Nitrogen and phosphorus variation in shallow groundwater and assimilation in plants in complex riparian buffer zones

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Abstract The study of purification efficiency and nutrient assimilation in plants was made in two riparian buffer zones with a complex of wet meadow and grey alder (Alnus incana) stand. In the less polluted Porijõgi test site, the 31 m wide buffer zone removed 40% of total nitrogen (total-N) and 78% of total phosphorus (total-P), while a heavily polluted 51 m wide buffer zone in Viiratsi retained 85% of total-N and 84% of total-P. The input of nutrients and purification efficiency displayed a significant relationship. The total-N removal in buffer zone was negative when the input value was less than 0.3 mg l–1 and the purification efficiency was always positive when the input value exceeded 5 mg l–1. The purification efficiency of total-P was positive when the input value exceeded 0.15 mg l–1. Grass vegetation plays an important role in nutrient retention in riparian buffer strips. The maximum phytomass production was measured in Porijõgi site where production of the Filipendula ulmaria community was up to 2,358 g m–2, assimilation of N 32.1 and of P 4.9 g m–2, respectively. This is much higher than the biomass production and N and P uptake of the grey alders (Alnus incana) at the same site – 1,730, 20.5 and 1.5 g m–2, respectively.

Keywords Alnus incana; assimilation of nitrogen; assimilation of phosphorus; buffer zones

Introduction

Buffer zones have many functions that improve water quality, protect air and soil, increase biological and landscape diversity (Mander et al., 1997b). One of the main functions of buffer zones and riparian wetlands, to purify water of contaminant substances, has been widely described in many regions (Peterjohn and Correll, 1984; Lowrance et al., 1984; Uusi-Kämpä and Yläranta, 1992; Haycock and Pinay, 1993; Vought et al., 1994). However, our knowledge concerning the water quality buffering effects of riparian zones is far from adequate (Correll, 1997). Different studies indicate that buffer zones can retain 0.0043 to 13 g N m–2 day–1 and 0.000057 to 8.67 g P m–2 day–1 (Mander et al., 1997b). Because retention and efficiency rates vary greatly under different climatic and physico-geographical conditions, few proposals have been presented with design criteria for buffer zones and their establishment and management (Dillaha and Inamdar, 1997; Mander et al., 1997b). The optimal vegetation and the most effective buffer width is still unclear (Correll, 1997). Haycock and Pinay (1993) found that forested buffer zones are more effective than grass buffer zones, while other works show good purification in grass buffer zones (Peterjohn and Correll, 1984; Groffman et al., 1991; Correll, 1997). Grass strips are considered sediment traps by which a large portion of nutrients, especially P is deposited from surface flow (Peterjohn and Correll, 1984; Young et al., 1980). At the same time grass buffer strips can also remove dissolved nutrients (Peterjohn and Correll, 1984; Haycock and Burt, 1993; Vought et al., 1994) which shows that grass strips can be an important part of a buffer zone. Although the assimilation of nutrients by vegetation in buffer zones has been described in only a few works, results indicate high nutrient assimilation ability. Van Oorschot (1994) measured above-ground N and P uptake in riparian communities up to

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7.1 and 1.07 g m\(^{-2}\) year\(^{-1}\), respectively. Prach and Rauch (1992) estimate the N and P removal by hay from a floodplain to be 15–30 and 2–4.5 g m\(^{-2}\), respectively.

In the study described here we provide an overview on the purification efficiency of complex riparian buffer zones in Estonia consisting of native riparian plant communities with emphasis on nutrient assimilation and input versus retention calculations.

**Materials and methods**

**Site description.** To study buffer zone efficiency we established two transects in south Estonia with similar physico-geographical conditions. The transects are situated on slopes adjacent to streams and follow surface water flow across agricultural fields and different riparian plant communities. The Viiratsi transect is situated in the Sakala heights (Varep, 1964) consisting of moraine hills and undulated plains with a variety of glacial deposits. The transect is located on the moraine plain in the vicinity of the pig farm (about 30,000 pigs during the study). Almost all the slurry from the pig farm is spread on the neighbouring fields and whole area is heavily impacted by pig slurry. The transect crosses the following plant communities: a cultivated field on planosols and podzoluvisols where slurry was spread in autumn 1994; an 11 m wide strip of grassland (*Elytrigia repens-Urtica dioica*) and young alder (*Alnus incana*) trees on colluvial podzoluvisol; a 12 m wide wet grassland (*Filipendula ulmaria*) on gleysol and a 28 m wide grey alder (*Alnus incana*) forest on podzolitic gleysol (Figure 1A).

The Poriõgi transect is situated in the plain of south-east Estonia (Varep, 1964), on the slope of a primeval valley where agricultural activities stopped in 1992, two years before we began our study. The Poriõgi transect crosses several plant communities: abandoned field (last cultivated in 1992) on planosols and podzoluvisols; abandoned cultivated grassland (last mowed in 1993) on colluvial podzoluvisol (dominated by *Dactylis glomerata* and *Alopecurus pratensis*); an 11 m wide wet grassland on gleysol (two parallel communities,

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**Figure 1** Study transects in complex riparian buffer zones in South Estonia. A – Viiratsi; B – Poriõgi. 3 – shallow groundwater sampling point; P-1 soil and phytomass sampling plots

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one dominated by *Filipendula ulmaria*, another by *Aegopodium podagraria*); and a 20 m wide grey alder stand (*Alnus incana*) on gleysol (Figure 1B).

*Water sampling and analysing.* Shallow ground water samples from upper aquifer were collected once to twice a month from piezometers installed on the borders of plant communities. The piezometers on the borders of riparian communities were installed with 3 replicates in 20 (Pori) to 30 (Viiratsi) metres wide zones. The depth of groundwater varied 1–2 m in the field sampling points and 10–80 cm in riparian communities. Samples were taken from July 1994 to December 1995. Filtered water samples were analysed for NH$_4^+$-N, NO$_2^-$-N, NO$_3^-$-N, total Kjeldahl-N, PO$_4^{3-}$-P, total-P, SO$_4^{2-}$, Fe, Ca$^{2+}$ in the laboratory of the Estonian Agricultural University following standard methods for examination of water and wastewater quality (*Standard Methods*, 1981).

*Soil and phytomass sampling and analysing.* Complex soil samples were taken in three replicates from two depths (0–10 cm and 10–20 cm) from all plant communities toposequent through the riparian buffer zones (Figure 1). Sampling was done twice a year: in spring (May) and autumn (October). A hand-held 4 cm diameter corer was used to collect samples. Soil pH value, organic matter (loss of ignition), and N and P content were analysed using standard methods (*Standard Methods*, 1981). The phytomass (i.e., standing crop) samples were collected from all riparian plant communities during the maximum flowering time of the dominant plant species (2nd and 3rd week in July; see Milner and Hughes, 1968). Sampling plots (six in Porijõgi and three in Viiratsi) were installed in typical areas of the community. The above ground phytomass was collected from three replicate quadrates (1 × 1 m) in each community. Below ground root phytomass was collected from soil cores taken by auger (diameter 158 mm) to a depth of 40–50 cm in three replicates from each location. Roots were washed of soil and from the dried roots and above ground phytomass, dry weight was measured and N and P content was analysed in the laboratory of the Estonian Agricultural University. In the grey alder community above ground phytomass and productivity of grey alders were estimated (without herb phytomass) using dimension-analysis techniques (Bormann and Gordon, 1984; Rytter, 1989). At both test sites (age 14 in Porijõgi transect and 40 years in Viiratsi transect) 17 and 5 sample trees per plot, respectively, were felled to collect data on the following tree components: stem (wood and bark), secondary branch growth (wood and bark), primary branch growth, leaves, generative organs (Lõhmus *et al*., 1996). The relative increments of the wood and bark of an over-bark fraction were assumed to be equal. Root systems for 6 and 3 out of the sampled 17 and 5 trees, respectively, were excavated. The dried weight of all tree components was measured and N and P content in dried phytomass were analysed in the laboratory of Estonian Agricultural University.

*Statistical analysis and calculations.* The Kruskal-Wallis test was performed due to inhomogeneity of variances to analyse N and P concentration changes between measurement points and the test for Binary Sequences for load versus purification efficiency probability analyses using Statgraphics Plus 7.1. The regression analysis of relation between input load and appearance of negative removal of nutrients was performed by *Microsoft Excel* 97.

*Results* The soil water nitrogen load in two transects was different. The total-N content in Viiratsi transect reached up to 76 mg l$^{-1}$ in the cultivated field after slurry application. In Porijõgi transect the highest total-N concentration was 13.5 mg l$^{-1}$. The results show that there were
considerable decreases in nitrogen content through the Viiratsi transect buffer zone (see Table 1). The average total-N decreased during the study period (1994 to 1995) from 19.1 mg l⁻¹ in the field (transect point 1, Figure 1A) to 2.9 mg l⁻¹ at the end of the buffer zone (transect point 5, Figure 1A). However, this decrease was not significant (Kruskal-Wallis test, \( P > 0.05 \)).

There was considerable decrease in nitrogen through the first 2 m of the buffer zone where the average total-N decreased from 19.1 to 11.8 mg l⁻¹ in the grass community (transect point 2) and in the following 11 m wide wet grass community to 3.6 mg l⁻¹ (in transect point 3). In the alder forest zone the nitrogen content decreased to 2.4 mg l⁻¹. This change from point 2 is highly significant (\( P < 0.01 \)) compared to the values at points 4 and 5. The change was highly significant also when comparing points 3 and 4, and 3 and 5.

Plant nutrient assimilation in the Viiratsi transect was higher in the wet meadow *Filipendula ulmaria* association (sampling plot V-2, Figure 1A), where an average of 21.1 g N m⁻² yr⁻¹ and 4.8 g P m⁻² yr⁻¹ was assimilated in grass (Table 1). This was higher than the nutrient uptake by alders (14.0 and 1.1 g m⁻² yr⁻¹, respectively). In the Porijõgi

Table 1  Nutrient variation in shallow groundwater (average ± standard error), soil and the plant phytomass in the complex buffer zone in Viiratsi. Sampling points are given in brackets as shown in Figure 1A

<table>
<thead>
<tr>
<th>Field</th>
<th>Grassland (1)(2)(V-1)</th>
<th>Wet meadow (3)(V-2)</th>
<th>Alder I (4)(V-3)</th>
<th>Alder II (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-N in shallow groundwater (mg l⁻¹)</td>
<td>19.1 ±7.0</td>
<td>11.8 ±3.2</td>
<td>3.6 ± 0.4</td>
<td>2.4 ± 0.5</td>
</tr>
<tr>
<td>N assimilation by plants (g N m⁻² yr⁻¹)</td>
<td>17.5</td>
<td>21.1</td>
<td>14.0</td>
<td>11.4</td>
</tr>
<tr>
<td>Topsoil (0–10 cm) N content (mg g⁻¹)</td>
<td>2.16</td>
<td>6.76</td>
<td>9.87</td>
<td>2.02</td>
</tr>
<tr>
<td>Soil (10–20 cm) N content (mg g⁻¹)</td>
<td>1.66</td>
<td>5.37</td>
<td>5.61</td>
<td>1.56</td>
</tr>
<tr>
<td>Total-P in shallow groundwater (mg l⁻¹)</td>
<td>0.43 ±0.28</td>
<td>0.17 ±0.04</td>
<td>0.05 ±0.005</td>
<td>0.05 ±0.004</td>
</tr>
<tr>
<td>P assimilation by plants (g P m⁻² yr⁻¹)</td>
<td>3.7</td>
<td>4.8</td>
<td>1.1</td>
<td>0.49</td>
</tr>
<tr>
<td>Topsoil (0–10 cm) P content (mg g⁻¹)</td>
<td>0.37</td>
<td>0.40</td>
<td>0.53</td>
<td>0.37</td>
</tr>
<tr>
<td>Soil (10–20 cm) P content (mg g⁻¹)</td>
<td>0.37</td>
<td>0.50</td>
<td>0.94</td>
<td>0.37</td>
</tr>
<tr>
<td>Phytomass production (g m⁻²)</td>
<td>1320</td>
<td>1015</td>
<td>1060</td>
<td></td>
</tr>
</tbody>
</table>

Table 2  Nutrient variation in shallow groundwater (average ± standard error, soil and the plant phytomass in the complex buffer zone in Porijõgi. Sampling points are given in brackets as shown in Figure 1B

<table>
<thead>
<tr>
<th>Field</th>
<th>Cultivated grassland I (1)(P-1)</th>
<th>Cultivated grassland II (2)(P-2)</th>
<th>Wet meadow I (3)(P-3)</th>
<th>Wet meadow II (4)(P-4)</th>
<th>Alder (5)(P-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-N in shallow groundwater (mg l⁻¹)</td>
<td>1.2 ±0.2</td>
<td>2.2 ±0.7</td>
<td>2.0 ± 1.0</td>
<td>1.7 ±0.3</td>
<td>2.0 ± 0.4</td>
</tr>
<tr>
<td>N assimilation by plants (g N m⁻² yr⁻¹)</td>
<td>11.4</td>
<td>13.2</td>
<td>13.6</td>
<td>21.3'</td>
<td>18.8''</td>
</tr>
<tr>
<td>Topsoil (0–10 cm) N content (mg g⁻¹)</td>
<td>2.02</td>
<td>2.82</td>
<td>10.74</td>
<td>2.02</td>
<td>2.82</td>
</tr>
<tr>
<td>Soil (10–20 cm) N content (mg g⁻¹)</td>
<td>1.56</td>
<td>2.36</td>
<td>9.54</td>
<td>1.56</td>
<td>2.36</td>
</tr>
<tr>
<td>Total-P in shallow groundwater (mg l⁻¹)</td>
<td>0.49 ±0.3</td>
<td>0.29 ±0.01</td>
<td>0.27 ±0.15</td>
<td>0.06 ±0.02</td>
<td>0.09 ±0.03</td>
</tr>
<tr>
<td>P assimilation by plants (g P m⁻² yr⁻¹)</td>
<td>2.7</td>
<td>2.1</td>
<td>2.6</td>
<td>3.0'</td>
<td>3.3''</td>
</tr>
<tr>
<td>Topsoil (0–10 cm) P content (mg g⁻¹)</td>
<td>0.45</td>
<td>0.63</td>
<td>1.02</td>
<td>0.45</td>
<td>0.63</td>
</tr>
<tr>
<td>Soil (10–20 cm) P content (mg g⁻¹)</td>
<td>0.35</td>
<td>0.53</td>
<td>0.9</td>
<td>0.35</td>
<td>0.53</td>
</tr>
<tr>
<td>Phytomass production (g m⁻²)</td>
<td>1113</td>
<td>1152</td>
<td>1493</td>
<td>1748</td>
<td>1977</td>
</tr>
</tbody>
</table>

* Aegopodium podagraria
** Filipendula ulmaria
transect the assimilation of nutrients was also highest in the wet meadow where the Filipendula ulmaria association (sampling plot P-5, Figure 1B, Table 2) assimilated 21.3 and 3.0 g m⁻² yr⁻¹ of N and P, respectively. This was higher than annual N and P uptake by alders: 20.5 and 1.5 g m⁻², respectively. Maximum nutrient assimilation in 1994 reached 32.1 g N m⁻² in the wet meadow of Poriõjõi transect (sampling plot P-5) and 5.5 g P m⁻² yr⁻¹ in the wet meadow of Viiratsi transect (sampling plot V-2).

The N and P contents in soil increase in wet meadow riparian communities. The nitrogen content in the Viiratsi topsoil layer increased from 2.16 to 9.87 mg g⁻¹ (sampling points V-1 and V-3, Figure 1) and the phosphorus content from 0.49 to 0.94 mg g⁻¹. In Poriõjõi transect the increase of nitrogen and phosphorus was from 2.02 to 10.74 and from 0.45 to 1.02 mg g⁻¹, respectively (sampling points P-3 and P-6, Figure 1). The highest values were in the alder Alnus incana communities.

Discussion
Both transects show high purification efficiency. The average removal of total-N and total-P in Viiratsi was 85% and 84% and in Poriõjõi 40% and 78%, respectively. The water quality had already improved within the first metres of the buffer zone. In Viiratsi transect the purification efficiency of total-N and total-P within first 2 m of the buffer grassland was 38% and 60%, respectively, whereas in Poriõjõi transect the purification efficiency of total-N and total-P in the 2 m from the edge of the cultivated grassland was 18% and 78%, respectively.

To analyse the relation between purification efficiency and input concentration we calculated the purification efficiency separately for each sampling day for every buffer strip between two sampling points. Data were divided by input concentration into 8 classes with 11 to 36 measurements in each class. The Tests of Binary Sequences were performed to calculate the level of significance between occurrence of positive or negative removal efficiency. The probability of negative removal was calculated by dividing the number of negative removal cases with the total measurement number (%). Comparison of removal efficiency and input concentration shows that the removal of total-N was negative (P<0.01), when the input was less than 1.0 mg l⁻¹ (Figure 2A). For input concentrations between 1.0 to 5.0 mg l⁻¹, removal of total-N showed no significant positive or negative tendency, although positive removal was more common – the probability of negative removal is 30.8 to 40.0% (P>0.05). For input concentrations greater than 5.0 mg l⁻¹ the purification efficiency is significantly positive (P<0.01), for input concentrations greater than 42 mg l⁻¹ purification efficiency is always positive (P<0.001). The relation between input concentration and appearance of negative removal of nitrogen (Nneg) is described by logarithmic regression:

\[ N_{neg} = 63.0 - 16.84 \ln(I_{N_{max}}) \]
\[ R^2 = 0.78, P > 0.001 \]

where \( I_{N_{max}} \) is maximum value of N input class.

For total-P there is no interval for negative removal (Figure 2B). The input concentration 0.01 to 0.15 mg l⁻¹ yields positive or negative removal. Positive removal is prevalent for input from 0.05 to 0.15 mg P l⁻¹ – the probability of negative removal is 18.8 to 38.9% (P>0.05). For input greater than 0.15 mg l⁻¹, the purification efficiency of total-P was significantly positive (P<0.01), for input concentrations greater than 2.1 mg l⁻¹ purification efficiency is always positive (P<0.01). The relation between input concentration and appearance of negative removal of phosphorus (Pneg) is described by logarithmic regression:
\[ P_{\text{neg}} = 7.9 - 10.20 \ln(I_{P_{\text{max}}}) \]
\[ R^2 = 0.72, P < 0.01 \]

where \( I_{P_{\text{max}}} \) is maximum value of \( P \) input class.

The load-retention relationship in various ecosystems has been discussed in earlier studies (Fleisher et al., 1991; Haycock and Pinay, 1993; Mander et al., 1997b). The results show strong positive correlation between nutrient load and removal. However, buffer zones have upper limits of purification and these regression formula cannot be used in the planning in the case of high input values. This analysis provides limits for buffer strips as water purification systems. The input concentration range (1.0–5.0 and 0.01–0.15 mg l\(^{-1}\) of N and P, respectively) can be considered to represent natural conditions of studied buffer strips where water output quality also depends on natural processes taking place in the buffer and on increased nutrient content in soils. This can explain certain increases of total-N and total-P content in groundwater inside both studied buffers. However, the highest increase of N and P content in soil is taking place in Alnus incana community, while the content of nutrients in groundwater is decreasing. This indicates that the increased N and P contents in soil are not affecting the water quality directly. The increased nutrient content in soil in Alnus incana community can be explained by very high nutrient content in litter of alder (Mikola, 1958). To achieve good purification ability it is important to design a complex buffer zone consisting of different ecosystem strips. The average outflow values from both buffer zones were lower than 3.1 and 0.07 mg l\(^{-1}\) of total-N and total-P in Viiratsi, respectively and 1.5 and 0.06 mg l\(^{-1}\) in Porižogi, respectively. Our estimation of denitrification intensity showed that this process does not play a substantial role in nitrogen removal (7.9–20.1 kg N ha\(^{-1}\) yr\(^{-1}\) in Porižogi and 8.5–19.3 kg N ha\(^{-1}\) yr\(^{-1}\) in Viiratsi, Mander et al., 1997a).

The nutrient assimilation in plants indicates that grass communities play an important role for nutrient retention in buffer zones. The average N and P content in herbal shoots in the wet meadows were 11.6 and 1.6 g m\(^{-2}\), respectively in the Porižogi and 10.6 and 2.3 g m\(^{-2}\), respectively in the Viiratsi transect. This gives good opportunity to remove a portion of nutrients by grass mowing and hay removing while felling of trees can be done with intervals of decades. Cutting should be done during the maximum flowering period of the dominant species when the nutrient content in the shoot phytomass is highest (Deinum, 1966). The mowed herbs should be removed after mowing to avoid rapid nutrient loss from hay (Schaffers et al., 1998).

The results show that complex buffer zones of grass and forest strips are very effective in N and P retention, which agrees with previous research (Schultz et al., 1995; Lowrance, 1997a).
1991). This kind of complex can be recommended for buffer strip design where grass strips are considered as sediment traps but also as an important mechanism for dissolved N and P removal. Both features provide the opportunity to remove part of the nutrients from the system. In addition to efficient nutrient purification potential, forest buffer strips have many other environmentally important functions such as protection against soil erosion, filtering polluted air, canopy shading, and increasing biological and landscape diversity.

**Conclusion**

In general, buffer zones can be effective multifunctional tools to control nutrient losses from intensively used watersheds. The studied buffer strips showed good purification efficiency for N and P when input concentrations were high (>5 mg N l\(^{-1}\) and >0.15 mg P l\(^{-1}\), respectively). At the same time the complex buffer zone consists of different buffer strips having high purification efficiency. For instance, a heavily loaded complex buffer zone consisting of grass and forest strips showed relatively low output concentrations for total-N and total-P, which are comparable with the output values from the unloaded transect. However, removal can be negative in case of lower input (<1 mg N l\(^{-1}\)). Some unpredictability of output concentration was observed when the initial input was intermediate. When planning and designing buffer zones, the role of grass buffer strips and wet meadows should be considered. Management of grasslands and forests can significantly decrease the load in complex buffer zones.

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