IMPACT OF GREEN MANURE AND STRAW ON BIOGENIC ELEMENTS LEACHING IN LUVISOL

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Abstract: The paper presents summarized results of lysimetric experiments intended to determine the impact of green manure crops and straw on chemical elements leaching (N, K, Ca, Corg) and of atmospheric precipitation infiltration in sandy loam Luvisol. Lysimeter surface area is 1.75 m², the test soil layer is 0.60 m. It was determined that under climatic conditions of Lithuania, cover crops for green manure reduce atmospheric precipitation infiltration in sandy soil loam during autumn, and the effects of nutrient leaching depend on the plant species. Fabaceae plants clover (Trifolium pratense L.) stimulate nitrogen leaching, while Poaceae orchard grass (Dactylis glomerata L.) and Brassicaceae fodder radish (Raphanus sativus L.) lessen it. Incorporation of green manure biomass does not alter potassium and calcium leaching, but substantially reduces the organic carbon leaching.

Key words: LYSIMETERS, LEACHING, PERCOLATING, GREEN MANURE, STRAW, NITROGEN, ORGANIC CARBON

1. Introduction

Percolating moisture regime is typical in many Western and Eastern European countries, and percolated precipitation significantly influences chemical composition of groundwater and river runoff. Lithuania is characterized by a temperate climate with a mean long-term (1961–1990) annual precipitation value of 664 mm, an annual mean air temperature of 6.0 °C. Such relationship between temperature and precipitation conditions leaching soil moisture regime in soil and is favourable for organic matter mineralisation. Agricultural lands, where various agro-technical measures are used for crop yield enlargement, very negatively affect the quality of underground water basins and reservoirs (Kutra et. al., 2006; Adomaitis et. al., 2010; Sørensen and Rubæk, 2012; Cicek et al., 2015). The use of green manure increases the accumulation of organic carbon in arable soil layer, but the newly formed mobile humic substances can be leached from the upper layer and increase groundwater contamination (Arlauskiene et. al., 2009; Sleutel et. al., 2006). During decomposition of organic fertilizers many other chemical elements (phosphorus, potassium, calcium) are also mineralized; they can be washed out by atmospheric precipitation into the deeper layers of soil or water and adversely affect the state of water bodies (Bhogal et. al., 2009; Pappa et. al., 2011; Randall et. al., 2012). The intensity of these processes depends on the soil properties (especially texture and saturation with chemical elements), plants cultivated, hydrothermal conditions as well as the abundance of precipitation. Studies of agrotechnical measures, regarding the peculiarities of geographic location of the soil and climate, are essential in order to systematically assess their impact not only on crop yield and product quality, but also on environmental sustainability, especially on the changes in the nutrient leaching resulting from the use of mineral and organic fertilizers. This paper presents the summarized data on results of agro-chemical experiments regarding the impact of green manure and straw on migration of chemical elements and of atmospheric precipitation infiltration.

2. Material and methods

2.1. Site description

Experiments were performed at the Vokė Branch of the Lithuanian Research Centre for Agriculture and Forestry (54°37’ N, 25°08’ E). Lysimetric equipment consists of a cylindrical concrete structure with a surface area of 1.75 m², the test soil layer is 0.60 m. Lysimeters are filled with sandy loam (sand 66%, silt – 16%, clay 18%) Haplic Luvisol (World Reference..., 2015). Thickness of the soil A horizon is 0.26 m. Underneath the arable layer there is a 0.09 m El and 0.25 m thick B horizon.

2.2. Experiments design

1 experiment. Influence of intermediate crops for green manure and straw on a filtration of an atmospheric precipitation and chemical elements leaching.

Scheme of the experiment: 1. control (without added organic matter) 2. barley straw + N30, 3. post-crop fodder radish (Raphanus sativus L.) + N30, 4. undersown red clover (Trifolium pratense L.). Plant segment: spring barley (Hordeum vulgare L.) → potato (Solanum tuberosum L.). The barley was fertilized with N90P60K60, potatoes with N90P60K60. In the years following the addition of green manure potato was cultivated.

2 experiment. The effect of different timing of undersowing plants and cereal straw incorporation into soil on nutrient leaching.

Scheme of the experiment: 1. no wintering plants (control), crushed barley straw inserted in autumn 2. no wintering plants, crushed barley (Hordeum vulgare L.) straw mulch inserted in spring 3. red clover (Trifolium pratense L.) for green manure and barley straw mulch (inserted in spring) 4. orchard grass (Dactylis glomerata L.) for green manure and barley straw mulch (inserted in spring). The impact of straw and green manure on nutrient leaching was studied in the chain barley → potatoes. The barley was fertilized with N90P60K60, potatoes with N90P60K60. In each experiment, each treatment was replicated three times every year.

2.3 Methods of chemical analyses.

The leachate was analysed for the chemical element concentration (mg L⁻¹): nitrates (NO₃⁻) – by colorimetric (LST EN ISO -13395-2000), potassium (K⁺) by photometric method (ISO 9964:1998), calcium (Ca²⁺) – atomic absorption (ISO 7890-86), total organic carbon (TOC) – ISO-8245:1999 method.

3. Results

3.1 Influence of intermediate crops for green manure and straw on a filtration of an atmospheric precipitation and chemical elements leaching.

The aim of the experiment was to evaluate the impact of undersowing (red clover), post crop (fodder radish) green manure as well as barley
straw with N$_{30}$ additives on nitrogen, potassium, calcium and organic carbon leaching in sandy loam soil when biomass is plowed under in autumn.

It was determined that in Lithuania cover crops (fodder radish, red clover) can reduce the rainfall infiltration by an average of 7.9-9.0 % a year, and during the autumn period – up to 16.5-16.9 %. Macdonald et. al. (2005) also note that early sown cover crops effectively reduce rainfall infiltration and leaching of nitrogen in light textured soils.

Results of the experiment showed that despite lower infiltration in soil with post crop plants, clover biomass plowed under in autumn, compared with barley stubble, increases nitrogen leaching by 11.5 % (P <0.05) on average, because the clover biomass adds around 260 kg ha$^{-1}$ N into the soil (Table 1). Post crop fodder radish produce different effect on nitrogen leaching. Unlike clover, fodder radish in autumn intensively use mineral nitrogen from soil and fertilizers for biomass formation, and it significantly reduces (31.9 %, P <0.05) nitrogen leaching in the autumn and per year. Similar data was published by Constantina et al. (2010).

**Table 1. The effects of straw and green manure on chemical elements leaching in sandy loam Luvisol**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Leaching kg ha$^{-1}$ N year$^{-1}$</th>
<th>Leaching kg ha$^{-1}$ K year$^{-1}$</th>
<th>Leaching kg ha$^{-1}$ Ca year$^{-1}$</th>
<th>Leaching kg ha$^{-1}$ C$_{org}$ year$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without organic matter</td>
<td>69.8</td>
<td>11.04</td>
<td>102.4</td>
<td>10.6</td>
</tr>
<tr>
<td>Straw + N$_{30}$</td>
<td>78.8</td>
<td>10.23</td>
<td>154.0</td>
<td>9.9</td>
</tr>
<tr>
<td>Fodder radish + straw + N$_{30}$</td>
<td>52.9</td>
<td>8.98</td>
<td>126.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Red clover + straw</td>
<td>77.8</td>
<td>11.17</td>
<td>168.6</td>
<td>8.5</td>
</tr>
<tr>
<td>LSD$_{05}$</td>
<td>3.56</td>
<td>1.403</td>
<td>16.43</td>
<td>1.98</td>
</tr>
</tbody>
</table>

Under hydrothermal conditions of Lithuania, incorporation of nitrogen fertilizers (N$_{30}$) in autumn in order to promote straw mineralization processes increased nitrogen leaching by 9.0 kg N ha$^{-1}$ on average. Fodder radish for green manure substantially reduce the leaching of calcium, as it is associated with lower rainfall infiltration. Potassium leaching increases after clover biomass is plowed under (+22.8 %, P <0.05).

Various humic substances are formed in soil during the green manure biomass decomposition processes. It was revealed that after 6 years of the experiment, due to incorporation of green manure, the content of humus in soil increased by 0.03-0.14 % on average. The formed mobile humic substances can be leached out of the upper soil layer. Depending on hydrothermal conditions, 1.97-14.9 kg C$_{org}$ ha$^{-1}$ leach from the sandy loam Luvisol per year. Incorporation of green manure slightly increased average annual concentrations of C$_{org}$ in the infiltrate, however, due to lower rainfall infiltration in the soil with cover crops, leaching of organic carbon decreased by 2.1-2.3 kg C$_{org}$ ha$^{-1}$.

### 3.2. The effect of different timing of undersowing plants and cereal straw incorporation into soil on nutrient leaching

The aim of the experiment was to evaluate the impact of green manure (red clover and orchard grass) and straw mulching on reduction of precipitation infiltration over the period of autumn-winter-early spring as well as chemical elements leaching when the biomass is plowed in spring.

It was determined that undersown crops stronger reduce rainfall infiltration during the period of their intense growth (summer and autumn) and when rainfall exceeds SCN. For example, during rainy autumn of 2011 undersown clover reduced the infiltration by 71 %, compared with barley crop, and during the rainy summer of 2013 orchard grass reduced the infiltration by 248 %. If precipitation is close to the SCN, undersown crops produce no significant influence on the infiltration. Therefore, the summarized data of the whole study period (2008-2014) show that in sandy soils undersown crops did not substantially reduce the rainfall infiltration during the autumn-winter-early spring period (Table 2).

**Table 2. The effect of undersown green manure crops and straw mulch incorporated into the soil in spring on the leaching of chemical elements**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Infiltration rates 1 m$^{-2}$</th>
<th>Leaching kg ha$^{-1}$ year$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No wintering plants, barley straw incorporated in autumn</td>
<td>336</td>
<td>21.3</td>
</tr>
<tr>
<td>Red clover for green manure and barley straw mulch (incorporated in spring)</td>
<td>328</td>
<td>31.8</td>
</tr>
<tr>
<td>Orchard grass for green manure and barley straw mulch (incorporated in spring)</td>
<td>333</td>
<td>16.7</td>
</tr>
<tr>
<td>LSD$_{05}$</td>
<td>21.6</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Nitrogen leaching losses after the undersown crops had been plowed in spring depended on nitrogen content incorporated with biomass, plant species and decomposition time. Almost five times larger amount of nitrogen got into soil with clover biomass (7.54 g N m$^{-2}$) than with orchard grass (1.53 g N m$^{-2}$) and considerably more than with barley stubble (0.27 g N m$^{-2}$). Larger amount of nitrogen in biomass resulted in increased leaching. In the infiltrate from the soil fertilized with clover green mass the average annual nitrate concentration was by 30.5 % higher compared with straw incorporation in spring and by 92.7 % higher compared with the infiltrate of soil with the incorporated orchard grass biomass.

Studies on the dynamics of nitrate concentration revealed that the impact of undersown orchard grass on nitrate leaching reduction became evident in summer, and after the barley harvest the nitrate concentration substantially decreased. Average data of the years of undersown crops cultivation show that orchard grass reduces nitrate concentration in infiltrate up to 4.7 mg l$^{-1}$ (control variant – 18.9 mg l$^{-1}$), and in winter up to 2.9 mg l$^{-1}$ (control variant – 24.8 mg l$^{-1}$). This experiment confirmed the results obtained by other researchers (Thomsen, 2005; Rinnofner et. al., 2008; Constantin et. al., 2010; Sapkota et. al., 2012) on the efficiency of grasses (orchard grass, ryegrass) to effectively reduce nitrate leaching.

The impact of symbiotic nitrogen-accumulating plants (clover) on nitrate leaching was different than of orchard grass. During the years of undersown clover cultivation slight increase in nitrate concentration (+5.1 mg l$^{-1}$), compared with the control, was recorded already during the summer, and the considerable increase in concentration (+43.9 mg l$^{-1}$) was recorded during the summer of the following year, when mineralization of the incorporated clover biomass became more intensive. According to Cookson et al. (2002), decomposition of clover biomass is intense even at a temperature of +2°C, therefore in order to prevent nitrogen leaching losses, nitrogenous organic residues
must be incorporated in spring and not in autumn. According to the dynamics of nitrate concentration changes, intense biomass decomposition proceeded for about 6 months and during this period, with sufficient rainfall, mineralized nitrogen leaches into groundwater. When barley straw without nitrogen additive was used for fertilization, the nitrogen leaching made 21.3-24.5 kg N ha⁻¹. Straw incorporation period (autumn or spring) had no significant influence on nitrogen losses (P > 0.05). The impacts of green manure on nitrogen losses vary depending on the plant species. Red clover, accumulating more nitrogen in their biomass, increased its leaching as well. Nitrogen losses in soil fertilized with clover biomass increased by 49.3 % (P < 0.05) on average, compared with straw incorporation in autumn, and by 29.8 % (P > 0.05) compared with straw incorporation in spring. The main nitrogen leaching took place during the year of undersown crops incorporation; the increase leaching 66.9%. During the years of undersown crops cultivation and plant residues mineralization in autumn - winter period the nitrogen leaching just slightly increased (16.3 %). During the years of undersown orchard grass cultivation, compared with barley field, the nitrogen leaching losses decreased by 39.4% on average, and in comparison with undersown red clover – even twice (P <0.05). The following year, when decomposition of orchard grass biomass was in progress, the nitrogen leaching was similar to that of straw incorporation, but by 80.5 % lower as compared to red clover (P <0.05). Results of these investigations correspond to data, received in the experiments executed in Denmark, Sweden, Finland and Norway (Valkama et. al., 2015). Incorporation of straw, red clover and orchard grass biomass in spring, compared with traditional straw incorporation in autumn, had no significant impact on potassium and calcium leaching but reduced organic carbon leaching by 2.6-3.1 kg C ha⁻¹. The decrease was due to lower Cₖₒ₉ concentration and lower rainfall infiltration in the crop with undersown clover. Investigations of Vinter et. al. (2006) showed the opposite trends. They have determined that clover biomass incorporation in spring increased the dissolved organic matter leaching from sandy loam and coarse sandy soils.

4. Conclusions
1. Under climatic conditions of Lithuanian undersown and post crop green manure plants substantially reduce rainfall percolation during their intense growth period. However, undersown crops have only slight effect on average annual percolation reduction.
2. The impact of cover plants for green manure on nitrogen leaching depends on their nitrogen consumption. Plants that during autumn period consume a lot of mineral nitrogen (orchard grass, fodder radish) reduce its leaching by 45-47 % (P <0.05) on average per year. Red clover increase nitrogen stocks in the soil resulting in higher nitrogen leaching (67 %, P <0.05) during the biomass decomposition.
3. Biomass of cover plants for green manure does not increase the potassium, calcium leaching (P> 0.05) and reduces the leaching of organic carbon (P <0.05).

5. Literature
10. Randall N. P., L.M. Donnison, P.J. Lewis How effective are slurry storage, cover or catch crops, woodland creation, controlled trafficking or break-up of compacted layers, and buffer strips as on-farm mitigation measures for delivering an improved water environment? Environmental Evidence, 1, 12, 2012.