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Experimental Comparison of Runoff Generation and Initial Soil Erosion Between Vineyards and Croplands of Eastern Croatia: A Case Study

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ABSTRACT: Soil and water loss in agricultural fields is a global problem. Although studies about soil erosion in croplands and vineyards exist, the direct comparison between these land uses is missing, especially under continental climates in Europe. Therefore, it is needed to find control measures to the impacts of these land-use management strategies on soil properties and hydrological response. The objective of this work is to estimate and compare the impacts of croplands and vineyards under conventional management croplands and vineyards on soil properties (water holding capacity—WHC; bulk density—BD; soil water content—SWC; water stable aggregates—WSA; mean weight diameter—MWD; soil organic matter—SOM; available phosphorus—AP; total nitrogen—TN) and hydrological response (runoff—Run; sediment content—SC; sediment loss—SL; carbon loss—C loss; phosphorus loss—P loss; nitrogen loss—N loss) in Eastern Croatia. To achieve these goals, a study was set up using rainfall simulation tests at 58 mm h^{-1} over 30 minutes on 2 locations (Zmajevac: 45°48′N; 18°46′E; Erdut: 45°30′N; 19°01′E). In total, 32 rainfall simulations were carried out, 8 repetitions in vineyards and 8 in cropland plots of 0.876 m^2, per location. Bulk density was significantly higher in cropland plots compared with the vineyard. Soil water content was significantly higher in Zmajevac cropland compared with Erdut plots. Also, SWC was significantly lower in Zmajevac vineyard than in the cropland located in the same area. Water stable aggregates and MWD were significantly higher in vineyard plots than in the cropland. Also, SOM and TN were significantly lower in Zmajevac cropland compared with the vineyard located in the same area. Available phosphorus was significantly high in Zmajevac plots than in Erdut. The rainfall simulations showed that Run was significantly higher in Erdut vineyard (8.2 L m^{-2}) compared with Zmajevac (3.8 L m^{-2}). Also, the Run in Erdut Cropland was significantly lower than in the vineyard. Sediment content did not show significant differences among locations. In Erdut, vineyard plots had a significantly lower SL (28.0 g m^{-2}) than the cropland ones (39.1 g m^{-2}). C loss was significantly higher in Zmajevac cropland than in Erdut. Also, C loss was significantly lower in Zmajevac vineyard compared with the cropland. We did not observe significant differences in P loss, and N loss also did not show significant differences. The principal component analysis showed that SOM was associated with WSA, AP, and TN. These variables were negatively related to slope, SWC, and C loss (factor 1). Also, MWD was inversely related to SL, P, and N loss (factor 2). Bulk density and SC were negatively related to Run. Overall, we conclude that noninvertive tillage practices in vineyards preserve soil structure, enhance soil quality, and reduce the extent of soil degradation.

KEYWORDS: Land use, management, soil erosion, runoff, rainfall simulation experiments

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Introduction

Erosion by water is considered one of the major threats to soil resources.[1] Although it is directly connected to the climatic, pedological, edaphic, and geomorphological conditions, the agriculture practices (tillage) used increase exponentially soil erosion rates[2,3] In this context, conventional tillage, involving a sequence of plowing, disking, and harrowing, and agrochemicals are recognized as primary drivers of unsustainable soil erosion rates.[4,5] Soil erosion rates can be 10 to 40 times higher than the rate of soil formation.[6]

Studies focused on soil erosion in croplands dominate in the international literature.[7] In the last 2 decades, there has been a high increase in studies conducted in vineyards, highlighting the importance of this land-use type in soil erosion works.[8,9] Several studies were carried out in the Mediterranean and reported soil erosion rates up to 14 t ha^{-1} y^{-1}.[10,11] Numerous studies also reported a positive impact of conservation strategies to mitigate soil erosion problems.[8,9,12] Nowadays, despite a few exceptions, most of the studies conducted to study soil erosion were focused on 1 land-use type.[13,14] Therefore, it is necessary to determine the impact of land use and the respective managements on soil erosion and identify which land uses and practices are more detrimental to the soil. This could be beneficial to identify areas and propose measures to achieve better sustainable management and land degradation neutrality.[15]

Some authors confirmed that in croplands, soil erosion by water is influenced by tillage intensity, slope direction, crop, planting direction, and/or orientation.[16,17] In plowed fields, unsustainable soil erosion rates were observed in per-humid,[18] semi-humid,[19] arid,[20] or semi-arid[21] environments on sandy,[22] silty,[23] or clay soils.[24] Similarly, soils in vineyards are highly sensitive to management, which affects their hydrological response dramatically. Vineyard management involves frequent tillage and tractor traffic. These practices reduce soil structure and hydraulic properties[25,26] and increase soil compaction, runoff, and soil erosion above the tolerant levels.[2] Previous works revealed that soil erosion in vineyards increases with the increasing slope,[8,10] tillage intensity,[9] and soil compaction.[26] On the contrary, a decrease in vegetation cover increases it.[2] In croplands, soil erosion increases with tillage intensity[21,27] and slope[20] and decreases with a plant density of cover crops.[16] Several works compared the impacts of different land uses and management on soil properties or hydrological response in Europe,[7,11,28-38] Africa,[39-41] Asia,[20,42-50] North America,[51-54] and South America.[55-57] Some studied the impact of land use on soil properties and hydrological response.[12,28-30,35,37,48,50,52,53,55,57] From these works, none has compared croplands and vineyards. To our knowledge, 1 study investigated cropland and vineyard soil management on soil properties and hydrological response, but in the Mediterranean environment and a different type of soil (terra rossa).[28] Therefore, studies at the pedon-scale are needed in croplands and vineyards to understand the impacts of land uses and the respective practices on soil properties and hydrological response in different climate zones such as temperate continental. Nowadays, standard methodology for determination soil erodability (rainfall simulator type, rainfall intensities, experimental time, plot sizes) often differs, which enables to make a qualitative comparison of the different land-use impact on soil erosion.[58,59] This work aims to study the impact of croplands and vineyards on soil properties and hydrological response in the Podunavlje region (Croatia). Both land uses are traditional in this area. The specific objectives are analyzing the effects on different soil properties (bulk density [BD], soil water content [SWC], mean weight diameter [MWD], water stable aggregates [WSA], soil organic matter [SOM], available phosphorus [AP] and total nitrogen [TN]) and their impact on the hydrological response: runoff (Run), sediment content (SC), sediment loss (SL), carbon loss (C loss), phosphorus loss (P loss), and nitrogen loss (N loss).

Materials and Methods

Study site

The study was carried out in 2 sites in Eastern Croatia (Zmajevac: 45°21′N; 13°26′E, 296 m a.s.l and Erdut: 45°48′N; 18°46′E, 155 m a.s.l), at an average elevation of 296 and 155 m above sea level, respectively (Figure 1). The landscape of the studied area was mainly flat. The parent material is loess, and both soils are loamy textured, classified as anthrosols created from chernozems.[60] Basic soil properties are presented in Table 1. The climate is moderate continental with Cfwbx description, according to Köppen climate classification.[61] The average annual precipitation (1980-2018) is 677.9 mm, ranging from a minimum of 317.0 mm (2000) to a maximum of 1038.2 mm (2010) (Hydrological and Meteorological Service of Croatia). The rainfall amount is the highest during June and May and the lowest in the period from January to March. However, high inter-annual and annual variations are usual too. The mean annual temperature is 11.5°C, where January is the coldest (0.1°C) and July the warmest (22.2°C) (Hydrological and Meteorological Service of Croatia). Cropland is the dominant land use in this region. However, vineyards and orchards cover the slopes in the study area.

Cropland and vineyard were used as treatments in Erdut and Zmajevac. Before initiating the experiment, we collected information from landowners about land-use practices. At Erdut site, vineyards are subsoiled every second season to 50 cm depth during spring, followed by cultivation (≈10 cm) or harrowing (≈10 cm), depending on soil moisture conditions. During the season, vegetation covers the inter-row position, whereas between the vines, herbicides are used to control the weeds. Following the season, inter-rows are not tilled, only mulched 2 to 3 times. Each year cropland soil is tilled using a mouldboard plow, followed by disking and roto-harrow and seedbed preparation before sowing. Herbicides and insecticides are used annually. Primary tillage for summer crops is implemented in October or November in the previous autumn, and supplementary tillage followed in the spring before planting. Tillage practices for winter crops (primary and secondary) were carried out in September or October. The crops that are grown followed a typical rotation for this area, which included maize, soybean, winter wheat, sunflower, and barley. During the measurements, winter wheat was a crop, whereas the preceding crop was sunflower. At Zmajevac location, annual vineyard management consists of chiseling (≈20 cm) in autumn, followed by tine tillage (≈12 cm) in the spring. Cropland management at Zmajevac is similar to the cropland at the Erdut site. Winter wheat was the crop, whereas the preceding crop was oil seed rape used as green manure. Vineyard and cropland treatments at both locations were similarly managed for at least 10 years.

Field experiments, soil sampling, and rainfall simulation experiments

In each treatment, a transect was established to carry out the experiments. We selected 8 sampling points, separated by 6 m. At each point, we sampled soils (disturbed and undisturbed—10 cm ring) before carrying out rainfall simulation experiments (8 per treatment, 16 per location, 32 in total). Plots were established in nontraffic areas on each plot. The rainfall simulation experiments were performed during April 2019 under relatively dry soil conditions (15% SWC). Rainfall simulation experiments were carried out in cropland in the stage of stem extension, whereas vineyard was tilled and generally bare (Figure 1). Rainfall simulator (UGT Rainmaker, Munich, Germany) was used in this experiment. Rainfall intensity was adjusted by the time that the nozzle (VeeJet 80/100 nozzle; pressure at 0.5 bar) remains at the reversal points and nozzle turning speed.[62] Plastic collectors (n = 144) were placed under the rainfall simulator to collect the drops. After 30 minutes of the experiment at an intensity of 58 mm h^{-1}, we observed an average of 64 g (CV 4.66). The mean drop size was 0.7 mm, and the mean falling velocity was 6.263 m s^{-1}. Plots used in this work

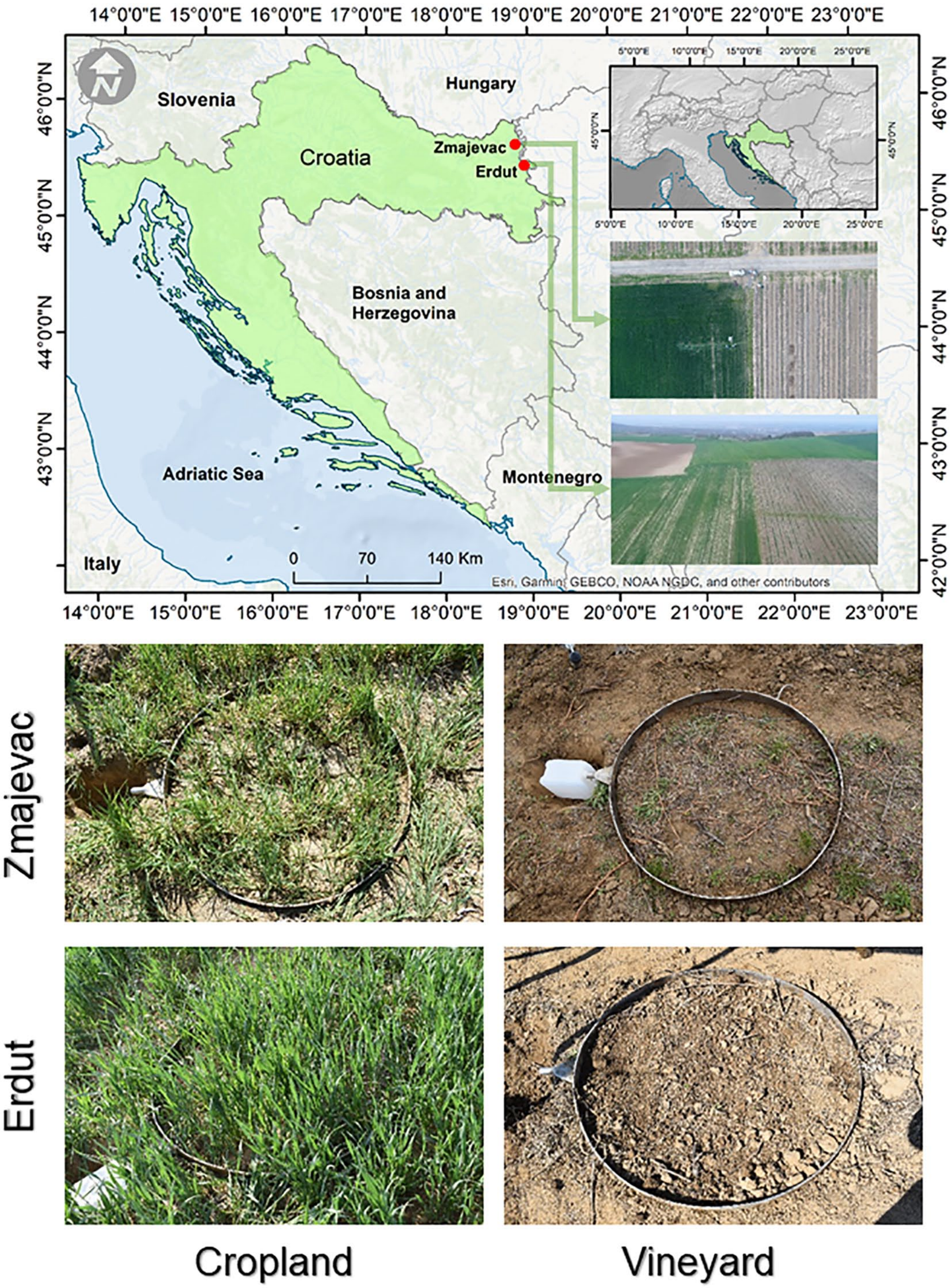

Figure 1. Study area.

are circular plots of 0.785 m^2 (metal ring of 100 cm diameter). This intensity was chosen because 93% of the annual soil loss was detected in a single rainstorm event at a rainfall intensity of 59 mm h^{-1}.[2] Before the simulations, the simulator was calibrated using the plastic vessel of known dimensions. The slope was measured inside the ring area.

Undisturbed soil samples were used to measure SWC and BD. These properties were determined by drying core samples in an oven at 105°C for 48 hours.[63] Additional undisturbed samples were collected to determine MWD, according to Diaz-Zorita et al.[64] The percentage of WSA was determined and calculated by the procedure described in Kemper and Rosenau.[65] Disturbed samples were dried in the laboratory for 5 days at room temperature (20°C-23°C). Subsequently, samples were sieved with <2 mm mesh to analyze chemical properties. The SOM content was calculated according to the digestion method.[66] The AP content was determined by extraction with the ammonium lactate (AL) method[67] using a spectrophotometer (model DR/2000; Hach, Dusseldorf, Germany). Total nitrogen in soils and carbon (C) and nitrogen

Table 1. General soil properties in investigated areas.

DEPTH, CM	TEXTURE	SAND, %	SILT, %	CLAY, %	PH H_2O	PH KCL	ORGANIC MATTER, %	$CACO_3$, %
Erdut								
0-35	Loam	48.9	28.2	22.9	6.3	5.2	1.8	0.0
35-65	Clay loam	42.4	26.3	31.3	6.2	4.9	0.8	0.0
65-85	Clay loam	43.1	29.8	27.1	6.7	5.8	–	0.0
85-120	Loam	49.2	31.8	21.0	7.9	6.9	–	19.2
Zmajevac								
0-21	Loam	52.1	28.5	19.4	8.1	7.3	2.7	6.2
21-40	Sandy clay loam	56.4	20.8	22.8	8.2	7.3	1.7	6.4
60-120	Sandy loam	65.8	21.4	12.8	8.5	7.7	–	23.8

(N) in sediments were obtained by a dry combustion method using Vario MACRO CHNS analyzer.

During rainfall simulation experiments, the overland flow was stored in plastic canisters. Canisters were weighed and filtered to obtain overland flow. Sediment yield was determined after air-drying at room temperature (20°C-23°C) and weighting of the filter paper. Mass of the sediment was deduced from the mass of overland flow to obtain the Run. Sediment content was calculated by dividing the mass of the sediment with the mass of the overland flow. Dried sediments were milled and passed through 2 mm mesh as a preparation for C, N, and P determination.

Statistical data processing

Prior to the statistical analysis, the Shapiro-Wilk (S-W) and Levene tests were applied to test the data normality and homogeneity of the variances ($P > .05$). Most of the variables did not respect the Gaussian distribution and heteroscedasticity. Therefore, several data normalization methods were performed to achieve the data normality, including natural logarithm, logarithm with base 10, and Box-Cox transformation. From all the tests, Box-Cox transformed data followed data normality and homogeneity of the variances. Therefore, it was used to apply the 2-way analysis of variance. The site and land use were used as factors. In cases where significant differences were found, the Tukey honestly significant difference post hoc test was applied. Significant differences were considered at $P < .05$. The data presented in the tables are the original one. A principal component analysis (PCA) was performed using the Box-Cox transformed data and was based on the correlation matrix to identify correlations among both soil and overland flow variables. No rotation procedure was applied. Statistical analyses were carried out using Statistica 12.0 for Windows (StatSoft, Tulsa, USA). Graphics were done using Plotly 4.9.2.[68]

Results

Environmental plot characteristics

The slope did not differ significantly between treatments in both locations. The slope was significantly higher in Zmajevac vineyard compared with the Erdut one (Table 2). Bulk density of the soils ranged from 1.20 to 1.44 g cm^{-3}. Bulk density was significantly higher in the cropland than in the vineyard at Erdut, whereas at Zmajevac it did not differ between land uses. However, BD was significantly higher in Erdut cropland than in Zmajevac. The SWC and MWD varied between 13.4% and 19.9% and 2.04 and 2.93 mm, respectively. In Zmajevac, SWC was significantly lower in the vineyard than in the cropland, whereas MWD was significantly higher in the vineyard compared with the cropland. Mean weight diameter was significantly lower in the cropland than in the vineyard at both sites. Water stable aggregates and SOM ranged from 58.9% to 88.8% and from 0.7% to 1.7%, respectively. Water stable aggregates were significantly higher in both land uses in Erdut compared with Zmajevac. In Erdut's location, WSA was significantly higher in the vineyard than in the cropland. The SOM content was significantly lower in the cropland than in the vineyard at Zmajevac, whereas the cropland in Erdut had significantly higher SOM than the cropland in Zmajevac. Finally, AP and TN ranged from 165.5 to 417.2 mg kg^{-1} and from 0.04% to 0.1%, respectively. The AP content was significantly lower in cropland and vineyard in the Zmajevac site, compared with Erdut. The TN content was significantly higher in Zmajevac cropland compared with the Erdut one. In the Zmajevac site, TN was significantly lower in the cropland compared with the vineyard (Table 2).

Hydrological response

The effects of soil management on the overland flow properties are summarized in Table 3. Run and SC varied from 28.0 to 82.0 m^3 ha^{-1} and from 3.6 to 12.3 g kg^{-1}, respectively. In Erdut, vineyard plots had a significantly higher Run than at vineyard in the Zmajevac site. In the Erdut site, vineyard Run was significantly higher compared with cropland. The SC was significantly higher at cropland than in vineyard plots in both sites. Also, SL ranged from 2.8 to 8.2 L m^{-2}. The SL content was significantly lower in the vineyard than in the cropland. Finally, C loss ranged from 0.86 to 2.23 kg m^{-2}. It was significantly lower in Erdut cropland compared with Zmajevac. The vineyard located in Zmajevac had significantly lower C losses than cropland. Finally, N loss and P loss ranged from 0.004 to 0.013 g m^{-2} and 0.604 and 0.570 g m^{-2}, respectively. In both cases, no differences were observed between sites and land use.

PCA analysis

The first 3 factors explained 87.4% of the total variance. Factor 1 explained 32.8% of all variance, whereas factors 2 and 3 explained 27.6% and 18.0%, respectively. Also, factor 1 had high positive loadings in WSA, SOM, AP, and TN and high negative loadings in slope, SWC, and C loss. Factor 2 had high negative loading in WSA and high positive loading in SL, P loss, and N loss. Finally, factor 3 had high positive loading in BD and SC and high negative loading in Run (Table 4). The intersection between factor 1 and factor 2 showed that WSA, SOM, AP, and TN are inversely related to slope, SWC, C loss, SC, and SL (Figure 2A). The impact of rainfall on soil properties and the hydrological response was more different in Zmajevac than in the Erdut site. The highest variability was observed in Zmajevac plots (Figure 2B).

Discussion

To understand the impact of land use on soils, it is crucial to recognize the impacts of soil structure. This is key to understand the hydrological response. The results obtained indicate that the cropland treatment had implications for BD in both study sites. In this study, BD was higher under cropland treatment than under the vineyard. Previous research generally studies the difference between forests, grasslands (or pastures), and croplands and reveals that BD is the highest in the croplands.[37,42,69] Direct comparison of soil properties in vineyards and croplands is scarce. Bogunovic et al[28] found that the soil BD was greater in croplands compared with tine-tilled vineyard treatments on a clay loam soil, whereas on sandy loam soils in South Africa Materechera[70] found higher BD at cultivated vegetable croplands in addition to untilled vineyards. High topsoil BD is usually attributed to compaction, structural damage, and destruction of macro-pores of topsoil by use of machinery[71] or intensive tillage operations.[72] Our results are thus consistent because croplands were managed annually with heavy machinery when compared with light tractor–used management in vineyards.

The intensity of land-use practices has an impact on soil structure as it has been observed in other studies.[25,72] Our study results reveal that croplands have lower MWD and WSA in

Table 2. Results of 2-way analysis of variance (n = 32).

TREATMENT	SLOPE, DEG	BD, G CM^{-3}	SWC, %	MWD, MM	WSA, %	SOM, %	AP, MG KG^{-1}	TN, %
Erdut cropland	6.3 ± 1.37Aa	1.44 ± 0.04 Aa	15.0 ± 2.26 Ba	2.09 ± 0.34 Aa	78.22 ± 5.95 Ab	1.69 ± 0.06 Aa	417.24 ± 25.42 Aa	0.095 ± 0.001 Aa
Erdut vineyard	5.8 ± 0.75 Ba	1.20 ± 0.05 Ab	13.4 ± 0.70 Aa	2.39 ± 0.12 Ba	88.78 ± 6.83 Aa	1.59 ± 0.06 Aa	361.51 ± 47.31 Aa	0.090 ± 0.002 Aa
Zmajevac cropland	7.8 ± 0.98 Aa	1.31 ± 0.05 Ba	19.9 ± 3.31 Aa	2.04 ± 0.26 Ab	58.90 ± 2.92 Ba	0.76 ± 0.30 Bb	169.70 ± 20.60 Ba	0.046 ± 0.016 Bb
Zmajevac vineyard	8.0 ± 1.26 Aa	1.29 ± 0.09 Aa	14.5 ± 1.73 Ab	2.93 ± 0.28 Aa	64.17 ± 2.04 Ba	1.35 ± 0.61 Aa	165.50 ± 72.13 Ba	0.077 ± 0.032 Aa
P value	*	***	*	*	*	*	*	*

The effects of soil management on soil properties. Different letters in column represent difference in treatment (lowercase) and location (uppercase) effects at $P < .05$. Abbreviations: AP, available phosphorus; BD, bulk density; MWD, mean weight diameter; SOM, soil organic matter; SWC, soil water content; TN, total nitrogen; WSA, water stable aggregates.
***Statistical significance at $P < .001$. *Statistical significance at $P < 0.05$.

Table 3. Results of 1-way analysis of variance (n = 32).

TREATMENT	RUN, L M^{-2}	SC, G L^{-1}	SL, G M^{-2}	C LOSS, G M^{-2}	P LOSS, G M^{-2}	N LOSS, G M^{-2}
Erdut cropland	2.8 ± 1.88 Ab	12.3 ± 3.80 Aa	39.1 ± 34.62 Aa	0.97 ± 0.72 Ba	0.013 ± 0.011 Aa	0.065 ± 0.045 Aa
Erdut vineyard	8.2 ± 1.97 Aa	3.6 ± 2.89 Ab	28.0 ± 19.46 Aa	0.97 ± 0.61 Aa	0.010 ± 0.006 Aa	0.604 ± 0.041 Aa
Zmajevac cropland	4.00 ± 1.40 Aa	11.8 ± 2.91 Aa	48.1 ± 26.80 Aa	2.23 ± 1.13 Aa	0.004 ± 0.002 Aa	0.570 ± 0.022 Aa
Zmajevac vineyard	3.8 ± 1.66 Ba	5.4 ± 4.05 Ab	16.4 ± 4.18 Ab	0.86 ± 0.25 Ab	0.007 ± 0.002 Aa	0.541 ± 0.016 Aa
P value	***	*	*	*	ns	ns

The effects of soil management on overland flow properties. Different letters in column represent difference in treatment (lowercase) and location (uppercase) effects at $P < .05$. ns, not significant at $P < .05$. Abbreviations: C loss, carbon loss; N loss, nitrogen loss; P loss, phosphorus loss; Run, runoff; SC, sediment content; SL, sediment loss.

***Statistical significance at $P < .001$. **Statistical significance at $P < .01$.

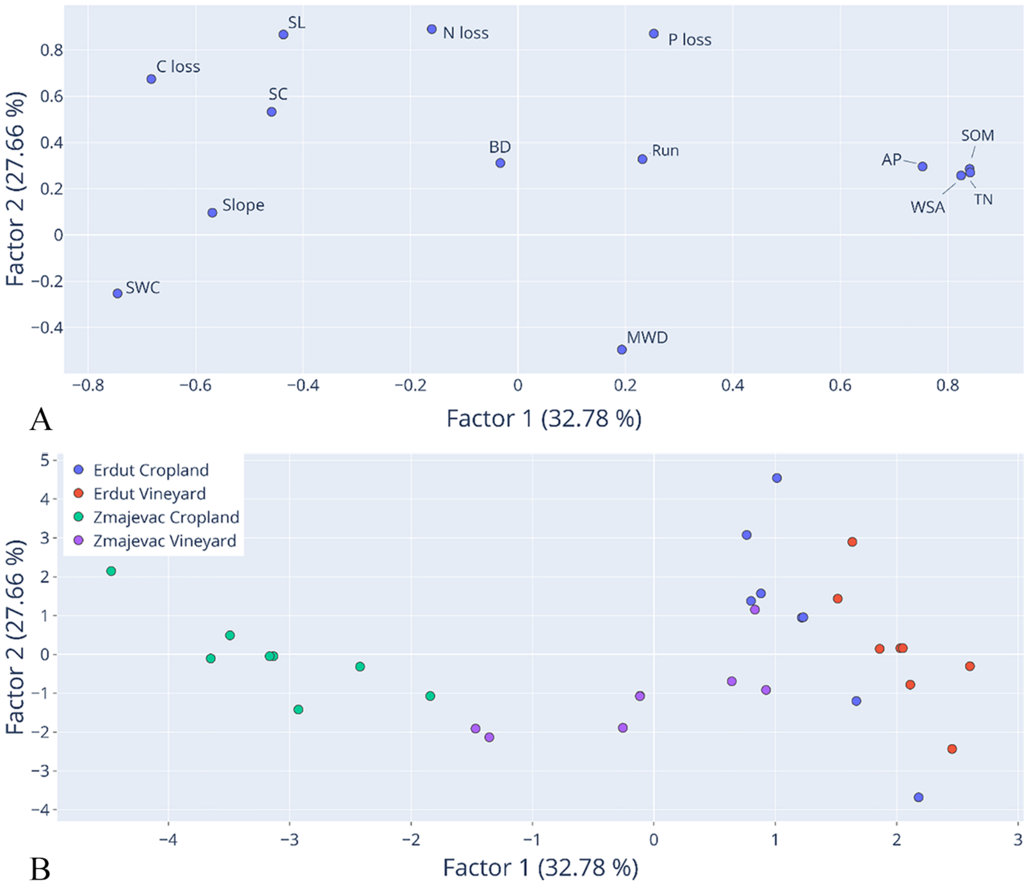

Figure 2. Relation between factor 1 and factor 2: (A) variables and (B) cases.
AP indicates available phosphorus; BD, bulk density; C loss, carbon loss; MWD, mean weight diameter; N loss, nitrogen loss; P loss, phosphorus loss; Run, runoff; SC, sediment content; SL, sediment loss; SOM, soil organic matter; SWC, soil water content; TN, Total nitrogen; WSA, water stable aggregates.

addition to vineyards. Such findings show that in the area of research, vineyard management favoring aggregates stability and enhances soil resistance to disaggregation. Small and unstable aggregates were found on soils that are heavily plowed, whereas more persistent soil structure was found on soils with noninvertive tillage operations.[73] Although direct studies involving vineyards and cropland are missing, we can support this statement with tillage management comparison. In different environments on loam,[74] sandy,[75] and clay[76] soils, chiseling and/or tine tillage management enhance soil aggregation in addition to plowed soils. The higher SOM concentrations provide higher aggregate stability, as has been observed in previous studies.[77] Intensive tillage distorts soil aggregates and exposes them to air, enhancing microbial activity and accelerating decomposition and mineralization of SOM.[44] Although our study results for SOM support the previous statement only in Erdut, no significant difference in SOM concentrations between treatments in Zmajevac can be explained by the occurrence of green manure (oil rapeseed) buried before winter wheat sowing. Therefore, the soil compaction observed for

Table 4. Loading matrix with the first 3 factors extracted from the principal component analysis.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3
Slope	**−0.57**	0.10	−0.28
SWC	**−0.75**	−0.25	0.37
BD	−0.03	0.31	**0.83**
MWD	0.19	**−0. 5**	−0.43
WSA	**0.82**	0.26	−0.11
SOM	**0.84**	0.29	0.19
AP	**0.75**	0.30	0.41
TN	**0.84**	0.27	0.20
Run	0.23	0.33	**−0.79**
SC	−0.46	0.53	**0.63**
SL	−0.44	**0.87**	−0.07
C loss	**−0.68**	0.67	−0.19
P loss	0.25	**0.87**	−0.23
N loss	−0.16	**0.89**	−0.27

Abbreviations: AP, available phosphorus; BD, bulk density; C loss, carbon loss; MWD, mean weight diameter; N loss, nitrogen loss; P loss, phosphorus loss; Run, runoff; SC, sediment content; SL, sediment loss; SOM, soil organic matter; SWC, soil water content; TN, Total nitrogen; WSA, water stable aggregates. Eigenvalues retained in each factor are in bold.

cropland soils is likely the result of tillage intensity and field traffic at a particular site, which modifies soil structure.[71]

Mitigation of soil erosion is obligatory in agriculture land to achieve sustainable management because of the high soil erosion rates that occur under intensive agro-technical management. This is especially important in agricultural soils in the Continental climate of Croatia, where bare topsoil prevails due to intense tillage or use of herbicides. In the case of Croatia, most of the farmers still perform conventional tillage,[21,27] indicating that current agricultural soil management is unsustainable. In this context, the adoption of environmental-friendly soil management is required because low soil quality and increased soil erosion act as a consequence of unsustainable soil management.[78] Our measurements in 16 cropland plots on 2 locations reveal high soil erosion rates with an average value of $43.6\,\text{g m}^{-2}$ per 1 rainstorm. Vineyard losses were in the average value of $22.2\,\text{g m}^{-2}$. Despite the differences in catchment size plots and dropping systems, other rainfall simulation experiments in vineyards report losses from 2.6 to $54.7\,\text{g m}^{-2}$,[12] and from 31 to $186\,\text{g m}^{-2}$,[79] at a rainfall intensity from 51 to $70\,\text{mm h}^{-1}$ and at $60\,\text{mm h}^{-1}$, respectively. This study demonstrates that the use of intensive tillage (cropland) increases Run, SC, and soil erosion rates. Although measured in different cropping systems, our study agrees with others. In the Swiss midlands, plowing seems to be responsible for 9.8 times higher soil erosion rates in addition to noninvertive tillage.[80] In clay soil, Bertol et al[81] reported 34% higher soil erosion rates on plowed plots in addition to harrowed plots. Similar results were reported by Dickey et al[13] for clay loam soil when they compared plowing and chisel tillage. Such results reveal that noninvertive, less-intensive tillage practice conserves soil better than plowing. Soil conserving tillage practices have been recognized as effective methods for controlling soil erosion.[8,15,17]

The PCA revealed that WSA, SOM, AP, and TN are positively associated. This agrees with other findings identified in the literature because usually high SOM concentration in soils increases WSA and acts as a source of nutrients.[73,82] This dynamic was observed in the Zmajevac location with a high SOM (Table 1). As mentioned previously, intensive tillage like plowing affects soil aggregate size, exposes them to air and fastens the decomposition of SOM, and reduces the aggregate stability.[19,28,75] Despite the increase in SOM, the studied soils record the decrease in C loss. Soil with high SOM content has a stabile structure where organic carbon was entrapped and unexposed to air, making aggregates resistant to particle detachment during rainfall.[44] Factor 1 relates slope and SWC. Usually, SWC decreases with an increasing slope.[53] In our case, SWC was high, where the slope was high as well. Nevertheless, the slope of these plots was small, and therefore this relationship is very likely an artifact. Factor 2 shows that the relation between MWD and SL, P loss, and N loss is negative. The MWD had the highest values in vineyard plots, whereas SL, P loss, and N loss had the lowest values (Table 1 and 2). The high values of MWD were attributed to favorable soil structure, which helps to reduce the SL,[78] as discussed above. Factor 3 relates BD and SC, whereas Run was negatively associated with the first 2 properties. This agrees with other studies that confirm the lower SC on plots with higher Run.[83] High SC in Run may be attributed to the effect of tillage practices that generally reduce the size of MWD[51] and increase the vulnerability of soil particles to be detached by raindrop impact. This is especially evident in plowed soils,[14] as we observed in our work (Tables 1 and 2). However, low BD usually decreases Run,[83] although our results showed differently. This was observed in both locations (Table 1 and 2). To our knowledge, no studies were performed on BD critical limit for water infiltration that was carried out in chernozems. However, Wilson et al[84] observed that this threshold was $1.44\,\text{g cm}^{-3}$ for mollisol. We hypothesize that the limits for chernozems can be higher than $1.44\,\text{g cm}^{-3}$ in mollisol. More research is necessary to reveal unanswered questions in this process.

Overall, the fact that soil has a low BD does not necessarily mean that it decreases Run. The type of tillage management trough disturbance is a crucial factor in controlling soil erosion. Noninvertive tilled soils (vineyards) have better structure, lover compaction, and are more resistant to sediment detachment and soil loss.

Conclusion

Different land-use practices affect soil properties and hydrological response. Noninvertive tillage practices reduced soil

BD and increased WSA and MWD in vineyards. In these plots, the better preservation of soil structure enhanced soil quality. Also, intensive invert tillage like plowing increased the SC and SL. Vineyard soils with loosening-type tillage had a high infiltration and resistance to soil detachment, and this shows that vineyard management in the studied area on loamy soils represents the less endangered practice and land use with higher resistance to rainfall impact. From a hydrological response perspective, the practices applied in croplands need to be either reconsidered or coupled with conservation strategies to mitigate soil erosion problems. Outcomes support the fact that management practices on the studied area should use reduced tilling frequency to have persistent structure and to avoid soil erosion. This study contributes to better land-use management in Eastern Croatia on Continental-type climate.

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Conceptualization and methodology: IB; Formal analysis: LJT and PP; Investigation: IB; Writing—original draft preparation: IB; Writing—review and editing: PP and LJT; Visualizatio: PP; Supervision: IB and PP.

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