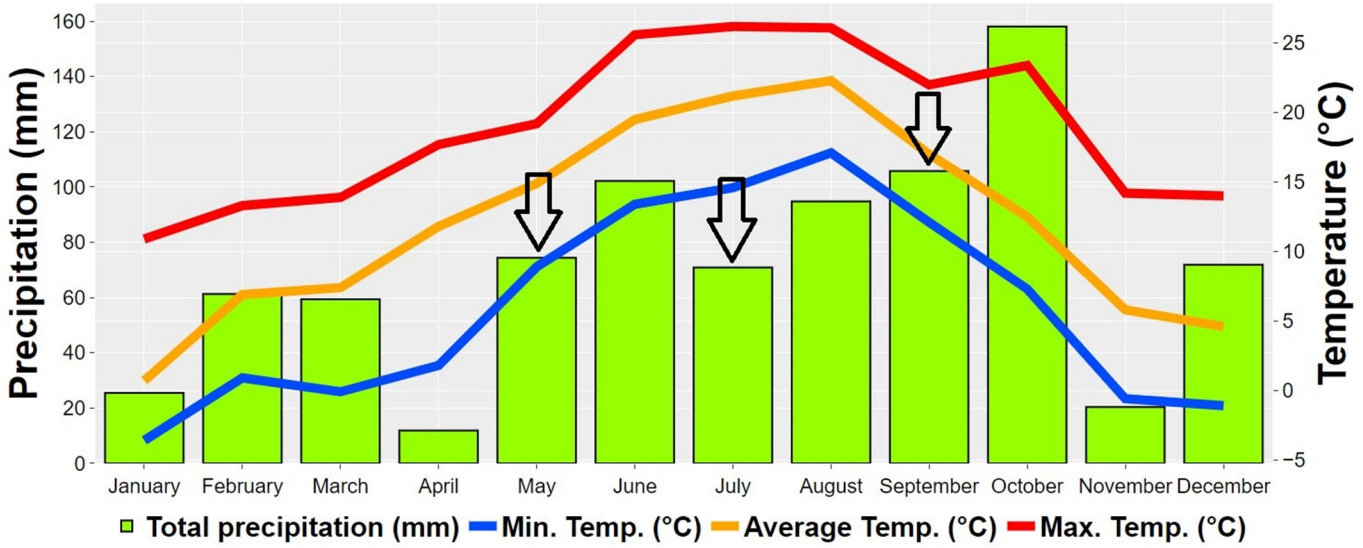


Figure 2. Monthly precipitation and temperature throughout the time of experimenting. The arrows indicate the time when the measurements were conducted.

2.3. Laboratory Work

Bulk density (BD) and soil water content (SWC) were determined using soil core samples. Weighing was carried out before and after capillary wetting and after drying at 105 °C for 48 h, after which they were calculated according to the gravimetric method:

$$\text{BD} = \text{dry sample}/\text{soil volume} \quad (1)$$

$$\text{SWC} = \left(\frac{\text{sample with field water content} - \text{dry sample}}{\text{soil volume}}\right) \times 100 \quad (2)$$

Undisturbed soil samples were prepared by hand, following the method of Diaz-Zorita et al. [35]. Samples were air dried for one week in the laboratory at room temperature (25 °C) and dry sieved in a sieve shaker for 30 s [36] to obtain particular aggregate size fractions (<0.25, 0.25–0.5, 0.5–1.0, 1.0–2.0, 2.0–4.0, 0.4–0.5, and 0.5–0.8 mm) and calculate mean weight diameter (MWD) using the following formula for calculation after weighting each aggregate size:

$$\text{MWD} = \sum_{i=1}^{n} \text{xi} \times \text{wi} \quad (3)$$

where xi is the mean diameter of any particular size range of aggregates separated by sieving, and wi is the weight of aggregates in that size range as a fraction of the total dry weight of soil used. Eijkelkamp's wet sieving method derived from Kemper and Rosenau [37] was used to determine water-stable aggregates (WSA) with Eijkelkamp's wet sieving apparatus on all previously dry sieved samples in the particle size range 1.0–2.0 mm. The percentage of WSA was calculated with the following equation:

$$WSA = \frac{\text{Wds}}{\text{Wds} + \text{Wdw}} \times 100 \quad (4)$$

where WSA is the percentage of stable water aggregates, Wds is the weight of aggregates dispersed in dispersing solution (g), and Wdw is the weight of aggregates dispersed in distilled water (g).

Sediment yield was determined after air drying at room temperature (25 °C) for two weeks and the weighting of the filter paper. Sediment concentration (SC) was calculated by dividing the sediment mass by the overland flow mass. The mass of the sediment loss (SL) was given from the mass of overland flow to obtain the runoff [24]. After determining MWD and WSA, all the undisturbed samples were milled and sieved through a 2 mm sieve so the samples could be prepared to determine SOM following the digestion method of Walkley and Black [38].

2.4. Statistical Analysis

Before further data analysis could be performed, the Shapiro–Wilk test ($p > 0.05$) was used to assess the normality of the data and homogeneity of variances. Since some variables did not follow the normal distribution (except for BD and WSA), some were normalized with SQRT, natural logarithm, and Box–Cox transformations (SOM, TR, SWC, SC). The two-way ANOVA and Kruskal–Wallis tests (MWD, TP, runoff, and SL) were performed to assess the impact of soil management and season on soil properties and soil hydrological response. For results that did not show significant differences at a $p < 0,05$, Tukey's LSD post hoc test was performed. Based on the correlation matrix, principal component analysis (PCA) was applied to determine the association between variables. For this purpose, were used Box–Cox transformed data. Data analyses were carried out using Statistica 12.0 [39] for MS Windows. Figures were drawn with Plotly [40]. The original data set was used to create all tables and graphs.

3. Results

3.1. Soil Properties

The statistical analysis showed a significant difference in BD for the Tilled and Straw treatment, where lower values were observed during Spring than in Summer and Fall. Unlike the Tilled and Straw treatments, the Grass treatment showed no significant differences for BD across seasons (Table 1). As for differences in season, significantly higher BD values were recorded for the Grass treatment during Spring compared to Tilled and Straw. BD did not differ between the treatments in Summer and Fall, although the Grass recorded the highest compaction level. The SWC values for the Grass treatment were significantly lower in Summer compared to Spring, while the values in Fall did not differ significantly from those observed in Summer and Spring. Significant differences in SWC values between treatments were observed only in Summer, where the Grass treatment had significantly lower values than Straw.

Table 1. Results of two-way ANOVA analysis considering soil properties (mean ± standard error). Different letters after mean values in the columns represent significant differences at $p < 0.05$. Capital letters show statistical differences in treatment between seasons. Lowercase letters show statistical differences between treatments in season. Abbreviations: BD, bulk density, SWC, soil water content, MWD, mean weight diameter, SOM, soil organic matter.

Treatment × Season	BD (g cm^{-3})	SWC (%)	MWD (mm)	WSA (%)	SOM (%)
Tilled (Spring)	1.08 ± 0.30 Bb	29.69 ± 1.93 Aa	3.67 ± 0.53 Aa	66.27 ± 1.46 Ab	1.81 ± 0.46 Aa
Straw (Spring)	1.09 ± 0.31 Bb	28.58 ± 1.89 Aa	3.45 ± 0.55 Aa	75.67 ± 2.22 Aa	1.80 ± 0.44 Aa
Grass (Spring)	1.49 ± 0.26 Aa	31.86 ± 1.76 Aa	3.52 ± 0.41 Aa	67.12 ± 1.99 Ab	1.95 ± 0.35 Aa
Tilled (Summer)	1.37 ± 0.32 Aa	30.35 ± 2.18 Aab	2.78 ± 0.47 Bb	61.21 ± 1.62 ABb	1.50 ± 0.48 Ab
Straw (Summer)	1.33 ± 0.29 Aa	30.86 ± 1.42 Aa	2.8 ± 0.38 ABb	71.82 ± 2.22 Ba	1.91 ± 0.44 Aa
Grass (Summer)	1.44 ± 0.34 Aa	25.31 ± 1.89 Bb	3.53 ± 0.43 Aa	63.39 ± 2.03 Ab	2.08 ± 0.52 Aa
Tilled (Fall)	1.29 ± 0.34 Aa	31.92 ± 1.50 Aa	2.68 ± 0.50 Bb	59.32 ± 1.96 Bb	1.42 ± 0.53 Ab
Straw (Fall)	1.32 ± 0.34 Aa	32.21 ± 1.22 Aa	2.59 ± 0.61 Bb	69.47 ± 1.74 Ba	1.83 ± 0.61 Aab
Grass (fall)	1.36 ± 0.25 Aa	29.25 ± 2.23 ABa	3.49 ± 0.38 Aa	68.63± 2.10 Aa	1.93 ± 0.76 Aa

Statistical analysis showed significantly higher MWD values for the Tilled treatment in Spring compared to Summer and Fall. Straw treatment showed significantly lower MWD values in Fall than in Spring (Table 1). The highest MWD value in Spring was for the Tilled treatment, which was followed by the Grass treatment and the Straw treatment. During Summer, MWD values were significantly higher in the Grass treatment compared to Tilled and Straw. The same pattern was noticed in the Fall (Table 1). The WSA values for the Tilled treatment were significantly lower in the Fall than in the Spring. Straw treatment showed significantly lower WSA values during Fall and Summer compared to Spring. As for intra-seasonal differences, the Straw treatment had significantly higher WSA values across all seasons than the Tilled and Grass treatments (Table 1).

SOM did not show significant differences in treatment through the seasons (Table 1). During the Summer, Straw and Grass treatments had significantly higher SOM values than the Tilled treatment. The Grass treatment in Fall had a significantly higher SOM value compared to the Tilled.

3.2. Hydrological Properties

Soil hydrological response showed significant differences for treatment and season (Table 2). Time to ponding values for the Tilled and Straw treatments were the lowest in Fall and the highest in Spring, and there were no statistically significant differences among seasons. Grass treatment also shows the highest TP value in Spring, which is significantly higher than in Fall. Between treatments, in the Fall, the TP value is significantly lower in the Grass treatment compared to the other two treatments. Straw treatment had a significantly higher value of TR in Spring than in Fall, while Grass treatment showed significantly lower values for TR in Fall compared to Summer and Spring. Tilled and Straw treatment during all seasons showed significantly higher TR values than Grass treatment. Furthermore, Straw treatment in all seasons had the highest values for TR (Table 2). Runoff did not show significant differences for any treatment during the seasons, while significant differences between the treatments occurred in each season. The Grass treatment in Spring had significantly higher runoff values compared to the Tilled and Straw treatments. Significantly higher runoff values were observed in the Grass treatment in Summer and Fall compared to the Straw treatment. Sediment concentration for the Tilled treatment was significantly higher in Summer compared to Spring. Straw treatment recorded a significantly lower SC during Spring than in other seasons. The SC values in the Grass treatment increased from Spring to Fall, and no significant differences in results were recorded between seasons. In Spring, the lower SC value was in the Grass treatment compared to the tilled, while the Straw treatment did not show a significant difference compared to the other two. During the Summer, there was a significant difference between all three treatments. The tilled treatment recorded the highest value of SC, which was followed by the Straw and Grass treatment. Sediment loss for the Tilled treatment was significantly higher in the Summer and Fall periods than in Spring. The Straw treatment followed the same pattern as Tilled, with the highest value of SL in Summer and the lowest in Spring. SL values increased from Spring to Fall for Grass treatment, and no significant difference existed between seasons (Table 2).

Table 2. Results of two-way ANOVA analysis considering hydrological properties (mean ± standard error). Different letters after mean values in the columns represent significant differences at $p < 0.05$. Capital letters show statistical differences in treatment between seasons. Lowercase letters show statistical differences between treatments in season. Abbreviations: TP, time to ponding; TR, time to runoff; SC, sediment concentration; SL, sediment loss.

Treatment × Season	TP (s)	TR (s)	Runoff (m^3 ha^{-1})	SC (g kg^{-1})	SL (kg ha^{-1})
Tilled (Spring)	192 ± 7.87 Aa	582 ± 12.24 Aa	19.71 ± 3.63 Ab	4.86 ± 1.56 Ba	87.15 ± 7.81 Ba
Straw (Spring)	288 ± 15.37 Aa	996 ± 20.51 Aa	2.47 ± 1.63 Ab	2.96 ± 1.81 Bab	11.97 ± 4.22 Ba
Grass (Spring)	198 ± 9.22 Aa	348 ± 8.89 Ab	160.24 ± 4.42 Aa	0.73 ± 0.62 Ab	118.08 ± 8.26 Aa

Table 2. *Cont.*

Treatment × Season	TP (s)	TR (s)	Runoff (m^3 ha^{-1})	SC (g kg^{-1})	SL (kg ha^{-1})
Tilled (Summer)	144 ± 7.11 Aa	462 ± 12.45 Aa	90.15 ± 5.77 Aab	18.79 ± 2.25 Aa	1742.84 ± 29.99 Aa
Straw (Summer)	180 ± 8.32 Aa	606 ± 10.71 ABa	45.78 ± 6.09 Ab	5.64 ± 1.25 Ab	268.4 ± 15.15 Aab
Grass (Summer)	120 ± 5.32 ABa	342 ± 9.22 Ab	159.31 ± 6.63 Aa	0.83 ± 0.54 Ac	133.2 ± 8.52 Ab
Tilled (Fall)	120 ± 7.00 Aa	444 ± 12.77 Aa	70.64 ± 6.15 Aab	11.57 ± 2.93 ABa	850.23 ± 25.94 Aa
Straw (Fall)	156 ± 8.02 Aa	484 ± 12.77 Ba	35.75 ± 6.83 Ab	11.53 ± 4.43 Aa	204.07 ± 15.65 Aa
Grass (Fall)	86 ± 6.87 Ba	225 ± 11.25 Bb	194.62 ± 6.41 Aa	2.67 ± 2.48 Ab	406.42 ± 29.30 Aa

3.3. Principal Component Analysis

The PCA revealed two major factors that explain 51.45% of the total variance: Factor 1—27.30% and Factor 2—24.16%. Figure 3 shows the projection of the variables for the relation between two major factors. Factor 1 showed a strong negative connection between BD and runoff with TP, TR, and WSA. While Factor 2 explains a positive relation between SC and SL, there is also a negative correlation between SOM and MWD with SWC (Figure 3). Differences are more clearly distinct for treatments than for seasons. The Tilled treatment is more closely related to negative variables, such as SC and SL.

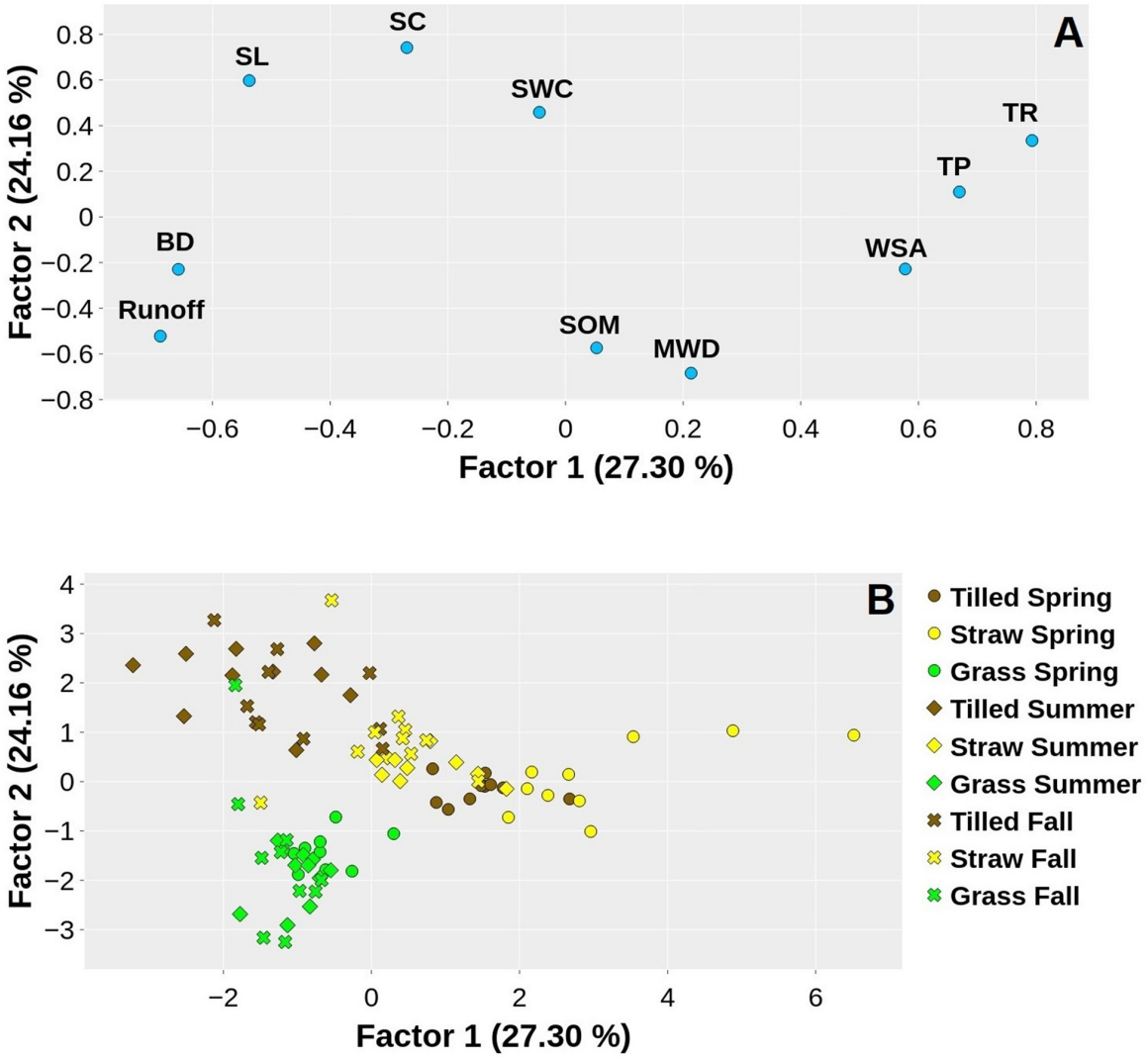


Figure 3. Relation between Factors 1 and 2 (**A**) variables and (**B**) cases. Bulk density (BD); soil water content (SWC); mean weight diameter (MWD); water stable aggregates (WSA); time to ponding (TP); time to runoff (TR); sediment concentration (SC); sediment loss (SL).

4. Discussion

4.1. Soil Properties

The higher BD values were recorded for the Grass treatment compared to Tilled and Straw in all seasons. This behavior was expected, since tillage was conducted for the Tilled and Straw treatment. Tillage loosens the topsoil layer and modifies soil structure [21,41], while greater compaction for the Grass treatment occurs due to natural settling and machinery trafficking, as observed previously [42–45]. There were no differences in SWC in Spring due to similar conditions between the treatments since the tillage and straw application were carried out where Grass was grown. In the Summer and Fall periods, lower SWC values were recorded for the Grass treatment compared to Tilled and Straw. This could be explained by high rainfall throughout the vegetation season (Figure 2), which ensures high SWC in all treatments. Partial consumption of SWC for the Grass treatment decreases the moisture in addition to other treatments. In this context, the Tilled and Straw treatments did not have vegetation consumption of water, while straw application additionally conserved soil moisture [46,47] through the high-temperature period in Summer and early Fall (Figure 2). Although SWC differences in treatments occur, the high SWC enables hazelnut water needs.

The MWD in Summer and Fall recorded higher values for the Grass treatment compared to Tilled and Straw due to (1) higher machinery-induced compaction [48,49], (2) absence of tillage for the Grass treatment, and (3) short period of straw decomposition to affect soil aggregation [50]. The Tilled and Straw treatment recorded higher MWD values in Spring than in Summer and Fall because of (1) frequent tillage events for the Tilled treatment later in the season [51], (2) lack of time for the soil to form aggregates [21], and (3) straw application, which enabled natural conditions to affect the soil, because the straw layer served as a physical barrier [52]. The Grass treatment did not show any significant differences in all seasons since the grass cover is well known for its established root system, which will contribute to stable aggregates by promoting root growth and the secretion of organic compounds [53,54]. The WSA in Spring and Summer recorded significantly lower values for the Tilled and Grass treatment. As Straw protects against the impact of raindrops, preventing soil particles from being dislodged and reducing soil crusting [55], it contributes to preserving soil aggregates. Likely, this affected the higher WSA values observed in the Straw treatment. As the SWC data highlight, the straw cover shields the soil from direct sunlight and wind, reducing the evaporation rate. This helps maintain a more consistent moisture content in the soil [56], supporting aggregate stability. Moreover, the straw cover creates a conducive environment for root growth [57], which aids in binding soil particles and enhancing aggregate stability. In Fall, lower values of WSA were noticed for the Tilled treatment compared to Straw and Grass. This pattern follows the values of SOM in that period, since SOM is most responsible for binding soil particles into larger and more stable aggregates [58]. Tilled treatment through seasons recorded lower WSA values in Fall, when the effect of frequent tillage was noticeable, because of soil disturbance and air exposure, which led to a decrease in SOM, thus directly affecting aggregate stability [59]. The Grass treatment showed no significant differences for WSA between seasons, since the permanent grass cover and well-developed root system secured aggregate stability through seasons. This is achieved when the root system binds soil particles together, thus enhancing aggregate stability [60]. On the other hand, grass plants shed organic material through roots, shoots, fallen leaves, and mowed grass, so this organic matter serves as a food resource for microorganisms. This activity will produce a substance that acts as natural glue that binds soil particles into aggregates [61]. In Summer and Fall, the Tilled treatment had lower SOM values than Grass and Straw, as observed elsewhere [62–66]. This phenomenon occurred due to (1) accelerated decomposition under high oxygen levels [67], (2) disruption of soil structure due to constant tillage events [58,68], and (3) a lack of vegetation cover, which plays a vital role in protecting the soil from erosion (loss of SOM by erosion) [69,70]. The Tilled treatment has higher SOM values in Spring than in other seasons, which is very likely

due to soil loss between investigated periods, as presented in Table 2. Also, organic matter mineralization can explain lower SOM values in later periods [71].

4.2. Hydrological Response

The Tilled and Straw treatment did not have any significant differences in TP between seasons because of the lower soil compaction, thus increasing the infiltration rate due to frequent tillage [45,72] and straw application, which served as a physical barrier, thus slowing the formation of surface ponds [52]. Time to runoff was low in the Grass treatment through all three seasons, as noted in other works [73–75]. The TR values were slightly higher for the Straw treatment than for the Tilled treatment during each season. So, the straw application contributed to reducing TR, as it served as a surface cover that acted as a physical barrier between raindrop impact and soil surface cover [76,77]. Straw, like grass, also absorbs moisture, thus postponing surface runoff [78]. The Tilled treatment recorded no significant differences between seasons for TR. In contrast, the Straw treatment had higher TR values in Spring because the first straw application successfully reduced TR. Later in the season, during Summer, Straw was slowly incorporated into the soil surface, thus losing its initial capability of reducing TR [79]. In Fall, TR was significantly lower on the Straw treatment compared to other seasons since (1) the Straw decomposed in time, thus increasing TR, (2) vegetation growth in Fall was lower and made soil prone to erosion [80], and (3) the absence of Straw contributed to crusting during the Fall period; because of decomposition, it can lose its protective qualities and transform into small particles that can clog soil pores [81]. The Grass treatment showed higher TR values in Spring and Summer than in Fall, which are also affected by mowing and the higher surface cover. At the same time, there was no additional cover in Fall, and regular vegetation growth was lower than in Spring and Summer. The runoff followed the behavior of TR. In every season, higher runoff was recorded for the Grass treatment compared to Tilled and Straw. This is attributed to several reasons: (1) higher compaction for the Grass treatment [82,83], (2) lack of surface roughness for the Grass treatment [84], and (3) the Straw treatment had a mulching effect [77,85]. Sediment concentration recorded significantly lower values for the Grass treatment since grass decreases sediment detachment during rainfall because of greater soil structure and a developed root system, which holds the soil particles bonded through root exudates [86,87]. Higher values of SC for the Tilled treatment occur primarily due to tillage, which decreases soil size particles and makes them more prone to soil erosion [88]. The Straw treatment recorded lower SC in Spring and Summer than in Fall due to losing the straw capability through the season and its incorporation into the soil surface [89]. An increase in SC for the mulched treatment is possible when the finer mulch particles are easily transferable during rainfall [90].

In the Summer, a higher SL was identified in the Tilled treatment than in Grass and Straw. This was due to the low SOM, which helps bind soil particles, making them more stable [91,92], and the lower surface roughness because of recent tillage events [88,93]. The Tilled treatment had a significantly lower SL in Spring than in Summer and Fall due to the freshly tilled soil surface, higher infiltration rate, and lower soil compaction [13]. Similar results were found for the Straw treatment, where higher SL was noticed in Summer and Fall when the straw application was insufficient to mitigate soil erosion processes and because of straw incorporation into the soil surface [52,78]. The Grass treatment showed no statistical differences for SL during all three seasons, with a slight increase in Fall, which was probably due to mowing grass residues, which ended up in the overland flow.

4.3. Interrelations between Properties

The PCA results showed that lower soil compaction leads to postponed pond forming on the soil surface layer and the start of the Runoff, which was also observed previously [94–97]. Moreover, the WSA showed a positive relation with TP and TR because of (1) WSA's capability to create channels within the soil that will enable water to infiltrate and move down the soil profile, which will improve the soil's ability

to store more water, thus reducing the water available for runoff [98,99], (2) higher aggregate stability will prevent crusting, since the soil particles are bounded into aggregates that are less prone to soil detachment during the raindrop impact [97,100], and (3) well-aggregated soil had a rougher surface texture due to the presence of clumps and particles, which will enlarge the surface area for rainfall catchment [101]. Another positive correlation was observed between BD and runoff, which can be associated with the previously mentioned statement that BD directly affects TP and TR. Due to higher soil compaction, there will be more time to produce the overland flow, which will enlarge the final amount [102,103]. The BD decreases porosity, resulting in limited storage capacity and lower infiltration capacity [104,105]. Furthermore, compacted soils are more prone to soil crust formation, thus enabling the rainfall drop impact to initiate soil detachment [106,107].

Factor 2 explains a positive relation between MWD and SOM. Soil organic matter acts as a binding agent that holds the soil particles together in aggregates [58,108,109]. Larger aggregates created through organic matter enhanced aggregation and will increase the pore space in the soil, thus enabling water to infiltrate and move through the soil [110,111]. A strong positive relation occurred between SC and SL, meaning SL is directly influenced by the amount of sediment in the overland flow [112,113]. In the case of this study, this statement could not be completely applicable because the Grass treatment in Spring recorded higher SL than the other two treatments, therefore not having the highest SC under higher runoff rates (Table 2). Similar findings were observed in Römkens et al. [93]. Finally, a positive correlation was observed between SWC, SC, and SL. This relation was expected because higher SWC will lead to pore clogging, thus decreasing the soil infiltration capacity [113]. On the other hand, it will also expedite the time to runoff, thereby increasing overland flow mass and with that increasing SL. Another vital thing to mention is the SWC's effect on hydraulic conductivity, where wetter soil can lead to rapid surface runoff, carrying away more sediment than in drier conditions [113].

This research yields valuable insight with significant implications and recommendations that can arise from it. However, some issues need to be mentioned. The timing of practices should be considered since the research showed the effectiveness of grass cover use, and as such, it could be crucial to emphasize and maintain the grass cover before the rainy season starts. Long-term research is necessary to obtain more appropriate information for identifying the practices that offer the most effective protection against soil loss. With that in mind, implementing practices that enhance soil structure to mitigate erosion must be broadened and applicable to this location and other endangered areas. Further investigation of the impacts of conservation practices is recommendable to minimize erosion events, thus mitigating sediment transport, which can lead to the pollution of soil and waterways. These practices must be emphasized long term to contribute to soil health, erosion prevention, and environmental conservation. Unfortunately, the rainfall simulator has shortcomings, such as a need for standardized methods and equipment. An experiment conducted on a small-scale area is unsuitable for large-scale modeling and needs to provide accurate data under natural climate conditions. One of the essential things that needs to be mentioned is the use of surface cover, whether it will be a permanent cover or just a temporal cover such as Straw. Straw use will mimic permanent grass cover in some percentage. However, its most significant advantage lies in its availability, cost-effectiveness, and immediate soil conservation, thus enhancing soil properties and hydrological response.

5. Conclusions

This study presented significant results regarding how different soil management and seasons affect soil properties and hydrological response. The Grass treatment was the most sustainable, as it enhanced soil properties, such as increasing SOM and WSA while decreasing BD, and effectively mitigated erosion processes to the bare minimum. Conversely, the Tilled treatment exhibited shortcomings, disrupting soil properties by decreasing MWD, SOM, and WSA while increasing runoff, SC, and SL. Meanwhile, the Straw treatment showcased its positive aspects, notably improving

soil properties by decreasing BD, increasing WSA and SOM, and having a beneficial impact on mitigating sediment movement downslope. The primary seasonal effect was observed in the hydrological response, with higher TR and TP in Spring and increased runoff rates, SC and SL in Fall across treatments. Conservation management must be deeply implemented into agricultural practices since it can reduce and slow down further degradation processes in endangered areas, such as permanent plantations characterized by wide rows and lack of surface cover, as a weeding practice. The Grass and Straw treatments demonstrated their sustainable and dependable practices, enhancing soil properties and minimizing potential degradation in hazelnut plantations.

Author Contributions: Conceptualization, I.B. and P.P.; methodology, I.B., I.D. and P.P.; software, M.M., I.D. and I.B.; validation, M.M., M.R., I.D., P.P., V.F., L.F., V.K. and I.B.; formal analysis, I.B., M.M. and I.D.; investigation, I.B. and I.D.; resources, I.B.; data curation, I.D.; writing—original draft preparation, M.M. and I.D.; writing—review and editing, M.M., M.R., I.D., P.P., V.F., L.F., V.K. and I.B.; visualization, M.M. and I.D.; supervision, I.B. and P.P.; project administration, I.B.; funding acquisition, I.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Croatian Science Foundation through the "Soil erosion and degradation in Croatia" project (UIP-2017-05-7834) (SEDCRO).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on reasonable request from the corresponding author.

Acknowledgments: The authors are grateful for the support of Family Farm Reljić.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the result.

References

1. Lal, R. Climate Change and Soil Degradation Mitigation by Sustainable Management of Soils and Other Natural Resources. *Agric. Res.* **2012**, *1*, 199–212. [CrossRef]
2. Moinet, G.Y.K.; Hijbeek, R.; van Vuuren, D.P.; Giller, K.E. Carbon for soils, not soils for carbon. *Glob. Chang. Biol.* **2023**, *29*, 2384–2398. [CrossRef]
3. Greiner, L.; Keller, A.; Grêt-Regamey, A.; Papritz, A. Soil function assessment: Review of methods for quantifying the contributions of soils to ecosystem services. *Land Use Policy* **2017**, *69*, 224–237. [CrossRef]
4. Bogunović, I.; Hrelja, I.; Kisić, I.; Dugan, I.; Krevh, V.; Defterdarović, J.; Filipović, V.; Pereira, P. Straw Mulch Effect on Soil and Water Loss in Different Growth Phases of Maize Sown on Stagnosols in Croatia. *Land* **2023**, *12*, 765. [CrossRef]
5. Wang, J.; Zhen, J.; Hu, W.; Chen, S.; Lizaga, I.; Zeraatpisheh, M.; Yang, X. Remote sensing of soil degradation: Progress and perspective. *Int. Soil Water Conserv. Res.* **2023**, *11*, 429–454. [CrossRef]
6. Kertész, A. The global problem of land degradation and desertification. *Hung. Geogr. Bull.* **2009**, *58*, 19–31. Available online: https://ojs.mtak.hu/index.php/hungeobull/article/view/3131 (accessed on 1 September 2023).
7. Weng, X.; Zhang, B.; Zhu, J.; Wang, D.; Qiu, J. Assessing Land Use and Climate Change Impacts on Soil Erosion Caused by Water in China. *Sustainability* **2023**, *15*, 7865. [CrossRef]
8. Bogunović, I.; Filipović, V. Mulch as a nature-based solution to halt and reverse land degradation in agricultural areas. *Curr. Opin. Environ. Sci. Health* **2023**, *34*, 100488. [CrossRef]
9. Francaviglia, R.; Almagro, M.; Vicente-Vicente, J.L. Conservation Agriculture and Soil Organic Carbon: Principles, Processes, Practices and Policy Options. *Soil Syst.* **2023**, *7*, 17. [CrossRef]
10. Oldeman, L.R. Global extent of soil degradation. In *Bi-Annual Report 1991–1992/ISRIC*; ISRIC: Wageningen, The Netherlands, 1992; pp. 19–36.
11. Rodrigo-Comino, J.; Martínez-Hernández, C.; Iserloh, T.; Cerda, A. Contrasted impact of land abandonment on soil erosion in Mediterranean agriculture fields. *Pedosphere* **2018**, *28*, 617–631. [CrossRef]
12. Nacinovic, M.G.G.; Mahler, C.F.; Avelar, A.d.S. Soil erosion as a function of different agricultural land use in Rio de Janeiro. *Soil Tillage Res.* **2014**, *144*, 164–173. [CrossRef]
13. Dugan, I.; Bogunovic, I.; Pereira, P. Soil management and seasonality impact on soil properties and soil erosion in steep vineyards of north-western Croatia. *J. Hydrol. Hydromech.* **2023**, *71*, 91–99. [CrossRef]
14. Blanco-Canqui, H.; Lal, R. *Principles of Soil Conservation and Management*; Springer: Dordrecht, The Netherlands, 2008.

15. Bogunovic, I.; Fernández, M.P.; Kisic, I.; Marimón, M.B. Agriculture and grazing environments. In *Advances in Chemical Pollution, Environmental Management and Protection*, 4th ed.; Pereira, P., Ed.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 23–70. [CrossRef]
16. Zhang, J.H.; Nie, X.J.; Su, Z.A. Soil profile properties in relation to soil redistribution by intense tillage on a steep hillslope. *Soil Sci. Soc. Am. J.* **2008**, *72*, 1767–1773. [CrossRef]
17. Telak, L.J.; Pereira, P.; Bogunovic, I. Soil degradation mitigation in continental climate in young vineyards planted in Stagnosols. *Int. Agrophysics* **2021**, *35*, 307–317. [CrossRef]
18. Lal, R. Soil erosion and the global carbon budget. *Environ. Int.* **2003**, *29*, 437–450. [CrossRef]
19. Pimentel, D. Soil Erosion: A Food and Environmental Threat. *Environ. Dev. Sustain.* **2006**, *8*, 119–137. [CrossRef]
20. Favis-Mortlock, D. Water erosion. In *Encyclopedia of Soil Science*, 3rd ed.; Lal, R., Ed.; CRC Press: Boca Raton, FL, USA, 2017; pp. 2485–2488.
21. Bogunovic, I.; Pereira, P.; Kisic, I.; Sajko, K.; Sraka, M. Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). *Catena* **2018**, *160*, 376–384. [CrossRef]
22. Suzuki, L.E.A.S.; Amaral, R.d.L.d.; Almeida, W.R.d.S.; Ramos, M.F.; Nunes, M.R. Oat Straw Mulching Reduces Interril Erosion and Nutrient Losses Caused by Runoff in a Newly Planted Peach Orchard. *Soil Syst.* **2023**, *7*, 8. [CrossRef]
23. Gao, Z.; Xu, Q.; Si, Q.; Zhang, S.; Fu, Z.; Chen, H. Effects of Different Straw Mulch Rates on the Runoff and Sediment Yield of Young Citrus Orchards with Lime Soil and Red Soil under Simulated Rainfall Conditions in Southwest China. *Water* **2022**, *14*, 1119. [CrossRef]
24. Bogunovic, I.; Telak, L.J.; Pereira, P. Experimental Comparison of Runoff Generation and Initial Soil Erosion Between Vineyards and Croplands of Eastern Croatia: A Case Study. *Air Soil Water Res.* **2020**, *13*, 1178622120928323. [CrossRef]
25. Bombino, G.; Denisi, P.; Gómez, J.A.; Zema, D.A. Mulching as best management practice to reduce surface runoff and erosion in steep clayey olive groves. *Int. Soil Water Conserv. Res.* **2021**, *9*, 26–36. [CrossRef]
26. Tsanis, I.K.; Seiradakis, K.D.; Sarchani, S.; Panagea, I.S.; Alexakis, D.D.; Koutroulis, A.G. The Impact of Soil-Improving Cropping Practices on Erosion Rates: A Stakeholder-Oriented Field Experiment Assessment. *Land* **2021**, *10*, 964. [CrossRef]
27. Duan, J.; Liu, Y.-J.; Yang, J.; Tang, C.-J.; Shi, Z.-H. Role of groundcover management in controlling soil erosion under extreme rainfall in citrus orchards of southern China. *J. Hydrol.* **2020**, *582*, 124–290. [CrossRef]
28. Martínez-Mena, M.; Carrillo-López, E.; Boix-Fayos, C.; Almagro, M.; García Franco, N.; Díaz-Pereira, E.; Montoya, I.; de Vente, J. Long-term effectiveness of sustainable land management practices to control Runoff, soil erosion, and nutrient loss and the role of rainfall intensity in Mediterranean rainfed agroecosystems. *Catena* **2020**, *187*, 104–352. [CrossRef]
29. Telak, L.J.; Dugan, I.; Bogunovic, I. Soil Management and Slope Impacts on Soil Properties, Hydrological Response, and Erosion in Hazelnut Orchard. *Soil Syst.* **2021**, *5*, 5. [CrossRef]
30. Allegrini, A.; Salvaneschi, P.; Schirone, B.; Cianfaglione, K.; Di Michele, A. Multipurpose plant species and circular economy: *Corylus avellana* L. as a study case. *Front. Biosci.* **2022**, *27*, 11. [CrossRef]
31. FOASTAT. FAO Statistics, Food and Agriculture Organization of United Nations. 2023. Available online: https://www.fao.org/faostat/en/#data (accessed on 4 August 2023).
32. IUSS WRB. *World Reference Base for Soil Resources 2014, Update 2015: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports No. 106; FAO: Rome, Italy, 2015; pp. 150–200.
33. Hydrological and Meteorological Service of Croatia. Available online: https://meteo.hr/index_en.php (accessed on 1 September 2023).
34. Schindewolf, M.; Schmidt, J. Parameterization of the EROSION 2D/3D soil erosion model using a small-scale rainfall simulator and upstream runoff simulation. *Catena* **2012**, *91*, 47–55. [CrossRef]
35. Diaz-Zorita, M.; Perfect, E.; Grove, J.H. Disruptive methods for assessing soil structure. *Soil Tillage Res.* **2002**, *64*, 3–22. [CrossRef]
36. Le Bissonnais, Y.L. Aggregate stability and assessment of soil crust ability and erodibility: I. Theory and methodology. *Eur. J. Soil Sci.* **1996**, *47*, 425–437. [CrossRef]
37. Kemper, W.D.; Rosenau, R.C. Aggregate stability and size distribution. In *Methods of Soil Analysis*; Klute, A., Ed.; American Society of Agronomy, Inc.: Madison, WI, USA, 1986; pp. 425–442.
38. Walkley, A.; Black, I.A. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
39. Statsoft. *Statistica 12.0 Software*; StatSoft Inc.: Hamburg, Germany, 2015.
40. Plotly Chart Studio. Available online: https://chart-studio.plotly.com/ (accessed on 28 August 2023).
41. Munkholm, L.J.; Schjønning, P.; Rasmussen, K.J.; Tanderup, K. Spatial and temporal effects of direct drilling on soil structure in the seedling environment. *Soil Tillage Res.* **2003**, *71*, 163–173. [CrossRef]
42. Bondi, G.; O'Sullivan, L.; Fenton, O.; Creamer, R.; Marongiu, I.; Wall, D.P. Trafficking intensity index for soil compaction management in grasslands. *Soil Use Manag.* **2021**, *37*, 504–518. [CrossRef]
43. Elaoud, A.; Chehaibi, S. Soil compaction due to tractor traffic. *J. Fail. Anal. Prev.* **2011**, *11*, 539–545. [CrossRef]
44. Newell-Price, J.P.; Whittingham, M.J.; Chambers, B.J.; Peel, S. Visual soil evaluation in relation to measured soil physical properties in a survey of grassland soil compaction in England and Wales. *Soil Tillage Res.* **2013**, *127*, 65–73. [CrossRef]
45. Van Dijck, S.J.E.; Van Asch, T.W. Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. *Soil Tillage Res.* **2002**, *63*, 141–153. [CrossRef]

46. Zhang, J.; Du, L.; Xing, Z.; Zhang, R.; Li, F.; Zhong, T.; Ren, F.; Yin, M.; Liu, X. Effects of dual mulching with wheat straw and plastic film under three irrigation regimes on soil nutrients and growth of edible sunflower. *Agric. Water Manag.* **2023**, *288*, 108453. [CrossRef]
47. Waheed, A.; Li, C.; Muhammad, M.; Ahmad, M.; Khan, K.A.; Ghramh, H.A.; Wang, Z.; Zhang, D. Sustainable Potato Growth under Straw Mulching Practices. *Sustainability* **2023**, *15*, 10442. [CrossRef]
48. Mileusnić, Z.I.; Saljnikov, E.; Radojević, R.L.; Petrović, D.V. Soil compaction due to agricultural machinery impact. *J. Terramechanics* **2022**, *100*, 51–60. [CrossRef]
49. Canillas, E.C.; Salokhe, V.M. Regression analysis of some factors influencing soil compaction. *Soil Tillage Res.* **2001**, *61*, 167–178. [CrossRef]
50. Abiven, S.; Menasseri, S.; Chenu, C. The effects of organic inputs over time on soil aggregate stability—A literature analysis. *Soil Biol. Biochem* **2009**, *41*, 1–12. [CrossRef]
51. Zheng, H.; Liu, W.; Zheng, J.; Luo, Y.; Li, R.; Wang, H.; Qi, H. Effect of long-term tillage on soil aggregates and aggregate-associated carbon in black soil of Northeast China. *PLoS ONE* **2018**, *13*, e0199523. [CrossRef] [PubMed]
52. Gholami, L.; Sadeghi, S.H.; Homaee, M. Straw mulching effect on splash erosion, Runoff, and sediment yield from eroded plots. *Soil. Sci. Soc. Am. J.* **2013**, *77*, 268–278. [CrossRef]
53. Erktan, A.; McCormack, M.L.; Roumet, C. Frontiers in root ecology: Recent advances and future challenges. *Plant Soil* **2018**, *424*, 1–9. [CrossRef]
54. Hudek, C.; Stanchi, S.; D'Amico, M.; Freppaz, M. Quantifying the contribution of the root system of alpine vegetation in the soil aggregate stability of moraine. *Int. Soil Water Conserv. Res.* **2017**, *5*, 36–42. [CrossRef]
55. Wang, J.; Wang, R. The Physical and Chemical Properties of Soil Crust in Straw Checkerboards with Different Ages in the Mu Us Sandland, Northern China. *Sustainability* **2019**, *11*, 4755. [CrossRef]
56. Song, C.; Du, H. Effects of corn straw cover years on soil organic matter and compactness in typical black soil areas of Songnen Plain. *Arab. J. Geosci.* **2023**, *16*, 44. [CrossRef]
57. Maurya, P.R.; Lal, R. Effects of different mulch materials on soil properties and on the root growth and yield of maise (*Zea mays*) and cowpea (*Vigna unguiculata*). *Field Crops Res.* **1981**, *4*, 33–45. [CrossRef]
58. Six, J.; Paustian, K.; Elliott, E.T.; Combrink, C. Soil structure and organic matter I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Sci. Soc. Am. J.* **2000**, *64*, 681–689. [CrossRef]
59. Pinheiro, E.F.M.; Pereira, M.G.; Anjos, L.H.C. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. *Soil Tillage Res.* **2004**, *77*, 79–84. [CrossRef]
60. Traoré, O.; Groleau-Renaud, V.; Plantureux, S.; Tubeileh, A.; Boeuf-Tremblay, V. Effect of root mucilage and modelled root exudates on soil structure. *Eur. J. Soil Sci.* **2000**, *51*, 575–581. [CrossRef]
61. Hannula, S.E.; Morriën, E. Will fungi solve the carbon dilemma? *Geoderma* **2022**, *413*, 115767. [CrossRef]
62. Khurshid, K.A.S.H.I.F.; Iqbal, M.; Arif, M.S.; Nawaz, A. Effect of tillage and mulch on soil physical properties and growth of maise. *Int. J. Agric. Biol.* **2006**, *8*, 593–596.
63. Derpsch, R.; Franzluebbers, A.J.; Duiker, S.W.; Reicosky, D.C.; Koeller, K.; Friedrich, T.; Sturny, W.G.; Sá, J.C.M.; Weiss, K. Why do we need to standardise no-tillage research? *Soil Tillage Res.* **2014**, *137*, 16–22. [CrossRef]
64. Bhatt, R.; Khera, K.L. Effect of tillage and mode of Straw mulch application on soil erosion in the submontaneous tract of Punjab, India. *Soil Tillage Res.* **2006**, *88*, 107–115. [CrossRef]
65. Alliaume, F.W.A.H.; Rossing, W.A.H.; Tittonell, P.; Jorge, G.; Dogliotti, S. Reduced tillage and cover crops improve water capture and reduce erosion of fine textured soils in raised bed tomato systems. *Agric. Ecosyst. Environ.* **2014**, *183*, 127–137. [CrossRef]
66. McCauley, A.; Jones, C.; Jacobsen, J. Soil pH and organic matter. *Nutr. Manag. Modul.* **2009**, *8*, 1–12.
67. Rhoton, F.E.; Shipitalo, M.J.; Lindbo, D.L. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. *Soil Tillage Res.* **2002**, *66*, 1–11. [CrossRef]
68. Gómez, J.A.; Guzmán, M.G.; Giráldez, J.V.; Fereres, E. The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. *Soil Tillage Res.* **2009**, *106*, 137–144. [CrossRef]
69. Berhe, A.A.; Kleber, M. Erosion, deposition, and the persistence of soil organic matter: Mechanistic considerations and problems with terminology. *Earth Surf. Process. Landf.* **2013**, *38*, 908–912. [CrossRef]
70. Ruiz-Colmenero, M.; Bienes, R.; Eldridge, D.J.; Marques, M.J. Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. *Catena* **2013**, *104*, 153–160. [CrossRef]
71. Szostek, M.; Szpunar-Krok, E.; Pawlak, R.; Stanek-Tarkowska, J.; Ilek, A. Effect of Different Tillage Systems on Soil Organic Carbon and Enzymatic Activity. *Agronomy* **2022**, *12*, 208. [CrossRef]
72. Abu-Hamdeh, N.H. Effect of compaction and deep tillage on soil hydraulic and aeration properties and wheat yield. *Commun. Soil Sci. Plant Anal.* **2003**, *34*, 2277–2290. [CrossRef]
73. Stagge, J.H.; Davis, A.P.; Jamil, E.; Kim, H. Performance of grass swales for improving water quality from highway runoff. *Water Res.* **2012**, *46*, 6731–6742. [CrossRef] [PubMed]
74. Le Bissonnais, Y.; Lecomte, V.; Cerdan, O. Grass strip effects on Runoff and soil loss. *Agronomie* **2004**, *24*, 129–136. [CrossRef]
75. Eghball, B.; Gilley, J.E.; Kramer, L.A.; Moorman, T.B. Narrow grass hedge effects on phosphorus and nitrogen in Runoff following manure and fertiliser application. *J. Soil Water Conserv.* **2000**, *55*, 172–176.

76. Donjadee, S.; Tingsanchali, T. Soil and water conservation on steep slopes by mulching using rice straw and vetiver grass clippings. *Agric. Nat. Resour.* **2016**, *50*, 75–79. [CrossRef]
77. Abrantes, J.R.; Prats, S.A.; Keizer, J.J.; de Lima, J.L. Effectiveness of the application of rice straw mulching strips in reducing Runoff and soil loss: Laboratory soil flume experiments under simulated rainfall. *Soil Tillage Res.* **2018**, *180*, 238–249. [CrossRef]
78. Parhizkar, M.; Shabanpour, M.; Lucas-Borja, M.E.; Zema, D.A.; Li, S.; Tanaka, N.; Cerda, A. Effects of length and application rate of rice straw mulch on surface runoff and soil loss under laboratory simulated rainfall. *Int. J. Sediment Res.* **2021**, *36*, 468–478. [CrossRef]
79. Yang, J.; Liu, H.; Lei, T.; Rahma, A.E.; Liu, C.; Zhang, J. Effect of straw-incorporation into farming soil layer on surface runoff under simulated rainfall. *Catena* **2021**, *199*, 105082. [CrossRef]
80. Zhao, G.; Mu, X.; Wen, Z.; Wang, F.; Gao, P. Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. *Land Degrad. Dev.* **2013**, *24*, 499–510. [CrossRef]
81. Kukal, S.S.; Sarkar, M. Splash erosion and infiltration in relation to mulching and polyvinyl alcohol application in semi-arid tropics. *Arch. Agron. Soil Sci.* **2010**, *56*, 697–705. [CrossRef]
82. Adekalu, K.O.; Okunade, D.A.; Osunbitan, J.A. Compaction and mulching effects on soil loss and Runoff from two southwestern Nigeria agricultural soils. *Geoderma* **2006**, *137*, 226–230. [CrossRef]
83. Morvan, X.; Naisse, C.; Malam Issa, O.; Desprats, J.F.; Combaud, A.; Cerdan, O. Effect of ground-cover type on surface runoff and subsequent soil erosion in C hampagne vineyards in France. *Soil Use Manag.* **2014**, *30*, 372–381. [CrossRef]
84. Puigdefábregas, J. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surf. Process. Landf.* **2005**, *30*, 133–147. [CrossRef]
85. Wang, C.; Ma, J.; Wang, Y.; Li, Z.; Ma, B. The influence of wheat straw mulching and straw length on infiltration, Runoff and soil loss. *Hydrol. Process.* **2022**, *36*, e14561. [CrossRef]
86. Zhang, W.; Gao, W.; Whalley, W.R.; Ren, T. Physical properties of a sandy soil as affected by incubation with a synthetic root exudate: Strength, thermal and hydraulic conductivity, and evaporation. *Eur. J. Soil Sci.* **2021**, *72*, 782–792. [CrossRef]
87. Albalasmeh, A.A.; Ghezzehei, T.A. Interplay between soil drying and root exudation in rhizosheath development. *Plant Soil* **2014**, *374*, 739–751. [CrossRef]
88. Lal, R.A.T.T.A.N. Soil degradation by erosion. *Land Degrad. Dev.* **2001**, *12*, 519–539. [CrossRef]
89. Cerdà, A.; Rodrigo-Comino, J.; Giménez-Morera, A.; Keesstra, S.D. An economic, perception and biophysical approach to the use of oat straw as mulch in Mediterranean rainfed agriculture land. *Ecol. Eng.* **2017**, *108*, 162–171. [CrossRef]
90. Dugan, I.; Pereira, P.; Barcelo, D.; Telak, L.J.; Filipovic, V.; Filipovic, L.; Kisic, I.; Bogunovic, I. Agriculture management and seasonal impact on soil properties, water, sediment and chemicals transport in a hazelnut orchard (Croatia). *Sci. Total Environ.* **2022**, *839*, 156346. [CrossRef]
91. Fonte, S.J.; Yeboah, E.; Ofori, P.; Quansah, G.W.; Vanlauwe, B.; Six, J. Fertilizer and residue quality effects on organic matter stabilisation in soil aggregates. *Soil Sci. Soc. Am. J.* **2009**, *73*, 961–966. [CrossRef]
92. Six, J.; Bossuyt, H.; Degryze, S.; Denef, K. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil Tillage Res.* **2004**, *79*, 7–31. [CrossRef]
93. Römkens, M.J.; Helming, K.; Prasad, S.N. Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. *Catena* **2002**, *46*, 103–123. [CrossRef]
94. Yao, C.; Chen, K.; Zhang, Q.; Wang, C.; Lu, C.; Wang, H.; Wu, F. The contribution rate of stem-leaf and root of alfalfa (*Medicago sativa* L.) to sediment and runoff reduction. *Land Degrad. Dev.* **2023**, *34*, 3991–4005. [CrossRef]
95. Liang, X.; Su, D.; Wang, Z.; Qiao, X. Effects of turfgrass thatch on water infiltration, surface runoff, and evaporation. *J. Water Resour. Prot.* **2017**, *9*, 799–810. [CrossRef]
96. Wang, H.; Wang, X.; Hao, M.; Li, J. Effects of Straw covering methods on Runoff and soil erosion in summer maise field on the Loess Plateau of China. *Plant Soil Environ.* **2015**, *61*, 176–181. [CrossRef]
97. Hu, W.; Shao, M.A.; Si, B.C. Seasonal changes in surface bulk density and saturated hydraulic conductivity of natural landscapes. *Eur. J. Soil Sci.* **2012**, *63*, 820–830. [CrossRef]
98. Ghestem, M.; Sidle, R.C.; Stokes, A. The influence of plant root systems on subsurface flow: Implications for slope stability. *Bioscience* **2011**, *61*, 869–879. [CrossRef]
99. Belnap, J. The potential roles of biological soil crusts in dryland hydrologic cycles. *Hydrol. Process. Int. J.* **2006**, *20*, 3159–3178. [CrossRef]
100. Amézketa, E. Soil aggregate stability: A review. *J. Sustain. Agric.* **1999**, *14*, 83–151. [CrossRef]
101. Darboux, F.; Davy, P.; Gascuel-Odoux, C.; Huang, C. Evolution of soil surface roughness and flowpath connectivity in overland flow experiments. *Catena* **2002**, *46*, 125–139. [CrossRef]
102. Alaoui, A.; Rogger, M.; Peth, S.; Blöschl, G. Does soil compaction increase floods? A review. *J. Hydrol.* **2018**, *557*, 631–642. [CrossRef]
103. Batey, T. Soil compaction and soil management–a review. *Soil Use Manag.* **2009**, *25*, 335–345. [CrossRef]
104. Shah, A.N.; Tanveer, M.; Shahzad, B.; Yang, G.; Fahad, S.; Ali, S.; Bukhari, M.; Tung, T.; Hafeez, A.; Souliyanonh, B. Soil compaction effects on soil health and cropproductivity: An overview. *Environ. Sci. Pollut. Res.* **2017**, *24*, 10056–10067. [CrossRef] [PubMed]

105. Castellano, M.J.; Valone, T.J. Livestock, soil compaction and water infiltration rate: Evaluating a potential desertification recovery mechanism. *J. Arid. Environ.* **2007**, *71*, 97–108. [CrossRef]
106. Janeau, J.L.; Bricquet, J.P.; Planchon, O.; Valentin, C. Soil crusting and infiltration on steep slopes in northern Thailand. *Eur. J. Soil Sci.* **2003**, *54*, 543–554. [CrossRef]
107. Onda, Y.; Dietrich, W.E.; Booker, F. Evolution of overland flow after a severe forest fire, Point Reyes, California. *Catena* **2008**, *72*, 13–20. [CrossRef]
108. Dalal, R.C.; Bridge, B.J. Aggregation and organic matter storage in sub-humid and semi-arid soils. In *Structure and Organic Matter Storage in Agricultural Soils*; Carter, M.R., Stewart, B.A., Eds.; CRC Press: Boca Raton, FL, USA, 2020; pp. 263–307. [CrossRef]
109. Puget, P.; Chenu, C.; Balesdent, J. Dynamics of soil organic matter associated with particle-size fractions of water-stable aggregates. *Eur. J. Soil Sci.* **2000**, *51*, 595–605. [CrossRef]
110. Badin, A.L.; Méderel, G.; Béchet, B.; Borschneck, D.; Delolme, C. Study of the aggregation of the surface layer of Technosols from stormwater infiltration basins using grain size analyses with laser diffractometry. *Geoderma* **2009**, *153*, 163–171. [CrossRef]
111. Lado, M.; Paz, A.; Ben-Hur, M. Organic matter and aggregate size interactions in infiltration, seal formation, and soil loss. *Soil Sci. Soc. Am. J.* **2004**, *68*, 935–942. [CrossRef]
112. Shi, Z.H.; Fang, N.F.; Wu, F.Z.; Wang, L.; Yue, B.J.; Wu, G.L. Soil erosion processes and sediment sorting associated with transport mechanisms on steep slopes. *J. Hydrol.* **2012**, *454*, 123–130. [CrossRef]
113. Valentin, C.; Agus, F.; Alamban, R.; Boosaner, A.; Bricquet, J.P.; Chaplot, V.; de Guzman, T.; de Rouw, A.; Janeau, J.L.; Orange, D. Runoff and sediment losses from 27 upland catchments in Southeast Asia: Impact of rapid land use changes and conservation practices. *Agric. Ecosyst. Environ.* **2008**, *128*, 225–238. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.