



Linking tillage practices to soil health, crop productivity, and erosion control in maize – wheat rotation

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Abstract: The suitability of conservation tillage in maize–wheat interrow farming in a young plum orchard in Croatia to control runoff, soil, and element loss under natural rainfall was evaluated. Paired runoff plots (20 m² size) comparing conventional (ploughing and discing) and conservation (chisel and harrow) tillage were implemented in triplicate across Stagnosols (11° slope). Soil physical (bulk density, penetration resistance, mean weight diameter, water stable aggregates) and chemical properties (carbon, nitrogen, phosphorous, potassium and copper) were assessed alongside event-based overland flow formation monitoring. After two years, conservation tillage maintained or improved soil structure, with significantly higher aggregate stability and soil carbon at 0–10 cm depth. Moreover, no clear increase in compaction was documented during the shift to conservation tillage. Conservation tillage exhibited a clear and significant mitigation effect on surface flows of water, sediment, and chemical elements. Sediment concentration decreased from 8.95 to 3.11 g L^{−1}, runoff was 40.5% lower, and cumulative soil loss declined from 8.57 to 2.97 t ha^{−1} over the two years. Importantly, reduced sediment export translated into markedly lower off-site losses. Conventional tillage increased losses of phosphorus (~3.4×), potassium (~3.2×), copper (~2.6×) and nitrogen (~1.7×) relative to conservation tillage. Overall, non-inversion loosening in orchard inter-rows proved an effective conservation practice for reducing runoff, soil erosion, and chemical export under natural rainfall, supporting on-site soil health and reducing off-site pollution.

Keywords: Agroforestry systems; Cereal cropping systems; Conservation agriculture; Soil degradation; Sustainable agriculture.

1 INTRODUCTION

Soil is Earth’s primary biological reservoir and the basis of terrestrial life (Zhang et al., 2023). Healthy soils provide multiple ecosystem services, including nutrient cycling, water filtration and quality regulation, carbon sequestration and food (Kopittke et al., 2025). To supply ecosystem services, the soil’s physical, biological, and chemical properties must not be degraded. Therefore, proper soil management is crucial for the future sustainability of agroecosystems. Food demand increases as population growth accelerates, while soil becomes severely degraded. The spread of soil degradation processes such as structure deterioration, compaction, salinisation, acidification, sealing, and erosion affects millions of hectares and continues to expand each year (Pereira et al., 2023; Právělie et al., 2024). Soil degradation results in a tremendous economic cost, estimated at over 300 billion USD annually, due to the loss of ecosystem services, agricultural productivity and biodiversity (Nkonya et al., 2016; Shen and Teng, 2023). Consequently, there is an urgent need to disseminate locally adapted strategies to restore these degraded soils and ensure their functionality.

Intense agricultural management, mainly conventional practices, has increased pressure on soil, largely due to intensification, e.g., inadequate crop rotations, insufficient return of organic matter to the soil, heavy tractors, trafficking, and repeated tillage

(Bogunovic et al., 2018; Li et al., 2025). These practices often leave soil bare, especially when herbicides are applied, triggering overland flow and soil erosion (Clement et al., 2025; Daimonakos et al., 2026; Liebhard et al., 2024a). Soil water erosion is the main source of sediment transport in sloped areas, which are highly enriched in organic matter and nutrients, resulting in losses of Carbon (C), Phosphorus (P), and Nitrogen (N) and disrupting nutrient cycling (Tian et al., 2024). In orchards and vineyards, runoff and sediment export increase off-site pollution (e.g., pollutants transfer), especially when fungicides are used (Dugan et al., 2024a; 2024b; Imfeld et al., 2023; Pesce et al., 2025). In central European agroecosystems, young plantations are especially vulnerable, due to practices that keep the soil bare for the first few years until the canopy develops (Telak et al., 2021a; 2021b). Unfortunately, this management exacerbates soil degradation, primarily by causing loss of soil organic matter, structural instability, compaction, and increased erosion (Bogunovic et al., 2022). Croplands with bare and intensively managed soils are the first to need conservation tillage. This practice does not fully incorporate residues and maintains surface roughness sufficient to prevent the negative impact of rain kinetic energy on soil aggregates (Liang et al., 2025). Recently, farmers have used the inter-row area to diversify production, increase income, and establish agroforestry systems of fruit-cereal

croplands (Bogunovic, 2025). In this context, evidence from young orchards integrating annual crops into the inter-rows remains limited, particularly under natural rainfall conditions. In the first few years after planting, inter-row management dominates hydrological responses because the soil is frequently disturbed by tillage and herbicides, and remains bare. At the same time, regular plant protection also provides additional agrochemicals that are transported by runoff. In permanent plantations, row orientation is often up and down the slope, enabling machinery traffic and inter-row operations in a direction perpendicular to the slope, which increases overland flow and soil loss (Bagagiolo et al., 2018). On the contrary, previous research confirms that tillage-induced berms help restore and conserve sloped terrain by resisting gravity-driven soil movement (Korba et al., 2024; Vieira and Dabney, 2011; Xu et al., 2019). To address the limited evidence on fruit–cereal inter-row systems in young orchards, we assessed erosion dynamics and element losses under natural rainfall in a sloping plum orchard in Croatia, comparing conventional inversion tillage with non-inversion conservation loosening. We hypothesised that conservation tillage would (i) reduce runoff and soil loss relative to conventional tillage, (ii) decrease sediment-bound losses of C, N, and P by limiting the export of fine particles, and (iii) reduce off-site transport of Copper (Cu) under orchard management, thereby supporting both on-site soil functionality and downstream environmental protection.

2 MATERIALS AND METHODS

2.1 Study site

The experimental site is situated in Zagreb County (Figure 1), a part of Continental Croatia (45°55' N; 15°45' E; elevation—197 m a.s.l.). The area is dominantly hilly, covered by a mosaic of forests (*Quercus robur* and *Robinia pseudoacacia*), annual croplands (dominant crops: maize, wheat, barley, alfalfa and clover) and orchards (dominant plums, apples and pears). The slope inclination in the study area is 11°. The climate of the study area is temperate continental (Dfb) (Köppen, 1900). The mean annual temperature in the study years (2024 and 2025) is 12.5 °C and 12.2 °C, and the total average precipitation is 1064 and 838 mm, respectively. The mean annual (1995–2023) precipitation is 979 mm, with October (120 mm) as the most humid and January (50.9 mm) and March (51.9 mm) as the most arid months. The weather conditions for the studied years (2024 and 2025) are shown in Figure 2. The soil is a Stagnosol (IUSS Working Group WRB, 2015), with a loamy topsoil and a clay loam subsoil. A plough Ap horizon overlies a stagnic subsoil. Although an anthropogenically influenced surface horizon is present, the Stagnosol classification is retained for consistency with WRB diagnostics. The general soil properties are shown in Table 1.

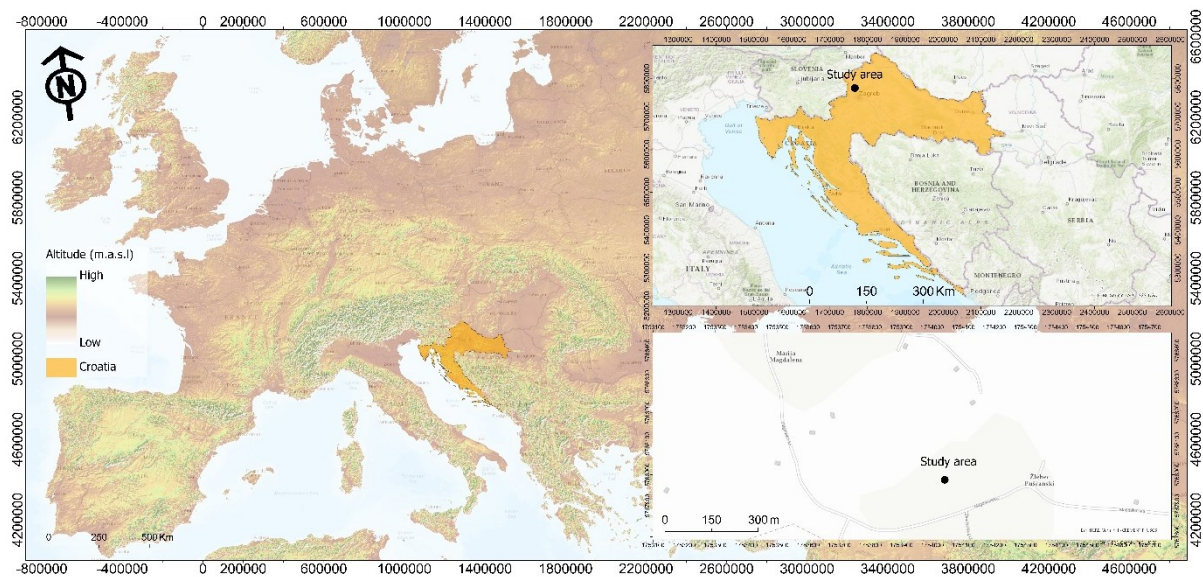


Fig. 1. Study area location.

Table 1. Soil properties at 0–35 and 35–70 cm depths.

Soil properties	0–35 cm	35–70 cm
pH in H ₂ O	7.29	5.10
P ₂ O ₅ (mg kg ⁻¹)	163	42
K ₂ O (mg kg ⁻¹)	282	79
Organic matter (%)	3.37	1.9
Bulk density (g cm ⁻³)	1.26	1.34
Water holding capacity (%)	44.04	30.68
Clay (%)	23.2	39.9
Silt (%)	30.4	21.0
Sand (%)	46.4	39.1
Texture	Loam	Clay Loam

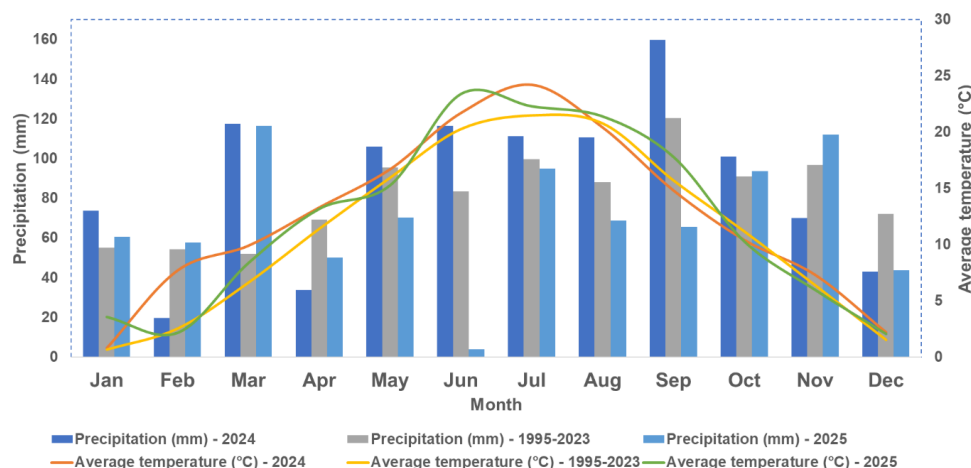


Fig. 2. Weather conditions during the experimental period relative to the long-term climate average.

2.2 Experimental design

The trial started in the spring of 2024. The paired plot strategy was applied to ensure geomorphological equity between treatments where tillage management was tested (Figure 1). Each plot (4 m wide by 80 m long) represents a tillage management treatment. The conventional system involves mouldboard ploughing to 30 cm and disking to 12 cm, while conservation tillage involves single-pass soil loosening to 30 cm, followed by harrowing to 10 cm. Each tillage treatment, performed in an up-and-down direction, has three replicates. After tillage, the conventional treatment left an almost residue-free soil surface, whereas the conservation treatment retained residues on about 25–30% of the surface (Fig. 3B). The crops grown were maize (*Zea mays* L.) in 2024 and winter wheat in 2024/2025 under rain-fed conditions. All plots were fenced (catchment area of 20 m²) with metal barriers extending 10 cm into the soil and 20 cm above the soil to ensure precise monitoring of soil and water loss (Figure 3). At the bottom of each plot, collector tanks were installed and connected to the fenced plot collector to collect runoff.

Tillage for both treatments in 2024 is performed on April 17, while maize (Syngenta “Infinite” FAO 410, 72,000 seeds per hectare) was sown on April 18. Between-row cultivation intervention was not performed. Maize harvest was performed on October 19, 2024. Tillage for both treatments was repeated on November 4 2024, when winter wheat was sown (Agricultural Institute Osijek “Brko”, 240 kg/ha). Wheat harvest was July 1 2025. Crop protection and fertilization were applied uniformly across all plots to avoid confounding tillage effects with differences in crop management. For maize, Adengo (Bayer AG, Germany) (tembotrione 90 g L⁻¹, isoxaflutole 225 g L⁻¹, safener: cyprosulfamide 150 g L⁻¹) was applied after sowing at 0.44 L ha⁻¹. For winter wheat, Lancelot 450 WG (florasulam 150 g kg⁻¹ + aminopyralid 300 g kg⁻¹) was used (Corteva Agriscience, Croatia). In both years, 300 kg ha⁻¹ of NPK (15-15-15) was applied before tillage. For maize, a single topdressing of 200 kg ha⁻¹ KAN (27% N) was applied, while for wheat, two applications of 120 and 80 kg ha⁻¹ KAN (27% N) were applied.

2.3 Sampling and laboratory procedures

Soil sampling followed a strategy similar to many other tillage vs degradation studies. Soil core samples were collected during crop emergence and post-harvest at 0–10 and 10–30 cm depth. In each plot, four core samples (two from 0–10 cm and

two from 10–30 cm) were collected, for a total of 12 per treatment, 24 per sampling time, and 96 in total. Similarly, to core sampling, the penetration resistance measurements were carried out using a hand-pushed cone penetrometer (Penetrologger, Eijkelkamp, Giesbeek, The Netherlands). For chemical soil properties and soil structure, samples were collected from 0–10 cm depth at the beginning of the experiment and following the harvest of each crop. Undisturbed samples (2 per plot) were gently stored in rectangular plastic boxes to avoid mechanical damage, while disturbed samples (2 per plot) were collected by handheld probe.

Core samples were weighted and dried at 105 °C for 48 hours to determine soil water content (SWC) and bulk density (BD). Before dry sieving, soil aggregates were gently prepared by hand. After sieving, the mean weight diameter (MWD) was calculated. The 1–2 mm aggregate fraction was used to determine the water-stable aggregate percentage following the method of Kemper and Rosenau (1986).

Disturbed soil samples were air-dried at room temperature (≈ 23 °C) for a week, milled, and sieved through a 2 mm mesh. Similarly, sediments isolated on filter paper (as described below) were homogenised in a mortar with a pestle. Total C and N on soil and sediments were determined by dry combustion using a vario MACRO CHNS analyser (Elementar Analysensysteme GmbH, Langenselbold, Germany). The element concentrations (P, K, and Cu) were determined using a portable X-ray fluorescence spectrometer, the VantaTM XRF analyser C Series (Olympus, Waltham, MA, USA, 2019).

2.4 Overland flow monitoring

Overland flow was quantified on an event basis after each rainfall event that produced runoff. In total, eight erosive events were monitored during the study period, five in the maize and three in the wheat vegetation cycles. For this purpose, collection tanks installed at the base of each plot provided sediment and runoff data. Runoff was determined by measuring the water level in the tanks. The runoff contents were then mixed with a paddle to homogenise them, and a subsample (~5 L) was collected. In the laboratory, soil loss (SL) and sediment concentration (SC) were determined by weighing the runoff subsamples and filtering them. After drying the filter paper, SL in the canister was obtained by subtracting the mass of the sediment and filter paper from the mass of the filter paper. SC was calculated by dividing the SL mass by the runoff mass. Sediments were analysed to determine elemental concentrations and the total elemental loss due to erosion.

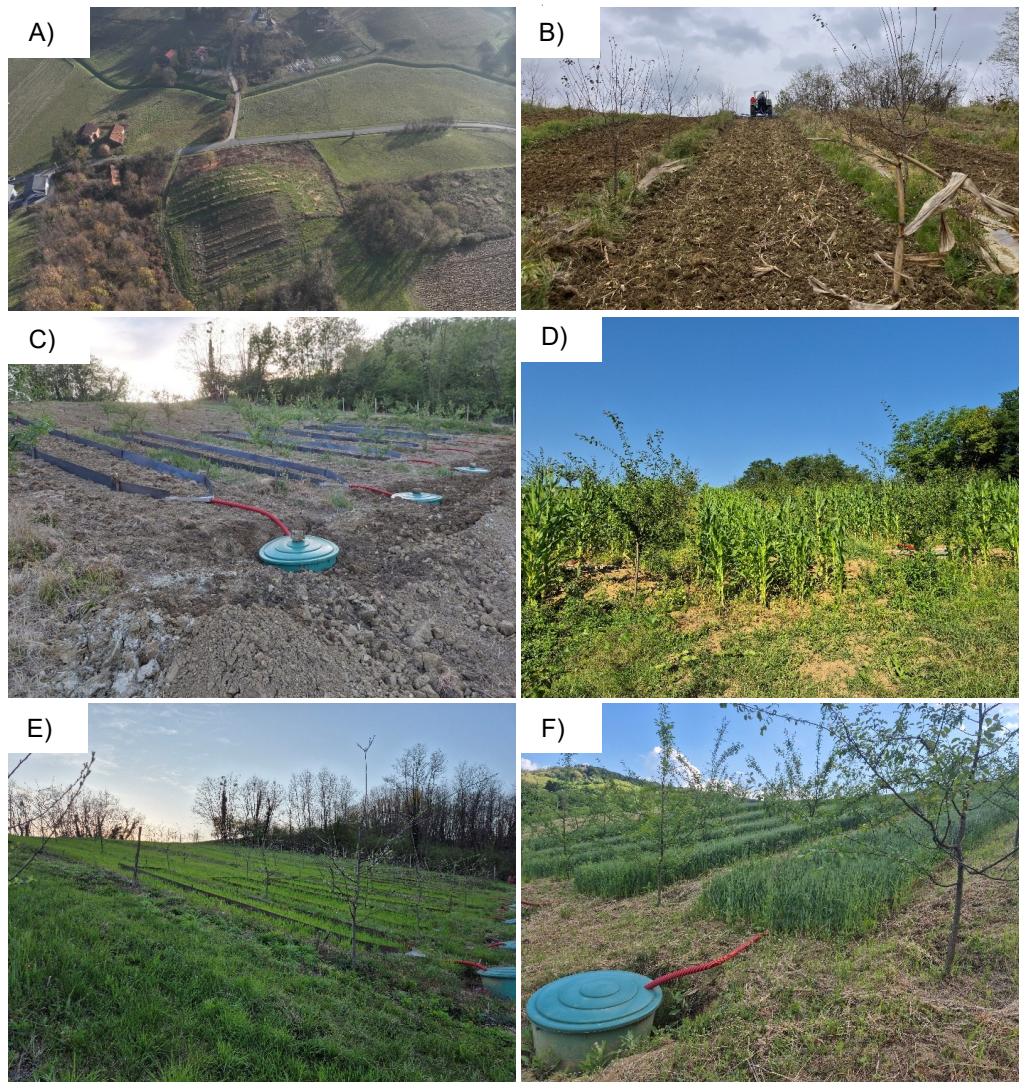


Fig. 3. Aerial view (A), tillage management (B), equipment installation (C), and maize (D) – wheat (E, F) cropping system.

2.5 Statistical analysis

Before statistical analysis, data normality was checked with the Kolmogorov–Smirnov and Shapiro-Wilk test. Data was considered normally distributed at a $p > 0.05$. SWC, BD, MWD, P, K, C, Cu, and yields followed the Gaussian distribution. In contrast, PR, WSA, N, and hydrological response data (SC, Runoff, Soil loss, P loss, K loss, N loss, C loss, Cu loss) were box-cox transformed to meet normality requirements. A factorial ANOVA was conducted to identify differences in SWC, BD, and PR (factors: season, soil depth, treatment). For MWD, WSA, SC, Runoff, Soil loss, P loss, K loss, N loss, C loss, and Cu loss, a two-way ANOVA design was applied (factors: treatment and time). Crop yield was analysed separately for each crop using one-way ANOVA (Treatment). If significant differences were identified at a $p < 0.05$, a Duncan's post hoc test was applied. Statistical analyses were computed with Statistica 12.0 (StatSoft, 2015), while graphs were prepared in Statistica and Excel.

3 RESULTS

3.1 Soil properties

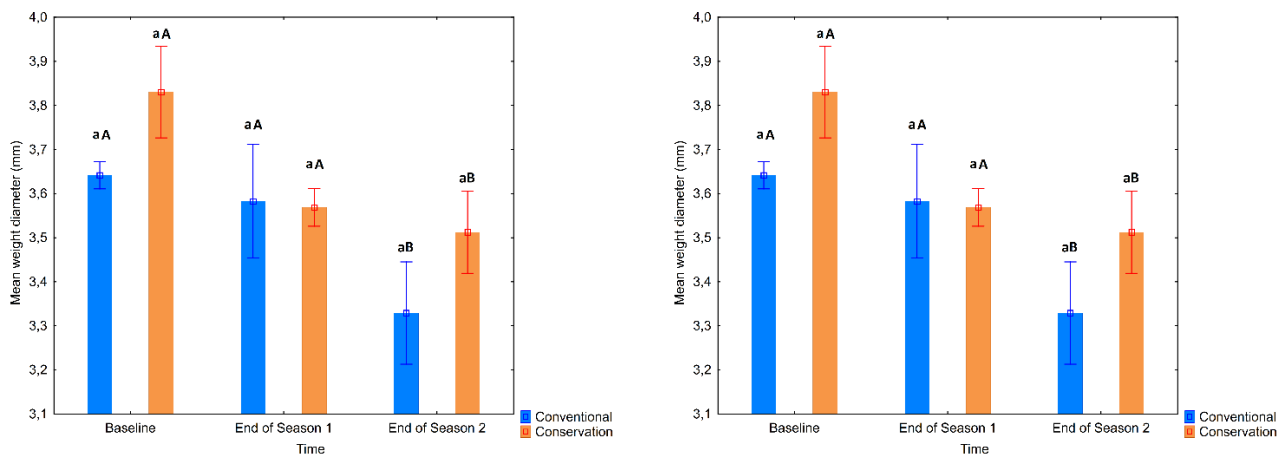
In both years studied, the SWC content is high, and treatments did not have a statistically significant impact. In 2025, fall SWC measurements were statistically lower than spring meas-

urements for both tillage treatments. In 2024, conventional tillage had significantly higher BD than conservation tillage, with a similar relationship observed in the spring period of the same year. When comparing tillage $\times$ depth, significantly lower BD at 10–30 cm is found in conservation tillage compared to conventional tillage. Both tillage treatments showed lower BD at 0–10 cm than at 10–30 cm depth. The season $\times$ depth $\times$ treatment interaction was significantly higher BD at 0–10 cm during spring. In 2025, significantly higher compaction occurred in the conventional treatment during both fall and spring. Moreover, both tillage treatments showed significantly increased compaction at depths of 0–10 cm and 10–30 cm. The season $\times$ depth $\times$ treatment interaction revealed significantly higher compaction at 10–30 cm depth in both tillage treatments during fall, and at the same depth during spring only in conventional tillage. Penetration resistance was significantly higher at 10–30 cm than at 0–10 cm in both years and seasons. The effect of tillage on interactions was not significantly different.

Figure 4 shows the structural soil characteristics during the study period. The MWD values ranged from 2.33 mm (conventional at the end of season 2) to 3.83 mm (conservation at baseline). The MWD values were significantly lower at the end of season 2 and at other measurement times for both tillage treatments. However, the WSA values did not show a significant temporal decrease. At the end of season 2, conventional tillage showed significantly lower WSA than conservation tillage.

Table 2. Soil physical properties (mean $\pm$ standard deviation). Different letters represent significant differences ($p < 0.05$) between tillage practices (lowercase) and seasons/depths (uppercase).

Season	Depth	Property	Soil water content		Bulk density		Penetration resistance	
		Treatment	2024	2025	2024	2025	2024	2025
Fall Fall Spring Spring 0–10 0–10 10–30 10–30 Fall Fall Fall Fall Spring Spring Spring Spring		Conventional	41.15 $\pm$ 2.45	39.37 $\pm$ 5.46	1.37 $\pm$ 0.07a	1.28 $\pm$ 0.14	0.94 $\pm$ 0.39	0.78 $\pm$ 0.41
		Conservation	41.84 $\pm$ 3.94	39.93 $\pm$ 6.91	1.33 $\pm$ 0.07b	1.27 $\pm$ 0.11	0.84 $\pm$ 0.29	0.74 $\pm$ 0.47
		Conventional	41.33 $\pm$ 2.45	34.81 $\pm$ 1.94B	1.35 $\pm$ 0.08	1.34 $\pm$ 0.11A	0.83 $\pm$ 0.32	0.71 $\pm$ 0.41
		Conservation	42.97 $\pm$ 4.54	34.39 $\pm$ 3.37B	1.33 $\pm$ 0.07	1.28 $\pm$ 0.14	0.79 $\pm$ 0.26	0.63 $\pm$ 0.33
		Conventional	40.97 $\pm$ 2.55	43.94 $\pm$ 3.61A	1.39 $\pm$ 0.05a	1.21 $\pm$ 0.15B	1.04 $\pm$ 0.44	0.85 $\pm$ 0.42
		Conservation	40.72 $\pm$ 3.01	45.47 $\pm$ 4.61A	1.33 $\pm$ 0.07b	1.26 $\pm$ 0.06	0.88 $\pm$ 0.32	0.85 $\pm$ 0.58
		Conventional	40.85 $\pm$ 2.43	38.17 $\pm$ 3.80	1.32 $\pm$ 0.07B	1.20 $\pm$ 0.11B	0.65 $\pm$ 0.22B	0.53 $\pm$ 0.30B
		Conservation	42.62 $\pm$ 3.59	38.79 $\pm$ 6.79	1.30 $\pm$ 0.05B	1.20 $\pm$ 0.04B	0.62 $\pm$ 0.13B	0.44 $\pm$ 0.16B
		Conventional	41.45 $\pm$ 2.54	40.58 $\pm$ 6.68	1.42 $\pm$ 0.03aA	1.35 $\pm$ 0.14A	1.22 $\pm$ 0.31A	1.03 $\pm$ 0.36A
		Conservation	41.07 $\pm$ 4.27	41.07 $\pm$ 7.17	1.37 $\pm$ 0.06bA	1.34 $\pm$ 0.11A	1.05 $\pm$ 0.24A	1.04 $\pm$ 0.50A
		Conventional	40.85 $\pm$ 2.68	35.30 $\pm$ 2.54	1.28 $\pm$ 0.05B	1.27 $\pm$ 0.05B	0.59 $\pm$ 0.15B	0.52 $\pm$ 0.37B
		Conservation	43.55 $\pm$ 3.41	33.29 $\pm$ 1.24	1.31 $\pm$ 0.05	1.18 $\pm$ 0.03B	0.65 $\pm$ 0.14B	0.44 $\pm$ 0.18B
		Conventional	41.82 $\pm$ 2.34	34.31 $\pm$ 1.13	1.42 $\pm$ 0.03A	1.41 $\pm$ 0.09A	1.07 $\pm$ 0.25A	0.91 $\pm$ 0.38A
		Conservation	42.38 $\pm$ 5.74	35.48 $\pm$ 4.54	1.36 $\pm$ 0.09	1.38 $\pm$ 0.14A	0.94 $\pm$ 0.28A	0.83 $\pm$ 0.34A
		Conventional	40.85 $\pm$ 2.42	41.03 $\pm$ 2.38B	1.36 $\pm$ 0.06a	1.14 $\pm$ 0.12B	0.72 $\pm$ 0.27B	0.55 $\pm$ 0.24B
		Conservation	41.68 $\pm$ 3.83	44.29 $\pm$ 5.22	1.29 $\pm$ 0.05bA	1.23 $\pm$ 0.04	0.59 $\pm$ 0.13B	0.45 $\pm$ 0.16B
		Conventional	41.08 $\pm$ 2.90	46.85 $\pm$ 1.64A	1.42 $\pm$ 0.03	1.28 $\pm$ 0.15A	1.37 $\pm$ 0.31A	1.15 $\pm$ 0.34A
		Conservation	39.75 $\pm$ 1.74	46.65 $\pm$ 4.03	1.38 $\pm$ 0.04B	1.29 $\pm$ 0.06	1.17 $\pm$ 0.12A	1.26 $\pm$ 0.56A

**Fig. 4.** Structural characteristics of soil properties at conventional and conservation tillage during the study period. Different letters indicate significant differences between tillage (lowercase) and time (uppercase) at $p < 0.05$. Hanging bars indicate standard deviation.**Table 3.** Soil chemical properties (mean $\pm$ standard deviation). Different letters represent significant differences ($p < 0.05$) between tillage practices (lowercase) and time (uppercase).

Time	Treatment	C (%)	N (%)	P (mg kg ⁻¹)	K (mg kg ⁻¹)	Cu (mg kg ⁻¹)
Baseline	Conventional	3.7 $\pm$ 0.6	0.178 $\pm$ 0.004B	676 $\pm$ 128A	1413 $\pm$ 149B	48.5 $\pm$ 1.0A
Baseline	Conservation	3.4 $\pm$ 0.9	0.170 $\pm$ 0.015B	797 $\pm$ 148A	1562 $\pm$ 195	43.7 $\pm$ 3.7bAB
End of Season 1	Conventional	3.5 $\pm$ 1.6	0.182 $\pm$ 0.019B	542 $\pm$ 97B	1661 $\pm$ 222A	46.8 $\pm$ 5.0
End of Season 1	Conservation	3.7 $\pm$ 1.5	0.178 $\pm$ 0.018B	510 $\pm$ 94B	1681 $\pm$ 206	47.8 $\pm$ 2.9A
End of Season 2	Conventional	3.0 $\pm$ 0.2b	0.284 $\pm$ 0.020A	318 $\pm$ 110C	1547 $\pm$ 124AB	44.5 $\pm$ 1.6
End of Season 2	Conservation	4.6 $\pm$ 0.9a	0.287 $\pm$ 0.014A	237 $\pm$ 86C	1742 $\pm$ 68	42.1 $\pm$ 6.2B

Soil C concentration statistically differed at the end of the experiment (Table 3). Conventional tillage had significantly lower C than conservation. Nitrogen concentrations did not differ between tillage plots. However, in both tillage treatments, we observed significantly higher N concentrations at the end of season 2 in addition to baseline and end of season 1. Soil P concentrations decreased significantly over time in both tillage treatments. At the same time, conventional treatments showed significantly higher K at the end of season 1 than at baseline. At baseline, Cu content was significantly higher in conventional plots. Temporal changes were observed only in the conservation

treatment, where the end of season 1 had significantly higher Cu than the end of season 2.

3.2 Overland flow monitoring data

The monitoring was conducted over two crop seasons (maize in 2024 and winter wheat in 2024/2025), and analyses (Table 4) focus on treatment comparisons throughout the entire experimental period due to natural, uneven rainfall. Significant differences between tillage treatments were observed for runoff, SC and SL.

Table 4. Runoff ($\text{m}^3 \text{ha}^{-1}$), sediment concentrations (g L^{-1}) and soil loss (t ha^{-1}) for the three replicate plots at each rainfall event and in total for the conventional and conservation tillage treatments. The * at each time point in the doubled rows (conventional vs conservation) indicates a statistically significant difference at $p < 0.05$. n.s. indicate not significant. Abbreviations: SD – standard deviation, CV – coefficient of variation, SE – standard error.

Runoff ($\text{m}^3 \text{ha}^{-1}$)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	77.5	1860.0	15.0	248.2	70.2	90.6	14.33	*
	Conventional	24	108.9	2613.3	41.7	192.4	48.5	44.6	9.91	
30.05.2024.	Conservation	3	78.2	234.5	59.9	99.9	20.2	25.9	11.7	*
	Conventional	3	150.9	452.7	134.4	169.1	17.4	11.6	10.1	
14.06.2024.	Conservation	3	26.6	79.9	15.0	39.9	12.6	47.1	7.2	*
	Conventional	3	64.4	193.1	49.4	79.3	15.0	23.3	8.6	
03.07.2024.	Conservation	3	94.5	283.5	59.7	139.3	40.7	43.1	23.5	*
	Conventional	3	151.4	454.1	133.5	167.4	17.0	11.3	9.8	
24.08.2024.	Conservation	3	34.9	104.8	24.9	49.9	13.2	37.9	7.6	*
	Conventional	3	70.9	212.7	59.4	89.1	15.9	22.5	9.2	
10.09.2024.	Conservation	3	244.8	734.4	238.1	248.2	5.8	2.4	3.4	n.s.
	Conventional	3	185.7	557.2	176.8	192.4	8.0	4.3	4.6	
22.11.2024.	Conservation	3	51.7	155.0	43.9	61.9	9.2	17.9	5.3	*
	Conventional	3	103.2	309.7	89.4	119.0	14.9	14.4	8.6	
27.02.2025.	Conservation	3	59.0	176.9	48.4	75.5	14.5	24.6	8.4	*
	Conventional	3	98.6	295.9	81.6	108.3	14.8	15.0	8.5	
15.03.2025.	Conservation	3	30.3	91.0	19.7	37.0	9.3	30.6	5.4	*
	Conventional	3	46.0	137.9	41.7	48.6	3.8	8.2	2.2	
Sediment concentration (g L^{-1})		N	Mean	Sum	Minimum	Maximum	SD	CV	SE	
Average	Conservation	24	3.11	74.72	0.29	8.16	2.27	72.8	0.46	*
	Conventional	24	8.95	214.82	2.70	17.83	4.13	46.1	0.84	
30.05.2024.	Conservation	3	2.4	7.1	0.8	4.8	2.1	91.1	1.24	*
	Conventional	3	5.0	14.9	4.6	5.2	0.3	6.3	0.18	
14.06.2024.	Conservation	3	1.0	3.0	0.3	1.5	0.6	63.6	0.37	*
	Conventional	3	10.3	30.9	8.4	12.1	1.9	18.0	1.07	
03.07.2024.	Conservation	3	5.2	15.7	4.9	5.9	0.5	10.4	0.31	*
	Conventional	3	12.9	38.6	11.3	15.8	2.5	19.7	1.47	
24.08.2024.	Conservation	3	2.2	6.7	1.5	2.8	0.6	28.2	0.37	*
	Conventional	3	11.1	33.2	9.4	13.5	2.2	19.7	1.26	
10.09.2024.	Conservation	3	7.6	22.8	7.3	8.2	0.5	6.3	0.28	*
	Conventional	3	14.1	42.2	11.1	17.8	3.4	24.5	1.99	
22.11.2024.	Conservation	3	1.7	5.0	1.0	2.5	0.8	46.6	0.45	*
	Conventional	3	4.6	13.9	3.3	5.8	1.3	27.2	0.73	
27.02.2025.	Conservation	3	3.1	9.4	2.6	3.6	0.5	15.7	0.28	*
	Conventional	3	9.8	29.4	7.8	11.8	2.0	20.4	1.16	
15.03.2025.	Conservation	3	1.6	4.9	1.4	2.1	0.4	26.9	0.25	*
	Conventional	3	3.9	11.7	2.7	4.8	1.1	27.7	0.62	
Soil loss (t ha^{-1})		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	0.37	8.92	0.00	1.96	0.60	162.3	0.12	*
	Conventional	24	1.07	25.73	0.13	3.21	0.83	77.4	0.17	
30.05.2024.	Conservation	3	0.18	0.53	0.08	0.36	0.16	91.0	0.09	*
	Conventional	3	0.76	2.27	0.62	0.88	0.13	17.3	0.08	
14.06.2024.	Conservation	3	0.03	0.10	0.00	0.06	0.03	88.2	0.02	*
	Conventional	3	0.65	1.95	0.60	0.68	0.04	6.3	0.02	
03.07.2024.	Conservation	3	0.49	1.48	0.30	0.69	0.19	39.2	0.11	*
	Conventional	3	1.99	5.98	1.56	2.68	0.60	30.3	0.35	
24.08.2024.	Conservation	3	0.07	0.22	0.06	0.08	0.01	15.2	0.01	*
	Conventional	3	0.79	2.37	0.56	0.93	0.20	25.1	0.11	
10.09.2024.	Conservation	3	1.88	5.63	1.82	1.96	0.07	3.9	0.04	n.s.
	Conventional	3	2.64	7.91	2.10	3.21	0.56	21.1	0.32	
22.11.2024.	Conservation	3	0.08	0.25	0.06	0.11	0.03	32.0	0.02	*
	Conventional	3	0.51	1.53	0.31	0.62	0.18	34.8	0.10	
27.02.2025.	Conservation	3	0.19	0.56	0.16	0.20	0.02	11.3	0.01	*
	Conventional	3	1.05	3.16	0.92	1.15	0.12	11.7	0.07	
15.03.2025.	Conservation	3	0.05	0.15	0.03	0.07	0.02	46.2	0.01	*
	Conventional	3	0.19	0.56	0.13	0.21	0.05	24.7	0.03	

On average, the conventional plots had a runoff of $108.9 \text{ m}^3 \text{ha}^{-1}$. On the contrary, the conservation plots reached $77.5 \text{ m}^3 \text{ha}^{-1}$. This is a large difference in the mean runoff during the two cropping seasons, with conventional plots exhibiting 40.5% higher runoff. A similar discrepancy was observed in individual events; in all cases except for 10.09.2024, no differences were found. The conventional plots had significantly higher runoff than the conservation plots, with runoff exceeding that of the conservation plots by 52% to 152%.

The SC in the runoff averaged 3.11 g L^{-1} for the conservation treatment and 8.95 g L^{-1} for the conventional. SC ranged from

2.7 to 17.8 g L^{-1} in the conventional plots and from 0.3 to 8.2 g L^{-1} in the conservation plots. In all individual events, SC was significantly higher in the conventional plots.

Total SL was 25.73 and 8.92 t ha^{-1} (average SL per event 1.07 and 0.37 t ha^{-1}) for conventional and conservation tillage, respectively. The ranges were 0.13 to 3.21 t ha^{-1} for conventional tillage and 0.004 to 1.96 t ha^{-1} for individual conservation plots. In the Marija Magdalena fields, the soil erosion response of the conventional and conservation plots was markedly different. The use of non-invertive loosening tillage reduced SL nearly three-

fold, bringing it to markedly lower levels than under conventional tillage. There was a significant difference between the two tillage management systems in both seasons and across all individual measurements, except for the event on 10.09.2024.

Sediment-bound exports of all quantified elements displayed a consistent pattern throughout the monitoring period, showing the event-scale SL dynamics. Overall, conventional tillage always resulted in greater element losses than conservation tillage (Table 5). The only exception was the extreme runoff event on 10.09.2024, when tillage differences were not significant.

Among all observed elements, sediment-bound losses were consistently higher under conventional than conservation tillage, with significant tillage effects for both event-wise and average values (Table 5), except for the 10.09.2024 event when differences were not significant. Average P losses were about 3.4 times higher under conventional than conservation tillage (803 vs 238 g ha⁻¹), and K losses were similarly elevated (1929 vs 603 g ha⁻¹)

(Table 5). P and K loss ranged from 100 to 2397 g ha⁻¹ and from 239 to 5761 g ha⁻¹ in the conventional plots and was reduced to 3–1252 g ha⁻¹ and 7–3175 g ha⁻¹ in the conservation plots. The largest losses occurred during the most severe erosion events (e.g., September 2024), whereas other rain events stimulated minor exports under conservation tillage. The same response was observed for C and N concentrations. Average C losses were more than double under conventional management (26.8 vs 11.5 kg ha⁻¹), while N losses increased from 921 to 1604 g ha⁻¹ (Table 5). Carbon and N loss ranged from 3.4 to 79.4 kg ha⁻¹ and from 206 to 4752 g ha⁻¹ in the conventional plots and was reduced to 0.1–61.0 kg ha⁻¹ and 11–4879 g ha⁻¹ in the conservation plots. Finally, Cu loss was also significantly higher in conventional plots (22.6 vs 8.6 g ha⁻¹ on average). The highest losses were recorded during the most erosive storms, and no significant difference during the 10.09.2024 rainstorm.

Table 5. Yearly losses of chemical elements for the three replicate plots for the ploughing, chisel, and subsoiling management treatments. Abbreviations: SD – standard deviation, CV – coefficient of variability, SE – standard error.

P loss (g ha ⁻¹)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	238	5704	3	1252	385	162.1	79	*
	Conventional	24	803	19262	100	2397	619	77.2	126	
30.05.2024.	Conservation	3	112	336	49	230	102	91.0	59	*
	Conventional	3	565	1695	465	659	98	17.3	56	
14.06.2024.	Conservation	3	20	61	3	39	18	88.2	10	*
	Conventional	3	487	1460	451	508	31	6.3	18	
03.07.2024.	Conservation	3	316	947	190	438	124	39.2	71	*
	Conventional	3	1490	4470	1162	2004	451	30.3	260	
24.08.2024.	Conservation	3	47	141	39	53	7	15.2	4	*
	Conventional	3	590	1769	420	692	148	25.1	85	
10.09.2024.	Conservation	3	1199	3597	1163	1252	46	3.9	27	ns
	Conventional	3	1970	5910	1568	2397	415	21.1	240	
22.11.2024.	Conservation	3	54	163	40	74	17	32.0	10	*
	Conventional	3	384	1153	230	470	134	34.8	77	
27.02.2025.	Conservation	3	120	360	105	130	14	11.3	8	*
	Conventional	3	795	2386	691	871	93	11.7	54	
15.03.2025.	Conservation	3	33	99	18	48	15	46.2	9	*
	Conventional	3	140	419	100	161	35	24.7	20	
K loss (g ha ⁻¹)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	603	14472	7	3175	977	162.1	199	*
	Conventional	24	1929	46296	239	5761	1488	77.2	303	
30.05.2024.	Conservation	3	284	852	123	582	258	91.0	149	*
	Conventional	3	1358	4074	1116	1584	234	17.3	135	
14.06.2024.	Conservation	3	51	155	7	98	45	88.2	264	*
	Conventional	3	1169	3508	1084	1220	74	6.3	428	
03.07.2024.	Conservation	3	800	2402	482	1110	314	39.2	181	*
	Conventional	3	3580	10742	2792	4816	1083	30.3	625	
24.08.2024.	Conservation	3	119	357	99	134	18	15.2	10	*
	Conventional	3	1417	4251	1009	1663	355	25.1	205	
10.09.2024.	Conservation	3	3041	9125	2951	3175	117	3.9	68	ns
	Conventional	3	4734	14204	3769	5761	997	21.1	575	
22.11.2024.	Conservation	3	137	413	102	187	44	32.0	25	*
	Conventional	3	924	2772	553	1130	321	34.8	185	
27.02.2025.	Conservation	3	304	914	265	328	34	11.3	19	*
	Conventional	3	1911	5734	1661	2092	223	11.7	129	
15.03.2025.	Conservation	3	84	252	44	122	38	46.2	22	*
	Conventional	3	335	1007	239	386	83	24.7	47	
Cu loss (g ha ⁻¹)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	8.6	205.3	0.1	45.0	13.9	162.1	2.8	*
	Conventional	24	22.6	541.5	2.8	67.4	17.4	77.2	3.6	
30.05.2024.	Conservation	3	4.0	12.1	1.8	8.3	3.7	91.0	2.1	*
	Conventional	3	15.9	47.7	13.1	18.5	2.7	17.3	1.6	
14.06.2024.	Conservation	3	0.7	2.2	0.1	1.4	0.6	88.2	0.4	*
	Conventional	3	13.7	41.0	12.7	14.3	0.9	6.3	0.5	
03.07.2024.	Conservation	3	11.4	34.1	6.9	15.8	4.5	39.2	2.6	*
	Conventional	3	41.9	125.7	32.7	56.3	12.7	30.3	7.3	
24.08.2024.	Conservation	3	1.7	5.1	1.4	1.9	0.3	15.2	0.1	*
	Conventional	3	16.6	49.7	11.8	19.5	4.2	25.1	2.4	
10.09.2024.	Conservation	3	43.2	129.5	41.9	45.0	1.7	3.9	1.0	ns
	Conventional	3	55.4	166.1	44.1	67.4	11.7	21.1	6.7	
22.11.2024.	Conservation	3	2.0	5.9	1.5	2.7	0.6	32.0	0.4	*

27.02.2025.	Conventional	3	10.8	32.4	6.5	13.2	3.8	34.8	2.2	
	Conservation	3	4.3	13.0	3.8	4.7	0.5	11.3	0.3	*
15.03.2025.	Conventional	3	22.4	67.1	19.4	24.5	2.6	11.7	1.5	
	Conservation	3	1.2	3.6	0.6	1.7	0.6	46.2	0.3	*
	Conventional	3	3.9	11.8	2.8	4.5	1.0	24.7	0.6	
N loss (g ha ⁻¹)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	921	22095	11	4879	1504	163.4	307	*
	Conventional	24	1604	38499	206	4752	1224	76.3	250	
30.05.2024.	Conservation	3	437	1310	190	895	397	91.0	229	*
	Conventional	3	1120	3361	921	1307	193	17.3	112	
14.06.2024.	Conservation	3	80	239	11	151	70	88.2	41	*
	Conventional	3	965	2894	895	1007	61	6.3	35	
03.07.2024.	Conservation	3	1231	3692	742	1707	483	39.2	279	*
	Conventional	3	2954	8861	2304	3973	894	30.3	516	
24.08.2024.	Conservation	3	183	550	152	206	28	15.2	16	*
	Conventional	3	1169	3507	833	1372	293	25.1	169	
10.09.2024.	Conservation	3	4674	14022	4536	4879	181	3.9	105	ns
	Conventional	3	3906	11717	3110	4752	823	21.1	475	
22.11.2024.	Conservation	3	199	597	148	270	64	32.0	37	*
	Conventional	3	792	2377	475	970	276	34.8	159	
27.02.2025.	Conservation	3	440	1321	383	475	50	11.3	29	*
	Conventional	3	1639	4917	1425	1795	191	11.7	111	
15.03.2025.	Conservation	3	122	365	65	177	56	46.2	32	*
	Conventional	3	288	864	206	331	71	24.7	41	
C loss (kg ha ⁻¹)		N	Mean	Sum	Min	Max	SD	CV	SE	
Average	Conservation	24	11.5	276.3	0.1	61.0	18.8	163.4	3.8	*
	Conventional	24	26.8	643.6	3.4	79.4	20.5	76.3	4.2	
30.05.2024.	Conservation	3	5.5	16.4	2.4	11.2	5.0	91.0	2.9	*
	Conventional	3	18.7	56.2	15.4	21.9	3.2	17.3	1.9	
14.06.2024.	Conservation	3	1.0	3.0	0.1	1.9	0.9	88.2	0.5	*
	Conventional	3	16.1	48.4	15.0	16.8	1.0	6.3	0.6	
03.07.2024.	Conservation	3	15.4	46.2	9.3	21.3	6.0	39.2	3.5	*
	Conventional	3	49.4	148.1	38.5	66.4	14.9	30.3	8.6	
24.08.2024.	Conservation	3	2.3	6.9	1.9	2.6	0.3	15.2	0.2	*
	Conventional	3	19.5	58.6	13.9	22.9	4.9	25.1	2.8	
10.09.2024.	Conservation	3	58.5	175.4	56.7	61.0	2.3	3.9	1.3	ns
	Conventional	3	65.3	195.9	52.0	79.4	13.8	21.1	7.9	
22.11.2024.	Conservation	3	2.5	7.5	1.8	3.4	0.8	32.0	0.5	*
	Conventional	3	13.2	39.7	7.9	16.2	4.6	34.8	2.7	
27.02.2025.	Conservation	3	5.5	16.5	4.8	5.9	0.6	11.3	0.4	*
	Conventional	3	27.4	82.2	23.8	30.0	3.2	11.7	1.8	
15.03.2025.	Conservation	3	1.5	4.6	0.8	2.2	0.7	46.2	0.4	*
	Conventional	3	4.8	14.4	3.4	5.5	1.2	24.7	0.7	

4 DISCUSSION

4.1 Soil

Generally, conventional plowing may decrease soil quality (mainly deterioration of soil physical quality and decline in organic matter) in agroecosystems, especially in poorly structured soils or hydromorphic soils such as Stagnosols (Crittenden et al., 2015; Hamza and Anderson, 2005; Rubinić et al., 2015). In the present study, Table 2 and Figure 4 showed how conservation tillage modifies soil properties and the overland flow generation. In many studies, conservation tillage can lead to greater soil compaction, especially in the first years after implementation (Nunes et al., 2020). In the present case, this drawback was not detected. Instead, conservation tillage resulted in lower BD in 2024, most clearly expressed at 10–30 cm (annual mean) and at 0–10 cm in spring (Table 2). A possible explanation is that single-pass loosening disrupted the naturally compacted layer or tillage pan, while reducing traffic and thereby compaction. These effects are important for Stagnosols, where structure is unstable and conventional tillage and repeated traffic can rapidly accelerate degradation (Bogunovic et al., 2018; Nunes et al., 2020). Penetration resistance showed a similar trend but was not significantly consistent, which may be explained by PR's high sensitivity to short-term soil moisture and within-plot variability, compared with bulk density measurements (Nunes et al., 2020). Overall, our results indicate that, in this hillslope orchard-cereal

system, non-inversion loosening can alleviate subsoil compaction without inducing a detectable short-term compaction penalty, while simultaneously improving hydrological response.

Soil structure declined over the course of the study in both treatments. WSA was also significantly low under conventional tillage at the end of the trial. This response is consistent with the disturbance of a previously structured soil after re-cultivation began. A long period of abandoned land can accumulate organic matter and structure restored to a high level, which decreases after tillage operations in 2024. In contrast, renewed tillage accelerates aggregate turnover and exposes previously protected organic matter to oxidation (Nunes et al., 2020). Organic matter oxidation increases CO₂ emissions, reduces the resilience of aggregates to external pressures (Liang et al., 2025), and MWD and WSA (Dugan et al., 2024b; Nunes et al., 2020). However, conventional tillage is more disruptive because soil inversion and intense mixing increase aeration and microbial access to organic substrates, thereby accelerating decomposition compared with non-inversion systems (Liang et al., 2025), as noted in the present study. Moreover, conservation tillage leaves more plant residues at or near the surface, protecting aggregates and decreasing C turnover (Bogunovic et al., 2018). Consequently, the C content in our study was significantly higher at the end of the experiment in conservation plots than in conventional plots, due to reduced oxidation and significantly lower C runoff loss (see discussion below). The nutrients released by organic matter decomposition

and fertilisation resulted in similar concentrations in the studied soil, indicating that a two-year period is too short to detect a tillage effect on nutrient losses and alter soil properties in the studied area. Liang et al. (2025) and Diop et al. (2024), reported similar results.

4.2 Hydrology and management implications

The bare soil resulting from conventional management in hillslope agriculture is the primary cause of most runoff-erosion problems. Our investigations in a maize-wheat inter-row cropping system demonstrate that a simple shift from inversion ploughing to non-inversion loosening reduces runoff from 108.9 m³ ha⁻¹ to 77.5 m³ ha⁻¹ over two years. This means there is a sudden decline in runoff due to increased surface roughness and residue retention under non-inversion tillage. Loosening tillage increases infiltration and reduces runoff, slows the C cycle and turnover and preserves soil aggregate size and stability (Armand et al., 2009; Du et al., 2022; Liu et al., 2023). The surface roughness created by loosening and partial cover of residues contributed to the preservation of soil organic matter and biological activity, increasing macropores, as observed by Blanco-Canqui and Ruis (2020) and Du et al. (2022). SC under conventional tillage is high mainly because repeated ploughing and discing can rapidly increase surface smoothing and the susceptibility of soil aggregates to raindrop impact and sealing. Therefore, when practices that enhance sediment detachment are used, elevated SC in runoff is a reality. In contrast, conservation loosening preserves crumbs and residues in the topsoil longer, reducing the negative rainfall energy required for sediment detachment, resulting in lower SC even under comparable runoff conditions. Because SC reflects detachment efficiency, differences between tillage systems can remain evident even when runoff differences diminish during most erosive events (in our monitoring period, this was most apparent during the September 2024 event, which had the highest sediment loss). However, during typical storms, reduced disturbance and residue retention generally shift erosion towards lower sediment concentrations and lower sediment export (Blanco-Canqui and Ruis, 2020; Diop et al., 2024).

SL from orchard inter-row tillage management shift responded even more strongly than runoff. Mean soil loss decreased 65% under conservation tillage (cumulative two-year export ~8.57 in conventional vs ~2.97 t ha⁻¹ in conservation), which is consistent with other works (Cao et al., 2023; Singh et al., 2023). Similar patterns are reported in vineyards, where reduced soil tillage and improved surface cover decrease sediment losses (Biddoccu et al., 2020; Liebhard et al., 2024b). As expected for natural rainfall monitoring, soil loss was also highly event-driven, with a small number of events with the highest runoff and sediment export accounting for a disproportionate share of cumulative export, a behaviour widely documented across climates and land uses (Wu et al., 2018). In the study region, orchard land management practices on hills are identical to those used in flat-bottom areas. Conventional practices remain dominant, resulting in bare soils and high soil erosion rates (Bogunovic et al., 2018), while loosening or cover crops are rarely used in Croatian orchards as strategies to reduce degradation. Land management practices involving excessive ploughing and herbicide use, along with narrow crop rotation, result in soil degradation, specifically compaction and low organic matter (Nunes et al., 2020). Present results demonstrated that highly eroded ploughed soils have lower infiltration, greater overland flow, and flood risk. High runoff from orchards used for both orchard and cereal production may reduce water quality and disturb river biota. The consequence is not limited to on-site soil

depletion: greater sediment export directly translates into significantly higher nutrient- and element-bound losses. In our study, conventional tillage increased loss of P (~3.4×), K (~3.2×), Cu (~2.6×) and N (~1.7×) relative to conservation management, indicating a substantially greater off-site pollution potential and a stronger depletion pressure on soil fertility pools. These sediments can degrade water quality, increase siltation in downstream water bodies, affect water supply, and affect flood control. Use of agrochemicals in orchards reduces soil biota, depletes organic matter, and degrades soil structure, resulting in poor soil health.

Fragmentation of parcels in north-west Croatia is high, averaging 0.25 ha, with average farm sizes of 2.24 ha (Krapina-Zagorje County, 2025), which creates constraints on economically viable, mechanised management on sloping terrain. Orchards and vineyards are traditionally present in the hilly landscapes of this region (Zara, 2022). Since the 1990s, rural depopulation and population ageing have intensified, and the combined effect of accelerated de-agrarisation, farmland abandonment, and conversion of previously perennial land uses into other land-cover and management types (Cvitanović et al., 2017; Eurostat, 2024). In these conditions, terracing and permanent grass cover became less common or were often not maintained, thereby predisposing these landscapes to increased runoff and erosion. Moreover, in recent years, annual croplands have dominated in hilly agricultural areas, favouring cash crops over grasses and legumes and predominantly using ploughing (Trevisani and Bogunovic, 2022). Therefore, dryland cereal farming shifted from flat valleys to hillslopes, using the same practices that were widely applied in broad, flat areas. This made the transition to other sustainable land management practices unsuccessful, as they failed to adapt to the new topography. Consequently, the newly reactivated hilly landscapes, heavily covered with cereals, require locally adapted, sustainable strategies to reduce soil erosion and nutrient export, which remain limited or unevenly implemented in practice. Conventional agricultural practices, namely intensive plowing and non-selective herbicide use on these lands, are causing the largest soil losses measured in Croatia (Bogunovic et al., 2022), with other orchards and vineyards, and high soil erosion rates observed in the Daruvar farm are also found in other conventionally managed annual croplands and underscore the urgent need to identify the causes and potential solutions (Dugan et al., 2024c; Kisić et al., 2017). Conventional agriculture and the predominant focus on income over sustainability are among the causes. The positive effect of the EU policy framework, through the EU Soil Strategy for 2030 and the Farm to Fork and EU Biodiversity Strategies for 2030, on reducing soil erosion is not always implemented in practice, as even today some farmers do not accept and implement conservation agriculture management (Dessart et al., 2019; European Commission, 2021). Our results therefore support non-inversion loosening and residue/ground-cover retention as immediately applicable measures for sloping orchard inter-rows temporarily used for cereal production, with direct benefits for runoff, soil loss, and sediment-bound nutrient export. Future work should scale monitoring beyond plot level and extend it over multiple years to quantify long-term effects on soil stocks and yields, and to evaluate complementary options (e.g., cover crops, diversified rotations, and traffic control) under variable natural rainfall.

5 CONCLUSION

This study demonstrates that, under natural rainfall in a young sloping plum orchard with a maize-wheat inter-row system on Stagnosols, shifting from conventional tillage using

ploughing and discing to conservation tillage using chisel and roto-harrow provides immediate erosion control benefits. Conservation tillage reduced runoff by 40.5%, sediment concentration from 8.95 to 3.11 g L⁻¹, and decreased soil loss by 65.3%, with treatment differences significant for almost all events. The reduction in sediment export directly resulted in markedly lower nutrient and element losses, with conventional tillage increasing exports of P (~3.4×), K (~3.2×), Cu (~2.6×), N (~1.7×) and C (>2×) relative to conservation management. This indicates a substantially higher off-site pollution potential and stronger depletion pressure on soil fertility pools under inversion-based inter-row tillage. Beyond soil protection, conservation tillage even improved topsoil quality, with significantly higher aggregate stability and higher soil carbon at the end of the experiment. At the same time, no consistent increase in compaction was detected compared with conventional tillage. Overall, a practically simple shift to non-inversion loosening is a readily adoptable conservation practice for cereal inter-rows in young orchards on hillslopes, providing a practical pathway to reduce runoff, soil erosion, and nutrient exports, thereby supporting on-site soil health and protecting downstream water quality.

Acknowledgements. This work was supported by the Croatian Science Foundation through the project "Forming Climate Smart Soils: Mitigation of Soil Erosion and Degradation Processes in Croatian Agricultural Systems" (IP-2022-10-5692) (FORMclimaSOIL). Mr Manuel Matisic and Ivan Dugan are acknowledged for their help during fieldwork. Paulo Pereira was supported by the project European Union NextGeneration EU through the National Recovery and Resilience Plan, Component 9. I8., grant number 760104/May 23, 2023, code CF245/November 29, 2022. This work was supported by the project "Sensing, Mapping, Interconnecting: Tools for soil functions and services evaluation" supported by the Romanian Government, Ministry of the Innovation and Digitization through the National Recovery and Resilience Plan (PNRR) PNRR-III-C9-2022-I8, contract no. CF245/29.11.2022.

Data Availability Statement. The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest. The authors declare no conflicts of interest.

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Received 24 April 2026

Accepted 25 May 2026