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Soil Management and Slope Impacts on Soil Properties, Hydrological Response, and Erosion in Hazelnut Orchard

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Abstract: Proper soil management is crucial to mitigate soil degradation. Hazelnut orchards are often raised on slopes and intensively managed, which makes them similar to the already defined highly erodible land uses like vineyards. This research aims to assess the impacts of soil management and the slope on the soil properties, hydrological response, and erosion in the hazelnut orchard. At eastern Croatia on Cambisols, four treatments were chosen, representing two soil managements in the study area (herbicide and mulched) on two different slope inclinations (high ~9° and low ~4.5°), for rainfall simulation experiments and soil sampling. The herbicide treatments on both slopes removed soil cover and reduced ($p < 0.05$) soil organic matter, mean weight diameter, and water-stable aggregates. Mulched treatments recorded a lower ($p < 0.05$) bulk density. These soil properties affected soil hydrological response, as the reduction of infiltration in herbicide plots lead to higher water and sediment losses. The higher slope increased erosion in herbicide soil to over 2.2 t ha^{-1}. Mulching was shown as a superior practice as it enhances soil properties and reduces soil erosion, even reducing the effect of the higher slope on erosional processes.

Keywords: herbicide application; mulching; soil sustainability; rainfall simulation; slope aspect

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1. Introduction

The degradation processes of soils are a major concern in the world today [1], because of which soils are one of the focuses of the United Nations Sustainable Development Goals [2]. The main cause of soil degradation (cover more than 56%) is soil water erosion [3], which causes both on-site (loss of nutrient-rich topsoil, reduction of agricultural productivity, ecosystem collapse, desertification) and off-site problems (blockage and alteration of waterways, eutrophication of waters, translocations of organisms to the new habitats) [4]. Agriculture has been defined as the main cause of soil water erosion as the anthropogenic influences are changing the landscape modifying soil-forming factors and processes which alter soils.

Soil erosion is under the influence of soil properties, such as the soil chemical and physical properties, which are also intertwined with and govern the soil hydrological response. How soil management impacts soil properties is well documented, as well as the impact on soil erosion [2], where tillage, removal of the soil cover, and herbicide applications are recognized as the major factors for high soil erosion [5], while grass-covering and mulching show the opposite effect [6]. Higher soil compaction decreases infiltration and increases runoff (Run) [7]. On the other hand, soil structural properties, such as mean weight diameter (MWD) and water-stable aggregates (WSA), are positively correlated with infiltration (IR) [8] and soil organic matter (SOM [9], and negatively with the sediment concentration (SC) and sediment loss (SL) [10,11]. Herbicide application was related to high soil erosion rates [9] as removal of vegetation cover and reduction of aggregate stability leads to increased Run, SC, and SL [12]. Conversely, grass-covering and mulching practices increase SOM, preserve soil structure, and reduce SC and SL [13].

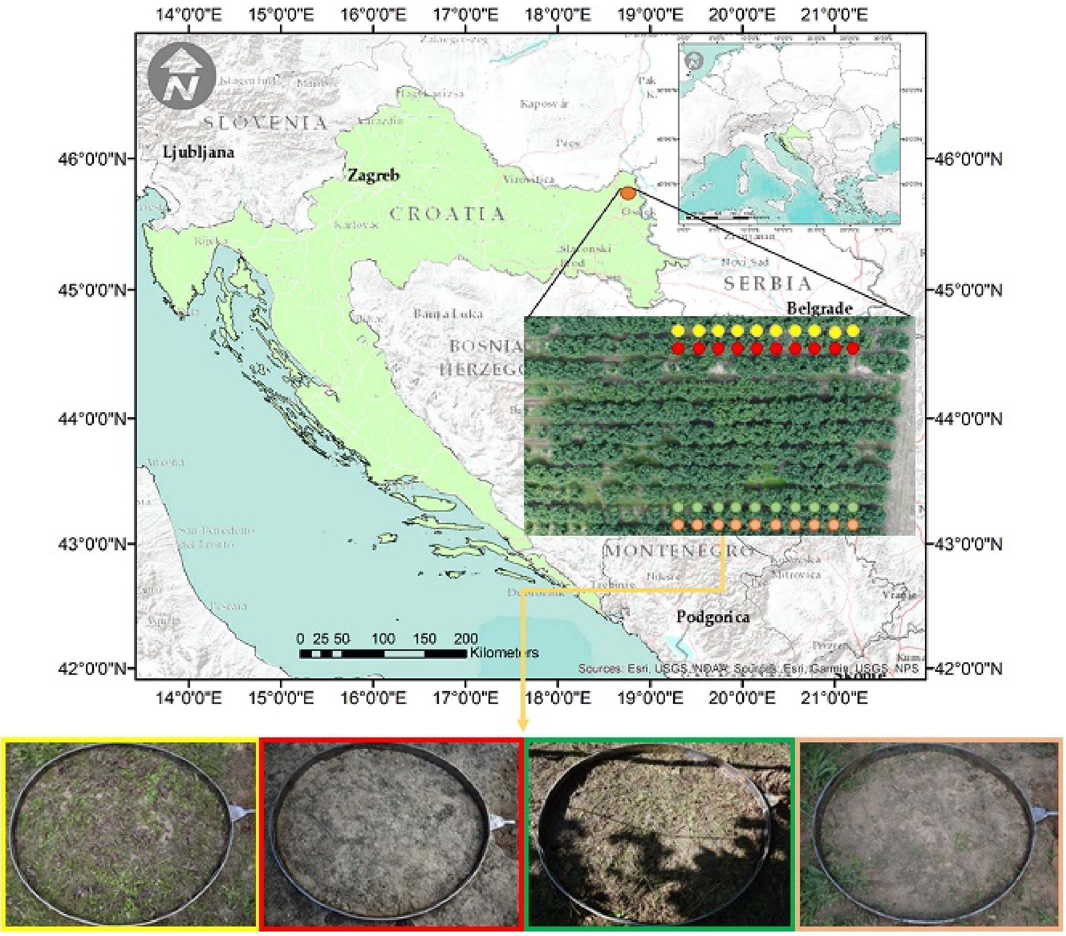
In soil erosion studies, the slope was proven to be a major factor that impacts soil water erosion, as on the steeper slopes, soil erosion is far more pronounced, while lower inclination results in lesser soil erosion rates [14]. Since permanent plantations require more intense soil management compared to croplands and are often raised on the slopes, such lands are under a greater threat from soil water erosion. In the literature, soil water erosion was measured in various permanent plantations; vineyards, olive, avocado, citrus, almond, persimmon, apple, apricot, and fig orchards [2,5,13,15–21], while research performed in hazelnut orchard has not been performed.

The European hazelnut (*Corylus avellana* L.) is an important economic crop on a global scale [22]. The increase in the demand for this fruit has led to the increase of harvested area on a global scale for hazelnut from 530,782 ha in 2003 to 966,196 ha in 2018 (182% increase). In Croatia, the increase of the harvested area in the last 15 years is even more evident, as we observe a 783% increase (614 ha in 2003 to 4810 ha in 2018) [23]. The hazelnut plant is a shrub originating from the coast of the Black Sea, where it grows on the steep slopes of the mountains [24,25], and as such, is often raised on the sloped terrain. Additionally, hazelnuts are intensively managed, as they require multiple interventions yearly (pruning, several plant protection applications, several weed management interventions, harvest). Thus, following the increase of the area of hazelnut orchards and their similarity (raised on slopes, intensively managed) to the already recognized highly erodible land uses, this research aims to assess the impacts of soil management and different slopes on the soil properties, hydrological response, and erosion in the hazelnut orchard. We hypothesize that hazelnut production intensity and the steepness of the slope increase the risk of runoff and soil erosion.

2. Materials and Methods

2.1. Study Area and Climate

The studied hazelnut orchard is located in the northeast area of Baranja, eastern Croatia (45°46′ N; 18°40′ E), at an average elevation of ~185 m above sea level (Figure 1). According to Köppen climate classification [26], the climate of the study area is moderate continental, with a Dfb description. The average annual temperature is 11.9 °C, where January is the coolest (1.0 °C) and July the warmest month (22.9 °C) (Figure 2). The average annual precipitation (2004–2019) was 702.0 mm, ranging from a minimum of 419.8 mm (2011) to a maximum of 1028.2 mm (2010) [27]. The soil in the study area was classified as a Cambisol [28] developed on loess. The general soil texture of the study area is a clay loam (41.4% sand, 26.8% silt, 31.8% clay) with $pH_{(KCl)}$ 7.9. The hazelnuts were planted 30 years ago, perpendicular to the direction of the slope, where for the first 5–6 years, soil management comprised of rotational harrowing (20 cm) as a mechanical weeding method three times a year. For the past 24 years, soil management in the orchard has differed for the inter-row and inner-row areas. The inner-row area has been treated with herbicides (glyphosate) twice a year (herbicide treatment), where the first application is usually performed in late April or early May, and the second one in the middle of August, 2–3 weeks before the harvest. For the inter-row area, the common practice is grass cover, which is trimmed to a 3–5 cm level and left on the surface as a mulch twice a year (mulched treatment). Mulching was performed at the same time as herbicide application. The herbicide application and mulching are performed to ease the harvest of the hazelnuts since they are harvested from the ground.



Mulched (High) **Herbicide (High)** **Mulched (Low)** **Herbicide (Low)**

Figure 1. Study area and experimental design.

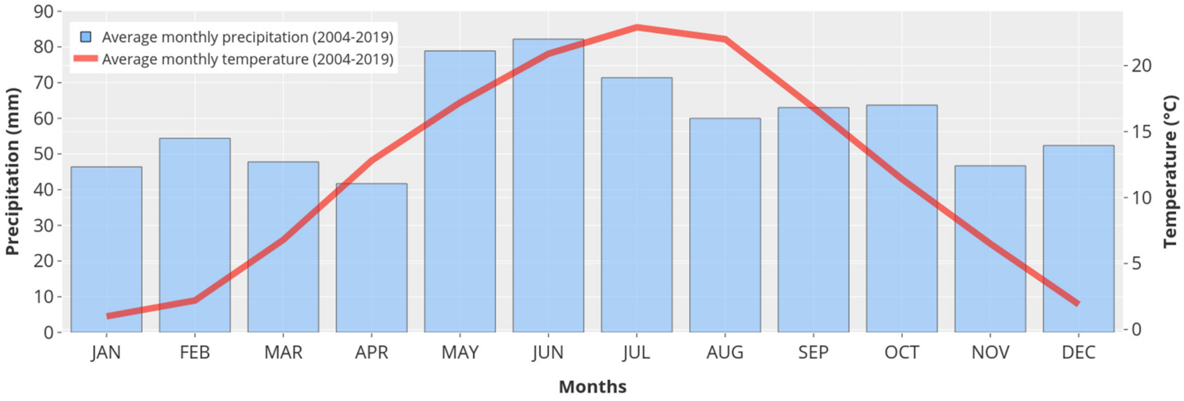


Figure 2. Monthly average precipitation and temperature between 2004 and 2019. The data is obtained from the Beli Manastir meteorological station (45°47′ N, 18°36′ E, 9 m above sea level.). The meteorological station is located 6.7 km from the studied hazelnut orchard.

2.2. Experimental Design, Rainfall Simulation Experiments, and Soil Sampling

At the study location, four treatments were chosen to represent two soil managements (herbicide and mulched) on two different slope inclinations (high ~9° and low ~4.5°). The treatments with lower slopes were located ~30 m downslope of the treatments with higher slope (Figure 1). For both slope inclinations, 20 plots were selected (10 per soil management, 40 in total), employing a paired plot strategy to ensure similarity of geomorphological conditions. At each plot, rainfall simulations were performed with the calibrated pressurized rainfall simulator Rainmaker (UGT, Müncheberg, Germany) set at 58 mm h^{-1} over 30 min. Plots were encased with the metal ring with the faucet (1 m diameter; 0.785 m^2) to which a plastic canister was connected for the collection of overland flow. Before each simulation, 10 cm downslope of the catchment area, soil core samples (0–10 cm), and undisturbed soil samples (0–10 cm) were collected, followed by the measurement of the slope inside the catchment area. During the simulations, ponding time (PT) and runoff time (RT) were measured using a chronometer.

2.3. Laboratory Analyses

The soil core samples (40 in total, 10 per treatment) were analyzed with a gravimetric core method following Casanova et al. [29] to obtain bulk density (BD), soil water content (SWC), and water holding capacity (WHC). Undisturbed soil samples were prepared for the analyses of the MWD and WSA following the methods of Martens [30] and Diaz-Zorita et al. [31]. Following the preparation, the analyses of MWD and WSA were performed according to the methods developed by Kemper and Rosenau [32]. Plastic canisters with the overland flow were weighed and filtrated through the filter paper of a known mass to obtain the Run, SC, and SL. The IR was calculated from the data of rainfall simulations and Run. Following physical analyses, undisturbed soil samples and collected sediments were milled and passed through a 2 mm sieve as a preparation for the chemical analyses. The SOM content in both soil and sediments was analyzed with a wet combustion method developed by Walkley and Black [33]. From the SOM content in the sediments and SL, we calculated SOM losses. For the easier understanding and visualization of the data, Run, SL, and SOM loss were up-scaled to represent the data on a larger scale, which has to be noted when discussing the data.

2.4. Statistical Analyses

The normality of data distribution and homogeneity of the variances were assessed with Shapiro–Wilk and Lavene tests ($p > 0.05$). Several variables did not respect the Gaussian distribution and heteroscedasticity, so they were normalized with a box-cox transformation (BC). Following data normalization, a two-way ANOVA was applied to analyze the impact of soil management and slope on soil properties and the hydrological response of the soil. Where significant differences were observed at a $p < 0.05$, Tukey's LSD post hoc test was applied. A principal component analysis (based on the correlation matrix) was performed on BC data to identify the intrinsic relationships between the variables. Data analyses were carried out with Statistica 12.0 [34]. Figures were elaborated with Plotly [35] presenting the original data.

3. Results

3.1. Soil Properties

The impacts of soil management and slope on soil properties, analyzed with two-way ANOVA are shown in Tables S1 and S2 and Figures 3 and 4. Both soil management and slope impacted BD and SWC. The significantly higher BD and SWC were observed in herbicide treatments and lower slopes (Figure 3A,B). In Figure 3C it can be observed that soil management did not impact the WHC, while significantly higher WHC values were noted in the higher sloped treatments. The MWD was affected by both soil management and slope, where significantly higher values were seen in the mulched and lower sloped treatments (Figure 3D). Impacts of both soil management and slope were also noted in WSA (Figure 3E), as mulched and higher sloped treatments resulted in significantly higher values of WHC. Figure 4 indicates that SOM was also affected by the soil management and slope, where significantly lower values were noted in herbicide treatments and higher slopes.

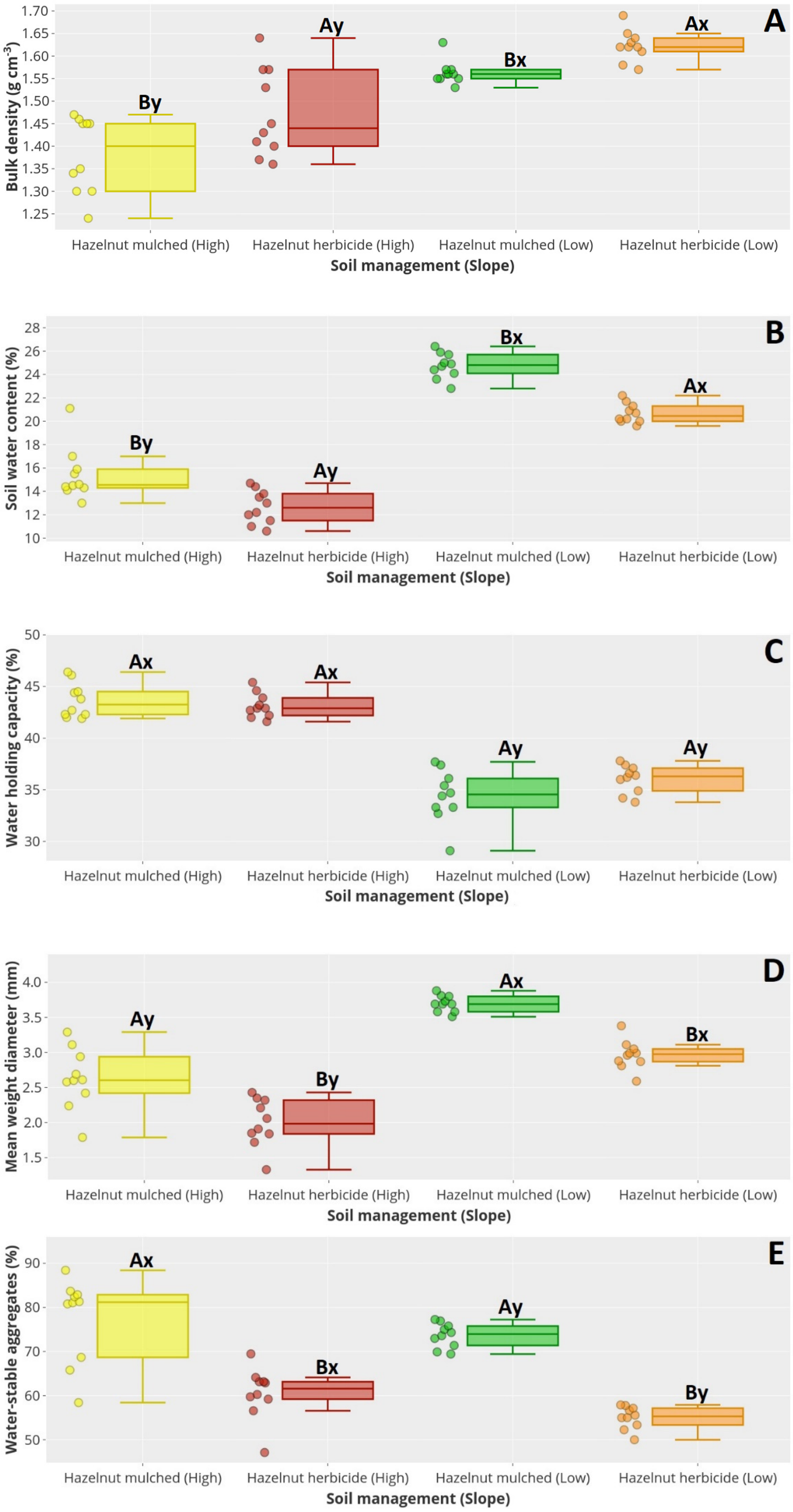


Figure 3. (**A**) Bulk density (BD), (**B**) water holding capacity (WHC), (**C**) soil water content (SWC), (**D**) mean weight diameter (MWD), and (**E**) water-stable aggregates (WSA) distribution according to the soil managements and slopes. Upper hanging bar (high edge), lower hanging bar (low edge), upper box line (third quartile), line (median), and lower box line (first quartile). Different uppercase letters (A, B) represent significant differences between soil managements ($p < 0.05$). Different lowercase letters (x, y) represent significant differences between slopes ($p < 0.05$).

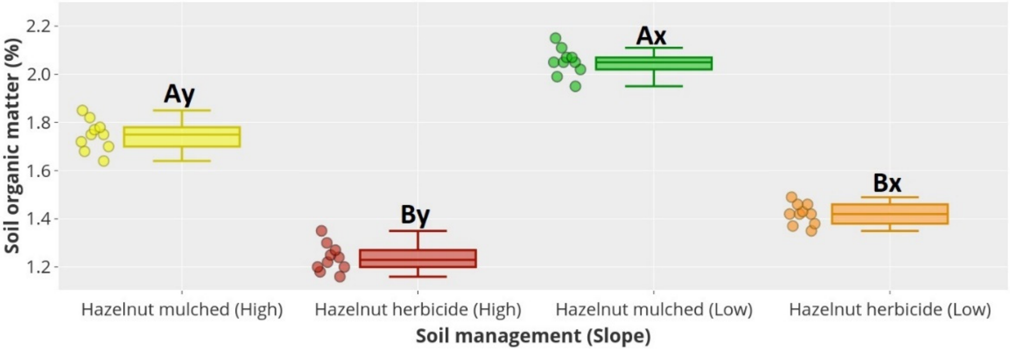


Figure 4. Soil organic matter (SOM) distribution according to the soil management and slopes. Upper hanging bar (high edge), lower hanging bar (low edge), upper box line (third quartile), line (median), and lower box line (first quartile). Different uppercase letters (A, B) represent significant differences between soil managements ($p < 0.05$). Different lowercase letters (x, y) represent significant differences between slopes ($p < 0.05$).

3.2. Hydrological Response and Soil Erosion

Figures 5 and 6 summarize the impacts of soil management and slope on the soil hydrological response and erosion. Soil management was shown to impact all of the properties besides RT. On the other hand, only the slope did not affect the SC and SOM loss. The significantly higher values of PT were noted in mulched treatments and lower slopes (Figure 5A). Figure 5B shows that RT was significantly higher in lower slopes. The observed IR (Figure 5C) was significantly higher in mulched treatments and lower slopes. The Run had the opposite reaction to the IR, where significantly higher values were noted in herbicide treatments and higher slopes (Figure 5D). Herbicide treatments resulted in a significantly higher SC compared to mulched (Figure 5E). The sediment losses were significantly higher in herbicide treatments and higher slopes (Figure 6A). Figure 6B shows that the significantly higher SOM losses were determined in herbicide treatments.

3.3. Principal Component Analysis

Two major factors were revealed with the PCA analysis, which explained 78.74% of the total variance, where Factor 1 explained 51.79%, and Factor 2, 26.95%, respectively. Figure 7A shows a relation between the loading values of Factor 1 and 2 for the variables. Variables loading values closely related Run, SC, SL, and SOM loss on the opposite side of SWC, SOM, MWD, WSA, PT, and IR, indicating the negative correlation between the groups. Additionally, WHC was loaded opposite of BD and RT which were closely related.

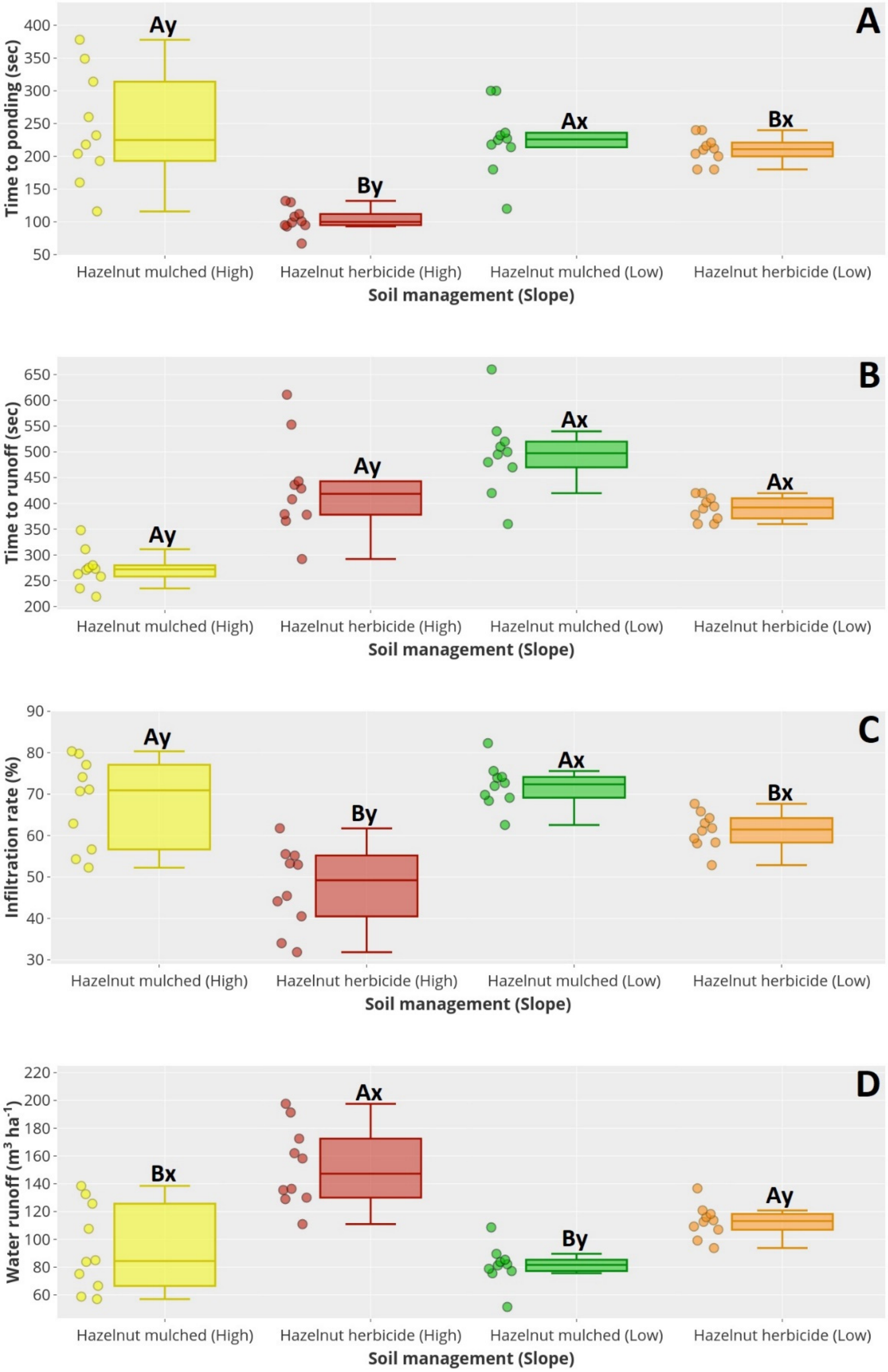


Figure 5. *Cont.*

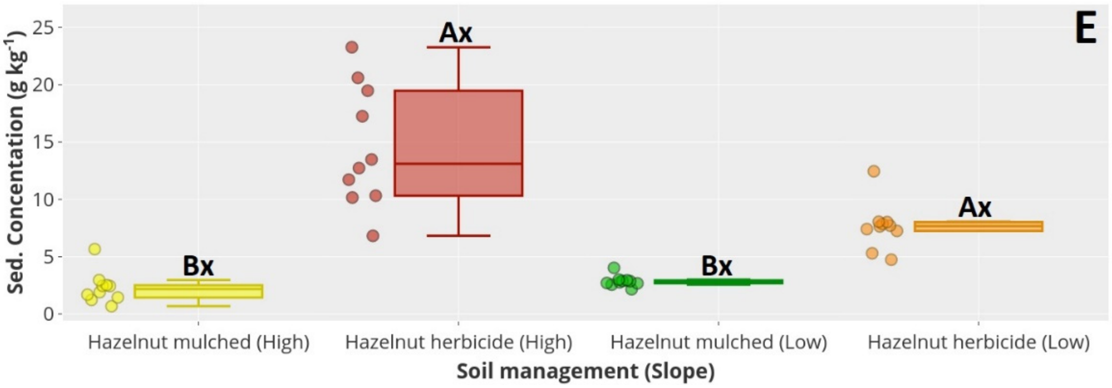
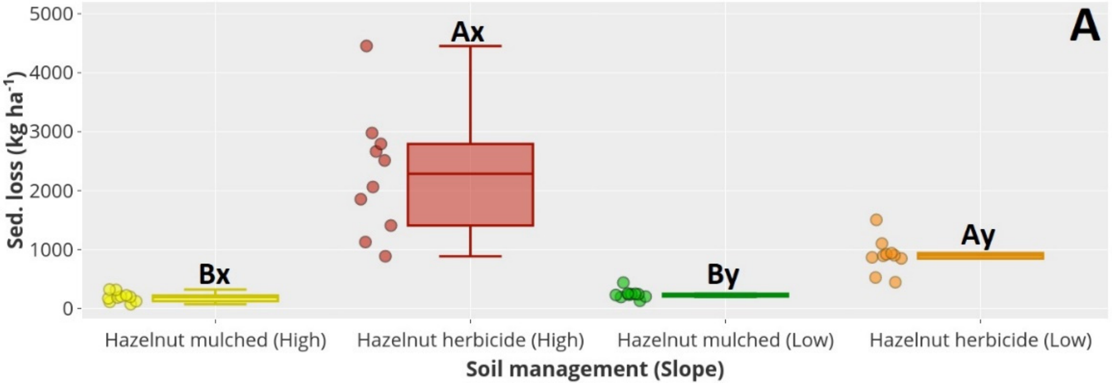


Figure 5. (**A**) Time to ponding (PT), (**B**) time to runoff (RT), (**C**) infiltration rate (RT), (**D**) water runoff (Run), (**E**) sediment concentration (SC) distribution according to the soil management and slopes. Upper hanging bar (high edge), lower hanging bar (low edge), upper box line (third quartile), line (median), and lower box line (first quartile). Different uppercase letters (A, B) represent significant differences between soil managements ($p < 0.05$). Different lowercase letters (x, y) represent significant differences between slopes ($p < 0.05$).



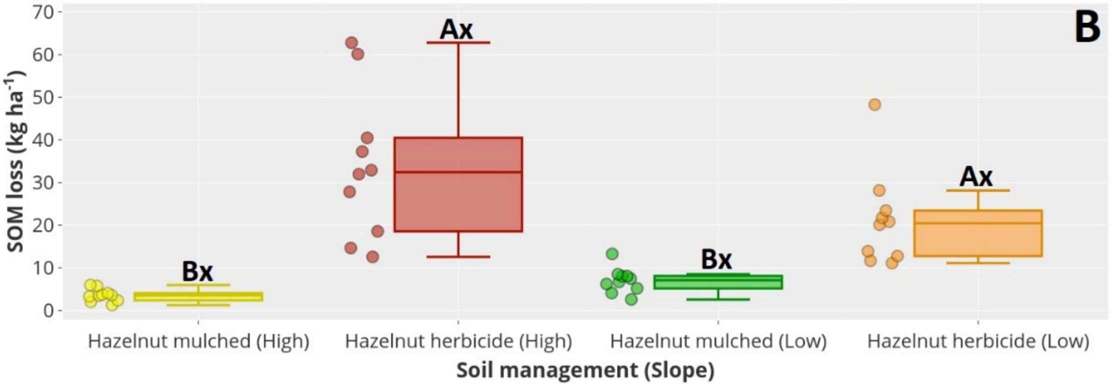


Figure 6. (**A**) Sediment loss (SL), (**B**) soil organic matter loss (SOM loss) distribution according to the soil management and slopes. Upper hanging bar (high edge), lower hanging bar (low edge), upper box line (third quartile), line (median), and lower box line (first quartile). Different uppercase letters (A, B) represent significant differences between soil managements ($p < 0.05$). Different lowercase letters (x, y) represent significant differences between slopes ($p < 0.05$).

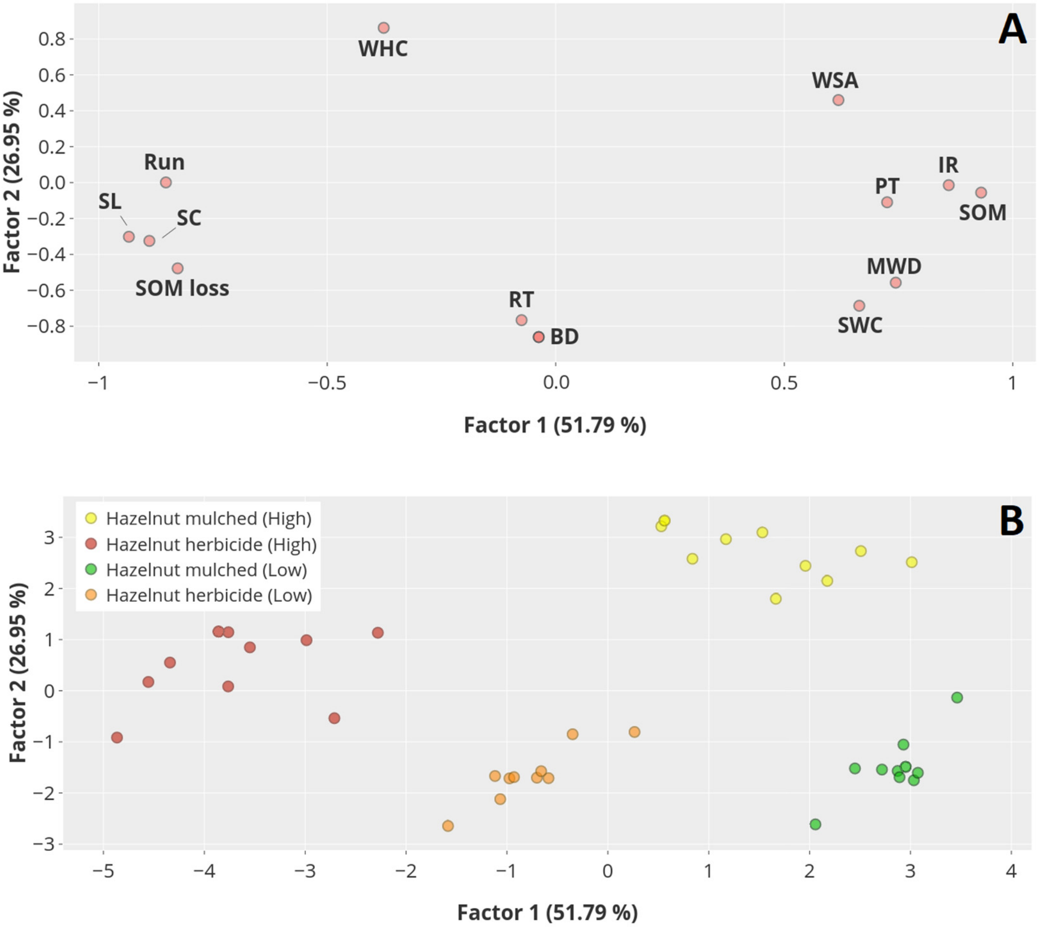


Figure 7. Relation between Factors 1 and 2: (**A**) Variables and (**B**) Cases; Bulk density (BD); water holding capacity (WHC); soil water content (SWC); mean weight diameter (MWD); water-stable aggregates (WSA); soil organic matter (SOM); time to ponding (PT); time to runoff (RT); infiltration rate (IR), runoff (Run), sediment concentration (SC); sediment loss (SL); soil organic matter loss (SOM loss).

Projection of the variable cases (Figure 7B) differentiated treatments as the cases formed separated groups based on their responses. The clear distinction of the management groups based on their properties and responses can be observed as the groups did not overlap each other. The higher inter-treatment variability could be noted in both managements on a higher slope. Both mulched treatments were more closely related to the more positive variables.

4. Discussion

The present study revealed lower BD in mulched plots than in herbicide plots. Such findings were in correspondence with Sajid et al. [36]. Since the herbicide application prevents grass growth, the addition of fresh organic matter to soil is stopped. On the contrary, mulching practice adds organic matter to the soil surface where it slowly decomposes, feeding back the organic matter to the soil, which was proven to partially alleviate the soil compaction [37] through its effects on the formation of soil structure [38]. Previous studies revealed that herbicide applications negatively impact soil compaction [39]. Significantly higher BD was recorded on low slopes. Such findings can be attributed to the erosional processes in this orchard in the last 30 years. The higher sloped area very likely had higher translocation of smaller particles to the lower parts of the slope affecting the soil texture in the way of a higher amount of silt and clay. Similar was also observed by Razaei et al. [40]. It is known that silty soils have a higher vulnerability to traffic-induced compaction than sandy or clay soils [41,42].

The higher SWC in mulched treatments can be attributed to the positive impacts of soil cover on soil properties, where it minimizes the weed infestation and helps with the control of soil temperature fluctuations, which leads to lower water evaporation [43]. The higher SWC in lower slopes can be attributed to the topography of the terrain, as the lower sloped treatments were located downhill from, the higher sloped treatments. Topographical factors were proven as an important influence on the spatial differentiation of SWC at a small scale [44–46], while Guo et al. [47] stated that the topography has a higher influencing degree on the topsoil. The higher WHC in high slope treatments is a result of a lower BD in those treatments as the BD was proven to be a major factor affecting soil porosity and WHC. As was mentioned earlier, we attributed the SOM differences between the management treatments to the deposition of organic matter with the grass cut mulching. Additionally, higher values of SOM could be observed in lower sloped values as a product of erosional processes, which translocated it from the higher sloped treatments located uphill, as was also observed by Razaei et al. [40]. However, higher sloped areas usually record greater solar radiation, temperature, and activity of the soil biota, which increases SOM mineralization [48]. The MWD followed the same pattern as the SOM since SOM is the main cementing agent leading to the formation of the aggregates [49]. Unlike MWD, higher values of WSA were observed in higher sloped terrain with lower SOM content. This is attributed to the difference in the erosional processes, which are more intense on the higher slopes from which they translocate unstable sediments downhill.

The mulched treatments recorded higher PT compared to herbicide treatments that can be attributed to the reduction of surface sealing and increased infiltration [5,50], as the mulch preserves surface roughness [50]. The slope also affected both PT and RT, as lower values were observed in higher sloped treatments due to lower surface roughness and a higher degree of crusting, which reduced IR. Additionally, IR was increased by better-structured treatments observed through MWD increase in mulched and lower sloped treatments. The Run is always in a direct negative correlation with IR and is a product of soil physical properties that affect infiltration, which, in this case, resulted in higher Run in herbicide and high slope treatments. In this study, we observed a high impact of the management on the SC, as the herbicide treatments significantly increased SC compared to mulched treatments. These results are in correspondence with the similar results reported by Prosdocimi et al. [5] in the straw-mulched vineyard, Garcia Moreno et al. [51] in the straw-mulched fruit orchards, and Cerdá et al. [18] in persimmon plantations. The reduction of SC by mulching can be attributed to the reduction of splash erosion, as the cover intercepts the kinetic energy of the rain while it increases surface roughness [50]. Furthermore, the mulch serves as a barrier that slows down and partially collects the sediments, blocking their transport with the Run. The SL is a direct product of Run and SC and is also governed by the properties that affect Run and SC, because of which, higher SL were observed in the herbicide and higher sloped treatments. The herbicide treatments recorded SL over 2.2 t ha^{-1} on the high slope and 0.9 t ha^{-1} on the low slope in a single rainfall event, which indicates their unsustainability. Usually, in similar studies, the SOM loss follows the pattern of the SL, wherein in this study, this was not the case. The observed discrepancy of the effect of slope on the SOM loss could be attributed to the higher SOM content in lower sloped treatments, which increased the SOM losses in treatments with lower SL and nullified the increasing effect of the slope on SOM losses.

The projection of the variables confirmed already stated correlations between Run, SC, SL, and SOM loss. The removal of the surface cover with herbicide application reduced the surface roughness and the protection of the surface from the kinetic energy of the raindrops. Furthermore, mulching increased the SOM, which was shown as a key binding agent that increases MWD and WSA, and with it improves IR and reduces Run. In this study, SWC was correlated with the positive factors of the soil (SOM, MWD, and WSA) and positive hydrological responses (PT and IR), as significantly higher values of mentioned properties were higher in lower sloped treatments due to the lower erosional processes that occur on lower slopes. This analysis also confirmed the already mentioned negative interrelation between the BD and WHC.

A clear distinction of the treatment responses observed in the projection of the variable cases confirms that both soil management and slope impact soil properties, hydrological response, and erosion. Both herbicide treatments were more closely related to the higher water and sediment losses, while both mulched treatments showed closer relation with SOM related group of variables, indicating lower sustainability of herbicide treatments. Lower sloped treatments were connected to an already stated higher BD and SWC, while higher sloped treatments showed more connection to WHC and WSA. The slope had a higher impact on the hydrological response of the herbicide treatments. Conversely, mulching with grass trimming is recognized as a management practice that preserves soil properties, hydrological response and mitigates erosion [50] in hazelnut orchards.

Even with the clear results of the study, certain shortcomings should be highlighted: (1) the research was carried out in only one season without repetitive measurements, which would provide an insight into the seasonal behavior of soil properties and erosion; (2) the research was carried out on a small scale in only one hazelnut orchard, which renders the data unavailable for large scale modeling; (3) the research was carried out with the use of rainfall simulators, which are noted as slightly problematic since the methods and the equipment are unstandardized. Therefore, this research might not fully reveal the full dimension of the erosional and degradation process in the hazelnut orchard of a certain area. However, this study revealed the impacts of soil management and slope on soil properties, soil hydrological response, and soil erosion in the yet unstudied hazelnut orchards, and it's beneficial for the decision of proper soil management in the hazelnut orchards. Future research should include long-term analyses on a larger scale (several hazelnut orchards) to define the impact of climatic conditions, soil types, and the age of the orchard on soil preservation.

5. Conclusions

Soil properties were affected by both soil management and slope, which lead to different hydrological responses and erosion rates in the defined treatments. The herbicide application on both slopes removed soil cover and reduced soil organic matter, with which mean weight diameter and water stable aggregates were also reduced, while bulk density increased. These changes affected soil hydrological response, as the reduction of infiltration leads to higher water and sediment losses. Conversely, grass cover with mulching increased soil structural quality, which resulted in lower runoff and sediment loss. The higher slope appeared to be a strong unsustainable factor in herbicide unprotected soil, as while grass cover and mulch treatment mitigate the impact of slope on soil and water losses. The herbicide application is recognized as an unsustainable practice in hazelnut orchards as it degrades soil properties and increases soil erosion even on low sloped terrain.

Supplementary Materials: The following are available online at https://www.mdpi.com/2571-8789/5/1/5/s1. Table S1: Two-way ANOVA results. Significant differences were observed at $p < 0.05$ *, $p < 0.01$ ** and $p < 0.001$ ***. Not significant (ns) at a $p < 0.05$. Table S2: Supplementary data.

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

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References

1. Bai, Z.G.; Dent, D.L.; Olsson, L.; Schaepman, M.E. Proxy global assessment of land degradation. *Soil Use Manag.* **2008**, *24*, 223–234. [CrossRef]
2. Keesstra, S.; Pereira, P.; Novara, A.; Brevik, E.C.; Azorin-Molina, C.; Parras-Alcántara, L.; Cerdà, A. Effects of soil management techniques on soil water erosion in apricot orchards. *Sci. Total Environ.* **2016**, *551*, 357–366. [CrossRef]
3. Kisic, I. *Antropogena Erozija Tla*, 1st ed.; Grafički Zavod Hrvatske d.d.: Zagreb, Hrvatska, 2016; p. 18.
4. Blanco, H.; Lal, R. Soil and water conservation. In *Principles of Soil Conservation and Management*; Springer: Berlin/Heidelberg, Germany, 2008.
5. Prosdocimi, M.; Cerdà, A.; Tarolli, P. Soil water erosion on Mediterranean vineyards: A review. *Catena* **2016**, *141*, 1–21. [CrossRef]
6. Sinkevičienė, A.; Jodaugienė, D.; Pupalienė, R.; Urbonienė, M. The influence of organic mulches on soil properties and crop yield. *Agron. Res.* **2009**, *7*, 485–491.
7. Olson, N.C.; Gulliver, J.S.; Nieber, J.L.; Kayhanian, M. Remediation to improve infiltration into compact soils. *J. Environ. Manag.* **2013**, *117*, 85–95. [CrossRef]
8. Bogunovic, I.; Telak, L.J.; Pereira, P.; Filipovic, V.; Filipovic, L.; Percin, A.; Durdevic, B.; Birkás, M.; Dekemati, I.; Rodrigo-Comino, J. Land management impacts on soil properties and initial soil erosion processes in olives and vegetable crops. *J. Hydrol. Hydromech.* **2020**, *68*, 328–337. [CrossRef]
9. Liu, H.; Blagodatsky, S.; Giese, M.; Liu, F.; Xu, J.; Cadisch, G. Impact of herbicide application on soil erosion and induced carbon loss in a rubber plantation of Southwest China. *Catena* **2016**, *145*, 180–192. [CrossRef]
10. Valmis, S.; Dimoyiannis, D.; Danalatos, N.G. Assessing interrill erosion rate from soil aggregate instability index, rainfall intensity and slope angle on cultivated soil in central Greece. *Soil Till. Res.* **2005**, *80*, 139–147. [CrossRef]
11. Gabet, E.J.; Dunne, T. Sediment detachment by rain power. *Water Resour. Res.* **2003**, *39*, ESG-1. [CrossRef]
12. Xu, Q.X.; Wang, T.W.; Cai, C.F.; Li, Z.X.; Shi, Z.H.; Fang, R.J. Responses of Runoff and Soil Erosion to Vegetation Removal and Tillage on Steep Lands. *Pedosphere* **2013**, *23*, 532–541. [CrossRef]
13. 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]
14. Quan, X.; He, J.; Cai, Q.; Sun, L.; Li, X.; Wang, S. Soil erosion and deposition characteristics of slope surfaces for two loess soils using indoor sumulated rainfall experiment. *Soil. Till. Res.* **2020**, *204*, 104714. [CrossRef]
15. 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]
16. Cerdà, A.; Morera, A.G.; Bodí, M.B. Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean basin. *Earth Surf. Process. Landf.* **2009**, *34*, 1822–1830. [CrossRef]
17. Rodrigo-Comino, J.; Martínez-Hernández, C.; Iserloh, T.; Cerdà, A. The Contrasted Impact of Land Abandonment on Soil Erosion in Mediterranean Agriculture Fields. *Pedosphere* **2017**, *28*, 617–631. [CrossRef]
18. Cerdà, A.; González-Pelayo, O.; Giménez-Morera, A.; Jordán, A.; Pereira, P.; Novara, A.; Brevik, E.C.; Prosdocimi, M.; Mahmoodabadi, M.; Keesstra, S.; et al. The use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency—High magnitude simulated rainfall events. *Soil Res.* **2015**, *547*, 323–330. [CrossRef]
19. Liu, Y.; Gao, M.; Wu, W.; Tanveer, S.K.; Wen, X.; Liao, Y. The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China. *Soil Till. Res.* **2013**, *130*, 7–12. [CrossRef]
20. Telak, L.J.; Pereira, P.; Ferreira, C.S.S.; Filipovic, V.; Filipovic, L.; Bogunovic, I. Short-term Impact of Tillage on Soil and the Hydrological Response within a Fig (Ficus Carica) Orchard in Croatia. *Water* **2020**, *12*, 3256. [CrossRef]
21. Capello, G.; Biddoccu, M.; Cavallo, E. Permanent cover for soil and water conservation in mechanized vineyards: A study case in Piedmont, NW Italy. *Ital. J. Agron.* **2020**, *15*, 323–331. [CrossRef]
22. Ascari, L.; Siniscalco, C.; Palestini, G.; Lisperguer, M.J.; Huerta, E.S.; De Gregorio, T.; Bregaglio, S. Relationships between yield and pollen concentrations in Chilean hazelnut orchards. *Eur. J. Agron.* **2020**, *115*, 126036. [CrossRef]
23. FOASTAT. FAO Statistics, Food and Agriculture Organization of United Nations. 2020. Available online: http://www.fao.org/faostat/en/ (accessed on 13 October 2020).
24. Kaya-Altop, E.; Haghnama, K.; Sariaslan, D.; Phillippo, C.J.; Mennan, H.; Zandstra, B.H. Long-term perennial weed control strategies: Economic analyses and yield effect in hazelnut (*Corylus avellana*). *J. Crop Prot.* **2016**, *80*, 7–14. [CrossRef]
25. Gonenc, S.; Tanrivemis, H.; Bulbul, M. Economic assessment of hazelnut production and the importance of supply management approaches in Turkey. *J. Agric. Rural. Dev. Trop.* **2006**, *107*, 19–32.

26. Chen, D.; Chen, H.W. Using the Koppen classification to quantify climate variation and change: An example for 1901–2010. *Environ. Dev.* **2013**, *6*, 69–79. [CrossRef]
27. Hydrological and Meterological Service of Croatia. Available online: https://meteo.hr/index_en.php (accessed on 10 October 2020).
28. IUSS Working Group 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.
29. Casanova, M.; Tapia, E.; Seguel, O.; Salazar, O. Direct measurement and prediction of bulk density on alluvial soils of central Chile. *Chil. J. Agric. Res.* **2016**, *76*, 105–113. [CrossRef]
30. Martens, D.A. Management and crop residue influence soil aggregate stability. *J. Environ. Qual.* **2000**, *29*, 723–727. [CrossRef]
31. Diaz-Zorita, M.; Perfect, E.; Grove, J.H. Disruptive methods for assessing soil structure. *Soil Till. Res.* **2002**, *64*, 3–22. [CrossRef]
32. Kemper, W.D.; Rosenau, R.C. Aggregate stability and size distribution. In *Methods of Soil Analysis*; Klute, A., Ed.; American Society of Agronomy: Madison, WI, USA, 1986; pp. 425–442.
33. 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]
34. Statsoft. *Statistica 12.0 Software*; StatSoft Inc.: Hamburg, Germany, 2015.
35. Plotly Chart Studio. Available online: https://chart-studio.plotly.com/ (accessed on 1 October 2020).
36. Sajid, M.; Ahmad, S.; Jaskani, M.J.; Yasin, M. Optimum weed control method increases the yield of kinnow by improving the physical properties of soil. *Planta Daninha* **2018**, *36*, e018168903. [CrossRef]
37. Chaudhari, P.R.; Ahire, D.V.; Ahire, V.D.; Chkravarty, M.; Maity, S. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *Int. J. Sci. Res.* **2013**, *3*, 1–8.
38. Virto, I.; Antón, R.; Apesteguía, M.; Plante, A. Role of carbonates in the physical stabilization of soil organic matter in agricultural Mediterranean soils. In *Soil Management and Climate Change*; Munoz, M.A., Zornoza, R., Eds.; Academic Press: Cambridge, MA, USA, 2018; pp. 121–136.
39. Linares, R.; de la Fuente, M.; Janquera, P.; Lissarrague, J.R.; Baeza, P. Effects of soil management in vineyard on soil physical and chemical characteristics. In Proceedings of the 37th World Congress of Vine and Wine and 12th General Assembly of the OIV (Part 1), Mendoza, Argentina, 9–14 November 2014.
40. Razaei, H.; Jafarzadeh, A.A.; Alijanpour, A.; Shahbazi, F.; Kamran, K.V. Effect of Slope Position on Soil Properties and Types Along an Elevation Gradient of Arasbaran Forest, Iran. *Int. J. Adv. Sco. Eng. Inf. Technol.* **2015**, *5*, 2088–5334. [CrossRef]
41. Nawaz, M.F.; Bourrie, G.; Trolard, F. Soil compaction impact and modelling. *Review. Agron. Sustain. Dev.* **2013**, *33*, 291–309. [CrossRef]
42. Bogunovic, I.; Bilandzija, D.; Andabaka, Z.; Stupic, D.; Rodrigo-Comino, J.; Cacic, M.; Brezniscak, L.; Maletic, E.; Pereira, P. Soil compaction under different management practices in a Croatian vineyard. *Arab. J. Geosci.* **2017**, *10*, 340. [CrossRef]
43. . Ramakrishna, A.; Tam, H.M.; Wani, S.P.; Long, T.D. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Res.* **2016**, *95*, 115–125. [CrossRef]
44. Legates, D.R.; Mahmood, R.; Levia, D.F.; DeLiberty, T.L.; Quiring, S.M.; Houser, C.; Nelson, F.E. Soil moisture: A central and unifying theme in physical geography. *Prog. Phys. Geog.* **2011**, *35*, 65–86. [CrossRef]
45. Crave, A.; Gascule-Odoux, C. The influence of topography on time and space distribution of soil surface water content. *Hydrol. Process.* **1997**, *11*, 203–210. [CrossRef]
46. Yu, B.W.; Liu, G.H.; Liu, Q.S.; Wang, X.P.; Feng, J.L.; Huang, C. Soil moisture variations at different topographic domains and land use types in the semi-arid Loess Plateau, China. *Catena* **2018**, *165*, 125–132. [CrossRef]
47. Guo, X.; Fu, Q.; Hang, Y.; Lu, H.; Gao, F.; Si, J. Spatial Variability of Soil moisture in relation to Land use Types and Topographic Features on Hillslopes in the Black Soil (Mollisols) Area of Northeast China. *Sustainability* **2020**, *12*, 3552. [CrossRef]
48. Bogunovic, I.; Kisic, I.; Mesic, M.; Percin, A.; Zgorelec, Z.; Bilandžija, D.; Pereira, P. Reducing sampling intensity in order to investigate spatial variability of soil pH, organic matter and available phosphorus using co-kriging techniques. *Case Study Acid Soils East. Croat. Arch. Agron. Soil Sci.* **2017**, *63*, 1852–1863. [CrossRef]
49. Neuman, J. *Soil Organic Matter Maintenance in No-till and Crop Rotation Management Systems*; Elsevier: Amsterdam, The Netherlands, 2017.
50. Jordán, A.; Zavala, L.M.; Gil, J. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena* **2010**, *81*, 77–85. [CrossRef]
51. García-Moreno, J.; Gordillo-Rivero, Á.J.; Zavala, L.M.; Jordán, A.; Pereira, P. Mulch application in fruit orchards increases the persistence of soil water repellency during a 15-years period. *Soil Till. Res.* **2013**, *130*, 62–68. [CrossRef]