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Agriculture Management Impacts on Soil Properties and Hydrological Response in Istria (Croatia)

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Abstract: The objective of this work is to study the effects of traditional land uses (vineyard, cropland, and olive orchard) on soil properties, overland flow, and sediment loss in the Istria region (Croatia), by using simulated rainfall. The results showed that soil bulk density (BD) was significantly higher in cropland plots compared to the vineyard and olive orchard. No differences were observed in soil water content (SWC) and mean weight diameter (MWD). Water stable aggregates (WSA), soil organic matter (SOM), and total nitrogen (TN) were significantly higher in the olive orchard compared to the other land uses. In cropland, during the experiment, we did not identify runoff or soil losses. Runoff (Run) and sediment loss (SL) were significantly higher in the olive orchard compared to the other plots. This was very likely a consequence of tillage practices in vertic soils, the use of herbicides, low vegetation cover, as well as the incorporation of hydrophobic organic matter in the soil matrix. The principal component analysis results showed that factor 1 explained the majority of the runoff and erosion variables. Erosion rates and nutrient losses were substantially different between olive orchard plots, and vineyard and cropland. Factor 2 showed that WSA was inversely related to the available phosphorus, water holding capacity, and sediment concentration. Management practices in the studied area should use minimum tilling frequency to have plant cover and avoid erosion.

Keywords: soil erosion; tillage; rainfall simulation; agriculture land management; Mediterranean

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1. Introduction

Soil erosion is one of the most important causes of land degradation. Non-sustainable agriculture practices increase soil losses and decrease soil fertility, crop yield, and income [1]. The Mediterranean area is affected by long-term human impact that has mainly become unsustainable as a consequence of the proliferation of cash crops. These types of agricultural practices, coupled with the natural characteristics of the regions (e.g., frequent intense rainfalls, vegetation cover, soil type, and steep slopes), are responsible for soil degradation [2–5].

In the Mediterranean area, vineyards have been recognized as one of the land uses more vulnerable to erosion [5,6]. However, high erosion rates were also observed in olive orchards [7] and croplands [8]. Agriculture is the key driver of the soil losses and runoff, regardless of the management [9]. Lack of contour management, intense tillage, machinery-induced compaction, and herbicide application are responsible for high erosion rates [10]. Unsustainable land practices are responsible for soil degradation [11], especially when heavy machinery is used. Compaction decreases water infiltration, and soil and nutrient losses are high [12]. However, tillage is a millenary tradition that can improve, preserve, or deteriorate soil quality [13]. In the Mediterranean, farmers use tillage to reduce water competition, increase water infiltration, and mix soil amendments [14]. Tilled soils are looser, warmer, and the mineralization rate is high.

Long-term studies are needed to understand the impacts of land-use practices on soil erosion [15–17], especially in areas where such studies are missing as in the Adriatic region of Croatia. The works carried out were mainly focused on areas with different management over time [8,18,19]. To our knowledge, no previous research was carried out concerning the impacts of long term traditional agricultural practices in vineyards, croplands, and olive orchards in this area of the Mediterranean. This work aims to study the impact of traditional land uses in three different types of cultures (vineyard, cropland, and olive orchard) in the Istria region (Croatia). The specific objectives is to analyze the effects of land use management on different soil properties and their hydrological response to simulated rainfall.

2. Materials and Methods

2.1. Study Site

The study was carried out in the northwest area of Istria, west Croatia (45°21′ N; 13°26′ E), at an average elevation of 296 m above sea level (a.s.l.) (Figure 1). The parent material is composed of carbonate material, and the soil has clay to clay-loam texture, classified as Chromic Luvisols or Cambisol Rhodic (local classification is *Terra Rossa*) [20]. The climate is Cfa—a hot-summer Mediterranean climate in the Köppen climate classification [21]. The average annual precipitation (1991–2010) is 927.3 mm, ranging from a minimum of 641.2 mm (2006) to a maximum of 1164.5 mm (2005). Rainfall is mainly concentrated from September to March with high inter-annual and annual variations. The mean annual temperature is 14.6 °C. Cropland, vineyard, and orchard were the main land-use types in the study area. The area lies on gentle slopes, and this is the reason for the absence of soil and water control practices.

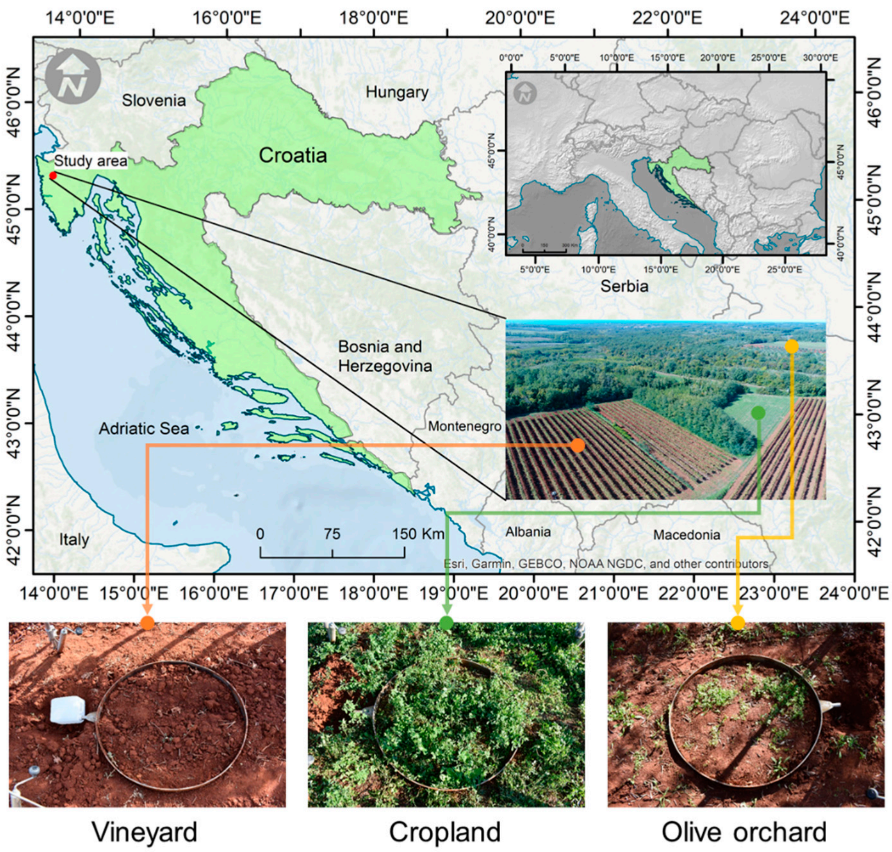

Figure 1. Study area.

2.2. Field Experiments and Laboratory Analyses

Cropland, vineyard, and olive orchard were used as treatments. Prior to the experiment initiation, land-use practices were investigated. The olive orchard is conventionally tilled each spring by disking to a depth of 10 cm. During the late spring, weeds are suppressed using herbicides (glyphosate-based herbicide "Cidokor" in doze 8 L ha^{-1}). After the harvest, olive and grape pomace are returned to the soil. Mineral fertilizer is also added in the spring before the tillage. Vineyards are tilled to 18 cm depth, 5–6 times per year, in order to keep the soil bare. Here, herbicides are not used since the weeds are suppressed mechanically. Vineyards are fertilized with mineral fertilizers only. Cropland soil for each culture in the rotation is tilled using a disc plow, followed by two passes of roto-harrow, and seedbed preparation before sowing. Herbicides and insecticides are used annually only for cash crops in the rotation. At this land-use, every several years, soils were fertilized with farmyard manure. In the time of measurements, the alfalfa (planted two years before) covered the soil and moved for fodder. In this part of Europe, alfalfa can be used as a source for fodder for 5–7 years, depending on the climate. Cropland was tilled last time in the autumn of 2016.

Each treatment was managed similarly for at least 20 years. At each treatment, a transect was established to carry out the experiments. We selected eight sampling points, separated by six meters, where we sampled soils and carried out rainfall simulation experiments. The rainfall simulation experiments were performed during September 2018 under wet soil conditions with a rainfall simulator (UGT Rainmaker, Muencheberg, Germany), calibrated to reproduce rainstorms of 58 mm h^{-1} rainfall intensity, over 30 min on the circular plots of 0.785 m^2 (metal ring 100 cm in diameter). We used rainfall parameters based on the research of Biddoccu et al. [22], which observed 93% of the annual soil loss in a single rainstorm event, as well as the highest soil erosion rates at the rainfall intensity of 59 mm h^{-1}. Before each simulation, undisturbed soil samples and soil core samples were taken from 10 cm downslope of each metal ring. The slope was measured inside the ring area. Time to ponding (TP) and time to runoff (TR) were measured with a chronometer during the rainfall simulations. In each plot (0.785 m^2), a photo was taken to measure vegetation cover (VC). The photo was georeferenced using ArcGIS 10.2 software. Subsequently, the % of pixels with vegetation in relation to the area of the plot was calculated.

Undisturbed samples were used to measure soil water content (SWC) and water holding capacity (WHC) determined using the gravimetric method in natural and wetted core samples [23]. After they dried in an oven at 105 °C for 48 h, they were weighed to obtain the bulk density (BD) [24]. Additional undisturbed soil samples were collected to determine mean weight diameter (MWD) of soil aggregates, according to Diaz-Zorita [25] and Le Bissonnais [26]. Water stable aggregates (WSA) in sampled soils were determined and calculated by the procedure described in Kemper and Rosenau [27]. Part of these samples was sieved (2 mm mesh) to determine soil chemical properties. Soil organic matter (SOM) content was calculated according to the digestion method [28]. For analyses of available phosphorus (P_2O_5) in soils and sediments (P loss), contents samples were subjected to extraction with ammonium lactate—AL method [29]. P_2O_5 content was analyzed using a spectrophotometer (Hach, Germany, model DR/2000) [30]. Total nitrogen (TN) in soils and C (C loss) and N (N loss) in sediments were obtained by a dry-combustion method with vario MACRO CHNS analyzer.

Water contained in plastic canisters (overland flow) were weighed and filtered (with 0.45 micron pore size) to obtain overland flow and sediment yield after drying of the filter paper. The mass of the sediment (SL) was deduced from the mass of overland flow to obtain the water runoff (Run). Sediment concentration (SC) was calculated, dividing the mass of the sediment with the mass of the water in the samples. Dried sediments were milled and passed through 2 mm mesh as a preparation for the C, N, and P_2O_5 determination.

2.3. Statistical Analysis

Before statistical comparisons, data normality was tested using the Kolmogorov–Smirnov test. Data normality and homogeneity of the variances were considered at a $p > 0.05$. Among all the variables, TP, TR, Run, and SL did not follow the Gaussian distribution. Even after performing logarithmic, square-root, and Box–Cox transformation, normality was not achieved. Therefore, we applied the non-parametric Kruskal–Wallis ANOVA (KW) test to identify differences among plots. For BD, SOM, SWC, WHC, MWD, and WSA, a one-way ANOVA was used to identify significant differences among plots. If significant differences were found, the Tukey HSD post-hoc test was applied. For the other variables, KW test was applied. If significant differences were observed, multiple comparisons of the mean ranks post-hoc test were applied. In all cases, the significant differences were considered at $p < 0.05$. A principal component analysis (PCA) was carried out (using the log-transformed data, since the data distributions were closest to normality), based on the correlation matrix, in order to identify correlations among the variables. Statistical analyses were carried out using Statistica 12.0 for windows. Graphics were carried out using the Plotly version 4.9.2 [31].

3. Results

3.1. Vegetation Cover and Soil Properties

Vegetation cover ranged from 6.19% in vineyards to 93.68% in cropland. It was significantly lower in the olive orchard and vineyard compared to the cropland (Table 1). BD and WHC of the soils ranged from 1.14 to 1.37 g cm^{-3} and from 39.7% to 43.8%, respectively. BD was significantly higher in the cropland than in the other land uses, while WHC was significantly lower in the cropland and olive orchard compared to a vineyard. SWC and MWD varied between 25.2–32.1% and 2.59–3.27 mm, respectively. In both cases, no significant difference was identified. WSA and SOM ranged from 81.4% to 92.9% and from 1.87% to 3.60%, respectively. WSA was significantly higher in the olive orchard, compared to the vineyard and cropland, while SOM was significantly lower in the vineyard and cropland than in the olive orchard. Soil P_2O_5 ranged from 343.6 to 328.2 (mg kg^{-1}). P_2O_5 values were significantly higher in the vineyard and olive orchard compared to the cropland. Finally, soil TN ranged from 0.10% to 0.19%. The concentration of TN was significantly lower in vineyard soils compared with the other treatments.

Table 1. Average values of BD, bulk density; WHC, water holding capacity; SWC, soil water content; MWD, mean weight diameter; WSA, water stable aggregates; SOM, soil organic matter; P_2O_5, available phosphorous and TN, total nitrogen and one-way and Kruskal–Wallis ANOVA analysis. The effects of soil management on soil properties. Small letters in the column represent the difference in treatment effects at $p < 0.05$. ns, not significant at $p < 0.05$.

Treatment	Slope (°)	Vegetation Cover (%)	BD (g cm^{-3})	WHC (%)	SWC (%)	MWD (mm)	WSA (%)	SOM (%)	P_2O_5 (mg kg^{-1})	TN (%)
Vineyard	3.8	6.19 c	1.21 b	43.8 a	31.1	2.59	81.4 b	1.87 c	343.6 a	0.10 c
Cropland	4.0	93.68 a	1.37 a	39.7 b	28.2	2.69	88.9 ab	2.47 b	61.9 b	0.14 b
Olive orchard	4.2	20.36 b	1.14 b	40.3 b	32.1	3.27	92.9 a	3.60 a	328.2 a	0.19 a
p value	n.s.	***	***	***	n.s.	n.s.	*	***	**	***

*** Statistical significance at $p < 0.001$. ** Statistical significance at $p < 0.01$. * Statistical significance at $p < 0.05$.

3.2. Overland Flow

The effects of soil management on the overland flow properties are summarized in Table 2. TP and TR ranged from 202.8 to 1800 s and 740 to 1504 s, respectively. In both cases, the olive orchard showed significantly lower values compared to the other plots. No hydrological response was observed in cropland plots. Run and SC varied from 0 to 53.69 (m^3 ha^{-1}) and from 0 to 5.77 (g kg^{-1}), respectively. SL ranged from 0 to 203.9 (kg ha^{-1}). Run and SL were always significantly higher in the olive orchard plots than in the vineyard and cropland. SC was significantly lower in the cropland compared to the other land uses. C loss, N loss, and P loss were in all cases significantly higher in the olive orchard (Figure 2).

Table 2. Average values of time to ponding, time to runoff, runoff, sediment concentration and sediment loss, and one-way and Kruskal–Wallis ANOVA analysis. The effects of soil management on the vegetation cover and the overland flow properties. Small letters in the column represent the difference of treatment effects at $p < 0.05$. ***, statistically significant at $p < 0.001$.

Treatment	Time to Ponding (sec)	Time to Runoff (sec)	Runoff (m^3 ha^{-1})	Sediment Concentration (g kg^{-1})	Sediment Loss (kg ha^{-1})
Vineyard	1082.4 ab	1504.8 ab	5.57 ab	5.77 a	37.8 ab
Cropland	1800 a	> 1800 a	0.00 b	0.00 b	0.0 b
Olive orchard	202.8 b	740.1 b	53.69 a	3.96 a	203.9 a
p value	***	***	***	***	***

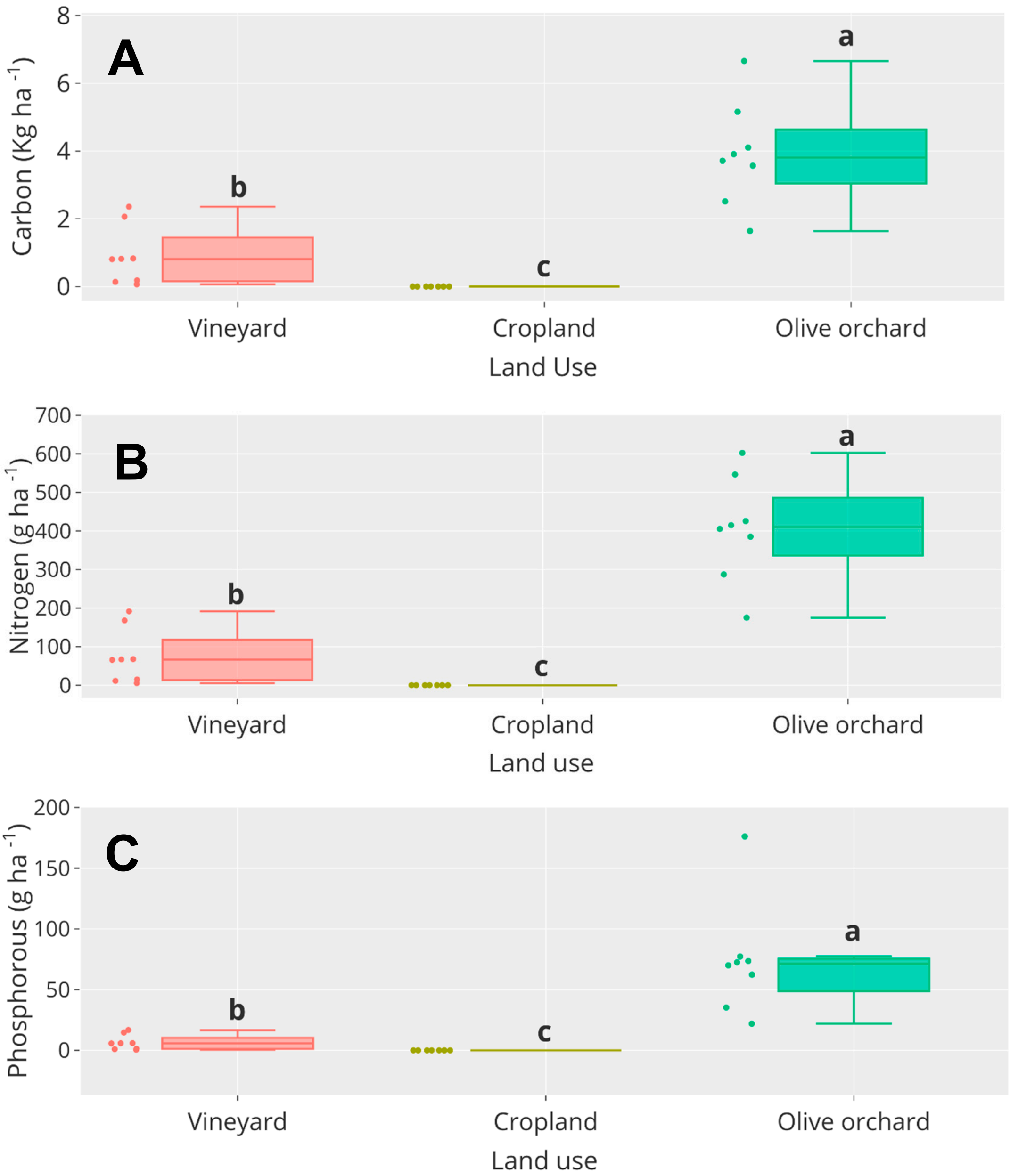

Figure 2. Nutrients loss in runoff: (**A**) Carbon, (**B**) Nitrogen, (**C**) Phosphorus. Different lower case letters represent significant differences at a $p < 0.05$.

3.3. PCA Analysis

The first three factors explained 83.98% of the total variance (Table S1 in Supplementary Material). Factor 1 explained 49.58%, and Factors 2 and 3 explained 24.71% and 9.96%, respectively, of all variance. Factor 1 had high positive loadings in BD, TP, and TR, and high negative in MWD, SOM, P_2O_5, TN, Run, SL, C, N, and P loss. Factor 2 had high positive loadings in WHC, and SC and high negative loadings in VC and WSA. Finally, factor 3 had high positive loadings in slope and SWC. The intersection between Factor 1 and Factor 2 shows that BD, TP, and TR are inversely related to the majority of the other variables, especially to Run, N loss, P loss, and SL (Figure 3A). The management practices have different impacts on soil properties and hydrological response in all the treatments. The impact is notably different between the olive orchard and the other treatments. The variability is high in the vineyard and low in cropland (Figure 3A).

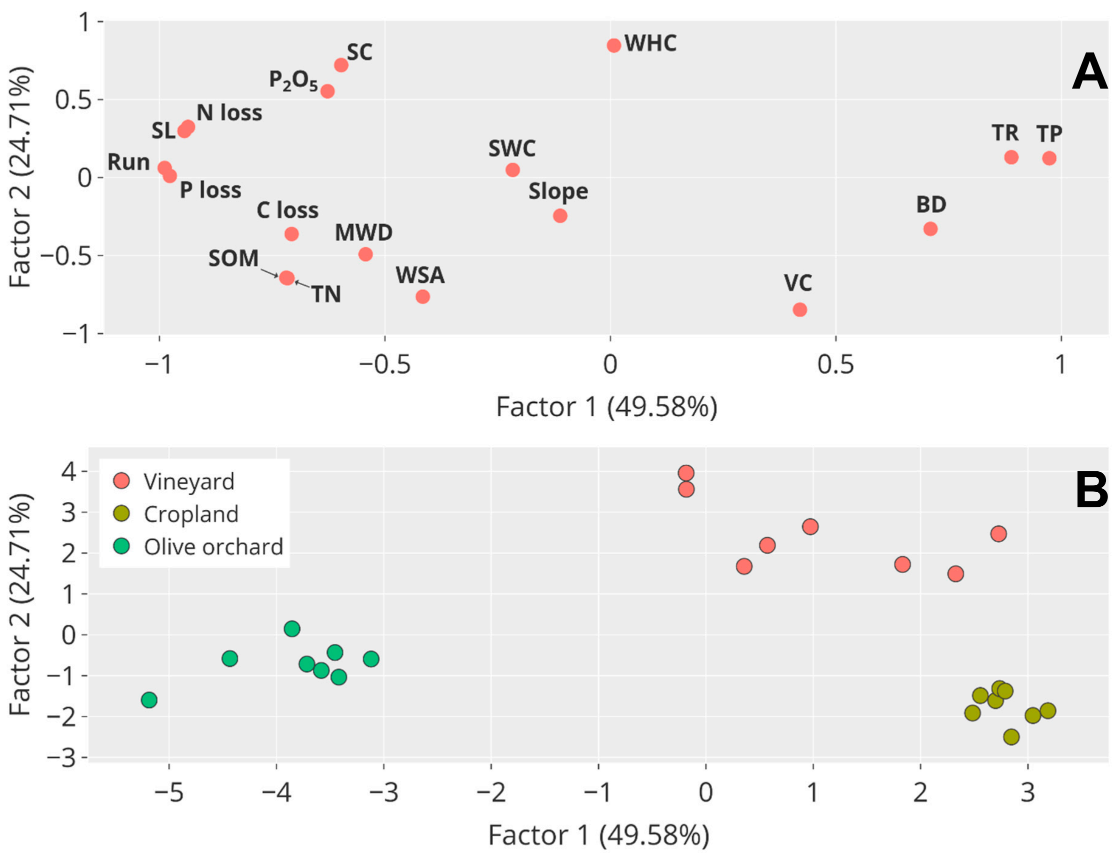

Figure 3. Relation between Factors 1 and 2, (**A**) Variables and (**B**) Cases. VC, vegetation cover; BD, bulk density; WHC, water holding capacity; SWC, soil water content; MWD, mean weight diameter; WSA, water stable aggregates; SOM, soil organic matter; P_2O_5, available phosphorous; TN, total nitrogen; TP, time to ponding; TR, time to runoff; Run, runoff, SC, sediment concentration; SL, sediment loss; N loss, nitrogen loss, C loss; carbon loss and P loss; phosphorous loss.

4. Discussion

The results of this work indicated that the BD was higher in the cropland compared to the vineyard and olive orchard treatments. This was attributed to the fact that tillage in the vineyard and olive orchard were carried out more recently than in the cropland (2 years before measurements). It is widely known that tillage reduces, in the short term, topsoil BD [13,32,33]. Natural consolidation and traffic-induced compaction cause the highest soil BD in this study [34]. High values of compaction in cropland soils were observed in previous works [35], although opposite results could also be found [36]. In Ethiopia, Bewket and Stroosnijder [37], on clay and silty soils, reported higher BD in Eucalyptus plantation than in cropland soils. In the Mediterranean environment on silty clay loam soil, Celik [38] reported the highest BD in cropland land-use type.

The MWD can explain the significantly higher WHC on the vineyard compared to the cropland and olive orchard. Although MWD did not show significant differences among treatments, aggregates were small in the vineyard soil. High MWD increases water infiltration [39], while smaller pore sizes increase water retention, and this may explain the high WHC in the vineyard soil [40].

The land use in this study changed soil structural characteristics. Soil compaction, MWD, WSA, and SOM concentration are often related [41]. In the present study, MWD is the highest in the olive orchard and the lowest in the vineyard. This is attributed to high SOM content [42]. The management can explain the reduced MWD, WSA, and SOM in the vineyard and cropland soils. The addition of olive pomace in the olive orchard, increased SOM, TN, P_2O_5, and WSA [43]. The studied vineyard is subjected to frequent tillage, decreasing WSA, and SOM [9,44]. Cropland and olive orchard management were less managed, decreasing the vulnerability of soils to disaggregation. Reduced tillage increases soil quality (e.g., increase of SOM, MWD, and WSA) as observed by others [43,45].

Soil erosion in the study area depends on the natural soil properties, tillage, herbicides application, vegetation cover, and organic matter properties. The soils of the study area have vertic properties and develop cracks and water preferential flow. It has been highlighted in several works that water infiltration is high in these types of soils [46,47]. Tillage practices reduced infiltration in vertisols as observed elsewhere [48,49], and this may be one of the causes for the high erosion rates in the vineyard and olive orchard plots compared to the cropland (despite the high BD). The measurements carried out in Istria simulated high magnitude storms and showed that the olive orchard could lose as much as 0.2 t ha^{-1} of soil in 30 min, when measured at the plot scale. Despite being tilled with high frequency, runoff and sediment concentration were lower in the vineyard compared to the olive orchard. This can be attributed to the soil roughness and porosity due to frequent tillage.

Historically, tillage is recognized as a significant cause of soil erosion since agriculture was developed [50] and acts as a driving factor for the acceleration of soil loss in vineyards and orchards [5,51–53]. The application of herbicides in the olive orchard may have contributed to the increase in soil erosion. Keestra et al. [4] reported that herbicides have a higher impact on soil erodibility than tillage. High runoff and soil losses on herbicide plots in different land-use treatments were also measured [54–56].

VC was the lowest in the vineyard as a consequence of frequent tillage and compensates its adverse effects on plant cover and soil structure, and thus on infiltration, explaining the low erosion rates compared to the olive orchard plots. The highest runoff and soil loss were observed in the olive orchard and can be attributed to several reasons. The percentage of VC in the olive orchard plots is relatively small (20%) to protect the soil. According to Cerda [57] soils, only 20% of cover can be described as bare. In soils where the cover was between 40% to 60%, the erosion rates are much lower [57] compared to bare soils (0–20 CV). In this context, VC reduced the soil erosion substantially, declining from 30–35 t ha^{-1} at 0% vegetative cover to 9 t ha^{-1} and 0.5 t ha^{-1} at 20% and 47% cover, respectively [58]. Similar findings were reported elsewhere. Hou et al. [59] observed that after a rainfall simulation (60 mm h^{-1}), soil erosion was reduced by 55%, 90%, and 100%, when VC was 30%, 60%, and 90%, respectively. In cropland, VC reduced the effect of splash erosion, as reported in previous works [1,4,5,9,10,60], contributed to the absence of runoff and erosion. Previous research highlighted that soil loss is reduced when VC is at least 40% [57–59]. Finally, the incorporation of olive pomace organic matter in olive orchard soils may have increased the amount of hydrophobic compounds as observed elsewhere [45,61].

PCA analysis supports the results described above. Factor 1 explained the majority of the erosion variables, and it is clearly observed that erosion was different between the olive orchard and vineyard and cropland. The values of TR, TP, BD, and VC were higher in the vineyard and cropland than in the olive orchard. The high TR and TP in soils with high BD, may be attributed to the vertic properties of the soil, as discussed previously. In opposition, the C loss, N loss, P loss, run, SL, and SC were high in the olive orchard plots. Erosion was substantially higher in the olive orchard compared to the other plots. On the other hand, Factor 2 was mainly related to SC, WHC, and P_2O_5 which was high in the vineyard and olive orchard. The opposite was identified in WSA.

Overall, despite the better soil conditions in olive orchard soils (low BD and high SWC, WSA, SOM, and TN), Run and erosion rates were high as a consequence of the disruption of water preferential flow with tillage practices, herbicides application, reduced vegetation cover and organic matter properties. Less tilled soils (cropland) are more resistant to Run and sediment detachment as a consequence of the low disturbance and high VC. This work highlighted the necessity to carry out integrate studies (soil properties and hydrological response) in order to have a better understanding of long term management impacts.

5. Conclusions

Long term soil management produced substantial impacts on soil properties and hydrological response in the studied plots. The tillage practices in the vineyard likely decreased soil BD and increased WHC. The application of organic fertilizers in the olive orchard most likely increased soil quality. Nevertheless, tillage management in soils with vertic properties, the application of herbicides probably reduced VC, and hydrophobic organic material apparently increased the overland flow and sediment and nutrient losses. Soil in the cropland area with minimal disturbance had a high infiltration and resistance to soil detachment, and this shows that less frequent tillage and cover crops probably increased soil resistance to rainfall impact. From a hydrological response perspective, the practices applied in the vineyard and olive orchard need to be reconsidered. The outcomes of this work showed that management practices should reduce tillage frequency and increase soil cover in order to decrease erosion. The present study contributes to better land-use management in Istria, although conclusions from a single measurement can be a limitation. Therefore, temporal studies will be considered in the future in order to have a clearer picture of management practices on soil and hydrological response.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/2/282/s1.

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Conflicts of Interest: The authors declare no conflict of interest.

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