doi: 10.17221/25/2017-SWR

Effects of Soil Erosion by Water under Different Tillage Treatments on Distribution of Soil Chemical Parameters

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Abstract

Kisic I., Bogunovic I., Zgorelec Z., Bilandzija D. (2018): Effects of soil erosion by water under different tillage treatments on distribution of soil chemical parameters. Soil & Water Res., 13: 36–43.

Soil losses by water erosion were studied under six different tillage treatments, which differ in depth and direction of tillage and planting during a twenty-year period (1995–2014) on Stagnosols in central lowland Croatia. Studied tillage treatments were: control plot (bare fallow-BF), ploughing up and down the slope to 30 cm (PUDS), no-tillage (NT), ploughing across the slope to 30 cm (PAS), very deep ploughing across the slope to 50 cm (VDPAS), and subsoiling to 50 cm + ploughing to 30 cm across the slope (SSPAS). The paper presents the following chemical parameters: soil pH, soil organic matter (OM), plant available phosphorus (P-P_2O_5), plant available potassium (K-K_2O), total carbon content (C_{tot}), total nitrogen content (N_{tot}) and CN ratio of non-eroded soil and soil loss from studied treatments. All soil sediments had significantly higher content of the studied parameters compared to non-eroded soil. The overall respective levels of OM, C_{tot}, N_{tot}, P-P_2O_5 and K-K_2O loss by eroded soil were as follows: 0.86 (NT) – 10.86 (BF) t/ha, 0.10 (SSPAS) – 2.60 (BF) t/ha, 0.015 (SSPAS) – 0.392 (BF) t/ha, 0.012 (NT) – 0.173 (BF) t/ha and 0.017 (SSPAS) – 0.158 (BF) t/ha. No-tillage and treatments with tillage across the slope (PAS, VDPAS, SSPAS) proved to be much more efficient in storing investigated soil nutrients.

Keywords: non-eroded soil; soil loss; soil management; soil nutrients

Soil erosion is a process whereby component materials are disintegrated, transported, and deposited by the action of water or wind (Pérez-Sánchez & Senent-Aparicio 2016). Soil erosion has long been regarded as a problem of unrecoverable soil loss (Boardman & Poesen 2006) and special attention has been given to the accelerated soil erosion which is a phenomenon as old as agriculture (Montgomery 2012). Currently, degradation processes in agricultural soils are triggered by anthropogenic causes such as intensive ploughing, deforestation, uncontrolled grazing and biomass burning (Blanco & Lal 2008; Podhrázská *et al.* 2015), which accelerate the process of compaction and water erosion in the region (Basic *et al.* 2001; Bogunovic & Kisic 2017). To offset the nutrient losses erosion inflicts on crop production, large quantities of fertilizers are often applied (Sharpley 1985; Shi *et al.* 2012), which represents only a part of the damage estimated in billions of US dollars (Uri 2000;Troeh *et al*. 2004). Soil tillage and cover crops play crucial roles in influencing the proportion of erosion processes. Ploughing performed on slopes can cause intolerable soil loss, especially if it is performed in up-slope and down-slope directions (e.g. Bertola *et al.* 2007; DeLaune & Sij 2012), while no-tillage (NT) preserves soil quality by reducing soil erosion (Lal 2007; Mwango *et al.* 2016), This practice is still not common in Croatian Stagnosols, mostly due to prejudices about soil compaction, low yields and lime and fertilizers mixing under NT. Since the recorded soil erosion is always higher under low density crops, the effects on the environment may be more pronounced (Lal 2006; Pimentel 2006).

doi: 10.17221/25/2017-SWR

Regardless of the total soil loss, concentrations of nutrients in soil sediments differ according to varying conditions – soil type, vegetation cover, soil management, rainfall intensity etc. Some contradictory results can be found in literature. Some authors (e.g. Young 1989; Gachene *et al.* 1997) show increase of nutrients in soil sediments in addition to non-eroded soil, while others find the opposite. For example, Fullen *et al.* (1997) and Zhang *et al.* (2004a) find lower organic matter, phosphorus and nitrogen content and lower pH values in sediment than in the non-eroded soil. Recently, the majority of soil erosion research has been focused on sampling the sediments and runoff after rainfall simulations (e.g. Kovář *et al*. 2012; Comino *et al*. 2016; Prosdocimi *et al*. 2016), which are performed to simulate highly intensive rainfall events. Although this approach enables measurement of the effects of one event, it is hard to estimate the long-term effect of soil management type on soil water erosion in particular agroecosystem. This is especially true when taking into consideration that the proportion of chemical properties predominantly depends on the impact of rainfall intensity (Jin *et al.* 2009). Therefore, the results provided from long-term trials more accurately represent the extent and severity of soil degradation processes in each given area. In Croatia, such research is lacking. Therefore, the aim of this research was to i) determine the effect of different tillage treatments on the chemical composition of non-eroded soil and soil sediments in Croatian Stagnosols under six different tillage treatments and ii) to identify the optimal tillage most appropriate for environmental protection. We hypothesize that contour tillage and NT will result in lower nutrient losses, regardless of crop rotation.

MATERIAL AND METHODS

Location, climate and experimental design. The experiment was carried out in central lowland Croatia (Figure 1) (N 45°33'48'' E 17°02'06'', altitude 133 m a.s.l.). The surrounding area is mostly a mixture of plains with gentle hills. The parent materials in the area are composed of loamy loess sediments that developed a silty loam Luvic Stagnosols (IUSS Working Group WRB 2006) formed by top down pedogenesis (Rubinić *et al.* 2015). Organic matter ranges from 16 g/kg at the surface to 6 g/kg at a depth of 35–95 cm (Table 1). Mean annual precipitation is 863 mm. Rainfall distribution is not uniform throughout the year, particularly in the spring and autumn, when most of the high-intensity rains occur. The mean annual temperature is 10.7°C, ranging from –0.4°C in January to 20.6°C in July.

The experimental design consisted of six treatments that were each 25 m wide and 50 m long with slopes of approximately 9%. The six tillage treatments were BF (black fallow, control plot) –ploughing up and down the slope (30 cm), seedbed preparation with a harrow, but the soil was kept bare at all time. The weeds were suppressed by total herbicides. Ploughing was carried out, in this and other treatments, by a 5-bottom Nardi reversible plough to a depth of 30 cm. The preparation of the seed layer was carried out with a combined Vaderstad tool. PUDS – planting and ploughing up and down the slope (30 cm) – and seedbed preparation (with a harrow and sowing) were performed in the same direction; NT (no-tillage)

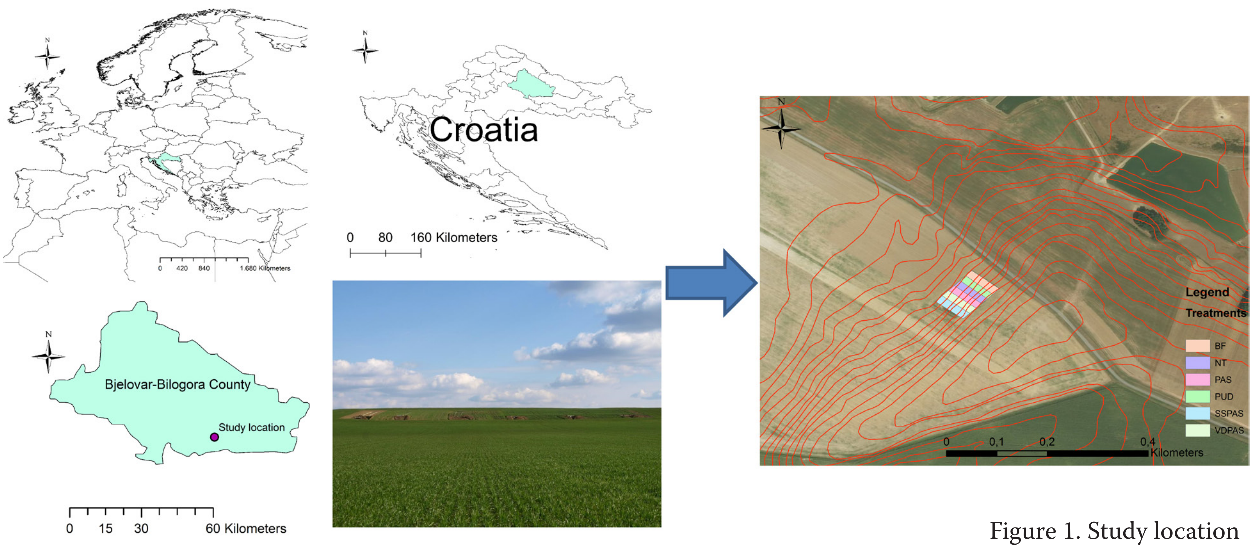

Figure 1. Study location

doi: 10.17221/25/2017-SWR

included sowing with a special seeder into the dead mulch up and down the slope. Two to three weeks before sowing, weeds were suppressed using total herbicides. Plant residues of the investigated crops were retained on the soil surface. Direct drilling was done with a John Deer seeder 750A (John Deere, Germany); PAS – planting and ploughing across the slope (30 cm) – was completed with similar equipment to what was used for BF; VDPAS – planting and very deep ploughing across the slope (50 cm) – was completed using asingle-bottom John Deere plough. SSPAS – planting and subsoiling (50 cm) + ploughing across the slope – were completed at depths of 50 cm and 30 cm, respectively.

Subsoiling tines were spaced 60 cm apart, and this process was performed with a Dondi ripper with three working bodies. Subsoiling (at SSPAS) and deep ploughing (at VDPAS) tillage was performed every 3–4 years when crop rotation allowed it. The crops on each experimental plot (apart from the control plot) were grown in a crop rotation that is typical for the southeast part of Europe: maize, $n = 4$ (*Zea mays* L.); soybean, $n = 4$ (*Glycine hispida* L.); winter wheat, $n = 4$ (*Triticum aestivum* L.); oil seed rape, $n = 4$ (*Brasicca napus* var. *oleifera* L.) and double crop ($n = 4$) – spring barley (*Hordeum vulgare* L.) with soybean (*Glycine max*). Soil samples from non-eroded soil were collected using a manual soil auger from 0–30 cm depth each year. Each soil sample was a composite of subsamples taken from 10–15 random points from each treatment plot. The samples were placed in plastic bags, air-dried, milled and sieved through a 2-mm mesh before analysis. Each treatment plot was fenced off with a tin fence (22.1 m long and 1.87 m wide) that was removed before each tillage operation and then placed back into the soil for the rest of season. Filtration equipment was set up at the lower end of each plot and was designed for volume measurement of water and sediment transported by surface runoff. After each rainfall event soil sediments were collected and transported to the laboratory for the analysis of the investigated chemical parameters. During the study period, 120 samples of non-eroded soil and 918 samples of soil sediments were collected. Details on tillage treatments, crop rotation and filtration equipment can be found in Kisic *et al.* (2017b).

Table 1. Soil profile characteristics of a Luvic Stagnosol; values following ± indicate standard deviation

Horizons	Ap + Eg	Eg + Btg	Btg
Depth range (cm)	0–24	24–35	35–95
pH in KCl (w/w 1:2.5)	4.21 ± 0.15	4.20 ± 0.18	4.81 ± 0.23
Organic matter (g/kg)	16 ± 3.3	14 ± 4.2	6 ± 3.8
Available P_2O_5 (g/kg)	172 ± 18	65 ± 4	244 ± 24
Available K_2O (g/kg)	308 ± 6	123 ± 8	502 ± 12
Clay (< 0.002 mm) (g/kg)	154 ±25	148 ± 44	196 ± 40
Silt (0.02–0.002 mm) (g/kg)	242 ± 35	260 ± 54	254 ± 32
Fine sand (0.2–0.02 mm) (g/kg)	586 ± 37	571 ± 59	545 ± 69
Coarse sand (2–0.2 mm) (g/kg)	18 ± 4.7	21 ± 5.5	5 ± 2.3

Laboratory analysis and statistical procedures. Soil reaction (pH) was determined by potentiometric measurement in accordance with modified HRN ISO 10390:2005 (1 : 2.5 suspension of soil in 1 mol/l potassium chloride solution). Plant available phosphorus (P-P_2O_5) and potassium (K-K_2O) were extracted by AL solution (ammonium lactate-acetate). The content of soil organic matter (OM) was determined in accordance with modified ISO 14325:1998 (Tjurin method). Total carbon (C_{tot}) and total nitrogen (N_{tot}) contents were determined by the method of dry combustion on the Vario, Macro CHNS analyser in accordance with HRN ISO 10694:2004 for carbon and HRN ISO 13878:2004 for nitrogen. Calculations of total losses of C_{tot}, N_{tot}, K-K_2O and P-P_2O_5 were derived by multiplying the content of each property from sediments with weight of sediment yield from each treatment after each erosion event. Total losses of soil chemical properties were presented as the sum across all years of investigation.

Analysis of variance (ANOVA) was conducted using the GLM procedure (SAS Institute, version 9.1.3) to evaluate the effects of tillage on the quantity of soil sediments and chemical parameters. An estimate of the least significant difference (Tukey's LSD) between treatments was obtained. Statistical differences were declared significant at the 0.05 level.

RESULTS AND DISCUSSION

Mean soil losses in the 1995–2014 period per crop and tillage treatment were obtained from Kisic *et al*. (2017) and ranged from 2.10 (NT) t/ha/year to 65.52 (BF) t/ha/year. Table 2 presents the values of chemical parameters of non-eroded soil and soil sediments. Significantly lower soil pH was observed

doi: 10.17221/25/2017-SWR

in non-eroded soil under BF and PAS compared to VDPAS and SSPAS treatments. The BF treatment showed significantly lower content of OM, P-P_2O_5 and K-K_2O compared to NT, PAS, VDPAS and SSPAS treatments in non-eroded soil. Additionally, significantly lower P-P_2O_5 content was observed under PUDS compared to VDPAS and SSPAS treatments in non-eroded soil. Significantly higher soil pH, OM content, P-P_2O_5 and K-K_2O were observed in soil sediments compared to non-eroded soil, regardless of treatment. Significantly higher soil pH and OM content in soil sediments was observed under NT treatment (and BF for OM) compared to other treatments. Significantly lower P-P_2O_5 and K-K_2O were observed under the BF treatment but were higher under the NT treatment compared to other treatments.

Significantly lower C_{tot} in non-eroded soil was observed under the BF treatment compared to other treatments except PUDS. Higher N_{tot} was observed under the NT treatment compared to BF and PUDS. Significantly lower CN ratio was observed under the BF treatment compared to other treatments except NT treatment. In the soil sediment, significantly higher values of C_{tot} and N_{tot} were recorded under the NT treatment compared to other treatments. Generally, higher values of C_{tot}, N_{tot} and CN ratio were observed in soil sediments compared to non-eroded soil under all studied treatments.

These results are consistent with the results of other researchers: Burwel *et al.* (1977), McIsaac *et al.* (1991), Fleige and Horn (2000), Kisic *et al.* (2002), Ali *et al.* (2006), Malam Issa *et al.* (2006) and Warrington *et al.* (2009) reported higher content of OM, plant available nutrients and other chemicals in soil sediments. Gaynor and Findlay (1995) concluded that conservation tillage reduces average soil loss compared to conventional tillage. The same authors concluded that conservation tillage has effectively reduced soil erosion but also increased phosphorus loss, a finding in opposition to the results obtained by Ulen *et al.* (2010). Hussain *et al.* (1999) determined that soil pH and TOC were higher at NT compared to conventional tillage.

Differences in soil pH between treatments could be explained by different erosion rates and nutrient

Table 2. Chemical parameters under different tillage treatments

Treatments	Soil pH	OM (%)	P-P_2O_5	K-K_2O	C_{tot}	N_{tot}	C/N
			(mg/kg)		(%)		
Non-eroded soil							
BF	$3.95^{B,bc}$	$1.14^{B,c}$	$75.1^{B,d}$	$126.0^{B,b}$	$0.50^{A,b}$	$0.07^{A,b}$	$7.48^{A,b}$
PUDS	$4.04^{B,abc}$	$1.36^{B,bc}$	$81.4^{B,cd}$	$142.4^{B,ab}$	$0.58^{A,ab}$	$0.07^{B,b}$	$8.51^{A,a}$
NT	$4.07^{B,ab}$	$1.72^{B,a}$	$90.2^{B,abc}$	$168.8^{B,a}$	$0.73^{B,a}$	$0.09^{B,a}$	$8.31^{A,ab}$
PAS	$3.94^{B,c}$	$1.47^{B,ab}$	$86.1^{B,bc}$	$168.3^{B,a}$	$0.68^{B,a}$	$0.08^{A,ab}$	$8.48^{A,a}$
VDPAS	$4.14^{B,a}$	$1.44^{B,ab}$	$91.5^{B,ab}$	$155.4^{B,a}$	$0.65^{A,a}$	$0.08^{B,ab}$	$8.74^{A,a}$
SSPAS	$4.11^{B,a}$	$1.51^{B,ab}$	$94.7^{B,a}$	$160.5^{B,a}$	$0.72^{A,a}$	$0.08^{A,ab}$	$9.00^{A,a}$
P value	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.0084**	0.0004***
Soil sediments							
BF	$4.46^{A,c}$	$2.91^{A,ab}$	$74.5^{A,c}$	$149.^{8A,}$c	$0.81^{A,b}$	$0.12^{A,b}$	7.41^{A}
PUDS	$4.83^{A,b}$	$1.98^{A,c}$	$106.2^{A,b}$	$190.2^{A,b}$	$0.99^{A,b}$	$0.14^{A,b}$	7.13^{B}
NT	$5.36^{A,a}$	$3.32^{A,a}$	$149.5^{A,a}$	$285.0^{A,a}$	$2.08^{A,a}$	$0.26^{A,a}$	7.84^{A}
PAS	$4.72^{A,bc}$	$2.04^{A,bc}$	$116.7^{A,b}$	$192.1^{A,b}$	$1.17^{A,b}$	$0.14^{A,b}$	8.23^{A}
VDPAS	$4.81^{A,b}$	$1.95^{A,c}$	$116.2^{A,b}$	$192.7^{A,b}$	$1.16^{A,b}$	$0.17^{A,ab}$	7.20^{B}
SSPAS	$4.77^{A,bc}$	$2.01^{A,bc}$	$106.2^{A,b}$	$202.6^{A,b}$	$0.84^{A,b}$	$0.12^{A,b}$	7.56^{A}
P value	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.0005***	0.0073**	$0.1095^{n.s.}$

different lowercase letters in same column indicate significant differences ($^{n.s.}P \geq 0.05$, $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$) between tillage treatments according to Tukey LSD; different uppercase letters in same row indicate significant differences ($P < 0.05$) between eroded and non-eroded soil for each variant; OM – soil organic matter; C_{tot} – total carbon content; N_{tot} – total nitrogen content; BF – control plot (bare fallow); PUDS – ploughing up and down the slope to 30 cm; NT – no-tillage; PAS – ploughing across the slope to 30 cm; VDPAS – very deep ploughing across the slope to 50 cm; SSPAS – subsoiling to 50 cm + ploughing to 30 cm across the slope

doi: 10.17221/25/2017-SWR

content in soil losses – primary base cations. Though not the subject of presented paper, Ca and Mg losses by water erosion are usually high (e.g. Fullen *et al.* 1997; Bertol *et al.* 2003; Zhang *et al.* 2004b) and their removal can affect soil pH. Treatment erosion rates were variable and base cation loss could have an influence on differences in original soil pH between treatments. Conversely, differences between treatments could also be explained by existence of small-scale variability before the experiment was established (OM from 1.28% to 1.68% and pH from 3.97 to 4.18, depending on treatments). In this context, OM variability between treatments can be explained. Soil pH, along with tillage (and other parameters) affects soil OM. Decades of intensive tillage had implications on aeration and rate of mineralization. Furthermore, variability of soil pH in the original soil, unequal OM loss by erosion, as well as management, may certainly cause differences between treatments as are visible in the present results.

The results of overall C_{tot} and N_{tot} losses in non-eroded soil and soil sediment are presented in Table 3. Although different tillage treatments were applied during the 20-year period, a significant change in C_{tot} was not determined in non-eroded soil. At the same time, N_{tot} had significantly increased under the NT compared to BF and PUDS treatments. Conservation tillage practices stored more C_{tot} and N_{tot} in soil compared to almost all other treatments. Significantly higher C_{tot} and N_{tot} losses in soil sediments were recorded at BF treatments, followed by the PUDS treatment, while the NT treatment and treatments with tillage and planting across the slope showed the lowest C_{tot} and N_{tot} losses. During the 20-year research period in studied crop rotation, overall C_{tot} losses (in t/ha) were: BF (2.60) > PUDS (0.70) > PAS (0.24) > NT (0.23) > VDPAS (0.22) > SSPAS (0.10) and overall N_{tot} losses (in t/ha) were respectively: BF (0.392) > PUDS (0.105) > PAS = VDPAS (0.035) > NT (0.032) > SSPAS (0.015).

Table 4 presents the OM content (t/ha) loss over the 20-year period under the investigated treatments and crops. The BF treatment recorded significantly higher OM loss compared to other studied treatments. Significantly higher losses of OM were determined during cultivation of row crops compared to high-density winter crops. During the 20-year period of research in crop rotation of corn – soybean – winter wheat – oilseed rape – double crop, overall OM losses (in t/ha) were: BF (10.86) > PUDS (3.22) > PAS = VDPAS (1.54) > SSPAS (1.14) > (NT 0.86).

Presented OM losses indicate that the application of the PUDS treatment is not considered to be sustainable in such a crop rotation. Because all other tillage treatments cause smaller OM losses, soil can be naturally rebuilt (Kisic *et al.* 2017a). These data suggest that treatments with tillage and planting direction across the slope, as well as NT treatment, are sustainable in the studied climatic conditions.

In the last few decades, low-density row crops are increasingly represented in crop rotation (Wilhelm *et al.* 2007) and high-density crops are less frequent. However, OM losses determined at some treatments indicate that the crop rotation should be expanded and returned to the form in which it had been used up until ~50 years ago. In this way, the application of conservation tillage will preserve the soil for future generations.

Table 4 presents average losses of P-P_2O_5 in soil sediments for individual crops and the overall 20-year loss of P-P_2O_5. According to the obtained results, on average 4.80 kg/ha of P-P_2O_5 was lost per each soil loss event during maize cultivation. Significantly higher losses of P-P_2O_5 were determined during cultivation of row crops compared to high density winter crops. During the 20-year period of research in crop rotation of corn – soybean –winter wheat – oilseed rape – double crop, overall P-P_2O_5 losses (in kg/ha) were: BF (172.79) > PUDS (52.29) > PAS (22.48) > VDPAS (21.15) > SSPAS (13.23) > (NT 12.74).

Table 3. State of total carbon content (C_{tot}) and total nitrogen content (N_{tot}) in non-eroded soil and the overall C_{tot} and N_{tot} loss by soil sediment in 20 year period (in t/ha)

Treatment	C_{tot}	N_{tot}	C_{tot}	N_{tot}
	non-eroded soil		soil sediments	
BF	19.50[a]	2.71[b]	2.60[a]	0.392[a]
PUDS	22.48[a]	2.73[b]	0.70[b]	0.105[b]
NT	28.84[a]	3.56[a]	0.23[c]	0.032[c]
PAS	29.37[a]	3.22[ab]	0.24[c]	0.035[c]
VDPAS	26.00[a]	3.22[ab]	0.22[c]	0.035[c]
SSPAS	28.27[a]	3.14[ab]	0.10[c]	0.015[c]
P value	0.1180[n.s.]	0.0341*	< 0.0001***	< 0.0001***

*different letters in same column indicate significant differences between tillage treatments ([n.s.]$P \geq 0.05$, *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$) according to Tukey LSD; BF – control plot (bare fallow); PUDS – ploughing up and down the slope to 30 cm; NT – no-tillage; PAS – ploughing across the slope to 30 cm; VDPAS – very deep ploughing across the slope to 50 cm; SSPAS – subsoiling to 50 cm + ploughing to 30 cm across the slope

doi: 10.17221/25/2017-SWR

Similar losses were also determined for K-K_2O (Table 4). Significantly higher losses of K-K_2O were determined during cultivation of low density spring crops compared to high density winter crops. Losses of K-K_2O in double crop cultivation were not significantly different compared to other crops except maize. During the 20-year period of research in crop rotation of corn – soybean – winter wheat – oilseed rape – double crop, overall K-K_2O losses (in kg/ha) were: BF (158.32) > PUDS (56.93) > PAS (26.34) > VDPAS (24.22) > (NT 18.55) > SSPAS (17.05).

Research conducted during the 20-year period indicates that there is no crop or tillage method that can completely prevent the erosional processes.

Table 4. The losses of soil organic matter, P-P_2O_5 and K-K_2O in soil sediments

Crop	Maize	Soybean	Winter wheat	Oil seed rape	Double crop	
Soil organic matter (t/ha)						
Mean (P < 0.0001***)	0.32^{A}	0.21^{AB}	0.07^{C}	0.07^{C}	0.12^{BC}	
Treatments	BF	PUDS	NT	PAS	VDPAS	SSPAS
Mean (P < 0.0001***)	0.54^{a}	0.16^{b}	0.04^{b}	0.08^{b}	0.08^{b}	0.06^{b}
Maize Σ	3.56	1.47	0.50	0.62	0.91	0.50
Soybean Σ	2.97	1.06	0.30	0.38	0.24	0.25
Winter wheat Σ	1.33	0.08	0.01	0.07	0.08	0.08
Oilseed rape Σ	1.52	0.09	0.01	0.06	0.02	0.04
Double crop Σ	1.48	0.52	0.03	0.42	0.29	0.26
All crops Σ	10.86	3.22	0.86	1.54	1.54	1.14
P-P_2O_5 (kg/ha)						
Mean (P < 0.0001***)	4.80^{A}	3.39^{AB}	0.98^{C}	1.12^{C}	1.90^{BC}	
Treatments	BF	PUDS	NT	PAS	VDPAS	SSPAS
Mean (P < 0.0001***)	8.63^{a}	2.61^{b}	0.62^{b}	1.10^{b}	1.04^{b}	0.64^{b}
Maize Σ	56.62	23.85	7.42	9.02	12.50	5.84
Soybean Σ	47.21	17.24	4.51	5.48	3.32	2.92
Winter wheat Σ	21.15	1.23	0.17	0.97	1.08	0.98
Oil seed rape Σ	24.12	1.54	0.19	0.84	0.25	0.44
Double crop Σ	23.48	8.45	0.45	6.18	4.00	3.05
All crops Σ	172.79	52.29	12.74	22.48	21.15	13.23
K-K_2O (kg/ha)						
Mean (P<0.0001***)	5.05^{A}	3.50^{AB}	0.93^{C}	1.06^{C}	1.96^{BC}	
Treatments	BF	PUDS	NT	PAS	VDPAS	SSPAS
Mean (P<0.0001***)	7.91^{a}	2.85^{b}	0.93^{b}	1.29^{b}	1.19^{b}	0.83^{b}
Maize Σ	51.94	25.96	10.81	10.57	14.32	7.60
Soybean Σ	43.31	18.77	6.56	6.42	3.80	3.73
Winter wheat Σ	19.41	1.34	0.25	1.14	1.24	1.26
Oil seed rape Σ	22.12	1.67	0.28	0.98	0.29	0.56
Double crop Σ	21.54	9.19	0.65	7.24	4.58	3.89
All crops Σ	158.32	56.93	18.55	26.34	24.22	17.05

Different lowercase (between tillage treatments) and uppercase (between cover crops) letters in same column indicate significant differences ($P \geq 0.05$ n.s., *P < 0.05, **P < 0.01 and ***P < 0.001) according to Tukey's LSD; BF – control plot (bare fallow); PUDS – ploughing up and down the slope to 30 cm; NT – no-tillage; PAS – ploughing across the slope to 30 cm; VDPAS – very deep ploughing across the slope to 50 cm; SSPAS – subsoiling to 50 cm + ploughing to 30 cm across the slope

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However, there are tillage methods which contribute to the mitigation of erosional processes. Additionally, the methods which have shown to be the best at mitigating erosional processes can partly lead to the pollution of surface water and groundwater by agrochemical inputs from agriculture.

CONCLUSIONS

These study results fill the gaps of knowledge about tillage effect on erosion by water and nutrient lost at Croatian Stagnosols. Tillage treatments type hasimplications (P < 0.05) on the chemical composition of non-eroded soil and soil sediment. Higher values of soil pH, OM content, P-P_2O_5, K-K_2O, C_{tot}, N_{tot} and CN ratio were determined in soil sediments compared to non-eroded soil under all studied treatments. This research supports the hypothesis that lower nutrient losses would occur in contour tillage and NT treatments. The highest C_{tot} and N_{tot} losses in soil sediments were recorded at BF treatments, followed by PUDS treatment. Crops also confirm the significant effect (P < 0.05) on nutrient losses. Significantly higher losses of OM, P-P_2O_5 and K-K_2O were determined during cultivation of row crops compared to high-density winter crops. No tillage and contour tillage treatments are identified as the most appropriate, regardless of cover crops, for environmental protection on Stagnosols on slopes; these treatments could be recommended for widespread agricultural practice. Further research will be focused on the identification of variables that can explain the spatio-temporal dynamic of soil erosion by water, such as soil structure, aggregate stability, infiltration and relation between rainfall intensity and canopy density. Such data will provide a better understanding of the variables that can be used to control soil erosion in arable Stagnosols.

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doi: 10.17221/25/2017-SWR

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Received for publication January 23, 2017
Accepted after corrections August 3, 2017
Published online September 27, 2017