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A lysimeter study of organic carbon leaching from green manure and straw into a sandy loam *Haplic Luvisol*

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Abstract

Lysimeter experiments (2002–2008) were conducted at the Vokė Branch of the Lithuanian Institute of Agriculture (currently – Lithuanian Research Centre of Agriculture and Forestry) to study the effects of green manure and straw on total organic carbon (TOC) leaching from a sandy loam *Haplic Luvisol* (*LVh*) in Eastern Lithuania. The replicated treatments were: i) control (without added organic matter), ii) straw + N_{30}, iii) post-crop fodder radish (*Raphanus sativus* L.) + N_{30}, and iv) undersown red clover (*Trifolium pratense* L.). In all treatments, except for the control, barley straw was left on the soil after harvesting. Leaching of organic compounds were measured in the years of green manure (2002, 2004, 2006) and straw incorporation and repeated the following years (2003, 2005, 2007). Analysis of lysimeter water showed TOC leaching losses were low and depending on annual meteorological conditions and experimental treatments varied from 1.97 to 14.92 kg ha^{-1} organic carbon (OC) per year. Incorporation of catch crops' (fodder radish, red clover) biomass and straw did not increase TOC leaching. In treatments grown with undersown red clover, infiltration decreased by 38.7% in summer and by 16.5% in autumn, whereas fodder radish sown in late August reduced infiltration by 25.3%. Due to low infiltration, soil organic carbon (SOC) leaching losses after green manure incorporation were less than in the treatments with only incorporated straw or barley stubble. Cultivation of catch crops (fodder radish, red clover) reduced infiltration during autumn, which decreased TOC leaching by 19.8–21.7%. Therefore, it is concluded that the application of straw and green manure on a sandy loam *Haplic Luvisol* does not increase organic carbon leaching below the rhizosphere and does not have negative effects on surface water quality.

Key words: green manure, leaching, lysimeter, organic carbon, straw.

Introduction

Lithuania lies between maritime Western Europe and continental Eastern Europe, with a mean annual air temperature of 6.2°C, a mean annual precipitation of 661 mm. Depending on soil texture an average of 36–53% of rainfall percolate through the soil; in sandy soils the filtration is more intense, in limnoglacial clay soils it is weaker (Lietuvos dirvožemiai, 2001). Winter lasts for 95–105 days, but the land is prone to frequent thaws. Unfortunately, these hydrothermal conditions are conducive to the destruction of soil organic matter (SOM), excessive humidity and leaching of biogenic elements from upper, humic soil layers (Galvonaitė et al., 2007).

Recent climatic trends (1991–2003) show a mean annual air temperature rise of 0.1–0.9°C and a mean seasonal air temperature rise of 1.1–1.7°C in late winter and spring, which caused a decline in days with sub-zero temperatures (Galvonaitė, Valiukas, 2005). This results in milder winters, longer and more favourable conditions for the infiltration of precipitation and increased biogenic leaching from agricultural land.

Lithuania's soils vary markedly, with the Central region providing high crop productivity, while the acidic soils of Western and Eastern Lithuania are low in humus (0.29–1.10% SOC) and productivity (Lietuvos žemės našumas, 2011). Consequently, there is a need for the latter soils to systematically receive organic and mineral fertilizers. However, due to their low buffering capacity, certain nutrients incorporated into the soil are leached to deeper soil horizons, which can have negative effects on the quality of both surface- and ground-water. To improve arable soil productivity, straw and various green manure crops are widely used as organic fertilizers in Lithuania. Their incorporation helps stabilize SOM content, but results in increased leaching of nitrogen (N) (Arlauskienė, Maikštėnienė, 2005; Kavdir et al., 2005). Other researchers suggest that catch crops reduce N leaching during autumn and winter (Lahti, Kuikman, 2003; Bendaravičius et al., 2004; Thomsen, 2005).

During decay and decomposition of straw and green manure, large quantities of mobile organic compounds are formed, which can be leached from the plant root zone. Leaching of dissolved organic carbon (DOC) largely depends on soil tillage. According to Brye et al. (2001), DOC leaching losses during the 4-yr period for no-tillage agroecosystem was 435 and 502 kg ha^{-1} C for chisel-ploughed agroecosystem. Typically, DOC leached from light-textured soils is lower than that leached from heavy-textured soils (Vinther et al., 2006). For instance, it was found that annual DOC leaching in a sandy loam soil was 22–40 and 174–310 kg ha^{-1} in a coarse sandy soil. Similarly, previous field experiments on a sandy loam *Haplic Luvisol* have revealed that the application of green manure (red clover and fodder radish) and cereal straw stimulates the formation of new humic substances, with an increase in the humic acid fraction of 0.01–0.02% for the mobile humic acid (HA-1) and the stable fraction (HA-3), which enhances their subsoil migration (Tripol'skaya et al., 2008). Field experiments carried-out on an *Endocalcari-Endohypogleic Cambisol* (*CMg-n-w-can*) show, in the first years after incorporation of catch crops biomass alone and together with straw, markedly increased mobile humic acid content compared with pre-trial levels. In the second year, incorporating of catch crop biomass with straw increased the content of relatively stable humic acids fractions (HA-2, HA-3) (Arlauskienė et al., 2009). However, an increase in mobile humus substances after application of green manure can intensify their migration in subsoil.

Through the use of replicated lysimeter treatments, this study reports the findings of a six-year field experiment designed to determine changes in TOC leaching after incorporation of barley straw and green manure (fodder radish, red clover) into a sandy loam *Haplic Luvisol*.

Materials and methods

Lysimeter experiments were conducted in 2002–2008 at the Vokė Branch of the Lithuanian Institute of Agriculture (54°37′ N, 5°08′ E). Fixed, round, lysimeters (n = 11, each covering 1.75 m^2) were packed (0.6 m depth) with a sandy loam soil (sand 2000–50 µm – 66%, silt 50–2 µm – 16%, clay <2 µm – 18%) *Haplic Luvisol* (*LVh*), typical of Eastern Lithuania, to evaluate the leaching of organic compounds (Fig. 1).

The replicated experimental design was: i) control (without added organic matter), ii) straw + N_{30}, iii) post-crop fodder radish (*Raphanus sativus* L.) + N_{30}, and iv) undersown red clover (*Trifolium pratense* L.). Changes in the leaching of chemical elements due to application of green manure were investigated in the segment barley (*Hordeum vulgare* L.) → potato (*Solanum tuberosum* L.). The test was performed in three replications (2002–2003, 2004–2005 and 2006–2007).

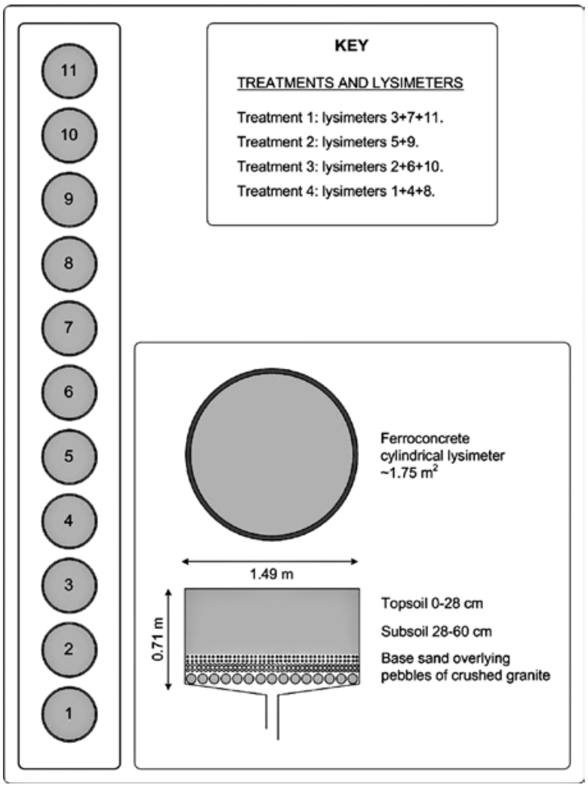

Figure 1. Lysimeter experiment design and lysimeter construction

Fodder radish was sown after barley harvesting; clover was undersown into barley in spring and, in all treatments, except for the control, barley straw was left in the soil after harvesting. Depending on the hydrothermal conditions of the autumn, before the addition of the green manure into the soil (15–20 October) fodder radish would reach the flowering or beginning of pods formation stage, the red clover – bud formation or beginning of flowering stage. In the years following the addition of green manure potato was cultivated. The barley was fertilized with $N_{60}P_{60}K_{60}$ and potatoes with $N_{90}P_{60}K_{90}$.

The leaching dynamics of mobile organic compounds was assessed in the same year as straw and green manure incorporation in the 0–20 cm soil layer (2002, 2004, 2006), and again in the following year (2003, 2005, 2007). Lysimetric water TOC was determined using the LST ISO 8245:2003 method. Mean OC concentration (mg L^{-1} OC), leaching losses (kg ha^{-1} OC) and infiltration rates were measured seasonally (spring – 01 March to 31 May, summer – 01 June to 31 August, autumn – 01 September to 30 November, winter – 01 December to 28 February). All experimental data were analysed using analysis of variance (*ANOVA*).

Results and discussion

Precipitation and infiltration. Annual and seasonal data in precipitation and infiltration rates are reported in Table 1. Annual precipitation (mean 681 mm) markedly varied during the experimental period from 535 (2002) to 747 (2005) mm. Seasonal precipitation (as a % of the annual rate) varied 17.2–29.2% in spring, 25.0–44.2% in summer, 13.4–43.2% in autumn and 13.2–27.8% in winter (Fig. 2).

Table 1. Infiltration of precipitation during the experimental period (2002–2008)

Treatment	Year						
	March 2002–Feb. 2003	March 2003–Feb. 2004	March 2004–Feb. 2005	March 2005–Feb. 2006	March 2006–Feb. 2007	March 2007–Feb. 2008	Mean
	Amount of infiltrated precipitation mm						
Without added organic matter	199.7	226.8	382.6	348.7	455.2	370.4	330.6
Straw + N_{30}	198.5	212.9	382.4	345.1	430.6	389.4	326.5
Fodder radish + straw + N_{30}	166.7	216.1	353.4	328.8	387.0	367.0	303.2
Red clover + straw	186.2	223.0	311.4	340.8	399.0	383.2	307.3
	Infiltrated precipitation %						
Without added organic matter	36.8	32.1	55.6	46.7	62.3	54.3	48.0
Straw + N_{30}	37.1	30.1	55.6	46.2	58.9	57.1	47.5
Fodder radish + straw + N_{30}	31.2	30.6	51.4	44.0	52.9	53.8	44.0
Red clover + straw	34.8	31.5	45.3	45.6	54.6	56.2	44.7

The lowest infiltration (166.7–199.7 L m^{-2}, 30.1–32.1% of annual precipitation) was in 2002 and the greatest (387.0–455.2 L m^{-2}, 44.0–46.7%) in 2005. During the winters of 2002 and 2006 precipitation accounted for 27.4–27.8% of annual precipitation and maximum infiltration (45.3–55.6 and 52.9–62.3 %, respectively) was also recorded. Mean data indicate 316.9 L m^{-2} of precipitation infiltrated through the sandy loam soil, which constitutes 46.4% of annual precipitation.

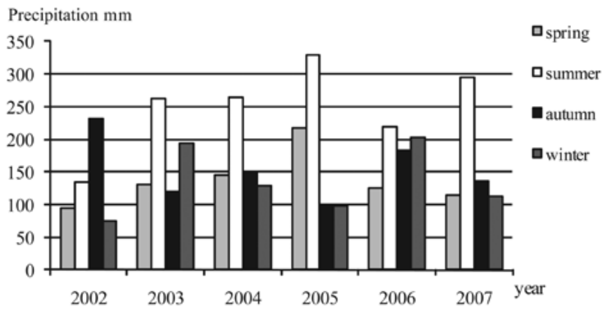

Figure 2. Seasonal distribution of precipitation (2002–2008)

Analysis of the filtration of precipitation in the course of a year evidently demonstrated that under climatic conditions of Southeastern Lithuania the filtration was higher in spring – approximately 116.6 L m^{-2} or 36.9% of the annual amount of filtered water percolated then. During autumn and winter the infiltration slightly decreased and was similar – 72.3 and 83.4 L m^{-2}, or 22.8% and 26.3% of the annual amount. During the summer period higher amount of precipitation evaporates from the ground or is consumed by plants, therefore only an average of 44.5 L m^{-2} of water percolates through the soil. Due to such seasonal dynamics of atmospheric precipitation filtration, the agro-technical measures, which increase the contents of nutritional elements or their availability in soil, should be particularly carefully applied in autumn.

Analysis of the effect of catch crops on filtration of precipitation revealed that it was strongest in August–October, i.e. during the vegetation of catch crops. It was determined that catch crops reduced the percolation of precipitation by 7.0–8.3% per year on average, and in autumn periods of the years of their cultivation – by 21.7–19.4% (Table 2). Such a phenomenon is very important in order to reduce nutrient leaching from agricultural land, especially lately as the duration of autumn period increases.

Table 2. Precipitation infiltration during green manure cultivation years (2002, 2004, 2006) and through the whole study period (2002–2008)

Treatment	Mean infiltration rates during green manure growing years (2002, 2004, 2006)						Infiltration rate mean of 2002–2008	
	summer season		autumn season		mean of year			
	L m^{-2}	%	L m^{-2}	%	L m^{-2}	%	L m^{-2}	%
Without added organic matter	21.7	100	107.5	100.0	345.8	100.0	330.6	100.0
Straw + N_{30}	21.1	97.2	111.4	103.6	337.2	97.5	326.5	98.8
Fodder radish + straw + N_{30}	16.2	74.7	89.3	83.1	302.4	87.4	303.2	91.7
Red clover + straw	13.3	61.3	89.8	83.5	298.8	86.4	307.3	93.0

Yield of green manure crops and straw. Depending on the weather conditions during the growing season, barley straw yield varied from 0.352–1.073 g m^{-2} of dry matter (DM), with a three year sum of 1.602–1.851 kg m^2 of straw incorporated into the soil of lysimeters (Table 3). Fodder radish, sown after barley harvesting and fertilized with N_{30}, produced 0.102–0.337 kg m^{-2} DM during autumn. The plant biomass for green manure yield depended on soil moisture content at sowing. When soil moisture content was sufficient, emergence of fodder radish was rapid and from mid-August to mid-October produced high biomass yields (≤0.337 kg m^{-2} DM). Rudokas (2003) indicated that similar green manure biomass yield (2.4 t ha^{-1} DM) is also produced by fodder radish during summer. When there is a moisture shortage (during autumn), the biomass of fodder radish amounted to 0.102 g m^{-2} DM. The biomass yield of undersown red clover produced after barley harvesting was 22% greater than fodder radish. However, clover biomass yields were highly variable (0.169–0.640 kg m^{-2} DM). Yields were strongly influenced by the growing conditions of clover as an undersown crop during summer and hydrothermal conditions during autumn. Mean data suggest greatest OM (1.024 kg m^{-2} DM) was incorporated with clover as a green manure, while OM incorporated with fodder radish was ~34% less (mean 0.766 kg m^{-2} DM).

Table 3. Straw and green manure contents (DM) incorporated into the soil of lysimeters during the experimental period

Year	Straw kg m^{-2} + N_{30}	Post-crops as green manure and straw kg m^{-2}			Undersown green manure crops and straw kg m^{-2}		
		fodder radish	straw	sum total	red clover	straw	sum total
2002	0.378	0.337	0.352	0.689	0.640	0.417	1.057
2004	0.992	0.102	0.842	0.944	0.412	1.073	1.485
2006	0.384	0.257	0.408	0.665	0.169	0.361	0.530
Σ	1.754	0.696	1.602	2.298	1.221	1.851	3.072
Mean	0.585	0.333	0.534	0.766	0.407	0.617	1.024
S.D.	0.327	0.099	0.234	0.156	0.208	0.356	0.393

In Lithuania, typically, the SOC content of sandy loam *Haplic Luvisol* ranges from 0.55–1.72% C, and the plough-layer (0–20 cm depth) contains 16.5–51.6 t ha^{-1} OC. The SOC content in the lysimeter soil was 0.77–0.81% and reserves in the plough-layer were 23.1–24.4 t ha^{-1} OC. The OC incorporated into the soil with straw was 0.234 kg m^{-2}, with fodder radish and straw it was 0.306 kg m^{-2}, and with clover and straw the value was 0.410 kg m^{-2}. Therefore, it is deduced that, with decomposition processes, part of the OC incorporated with plant mass is leached by precipitation from the plough-layer in the subsoil horizons and transferred to surface soil water. It is known that SOM decomposition rates depend on moisture and temperature regimes, which affect the abundance and activity of mineralizing micro-organisms (Johnson et al., 2005; Тулина и др., 2009; Singh et al., 2011).

Total organic carbon (TOC) leaching. Catch crops are ploughed-in as green manure during late autumn (mid-October), when the air temperature approaches ~0°C and, therefore, slows the decomposition of green matter and straw. However, in recent years, Lithuania's climate has been characterized by frequent winter thaws, which means virtually perennial mineralization of OM. A similar study found that in a sandy loam *Haplic Luvisol*, organic fertilizer nitrification occurred quite intensively in winter when the soil temperature was 2–5°C (Tripol'skaya et al., 2004)

Investigations on OC concentration in lysimeter water showed that during the experimental period incorporation of catch crops' (fodder radish, red clover) biomass and straw did not increase TOC leaching (Fig. 3). Significant ($p < 0.05$) decreases in TOC concentration after green manure incorporation were only observed in 2003. In other years, treatment differences were not significant ($p > 0.05$). Analysis of TOC seasonal data shows no consistent changes in the concentration after green manure and straw incorporation, since many factors affect OM destruction and leaching of mobile organic compounds. However, experimental data averaged over the period (2002–2008) suggest that incorporation of green manure in late autumn decreased annual TOC concentration in lysimeter water by 0.56–0.57 mg L^{-1} (17.6–17.9%). These results were determined by the 2003 data, but in the other experimental years there was no change ($p < 0.05$) in TOC concentration.

TOC leaching losses varied considerably, with minimum in 2004 and 2005 (6.49–8.31 and 5.48–6.83 kg ha^{-1}, respectively), whereas in the other years they were almost double (10–15 kg ha^{-1}) (Table 4). In treatments grown with undersown red clover, infiltration during summer declined by 38.7%, and by 16.5% in autumn, whereas fodder radish (sown in late August) reduced infiltration by 25.3% and 16.9%, respectively. Due to the decreased infiltration, TOC leaching losses after green manure incorporation were lower than those in the soil with only straw or barley stubble incorporated. Significant ($p < 0.05$) reductions in TOC leaching due to green manure growth were identified in lysimeters with undersown red clover in 2002 (autumn) and 2004 (summer and autumn), which grew profusely (0.41–0.64 kg m^{-2}) during these times. In 2006, TOC leaching from the treatments with green manure crops was also lower, yet differences between treatments were not significant ($p > 0.05$). In the years following the green manure incorporation (2003, 2005, 2007) TOC leaching losses, due to the decomposition of green manure, did not change significantly ($p > 0.05$) but, compared with the control treatment, it did reduce TOC leaching.

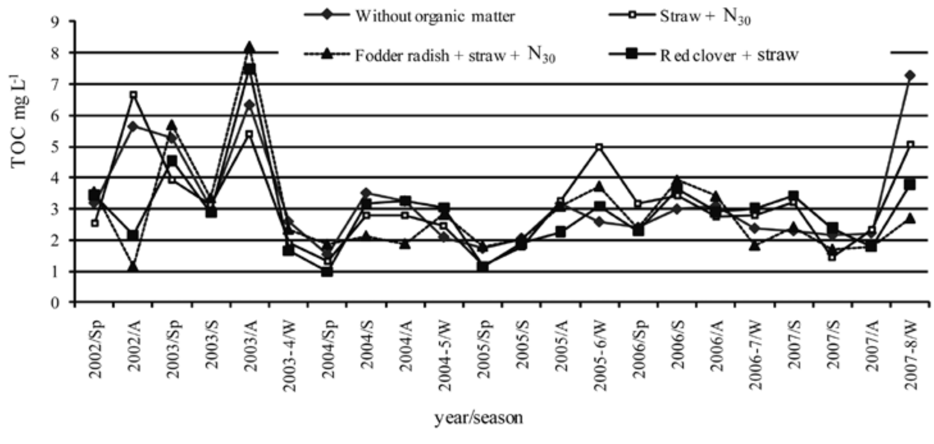

Figure 3. Total organic carbon (TOC) average concentration in lysimeter water

Table 4. The effect of straw and green manure on organic carbon leaching in a sandy loam *Haplic Luvisol*

Treatment	March 2002–Feb 2003	March 2003–Feb 2004	March 2004–Feb 2005	March 2005–Feb 2006	March 2006–Feb 2007	March 2007–Feb 2008	Mean 2002–2008	
	kg ha^{-1}						kg ha^{-1}	%
Without added organic matter	9.5	10.7	8.3	6.8	12.0	16.0	10.6	100.0
Straw + N_{30}	10.3	8.2	7.8	6.0	12.4	14.8	9.9	93.4
Fodder radish + straw + N_{30}	3.6*	11.9	7.9	6.8	10.8	8.7	8.3*	78.3
Red clover + straw	5.0*	10.5	6.5	5.5	11.1	12.2	8.5*	80.2
LSD_{05}	5.00	3.30	4.56	2.59	5.62	6.78	1.98	

* − indicates significant differences between treatments at p < 00.5

Results of the lysimeter experiment demonstrate that green manure and straw incorporation does not activate leaching of OC in sandy loam *Haplic Luvisol*. Field experiments performed at Vokė Branch of the Lithuanian institute of Agriculture on the impact of biomass of clover and fodder radish on soil humus content show that their incorporation did not increase soil humus content in sandy loam *Haplic Luvisol* (Romanovskaja, Tripolskaja, 2003). It reveals that mineralization processes dominate in the course of green manure decomposition resulting in low contents of humic substances. This statement is indirectly confirmed by changes in N concentrations in lysimeter water after the green manure incorporation. Lysimeter experiment showed that after green manure incorporation, N leaching significantly increased. Compared with the control treatment, after straw and N_{30} incorporation N leaching losses increased by 7.4% after fodder radish by 24.0% and after clover by 87.9%.

Conclusions

Experimental evidence suggests that the application of straw and green manure on a sandy loam *Haplic Luvisol*, with the aim of improving its properties, does not increase OC leaching. Specific findings include:

1. Total organic carbon (TOC) leaching losses from a sandy loam *Haplic Luvisol (LVh)* were low and depending on annual meteorological conditions and experimental treatments varied from 1.97 to 14.92 kg ha^{-1} organic carbon (OC) per year.

2. Incorporation of barley straw (0.585 kg m^{-2} DM) and catch crops for green manure (fodder radish 0.333 kg m^{-2} DM, red clover 0.407 kg m^{-2} DM) in late autumn did not have any significant (p > 0.05) effect on TOC concentrations in lysimeter water. Mean OC concentration in lysimeter water was 2.61–3.18 mg L^{-1} OC.

3. Cultivation of catch crops (fodder radish and red clover) reduced infiltration during autumn, which in turn resulted in decreased TOC leaching by 2.1–2.3 kg ha^{-1} (19.8–21.7%).

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Žaliosios trąšos ir šiaudų įtakos organinės anglies išplovimui lizimetriniai tyrimai priesmėlio išplautžemyje (*Haplic Luvisol*)

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Santrauka

Lizimetrinių tyrimų, 2002–2008 m. atliktų Lietuvos žemdirbystės instituto (dabar – Lietuvos agrarinių ir miškų mokslų centras) Vokės filiale, tikslas – nustatyti žaliosios trąšos ir šiaudų įtaką suminės organinės anglies (SOA) išplovimui Rytų Lietuvos priesmėlio išplautžemyje (IDp). Tyrimų schema: 1) be organinių trąšų, 2) šiaudai + N_{30}, 3) posėlinis augalas aliejinis ridikas (*Raphanus sativus* L.) + N_{30}, 4) raudonojo dobilo (*Trifolium pratense* L.) įsėlis. Visuose variantuose, išskyrus kontrolinį, šiaudai po derliaus nuėmimo buvo smulkinti ir palikti dirvos paviršiuje lizimetruose. Organinių junginių išplovimas tirtas žaliosios trąšos bei šiaudų įterpimo (2002, 2004, 2006) ir jų įtakos (2003, 2005, 2007) metais. Lizimetrinių vandenų tyrimų rezultatai parodė, kad priesmėlio dirvožemyje SOA išplovimo nuostoliai buvo nedideli ir, priklausomai nuo metų hidroterinių sąlygų bei naudotų organinių trąšų, varijavo nuo 1,97 iki 14,92 kg ha^{-1} SOA. Tarpinių pasėlių (aliejinių ridikų ir raudonųjų dobilų) biomasės ir šiaudų įterpimas SOA išplovimo nedidino. Variante su dobilų įsėliu kritulių filtracija vasaros laikotarpiu sumažėjo 38,7 %, rudens – 16,5 %, o rugpjūčio antroje pusėje pasėtų aliejinių ridikų pasėlis filtraciją sumažino 25,3 %. Dėl mažesnės filtracijos SOA išplovimo nuostoliai po žaliosios trąšos įterpimo buvo mažesni, palyginti su variantu, kai buvo įterpti tik šiaudai arba miežių ražienos. Tarpinių pasėlių (aliejinių ridikų ir raudonųjų dobilų) auginimas rudens laikotarpiu SOA išplovimą per metus sumažino vidutiniškai 19,8–21,7 %. Tyrimų rezultatai leidžia teigti, kad žaliosios trąšos ir šiaudų naudojimas tręšimui priesmėlio išplautžemyje nedidina SOA išplovimo iš ariamojo sluoksnio.

Reikšminiai žodžiai: išplovimas, lizimetrai, organinė anglis, šiaudai, žalioji trąša.