Effects of sward botanical composition on nitrogen and potassium leaching in cut grassland

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Abstract
The leaching of nutrients in regions where annual precipitation considerably exceeds evaporation needs to be minimised. Our objective was to study the dependence of leached nitrogen and potassium on botanical composition of grassland sward. Mini-lysimeters filled with loamy sand were embedded in three swards (a mixture of three grass species, grasses mixed with white clover and grasses mixed with lucerne). Annual nitrogen application rates (0, 60, 120 and 180 kg ha\(^{-1}\)) in conjunction with three fertilizers (mineral fertilizer, cattle slurry and sewage sludge) were applied. The nitrogen and potassium leaching was measured monthly during three years. We concluded that nitrogen and potassium leaching are affected by sward botanical composition. The leaching of both elements was the lowest from grass-clover sward.

Key words: leaching, nitrogen, potassium, sward type, water percolation, yield.

Introduction
Nutrient leaching has become a major concern worldwide, mainly due to the intensification of agricultural production involving the application of fertilizers and organic wastes (Di, Cameron, 2002). Leaching of fertilizer NO\(_3\)-N through the soil profile can contribute to eutrophication of streams and lakes, contaminate surface and groundwater resources (Mašauskas et al., 2006) and cause several health problems to humans (Di, Cameron, 2002). Nutrient leaching is a problem in regions where precipitation exceeds evaporation considerably. Estonia is located in a moderately cold and humid region, where total annual precipitation exceeds evaporation by 1.5–2 times; hence weather conditions for nutrient leaching are favourable.

Concerning the grasslands it has been found that nutrient leaching is high only from pastures, in cut grassland it is often estimated to be low (Eriksen, Vinther, 2002). Although nutrient leaching from grassland is lower than from arable land it is still important to find opportunities for its reduction. Under the conditions of climate change the risk of nutrient leaching is expected to become more favourable also from grasslands (Olesen et al., 2011). So far the research work in grassland has paid only little attention on the identification of relationships between nutrient leaching and sward species composition. Studies have shown that the ability of grasses to take up nitrogen (N) varies in great extent (Zemenchik, Albrecht, 2002). Therefore it can be presumed that N leaching at the same N application rate in swards with different botanical composition can be different. The study of Bouman et al. (2010) showed that NO\(_3\)-N leaching decreased in a treatment with bluegrass (\textit{Poa pratensis} L.), while the number of grasses did not affect leaching.

Due to the decreasing amount of resources in agricultural production it has been suggested that the targeted use of biodiversity, especially grass-legume mixtures, could play a role (Peyraud et al., 2009). According to several current studies, livestock production systems based on legumes are more sustainable than those based on mineral fertilizers (Thomas, 1992; Jarvis et al., 1996). The use of legumes in seed mixtures is an efficient strategy to reduce the external N-input on farms (Pötsch et al., 2013). But the impact of legumes on N leaching is not so clear. The amount of N fixed by legumes depends on their proportion in the sward and on environmental conditions, which may vary greatly (Frame, 1992). Bouman et al. (2010) showed that in midsummer when the percentage of white clover in the sward is high, N leaching also increases. Eriksen et al. (2004) have reported that less leaching occurs from unfertilized grassland containing white clover than from fertilized grass-only grassland. Low and Armitage (1970) studies have demonstrated increased leaching in the swards with reduced legume content.

Most research so far has focused only on N leaching (Eriksen et al., 2004; Mašauskas et al., 2006; Bouman et al., 2010). The leaching of potassium (K), which is also a very mobile element in the soil, but which does not cause eutrophication (Alfaro et al., 2004) or lower the quality of groundwater (Kayser, Isselstein, 2005) has received less attention. Potassium is a very important nutrient for the growth of grasses and the reduction of its
leaching loss is important in economical aspect. As was showed by Kayser and Isselstein (2005), high levels of available K in the soil and large quantities of fertilizers may increase K losses significantly. Bučienė et al. (2014) found that K leaching increases with the higher rate of soil aggregates <0.25 mm and humus in topsoil.

A three-year experiment of nutrient leaching was conducted in Estonia with the aim of examining the impact of sward botanical composition on N and K leaching from grassland during and after the vegetative period. We hypothesised that N and K leaching from grass-only and grass-legume swards is different.

**Materials and methods**

The experiment was conducted from May 2008 to January 2011 at the Eerika Experimental Station, Estonian University of Life Sciences (58°23′32″ N, 26°41′31″ E; 60 m a.s.l.). Plastic mini-lysimeters with 0.0706 m² area and 30 cm depth were used. The construction of lysimeters used in the experiment is described in more detail by Raave et al. (2014). Mini-lysimeters were filled with loamy sand (64% sand, 29% silt, 7% clay; specific surface area of 30.6 m² g⁻¹). The general chemical properties of the soil were as follows: soil organic matter (OM) – 1.7–1.9%, total nitrogen (N) content – 0.11%, plant available phosphorus (P) – 94–102 mg kg⁻¹ and potassium (K) – 165–180 mg kg⁻¹. Soil OM was determined by loss-on-ignition following heating at 500°C for four hours, total N – by Kjeldahl procedure, available P and K – by the A-L method, where 0.1 M ammonium lactate solution (pH = 3.7) was used as an extract (Egner et al., 1960).

The experiment was 3 × 3 × 4 factorial design with three replicates. We tested the effects of (i) sward type: grass-only mixture including timothy (Phleum pratense L.), perennial ryegrass (Lolium perenne L.) and smooth meadow-grass (Poa pratensis L.); above mentioned grasses mixed with white clover (Trifolium repens L.) and grasses mixed with lucerne (Medicago sativa L.), (ii) fertilizer type: mineral fertiliser, cattle slurry and sewage sludge, and (iii) fertilizer application rate based on N rate applied. The grass-lucerne plot was treated with organic manure. All fertilizers were applied in one to three split applications, depending on the vegetation period. The application rates of mineral fertilizers in kg ha⁻¹ were: N₆₀P₆₀K₆₀ (control), N₆₀P₆₀K₆₀, N₆₀P₆₀K₆₀, N₆₀P₆₀K₆₀, N₆₀P₆₀K₆₀ and N₂₀P₂₀K₂₀. We used NH₄NO₃, Ca(H₂PO₄)₂ and KCl as the sources of N, P and K, respectively. Organic fertilizers were applied to provide N rates of 60, 120 and 180 kg ha⁻¹. Their application rate was calculated based on the NH₄⁺-N content. The amounts of K applied with cattle slurry and sewage sludge when applied based on N rate of 60 kg ha⁻¹ are presented in Table 1. Both organic fertilizers were applied manually. Sewage sludge was spread on the sward surface, cattle slurry was applied either by spreading or by injection. The injection method is described in Tampere (2012). Mineral P and K fertilizers were not applied with organic manure. All fertilizers were applied to the plots in one to three split applications, depending on the N rate. Fertilizers were applied at once based on N rate 60 kg ha⁻¹ as follows: one week after the grass began to grow in spring, in June/July (after the second harvest) and in August (after the third harvest). PK fertilizers were applied once a year in spring together with N fertilizer.

The sward yield and its botanical composition were determined five times during the growing season. Species were selected by hand separation based on functional groups (grasses, legumes, and invasive species). Functional groups were weighed, dried and their dry matter (DM) yield and proportion (% on the basis of dry weight) in the yield was calculated. The quantities of leachate water and total N and K contents in the water were measured on a monthly basis throughout the year, except in the period when the soil was frozen. Leachate was removed from the lysimeter with a vacuum pump. After the leachate was measured with a beaker, water samples (20 ml) were collected for the determination of N and K content in the leachate. Water samples were stored at −18°C until analysis. An elemental analyzer “VarioMax” (“Elementar”, Germany) was used to measure the total N content, and a flame photometer “Jenway PFP7” (“Bibby Scientific”, UK) to measure the K content in the leachates.

All chemical analyses were performed in the Laboratory of the Department of Soil Science and Agrochemistry in Estonian University of Life Sciences.

The amounts of leached N and K were calculated as follows: (i) amount of leached N or K (g m⁻²) = amount of percolated water (L) × N or K content in leachate (g L⁻¹) / lysimeter surface area (0.0706 m²); (ii) amount of leached N or K in a year (g m⁻²) = ∑ leached N or K amounts (g) in the individual months; (iii) amount of leached N or K in the vegetative period (g m⁻²) = ∑ leached N or K amounts (g) in the individual months from May to October; (iv) amount of leached N or K after the vegetative period (g m⁻²) = ∑ leached N or K amounts (g) in the individual months from November to April.

Statistical analysis was conducted using cumulative leaching data calculated individually for each treatment replication. Correlation and multiple regression analyses were used to test the relationships between water percolation, sward DM yield and nutrient leaching. Fisher’s least significant difference (LSD) test for homogeneous groups was used for testing the significance of differences between treatments. All calculations were performed using the statistical package *Statistica 9.0* (StatSoft Inc., USA). The probability level was set at 0.05.

The meteorological conditions during the experimental period (Table 2) were monitored with weather stations “Metos Model MCR300” (Pessl Instruments GmbH, Austria); the sensors were positioned 2 m above the ground.

**Results and discussion**

**Nitrogen (N) leaching during and after the vegetative period.** During the vegetative period (vegetation period is the part of the year with daily mean temperatures steadily above +5°C) N leaching was significantly the lowest (P < 0.05) from grass-clover sward (Table 3). Between grass-only and grass-lucerne sward N leaching did not vary.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>Amount of K kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st year</td>
</tr>
<tr>
<td>Cattle slurry</td>
<td>75.58</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>9.31</td>
</tr>
</tbody>
</table>

Table 1. The amount of applied potassium (K) with organic fertilizers per one split application

The amount of K applied per sward was 90, 180 and 270 kg ha⁻¹. The amount of K applied per sward was 90, 180 and 270 kg ha⁻¹. The amount of K applied per sward was 90, 180 and 270 kg ha⁻¹.
N leaching was positively correlated with the amount of percolated water (Fig. 1). The relationships in individual swards were as following: $R^2 = 0.89$, $P < 0.05$, $n = 135$ (grass-clover); $R^2 = 0.85$, $P < 0.05$, $n = 90$ (grass-lucerne) and $R^2 = 0.87$, $P < 0.05$, $n = 135$ (grass-only). The three-year average correlation between N leaching and N concentration in the leachate was not significant. Only exception was the grass-lucerne sward, where N leaching increased with N content increase in the leachate ($R^2 = 0.63$, $P < 0.05$, $n = 90$). Our results are in accordance with Webster et al. (2003), who found that drainage volume has major influence on N leaching.

In our experiment the percolated water amount correlated most with sward yield. The correlations between the amounts of percolated water and sward yields were significant only within single experimental years: $R^2 = 0.51$, $P < 0.000$, $n = 135$ (1st year); $R^2 = 0.59$, $P < 0.000$, $n = 135$ (2nd year) and $R^2 = 0.43$, $P < 0.000$, $n = 90$ (3rd year). The relationship in three-year summary was not significant due to the variable annual rainfall and significantly different annual yields ($P < 0.01$). This result suggests that N leaching differences between swards in our experiment were mainly due to different sward yields. Higher yielding sward used more water for yield formation, and therefore water percolation and N leaching depending on it were lower. Leaching was also influenced by the water demand of the plants and it was higher for white clover when compared to grasses (data not shown). This is in accordance with Bouman et al. (2010), who concluded that different water demand of the plants impacts N leaching.

After vegetative period N leaching between the compared swards was similar (Table 3). In grass-lucerne sward N leaching was measured only in the first two years, therefore average N leaching from this sward was less when compared to other swards (Table 3). Based on the results of the first two years, average N leaching from grass-lucerne sward was the same as from grass-clover sward (0.8 g m$^{-2}$). The amount of leached N in the first two years was less from grass-only sward (0.7 g m$^{-2}$) (Table 4).

\begin{table}[h]
\centering
\caption{Meteorological data during the experimental period from May 2008 to January 2011}
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|}
\hline
\textbf{Month} & \textbf{Precipitation mm} & \textbf{Average air temperatures °C} & \\
\hline
\textbf{May} & 30.6 & 18.4 & 97.4 & 37.6 & 10.4 & 11.3 & 12.2 & 10.1 \\
\textbf{June} & 108.2 & 151.0 & 98.0 & 63.2 & 14.2 & 13.6 & 14.3 & 14.5 \\
\textbf{July} & 59.6 & 97.4 & 38.4 & 59.5 & 15.9 & 16.8 & 21.7 & 17.5 \\
\textbf{August} & 216.6 & 85.0 & 148.4 & 68.0 & 15.4 & 14.9 & 17.8 & 16.6 \\
\textbf{September} & 67.6 & 57.6 & 99.4 & 48.1 & 9.5 & 12.4 & 10.7 & 11.8 \\
\textbf{October} & 96.4 & 132.4 & 59.2 & 67.3 & 7.9 & 3.7 & 3.8 & 6.5 \\
\textbf{November} & 27.8 & 77.8 & 72.4 & 55.0 & 1.8 & 1.9 & 2.9 & 4.3 \\
\textbf{December} & 42.6 & 57.0 & 0.0 & 44.0 & -1.6 & -5.5 & -8.6 & -15.5 \\
\hline
\textbf{Year} & 726.4 & 743.8 & 654.2 & 584.6 & 5.6 & 4.1 & 5.0 & 6.2 \\
\hline
\end{tabular}
\end{table}

\begin{table}[h]
\centering
\caption{Average yields, amounts of percolated water, nitrogen (N) and potassium (K) concentrations in the leachate, and amounts of leached N and K in different swards during and after the vegetative period (averaged for the three-year period)}
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
\textbf{Sward type} & \textbf{DM yield kg m$^{-2}$} & \textbf{Amount of percolated water L m$^{-2}$} & \textbf{N content in leachate mg L$^{-1}$} & \textbf{K content in leachate mg L$^{-1}$} & \textbf{Amount of leached N g m$^{-2}$} & \textbf{Amount of leached K g m$^{-2}$} \\
\hline
\textbf{During vegetative period} & & & & & & \\
\textbf{Grass-clover} & 0.8 A & 79.8 A & 20.9 A & 5.0 A & 1.6 A & 0.4 A \\
\textbf{Grass-lucerne*} & 0.7 B & 127.4 C & 17.5 B & 15.7 B & 2.2 B & 2.1 B \\
\textbf{Grass-only} & 0.4 C & 117.3 B & 19.6 C & 17.0 B & 2.2 B & 2.1 B \\
\hline
\textbf{After vegetative period} & & & & & & \\
\textbf{Grass-clover} & – & 55.4 A & 19.9 A & 3.5 A & 1.1 A & 0.1 A \\
\textbf{Grass-lucerne*} & – & 42.3 B & 18.1 B & 11.9 B & 0.8 B & 0.4 B \\
\textbf{Grass-only} & – & 55.3 A & 17.7 B & 10.8 B & 1.0 A & 0.5 C \\
\hline
\end{tabular}
\end{table}

\footnotesize{Note. Within the same column, values with different letters are significantly different ($P < 0.05$); * – results from two years; DM – dry matter.}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure1.png}
\caption{The dependence of nitrogen (N) leaching during the vegetative period on quantities of percolated water (three-year experimental period, $n = 360$)}
\end{figure}
Effects of sward botanical composition on nitrogen and potassium leaching in cut grassland

After vegetative period N leaching depended substantially on the length of the period when the ground remained unfrozen. In the first two years, ground froze permanently already at the end of November – beginning of December, therefore N leaching after vegetative period in those years was low. However, in the third year when ground did not freeze until the middle of January N leaching was substantially higher (Table 4). As with N leaching during the vegetative period, N leaching after the vegetative period depended mostly on the amount of water percolation (Fig. 2). Correlations in individual swards were strong in the vegetative period and the increase was the highest in grass-clover and grass-only swards throughout the experimental period.

Nitrogen leaching between grass-clover and grass-only swards differed most in the first year. In subsequent years the difference between those two swards decreased and disappeared by the third year. The increase in N leaching throughout the experiment in grass-clover sward was 42.0%, but in grass-only sward just 4.6% (Table 4). Leaching increased in both swards after the vegetative period and it was greater in grass-clover sward. In vegetative period it decreased in both swards due to the decrease in precipitation throughout the experimental period (Table 2). Precipitation impacted the amount of percolated water, which in grass-only sward was twice as low in the third year when compared to the first year. In grass-clover sward the amount of percolated water decreased less throughout the experimental period, due to the higher water uptake by the sward in the first year, when the amount of rainfall was the highest of the total experimental period.

Nitrogen leaching during and after the vegetative period. Three-year average K leaching during the vegetative period was significantly ($P < 0.05$) lowest from grass-clover sward (Table 3). Potassium leaching in vegetative period correlated most with its concentration in leachate (Fig. 3). Correlations in individual swards were as following: $R^2 = 0.97$, $P < 0.05$, $n = 135$ (grass-clover sward); $R^2 = 0.95$, $P < 0.05$, $n = 90$ (grass-lucerne sward) and $R^2 = 0.85$, $P < 0.05$, $n = 135$ (grass-only sward). The correlation between three-year average K leaching and percolated water amount was less in all swards: $R^2 = 0.68$, $P < 0.05$ (grass-clover sward); $R^2 = 0.70$, $P < 0.05$ (grass-lucerne sward) and $R^2 = 0.88$, $P < 0.05$ (grass-only sward). This shows that K leaching was mainly determined by the content of exchangeable K in the soil, in accordance with Askegaard et al. (2003), Alfaro et al. (2004) and Kayser et al. (2007).

Potassium concentrations in the leachate were significantly affected by sward type ($P < 0.01$), being lowest in the grass-clover sward (Table 3). Higher K uptake by plants in grass-clover sward was probably due to its higher N supply. The impact of lucerne on K concentration in the leachate was less due to its lower percentage in the sward (Table 5). Therefore the amount of symbiotically fixed N in this sward was probably less

![Figure 2](image)
when compared to grass-clover sward and it did not affect K uptake by plants. The highest K concentration appeared in the leachate of grass-only sward. These results suggest that K leaching depends mostly on N supply which is in agreement with Alfaro et al. (2003).

Potassium leaching after vegetative period was significantly ($P < 0.05$) lowest in the grass-clover and the highest in the grass-only sward (Table 3) and it correlated most to K concentration in the leachate: $R^2 = 0.90$, $P < 0.05$, $n = 135$ (1st year); $R^2 = 0.94$, $P < 0.05$, $n = 135$ (2nd year) and $R^2 = 0.98$, $P < 0.05$, $n = 90$ (3rd year). Correlations were significant only in individual experimental years. The three-year average correlation between K leaching and the amount of percolated water was weak: $R^2 = 0.24$, $P < 0.05$, $n = 360$. After vegetative period average K content in the leachate decreased throughout the experimental period – 12.7 (1st year), 6.8 (2nd year) and 4.0 mg L$^{-1}$ (3rd year), in contrast to N. Our results suggest that K leaching from that sward was the lowest. Our results suggest that K leaching is mainly determined by the N and K ratio in the soil, which impacts K uptake by plants.

Conclusions

1. Our study supports the hypothesis that nitrogen (N) and potassium (K) leaching is affected by sward botanical composition. From three compared swards N and K leaching was less in grass-clover sward.

2. The impact of botanical composition on N leaching was related to sward yield, which was different between the swards. In higher yielding swards water percolation and N leaching depending on it were lower. Sward botanical composition also influenced N content in the leachate. It was the highest in the leachate of grass-clover sward.

3. Potassium leaching between three swards was different due to their unequal N supply. The highest amount of plant-available N was in the grass-clover sward, because of the symbiotically fixed N. Therefore K leaching from that sward was the lowest. Our results suggest that K leaching is mainly determined by the N and K ratio in the soil, which impacts K uptake by plants.

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Žolyno botaninės sudėties įtaka azoto ir kalio išsplovimui į šienaujamo žolyno

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