



GLOBAL JOURNAL OF SCIENCE FRONTIER RESEARCH
AGRICULTURE AND VETERINARY

Volume 13 Issue 12 Version 1.0 Year 2013

Type : Double Blind Peer Reviewed International Research Journal

Publisher: Global Journals Inc. (USA)

Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Leaching of Nutrients in *Luvisol* as Affected by Catch Crops and Straw

By Liudmila Tripolskaja, Colin A. Booth & Michael A. Fullen

University of the West of England Frenchay Campus, Lithuania

Abstract - The aim of this work was to determine the impact of green manure (*Trifolium pratense* L., *Raphanus sativus* var. *oleiformis* L.) and barley (*Hordeum vulgare* L.) straw on filtration of precipitation and leaching of chemical elements (N, K, Ca, C_{org}) in Haplic Luvisol. The lysimetric data during 1987– 2008 was used in the study. Lysimetric equipment surface area was 1.75 m²; the test soil layer is 0.60 m. Catch crops reduce precipitation filtration by 7.0-8.3 % on average. Insertion in autumn of straw and catch crops increases the concentration of N, Ca and K and C_{org} in lysimeter waters. Substantial increase in concentration takes place mostly during the first months after insertion and in warm and rainy autumn period. Due to lower precipitation of catch crops the loss of Ca and K, as compared with unfertilized soil, did not substantially increase, and the C_{org} decreased from 10.6 to 8.3-8.5 kg ha⁻¹ TOC.

Keywords : lysimeter; leaching; catch crops; straw; leaching; nitrogen; potassium; calcium, C_{org}.

GJSFR-D Classification : FOR Code: 070306



Strictly as per the compliance and regulations of :



Leaching of Nutrients in *Luvisol* as Affected by Catch Crops and Straw

Liudmila Tripolskaja^α, Colin A. Booth^σ & Michael A. Fullen^ρ

Abstract - The aim of this work was to determine the impact of green manure (*Trifolium pratense* L, *Raphanus sativus* var. *oleiformis* L.) and barley (*Hordeum vulgare* L.) straw on filtration of precipitation and leaching of chemical elements (N, K, Ca, C_{org}) in Haplic Luvisol. The lysimetric data during 1987–2008 was used in the study. Lysimetric equipment surface area was 1.75 m²; the test soil layer is 0.60 m. Catch crops reduce precipitation filtration by 7.0–8.3 % on average. Insertion in autumn of straw and catch crops increases the concentration of N, Ca and K and C_{org} in lysimeter waters. Substantial increase in concentration takes place mostly during the first months after insertion and in warm and rainy autumn period. Due to lower precipitation of catch crops the loss of Ca and K, as compared with unfertilized soil, did not substantially increase, and the C_{org} decreased from 10.6 to 8.3–8.5 kg ha⁻¹ TOC.

Keywords : lysimeter; leaching; catch crops; straw; leaching; nitrogen; potassium; calcium, C_{org}.

I. INTRODUCTION

About 40 % of the farmland in Lithuania are light textured soils, and fertilization with a variety of organic fertilizers is necessary to maintain their productivity. Currently green manure crops are being extensively used as the source of organic matter. However, due to favourable conditions for decomposition of organic matter and surplus moisture content, resulting in the percolative soil moisture regime, part of the mineral elements released from the green manure may be leached into groundwater and adversely affect its chemical composition (Kutra et. al., 2006; Strusevičius et. al., 2009; Adomaitis et. al., 2010; Baigys, 2010). In order to reduce the nutrient leaching after autumn crop harvest, in Lithuania various catch crops are cultivated for green manure. According to the soil characteristics and hydrothermal conditions of autumn, the following plants are considered most suitable for cultivation: fodder radish, spring rape, red clover, orchard grass (Nedzinskas, Nedzinskienė, 1999; Arlauskienė, Maikštienienė, 2008).

Nutrient leaching losses are associated not only with the agrarian use of soils, but also with climatic

factors – amount of precipitation and air temperature. The mean annual amount of precipitation on the territory of Lithuania is 681 mm, the mean annual air temperature is 6.2 °C; that creates the conditions for filtration of atmospheric precipitation and consequent leaching of chemical components from the arable soil layer (Galvonaitė et. al., 2007). Meteorological data of the past decades (1993–2003) indicate the tendencies of climate warming: average annual air temperature increased by 0.1–0.9 °C. The most evident increase is observed in late autumn and spring temperatures; the number of days with below zero temperatures decreased (Galvonaitė, Valiukas, 2005). Longer autumn and spring periods have a positive impact as well because it allows growing more catch crops for green manure and using them to improve soil fertility. However, plant selection and cultivation technologies must be based not only on their impact on soil in supplementing it with organic matter and nutrients but also on the impact produced on the leaching of chemical elements.

The aim of this work was to determine the impact of green manure (clover, fodder radish) and barley straw on filtration of precipitation, plant nutrition and leaching of chemical elements (N, K, Ca, C_{org}), which influence the soil agrochemical properties.

II. MATERIALS AND METHODS

Experiments were performed at the Vokė Branch of the Lithuanian Research Centre for Agriculture and Forestry (54°37' N, 25°08' E) in 2002–2008. Lysimetric equipment consists of a cylindrical concrete structure with a surface area of 1.75 m², the test soil layer is 0.60 m (corresponding to the drainage depth). Lysimeters are filled with typical soil of Southeastern Lithuania – sandy loam *Haplic Luvisol* (LVh). Agrochemical characteristics of the arable layer (0–20 cm) were the following: pH_{KCl} 5.4–5.6, available phosphorus (A-L) – 208–225 mg kg⁻¹, potassium (A-L) – 101–112 mg kg⁻¹, organic carbon (C_{org}) – 0.77–0.80 %. Changes in the leaching of nutrients due to application of green manure and straw 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). Testing scheme (variants of organic matter): 1) control variant (without organic matter), 2) barley straw + N₃₀, 3) aftercrop fodder radish for green manure + N₃₀ + barley straw, 4) red clover catch crop for green manure + barley straw.

Author α : Vokė Branch, Lithuanian Research Centre for Agriculture and Forestry Žalioji 2, Vilnius, Lithuania.

E-mail : liudmila.tripolskaja@voke.lzi.lt

Author σ : University of the West of England Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, UK.

E-mail : colin.booth@uwe.ac.uk

Author ρ : University of Wolverhampton Wulfruna Street, Wolverhampton, West Midlands, WV1 1LY, UK. E-mail : m.fullen@wlv.ac.uk

Barley of the cultivar 'Aura' were sown during the third decade of April, seed rate – 180 kg ha⁻¹. Before sowing the barley, N₆₀P₆₀K₆₀ fertilizers were used. Catch crop clover (*Trifolium pratense* L.) sown in spring into the barley crop (variant 4) and aftercrop fodder radish (*Raphanus sativus* var. *oleiformis* L.) sown after barley harvest (variant 3) were used for green manure. Barley straw was chipped to 4–6 cm in length and left on the soil surface, while in lysimeters of the control variant (variant 1) it was removed. In order to obtain larger amount of fodder radish biomass (variant 3), they had been fertilized with N₃₀ before sowing. The same nitrogen amount (N₃₀) was used to optimize the processes of straw mineralization in variant 2. In the years following the addition of green manure potato cultivar 'Goda' was cultivated. The potatoes were fertilized with N₉₀P₆₀K₉₀.

a) *Estimation of the filtration of precipitation and calculation of chemical elements leaching losses*

The amounts of filtrate were calculated for separate months, periods of a year (seasons) and years. Season length of spring (March–May), summer (June–August) and autumn (September–November) matched the calendar periods of a year. Estimation of atmospheric precipitation in winter corresponded with the accounts of filtration during this period, i.e. the precipitation amount in December of the current year (n) was summed up with precipitation amount of January and February of the following year (n + 1). Such calculation is based on the temperature regime of winter period, because at temperatures below 0 °C solid precipitation occurs, which takes a liquid form only at positive air temperatures, and the infiltration can start much later than the precipitation occurrence. Thus, the amount of atmospheric precipitation filtrate per year was calculated from 1 March of the current year till 28 February of the following year (12 months); the studies lasted from 1 March, 2002 to 28 February, 2008. Nitrate concentration (NO₃⁻ mg L⁻¹) in lysimetric water was determined monthly, concentrations of potassium, calcium and organic carbon – once per season. The weighted concentrations of the elements were calculated for separate months, seasons and years. The average concentration was calculated by the formula:

$$K_{\text{average}} = (K_1 \cdot V_1 + K_2 \cdot V_2 + K_3 \cdot V_3) / (V_1 + V_2 + V_3),$$

where K_{1,2,3} – concentration of a chemical element in mg L⁻¹ in lysimetric water of one lysimeter of a particular variant (1, 2, 3 – replications) over a given period (month, season),

V_{1,2,3} – amount of atmospheric precipitation filtrate in L m⁻² from one lysimeter of a particular variant over a given period (month, season, year).

The standard deviation (S) of the concentration and coefficient of variation (V %) were calculated.

Elements leaching losses (kg ha⁻¹) were calculated by multiplying the average concentration and the amount of filtrate of a particular period:

$$FN = K_{\text{average}} \times F \times 1000000/10000$$

when K_{average} – the average element concentration over a season (year) mg L⁻¹, F – amount of the filtrate L m⁻², 1000000 – transfer coefficient from mg to kg; 10000 – transfer coefficient from m⁻² to ha.

b) *Methods of chemical analyses*

The amount of total nitrogen was determined employing the Kjeldahl (ISO 11261) method, of nitrates – by colorimetry, of Ca – ISO 7890-86 (atomic absorption), K – LST ISO 9964-3; 1998 (flame emission), C organic – ISO-8245:1999 method.

All experimental data were analysed using Analysis of Variance (ANOVA).

III. RESULTS

a) *Biomass yield of catch crop plants and straw*

Meteorological conditions during the vegetation season had a significant impact on the yield of barley and other plants grown for green manure. Depending on the applied agro-technical measures and the hydrothermal conditions of a year, the dry matter (DM) yield of barley straw ranged from 0.358 to 0.992 kg m⁻², and during the study period (2002–2008) approximately 585 g m⁻² of DM were added into the soil with the straw (Table 1). Green mass yield of fodder radish very much depended on soil moisture conditions at sowing time and ranged from 102 to 337 kg m⁻² of DM. Together with barley straw and green mass of fodder radish the soil was supplemented with 766 g m⁻² of DM. The biomass yield of red clover catch crop was by 22 % on average higher than of fodder radish, but the yield variation was larger – from 0.169 to 0.640 kg m⁻² of DM. Throughout the study period, higher amount of organic matter (1024 kg m⁻² DM) was added with green mass of clover catch crop, while the amount added with fodder radish was by 34 % lower (766 kg m⁻²).

Table 1 : The total amount of green manure and straw biomass as well as biogenic elements added into soil during the study period

Organic matter	Dry matter yield g m ⁻²	S.D.	Added with straw and green manure biomass g m ⁻²		
			N	K	C _{org}
Barley straw	585	327	6,2	19,4	234
Fodder radish and straw	766	156	17,4	37,2	306
Undersown red clover and straw	1024	393	26,0	39,0	410

Considerably higher (26.0 g m⁻²) nitrogen content was added into soil with clover and straw than in case of other fertilization variants. Depending on the hydrothermal conditions during plant vegetation, variation in the content of nitrogen added with green manure was quite high – 52.4 and 85.1 %. Less nitrogen were added into soil with straw than with the green manure crops – an average of 6.2 g m⁻² over the study period. Potassium accumulation in the biomass of fodder radish and red clover did not differ significantly and was 37.2 and 39.0 g m⁻² respectively, while in barley straw it was almost twice lower.

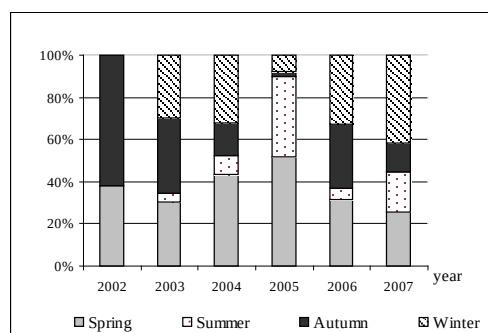
Filtration of atmospheric precipitation

During the study period, annual precipitation amount ranged from 607 mm (in 2006) to 785 mm (in 2005). Deviation from the climate normal (681 mm) made 11–15 % respectively (Table 2). Filtration of precipitation depended not only on the precipitation amount, but also on the intensity and plant cover. According to the average survey data, in sandy loam *Luvisol* 46.4 % of the annual precipitation infiltrated to a depth of 0.60.

Table 2 : The amount of atmospheric precipitation and its infiltration into sandy loam *Luvisol*

Indicator	Year						Mean
	2002	2003	2004	2005	2006	2007	
Annual amount of precipitation mm	615	647	724	785	607	722	683
Treatments	Infiltration of atmospheric precipitation L m ⁻²						
Without organic fertilisers	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 + N ₃₀ + straw	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

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 (Fig. 1). 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. Sometimes the filtration ceases for the summer. Only abundant atmospheric precipitation over a short period of time, as happened in 2005 and 2007, may significantly increase the filtration in summer. 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.

**Figure 1 :** The distribution of the amount of atmospheric precipitation according to the seasons of the year

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 %. Such a phenomenon is very important in order to reduce nutrient leaching from agricultural land,

especially lately as the duration of autumn period increases.

b) Leaching of Nutrients

Nitrogen (N). Decomposition rate of organic fertilizers and migration of mineralized chemical elements in the soil depend on various factors, but especially on the hydrothermal regime. In leachate of the non-fertilized soil lower concentration of NO_3^- was observed in spring (37.8 mg L^{-1}), while during other seasons it was quite similar ($57.2\text{--}67.2 \text{ mg L}^{-1}$). The coefficient of variation was quite high – $35.4\text{--}95.6 \%$.

Compared with the control variant, the addition of straw supplemented with mineral nitrogen fertilizers (N_{30}) increased the nitrate concentration in lysimetric water in autumn – by 25.9 mg L^{-1} on average (Fig. 2). Probably, mineral nitrogen (N_{30}), added in order to activate the decomposition of straw, is not immediately incorporated into the biological cycle and, in case of heavy rainfall, part of it migrate into the deeper soil layers. No significant differences ($p > 0.05$) in nitrate concentrations compared with the control variants were recorded during other seasons because only small amount of nitrogen got into the soil with straw.

The applied agro-technical measures produced varying effects on nitrogen migration. Compared with the control, the addition of cereal straw supplemented with mineral nitrogen fertilizers (N_{30}) increased the annual nitrogen leaching by 9.0 kg ha^{-1} or 12.9% , and the addition of clover green mass and straw – by 8.0 kg ha^{-1} or 11.5% . Cultivation of aftercrop fodder radish following the addition of cereal straw was very efficient for the reduction of nitrogen and precipitation filtration. Such agro-technical measure reduced the nitrogen leaching by 16.9 kg ha^{-1} or 24.2% on average, compared with the control variant and by 25.9 and 24.9 kg ha^{-1} compared with the addition of straw supplemented with N_{30} or of red clover and straw.

Cultivation of aftercrop fodder radish for green manure produced a different effect on the concentration

of nitrates, although fodder radish, likewise the straw, were fertilized with mineral nitrogen fertilizers (N_{30}) before sowing (August). However, the used fertilizers were rapidly consumed by intensively growing plants, and nitrogen concentration in lysimetric water in autumn was significantly lower ($24.0\text{--}64.6 \text{ mg L}^{-1}$) than in case of other agro-technical measures. In winter, spring and summer periods, as fodder radish biomass mineralization proceeded, no significant increase in nitrate concentration was established, but the tendency towards the increase was observed.

During autumn, clover accumulated more biomass and higher amount of nitrogen was added into soil with clover than with fodder radish. Although clover is a highly nitrogenous plant, hosting nitrogen accumulating bacteria on their roots, but their use for green manure, as compared with the control variant, did not increase the nitrate concentration during the autumn. This may be related to a slower decomposition of clover biomass, because at positive winter temperatures in 2006–2007, the nitrate concentration in lysimetric water slightly increased, and it is an evidence of the ongoing process of biomass mineralization. The analysis of the research data of the whole study period suggests that the effect of clover green mass on nitrate concentration depended on the amount of the added biomass. In case of rich harvest, as it was in 2004, in the course of decomposition of clover biomass the nitrogen effect on nitrate concentration was clearly evident for longer than a year. Regression and correlation analyses of the research data showed that in the year following the addition of green manure a strong relation of the nitrate concentration in lysimetric water (y) in spring and summer periods with the content of nitrogen added with clover and straw biomass (x) could be observed; it is described by regression equations:

$$y_{\text{spring}} = 0,358x + 15,65, R^2 - 0,747;$$

$$y_{\text{summer}} = 0,665x - 3,1815,65, R^2 - 0,688.$$

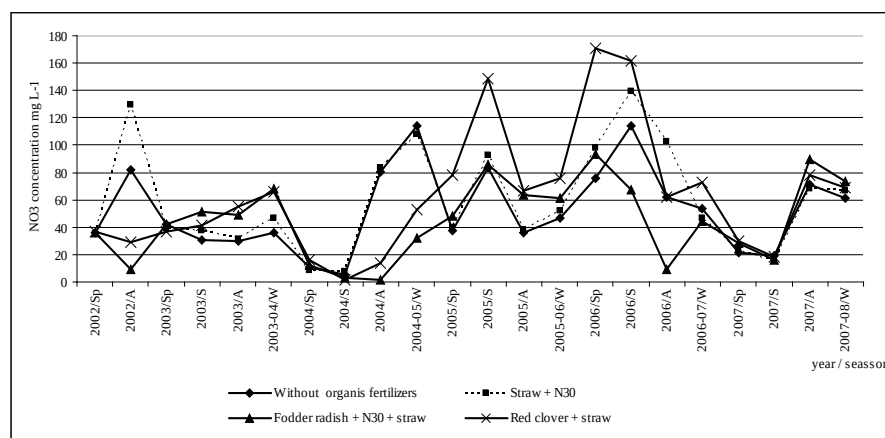


Figure 2: The impact of green manure and straw on nitrate concentration in leachate (NO_3^- mg L^{-1}) according to the seasons of the year

In the autumn of the year following the addition of clover (10–12 months after addition) its effect on nitrate concentration decreased ($R^2 = 0,117$) and was insignificant.

The studies show that the least nitrogen leaching ($4.3\text{--}7.6 \text{ kg ha}^{-1} \text{ N}$) is recorded in summer because filtration of precipitation during this period is negligible, and in some years it may cease for the summer (Fig. 3). Regarding the nitrogen leaching losses, other seasons were quite similar – an average of $10.5\text{--}16.0$ in spring, $3.9\text{--}15.9$ in autumn, $11.3\text{--}14.1 \text{ kg ha}^{-1}$ in winter. Effect of the applied agro-technical measures on nitrogen leaching was particularly evident

during autumn – at the period of catch plants growth. They significantly reduced the filtration of precipitation; nitrate concentrations in lysimetric water were also lower, and therefore the nitrogen leaching decreased significantly ($p < 0.05$) compared with the control: by 65.5% in case of fodder radish cultivation and by 31.9% while growing clover. Plough in of straw supplemented with mineral nitrogen fertilizers (N_{30}) had no significant effect on filtration of precipitation but increased the concentration of nitrates in water, leading to 40.7% ($p > 0.05$) average of nitrogen leaching losses in autumn.

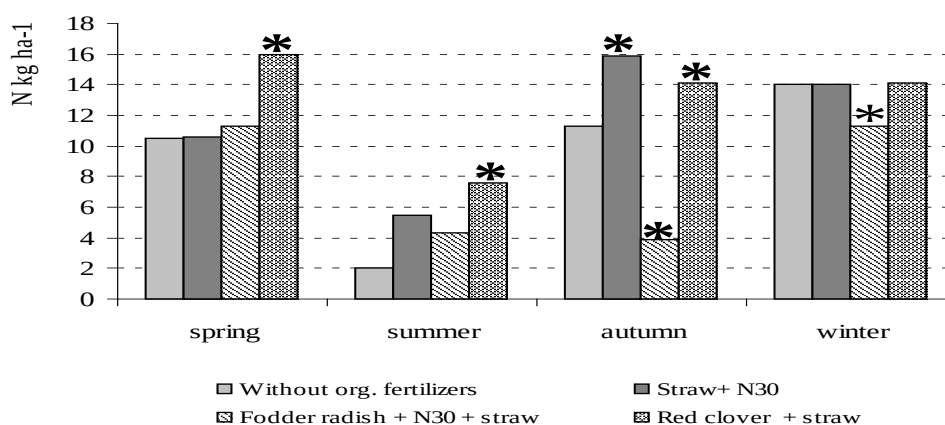


Figure 3: The impact of green manure and straw on nitrogen leaching (N kg ha^{-1}) according to the seasons of the year

Note. * – significant differences from the control variant (without organic fertiliser) at 95 % significance level.

The effect of the addition of plant biomass in autumn on nitrogen leaching remained evident during other seasons as well. In winter significantly lower (19.3%) nitrogen leaching was determined in the soil where biomass of fodder radish and straw had been added. Compared with control, the effect of clover biomass on nitrogen leaching in winter was significant during the year of its addition into the soil. During other years no significant increase was observed.

According to the data of 2002–2008, the average annual nitrogen leaching losses were $52.9\text{--}77.8 \text{ kg N ha}^{-1}$, depending on the applied agro-technical measures. Hydrothermal conditions played the key role in filtration of atmospheric precipitation, so nitrogen leaching losses in different years ranged from $7.7\text{--}43.1 \text{ kg N ha}^{-1}$ in 2002 to $45.3\text{--}90.5 \text{ kg ha}^{-1}$ in 2006.

The applied agro-technical measures produced varying effects on nitrogen migration. Compared with the control, the addition of cereal straw supplemented with mineral nitrogen fertilizers (N_{30}) increased the annual nitrogen leaching by 9.0 kg ha^{-1} or 12.9% , and the addition of clover green mass and straw – by 8.0 kg ha^{-1} or 11.5% (Table 3). Cultivation of aftercrop fodder radish following the addition of cereal straw was very efficient for the reduction of nitrogen and precipitation filtration. Such agro-technical measure reduced the nitrogen leaching by 16.9 kg ha^{-1} or 24.2% on average, compared with the control variant and by 25.9 and 24.9 kg ha^{-1} compared with the addition of straw supplemented with N_{30} or of red clover and straw.

Table 3: The effect of straw and green manure on chemical elements leaching of a sandy loam *Luvisol*

Treatment	Leaching kg ha^{-1}			
	N	K ⁺	Ca ²⁺	C _{org}
Without organic fertiliser	69,8	19,7	135,5	10.6
Straw + N ₃₀	78,8*	20,7	136,4	9.9
Fodder radish + N ₃₀ + straw	52,9*	20,6	119,7*	8.3*

Red clover + straw	77,8*	24,2*	137,1	8.5*
LSD ₀₅	3,56	2,78	8,28	1.98

Note. * – significant differences from the control variant (without organic fertiliser) at 95 % significance level.

Potassium (K^+). Rather high amount of potassium 37.2–39.0 g m⁻² was added into the soil with the green manure biomass; in the course of the biomass decomposition the soil is enriched with mobile potassium compounds and the plant requirements for potassium are optimized. Changes of potassium concentration in the leachate during the period of investigation show that straw and green manure increased its leaching, and their effect had a tendency to increase after each addition of the biomass (Fig. 4). Increased potassium concentration in lysimetric water was recorded not only in autumn, when mineralization of freshly added organic matter begins, but also the next year, i.e. 10–12 months after its addition. However, it should be noted that the increase in concentration was not always significant; only the tendency towards the

increase could be mentioned. The average concentration of potassium in the leachate of non-fertilized soil was 6.0 ± 2.67 mg L⁻¹ K^+ , and, depending on the hydrothermal conditions of a year, ranged from 2 to 14 mg L⁻¹. After the addition of green manure and straw its concentration increased by 1–5 mg L⁻¹ K^+ and was from 6.7 ± 3.11 up to 8.60 ± 4.13 mg K^+ L⁻¹. Compared with the control variant, potassium concentration statistically significantly increased ($+2.60$ mg L⁻¹) only in leachate of the soil fertilized with red clover biomass.

During the study period, coefficient of variation in potassium concentration was high (44.4–49.9 %), because its leaching was influenced not only by the amount and intensity of atmospheric precipitation but also by the amount of the added organic matter.

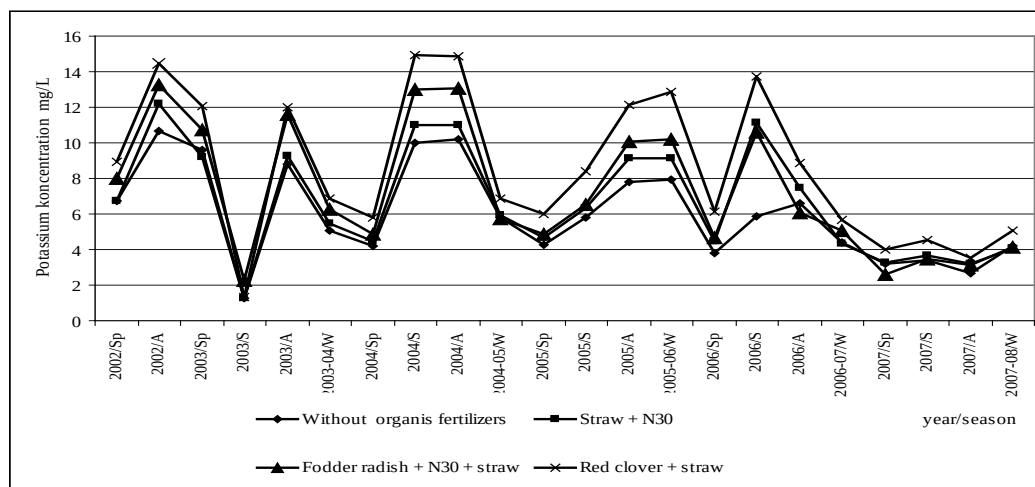


Figure 4: The impact of green manure and straw on potassium concentration in leachate (K^+ mg L⁻¹) according to the seasons of the year

In sandy loam soil, with no catch crop cultivated for green manure, the average amount of leached potassium was 19.7 kg K^+ ha⁻¹ per year (Table 4). The smallest losses (3.11–3.73 kg K^+ ha⁻¹) were determined in summer; it is related with lower filtration of precipitation and smaller potassium concentration in the leachate. Almost twice higher losses were determined in spring and autumn (5.82–97.39 and 6.52–7.69 kg K^+ ha⁻¹ respectively) when filtration of precipitation was significantly higher. Although not very strong, but frequent increase of potassium concentration in leachate after the addition of green manure preconditioned the fact that its leaching losses, despite infiltration reduction while growing catch crops, were almost identical as in the control variant or even higher. Compared with the control variant or the variant of fertilization with straw and fodder radish, the leaching of potassium statistically significantly increased (3.6–4.5 kg

K^+ ha⁻¹ or 11.7–22.8 %) only after the addition of red clover. It should be mentioned that significant increase in potassium leaching was recorded not immediately after the red clover addition but in the period of spring – autumn of the next year. This evidently suggests the prolonged period of potassium release from organic compounds and its slower migration in the soil profile, compared with nitrogen compounds.

Calcium (Ca^{2+}). In this experiment, the leaching of calcium was also studied because it is an important element not just for plant nutrition it also stabilizes the soil acidification processes. In acidic soils, that are characteristic of the Eastern Lithuania, the exchange calcium is not abundant (700–900 mg kg⁻¹ Ca), therefore it is important that the applied agro-technical measures would not induce the migration of calcium from the arable layer.

The research showed that the average annual concentration of calcium in the control variant was

$41.1 \pm 0.21 \text{ mg Ca L}^{-1}$, in the variant fertilized only with straw or together with green manure it changed insignificantly – from 38.2 ± 3.46 to $44.63 \pm 3.99 \text{ mg Ca L}^{-1}$ (Fig. 5). Statistical processing of the test data showed only a slight upward tendency in the concentration of calcium during the whole study period.

The concentration somewhat increased in the leachate of soil fertilized with clover biomass, but the changes were statistically insignificant ($p > 0.05$). During the study period the variation in calcium concentration was 0.51–9.05 %.

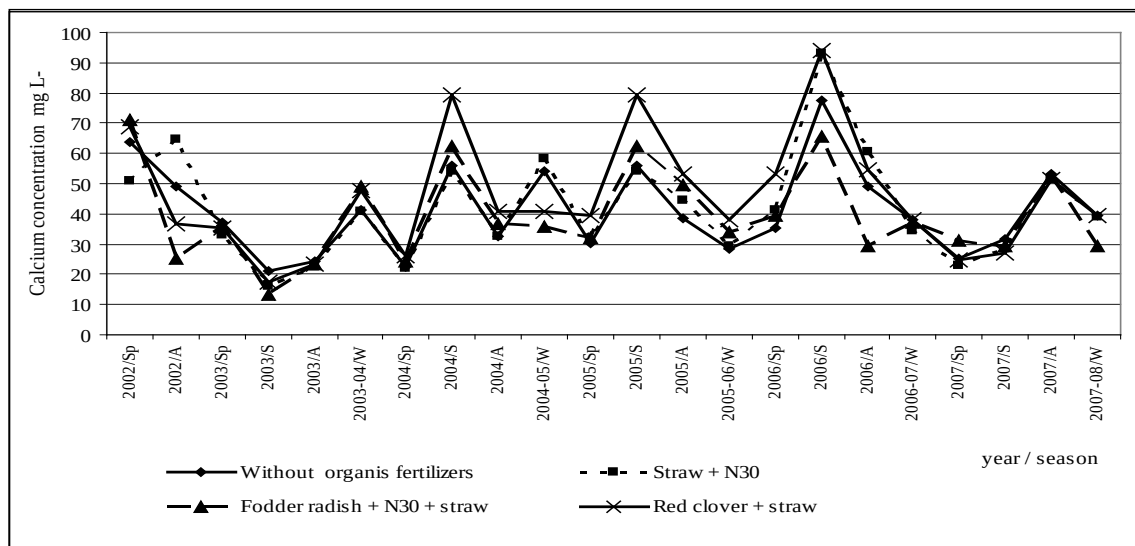


Figure 5 : The impact of green manure and straw on calcium concentration in leachate ($\text{Ca}^{++} \text{ mg L}^{-1}$) according to the seasons of the year

As the green manure and straw had no significant effect on calcium concentration, so its leaching losses in the soil of all variants were similar, except for the variant with fodder radish (Table 5). From sandy loam soil an average of $119.7\text{--}135.5 \text{ kg Ca}^{2+} \text{ ha}^{-1}$ leached per year. Less calcium leaches in summer ($21.1\text{--}25.7 \text{ kg Ca}^{2+} \text{ ha}^{-1}$), higher amounts – in spring and autumn ($37.1\text{--}43.9$ and $25.2\text{--}42.6 \text{ kg Ca}^{2+} \text{ ha}^{-1}$ respectively).

Cultivation of fodder radish for green manure reduced the calcium leaching by 16.3 kg ha^{-1} or 10.9 % on average. This is due to two factors: lower filtration of precipitation in autumn in fodder radish crop and lower amount of calcium released from radish green biomass. The clover green mass accumulates more calcium than fodder radish biomass, and its decomposition results in larger amount of mobile calcium compounds. Therefore during the year following the addition of clover, the calcium leaching increased significantly ($15.7 \text{ kg of Ca}^{2+} \text{ ha}^{-1}$ or 12.5 %) compared with the control variant. But during the year of clover cultivation, due to lower filtration of precipitation, the calcium losses were lower than in the leachate of the control variant.

Total organic carbon (TOC). Investigations on OC concentration in lysimetric water showed that during the experimental period incorporation of catch crops (fodder radish, red clover) biomass and straw did not increase TOC leaching (Figure 6). Significant ($p < 0.05$)

decreases in TOC concentration after green manure incorporation was only observed in 2002. 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 (2002–08) suggest that incorporation of green manure in late autumn decreased annual TOC concentration in lysimetric water by $0.56\text{--}0.57 \text{ mg l}^{-1}$ (17.6–17.9%). These results were determined by the 2002 data, but in the other experimental years there was no observed change ($p > 0.05$) in TOC concentration.

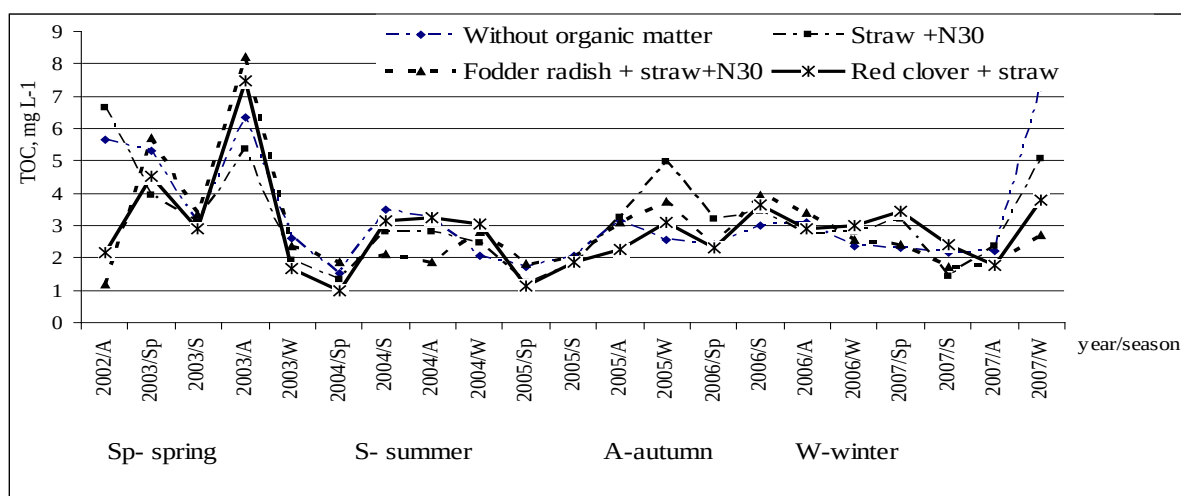


Figure 6 : Organic carbon (TOC) weighted concentration (Corg mg L⁻¹) in lysimetric water

TOC leaching losses varied considerably, with the least 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 6). 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 was identified in lysimeters with undersown red clover in 2002 (autumn) and in 2004 (summer and autumn), which grew plentiful (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 of green manure effect (2003, 2005) TOC leaching losses, due to the decomposition of green manure, did not change significantly ($p > 0.05$) but, in comparison with the control treatment, it did reduce TOC leaching.

IV. DISCUSSION

Due to warming climate in Europe (Krauciunene et al., 2010), the plant growth season becomes longer and it facilitates the cultivation of cover crops. In the course of the last 100 years, in Lithuania the temperature increased by 0.1-0.9 °C (Galvonaitė et al. 2007), and plant growth season elongated by 7 days (Kalvane et al., 2009). Changing climatic conditions cause the need for a new assessment of the impact of green manure on soil properties and nutrient leaching.

Studies have shown that in case of prolonged warm period of the year, cover crops for green manure effectively reduce rainfall leaching in sandy loam soil. It was determined that catch crops (red clover, fodder

radish), on average, reduce the leaching by 19.4-21.7 % in autumn and by 7.0-8.3 % during the year. Stauffer (2000) determined that under rotations with cover crops, percolate formation was reduced by 10-15%, compared to rotations without or with a reduced presence of cover crops. Dry matter yield had no direct effect on the formation of percolate.

During the decomposition of green manure and straw various chemical elements present in them turn into mobile mineral compounds and can be re-used by plants or increase the nutrient leaching losses (Goulding, 2000 ; Adomaitis et. Al., 2010 ; Erickson et. Al., 2005). Studies showed that the influence of cover crops on nitrogen leaching depended on its chemical composition and biomass decay time (Hansen, Djurhuus, 1997; Jonson et. al., 2005 ; Shi, 2013). In autumn fodder radish consume a lot of mineral nitrogen for their biomass formation, which significantly reduces rainfall filtration. This consequently reduces the concentration of nitrates in filtering water and their leaching by an average of 24.2 % during the year. Capacity of non-leguminous plants for rapid absorption of soil mineral nitrogen in autumn is comprehensively described by various authors (Farthofer et. al, 2004 ; Askegaard et. al., 2006). The content of nitrogen accumulated in red clover biomass was by about 50 % higher than in the fodder radish biomass, so their influence on nitrogen leaching was different. Intensive decomposition of clover biomass begins in spring with the rise in temperature, thus a significant increase of nitrate concentration in lysimetric water took place in the spring (52.4 %) and summer (52.0 %) of the following year. Despite the lower filtration, significantly elevated levels of nitrate concentration resulted in increased nitrogen leaching (by 11.5 % during the year) after clover biomass insertion. Nitrogen migration to deeper soil layers after the insertion of clover was also described by Nykänen et al. (2008). Contrarily, Dabney et al. (2010) stated that winter cover crops reduce the nitrogen

leaching from 70 to 45 kg NO₃-N ha⁻¹, while summer cover crops – up to 30 kg NO₃-N ha⁻¹.

Under Lithuanian climatic conditions insertion of cover crops for green manure increased potassium concentration in lysimetric water during the following year. The increase was not always statistically significant ($p > 0.05$). Only after red clover insertion a substantial increase in potassium concentration (+2.60 mg L⁻¹ K⁺, $p < 0.05$) and its higher leaching (4.5 kg ha⁻¹ K⁺ or 22.8%, $p < 0.05$) were determined. According to Askegaard et. al. (2003), in sandy soils (<5 % clay) the green manure crop rotation reduces the potassium leaching from 42 to 21 kg ha⁻¹, while the addition of barley straw helps to reduce the amount of exchange potassium in the soil.

Green manure crops had no significant effect on calcium migration in sandy soils, except for fodder radish, which is related with a lower rainfall filtration in autumn. For this reason calcium leaching decreased by 16.3 kg ha⁻¹ or 10.9 % ($p < 0.005$). Under different climatic conditions application of cover crops (*Crotalaria juncea*, *Sorghum bicolor* S. *bicolor* var. *sudanense*) increased K, Ca and Mg concentrations and considerably higher leachate concentrations of these elements occurred in the treatment with the leguminous cover crop, sunn hemp, than in sorghum sudangrass treatment. However, only the amount of leached Mg was significantly higher in the sunn hemp (5.7 kg ha⁻¹) than in sorghum sudangrass (Wang et. al., 2003)

Decomposition of green manure generates different humic compounds which can stabilize or increase the amount of humus in the soil (Blombäck et. al., 2003; Tripolskaja et. al., 2008), but their mobile forms leach into the subsoil. These studies showed that in the sandy loam *Luvisol*/incorporation of green manure did not essentially increase ($p > 0.05$) TOC concentration in lysimetric water or its leaching. Positive effect of green manure (*Trifolium pratense*, mixture of *Trifolium repens* and *Lolium multiflorum*) on the reduction of organic carbon leaching was also determined on *Endocalcar-Endohypogleyic Cambisol* (Arlauskienė et. al., 2011). Walmsley et. al. (2011) assessed dissolved carbon leaching from an Irish arable soil. They established that carbon leaching was twice as large from the non-inversion tillage + cover crop treatment. The leaching increased because of increased dissolved inorganic carbon concentrations. However, cover cropping and related additional inputs of organic matter into soil did not increase concentrations and leaching losses of DOC. Smukler et al. (2012) adds that cover crops successfully reduced runoff and loads of several constituents during the storm events, when compared to fallow. Losses of dissolved organic carbon (DOC) were reduced by 58%. Estimates of leaching losses of DOC in the cover cropped fields, however, were 70% higher than the fallow fields in the winter rainy season and were

30% higher than the fallow fields in the summer irrigation season.

V. CONCLUSIONS

1. In sandy loam *Luvisol* the catch crops grown for green manure (fodder radish, red clover) reduce the infiltration of atmospheric precipitation by 7.0–8.3 % on average, and in the autumn period of the year of their cultivation – by 19.4–21.7 %. Therefore, plough in of their biomass in spring can serve as a measure preventing the nutrient leaching.
2. Application of mineral nitrogen fertilizers to improve the straw mineralization leads to increased nitrate leaching during the first months after addition (October–December). In case of surplus precipitation, the increase of nitrate concentration can be significant.
3. Application of straw supplemented with N₃₀ for fertilization increased the nitrogen leaching losses by 9.0 kg ha⁻¹ or 12.9 %, while the addition of clover green mass and straw – by 8.0 kg ha⁻¹ or 11.5 %. Fodder radish intensively assimilated mineral nitrogen, reduced filtration of precipitation thus leading to significant reduction of nitrogen leaching compared with the control variant (by 16.9 kg ha⁻¹ or 24.2 %) and by 25.9 and 24.9 kg ha⁻¹ respectively compared with the application of straw supplemented with N₃₀ or clover and straw.
4. Fertilization with barley straw and fodder radish green mass produced no effect on the migration of potassium in the soil. But the addition of red clover green mass, compared with non-fertilized soils, significantly ($p < 0.05$) increased the annual average potassium concentration in the leachate by 2.60 mg of K⁺ L⁻¹ and the leaching losses – by 4.5 kg K⁺ ha⁻¹ or 22.8 %.
5. As a result of fertilization with barley straw as well as fodder radish and clover biomass, calcium concentration in the leachate slightly increased, but the changes were statistically insignificant ($p > 0.05$). Calcium leaching losses significantly increased (15.7 kg Ca²⁺ ha⁻¹ or 12.5 %, $p < 0.05$) only in the year following the addition of red clover, but over the entire study period the changes were insignificant. Due to lower filtration of precipitation, the aftercrop fodder radish, compared with the control variant, significantly ($p < 0.05$) reduced the calcium leaching losses.
6. TOC leaching losses from a sandy loam soil were low and amounted to, on average, 8.3–10.6 kg OC ha⁻¹. Depending on annual meteorological conditions and experimental treatments, leaching losses varied from 1.97–14.92 kg OC ha⁻¹ per year. Mean OC concentration in lysimetric water was 2.61–3.18 mg OC l⁻¹ (control and with green manure or straw, respectively). Incorporation of barley straw

and catch crops for green manure (fodder radish, red clover) in late autumn did not have any significant ($p > 0.05$) effect on the TOC concentrations of lysimetric water.

VI. ACKNOWLEDGEMENTS

The paper presents research findings, obtained through the long-term research programme "Productivity and sustainability of agricultural and forest soils" implemented by Lithuanian Research Centre for Agriculture and Forestry.

REFERENCES RÉFÉRENCES REFERENCIAS

- ADOMAITIS, J. MAZVILA, Z. VAISVILA, ARBACIAUSKAS, J. A. ANTANAITIS, A. LUBYTE, J., ŠUMSKIS, D. (2010) The effect of long-term fertilisation on anion leaching. *Žemdirbystė = Agriculture*, 97 (1), pp. 7182. (in Lithuanian, with English summary)
- ARLAUSKIENĖ, A. and MAIKŠTĖNIENĖ, S. (2008) The effects of cover crops and straw on soil mineral nitrogen dynamics and losses from arable land. *Agronomijas Vestis (Latvian Journal of Agronomy)*, 11. pp. 195201.
- ARLAUSKIENĖ, A., MAIKŠTĖNIENĖ, S., ŠLEPETIENĖ, A. (2011) Application of environmental protection measures for clay loam *Cambisol* used for agricultural purposes. *Journal of Environmental Engineering and Landscape Management*, 19 (1), pp. 7180.
- ASKEGAARD, M., ERIKSEN, J., OLESEN, J.E. (2003) Exchangeable potassium and potassium balances in organic crop rotations on a coarse sand. *Soil Use and Management*, 19 (2), p. pp.96103.
- ASKEGAARD, M., OLESEN, J.E., KRISTENSE, K. (2006) Nitrate leaching from arable crop rotations: effects of location, manure and catch crop. *Soil use and management*, 95 (2), pp. 181188.
- BAIGYS, G. (2010) The influence of reduced soil tillage on drainage runoff and leaching of phosphates. *Vandens ūkio inžinerija*, 36 (56), pp. 3340. (in Lithuanian)
- BLOMBÄCK, K., ECKERSTEN, H., LEWAN, E. ARONSSON, H. (2003) Simulations of soil carbon and nitrogen dynamics during seven years in a catch crop experiment. *Agricultural Systems*, 76 (1), pp. 95114.
- DABNEY, S.M., DELGADO, J.A., MEISINGER, J.J., SCHOMBERG, H.H., LIEBIG, M.A., KASPAR, T., MITCHELL, J., REEVES, W. (2010) Using Cover Crops and Cropping Systems for Nitrogen Management, *Advances in nitrogen management*, pp. 230281
- ERICKSON, J. E., CISAR, J. L., SNYDER, G. H., VOLIN, J.C. (2005) Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. *Crop Science*, 45, pp. 546552.
- FARTHOFER, R.; FRIEDEL, J. K.; PIETSCH, G.; RINNHOFFER, T.; LOISKANDL, W. AND FREYER, B. (2004) Plant biomass nitrogen and effect on the risk of nitrate leaching of intercrops under organic farming in Eastern Austria. *Eurosoil*. Freiburg, Germany, p. 6569.
- GALVONAITE, A., VALIUKAS, D. (2005) Some indicators of climatic changes during the last decade in Lithuania. *Meteorology and Hydrology in Lithuania: Evolution and Prospects*, scientific conference. Vilnius, p. 3132. (in Lithuanian)
- GALVONAITE, A., MISIUNIENE, M., VALIUKAS, D., BUITKUVIENE, M. S. (2007) *Lithuanian climate*. Vilnius: ARX Baltica. (in Lithuanian)
- GOULDING, K. W. T., POULTON, P. R., WEBSTER, C. P. HOWE, M.T. (2000) Nitrate leaching the Broadbalk Wheat Experiment, Rothamsted, UK, as influenced by fertilizer and manure inputs and the weather. *Soil Use Management*, 16, pp.244250.
- HANSEN, E. M., DJURHUUS, J. (1997) Nitrate leaching as influenced by soil tillage and catch crop. *Soil and Tillage Research*, 41 (3-4), pp.203219.
- JOHNSON, J. M.-F., BARBOUR, N. W., WEYERS, S. L. (2005) Chemical Composition of Crop Biomass Impacts Its Decomposition. *Soil Science Society of America Journal*, 71 (1), pp.155162.
- KALVANE, G., ROMANOVSKAJA, D., BRIEDE, A., BAKSIENE, E. (2009) Influence of climate change on phenological phases in Latvia and Lithuania. *Climate research*, 39, pp. 209219.
- KRIAUCIUNIENE, J., REIHAN, A., KOLCOVA, T., MEILUTYTE-BARAUSKIENE, D., LIZUMA, L. (2010) Regional temperature, precipitation and runoff series in the Baltic countries. *Conference on Future Climate and Renewable Energy: Impacts, Risks and Adaptation*, Oslo, Norway, p. 1416.
- KUTRA, G., GAIGALAS, K., ŠMITIENE, A. (2006) Land use influence on nitrogen leaching and options for pollution mitigation. *Žemdirbystė-Agriculture*, 93 (4), pp. 119129.
- NYKÄNEN, A., GRANSTEDT, A., JAUHAINEN, L. (2008) Residual effect of clover-rich leys on soil nitrogen and successive grain crops. *Agricultural and Food Science*, 17 (1), pp. 7387.
- NEDZINSKAS, A., NEDZINSKIENE, T. (1999) Crops for green manure in the light soil. *Žemdirbystė-Agriculture. LIA scientific articles*, 66, pp. 3743. (in Lithuanian, with English summary)

21. SHI, J. R. (2013) *Decomposition and Nutrient Release of Different Cover Crops in Organic Farm Systems (Master Thesis)*. University of Nebraska, Lincoln, NE
22. SMUKLER, S.M., O'GEEN, A.T., JACKSON, L.E. (2012) Assessment of best management practices for nutrient cycling: A case study on an organic farm in a Mediterranean-type climate. *Journal of Soil and Water Conservation*, 67 (1), pp. 1631.
23. STAUFFER, W. Remove from marked Records. Percolation and yield of different crop rotations. (2000) *Agrarforschung*, 7 (11/12), pp. 535540.
24. STRUSEVICIUS, Z.; KAZAKEVICIENE, J.; BERANKIENE, L. (2009) Changes in river water quality downstream from the pig complex. *Vandens ūkio inžinerija*, 35 (55), pp. 4251. (in Lithuanian, with English summary)
25. TRIPOLSKAYA, L., ROMANOVSKAYA, D., SHLEPETENE, A. Humus status of soddy-podzolic soil upon application of different green manure. (2008) *Eurasian soil science*, 41 (8), p. 882889.
26. WALMSLEY, D.C., SIEMENS, J., KINDLER, R., KIRWAN, L., KAISER, K., SAUNDERS, M., KAUPENJOHANN, M., OSBORNE, B.A. (2011) Dissolved carbon leaching from an Irish cropland soil is increased by reduced tillage and cover cropping. *Agriculture, Ecosystems & Environment*, 142 (3-4), pp. 393402.
27. WANG, Q.-R., LI Y.-C., KLASSEN, W. (2003) Effects of Soil Amendments at a Heavy Loading Rate Associated with Cover Crops as Green Manures on the Leaching of Nutrients and Heavy Metals from a Calcareous Soil. *Journal of environmental science and health*, B38 (6), pp. 865881.

