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Phosphorus management in Nordic-Baltic agriculture – reconciling productivity and environmental protection



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Evaluating vegetated buffer zones for phosphorus retention in cereal and grass production

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Introduction

Agriculture is estimated to be the main cause of eutrophication and blue-green algae blooms in shallow freshwater lakes and coastal waters. One way to mitigate phosphorus (P) losses from agricultural soils is to establish buffer zones (BZs) between field areas and waterways. The BZs mitigate significantly erosion and the losses of particle phosphorus (PP) and total P (TP) in surface runoff (e.g. Dillaha *et al.*, 1989; Uusi-Kämpä *et al.*, 2000). Instead, retention of dissolved reactive P (DRP) may be poor on the BZs. This paper aims to evaluate the P removal efficacy of BZs when the field above is either conventionally tilled with autumn ploughing (1992–2002), pastured (May 2003–Apr. 2006) or direct drilled (May 2006– Apr. 2008).

Materials and methods

The effects of 10-metre wide grass buffer zones (GBZs) and buffer zones under natural vegetation (VBZs) on the losses of total solids (eroded material), TP, PP and DRP in surface runoff on a 6-plot clay soil (Vertic Cambisol) were studied for 16 years at Jokioinen, SW Finland (Figure 1). The grass was cut and residue removed annually on the GBZs, whereas scrubs and herbs were not harvested on the VBZs. The results of field plots with GBZ and VBZ were compared with those of 70-m-long and 18-m-wide plots without a buffer zone (NBZs). The field area above the BZs was fairly even, whereas the BZs were on a steep slope (12–18%). The field above the BZs and the slope on the NBZs were ploughed in autumn and barley or oats were sown in spring 1992–2002 (Uusi-Kämpä, 2005). The annually used fertilizer amounts on the cereal field were typical on Finnish farms. The area was grazed by cattle (72, 234 and 128 cow grazing days ha⁻¹ yr⁻¹ in summer 2003, 2004 and 2005 respectively). The grass was killed off with Roundup in Aug. 2005, and barley was direct drilled into grass stubble the following spring. The fertilizer N and P amounts on the field were 150 kg N ha⁻¹, 190 kg N ha⁻¹ and 6 kg P ha⁻¹, 130 kg N ha⁻¹, and

100 kg N ha⁻¹ in 2003, 2004, 2005 and 2006 respectively. After the harvesting of the barley in Aug. 2006, 20 t cattle slurry ha⁻¹ (40 kg N ha⁻¹, 6 kg P ha⁻¹) was surface applied to the field area and to the slope of the NBZs, and after that winter wheat was direct sown.

Surface runoff to a depth of 0.3 m was collected in a modified collector trench designed by Puustinen (1994) at the lower end of each plot. The water volume was measured with a tipping bucket, and representative samples were taken for nutrient analyses (Uusi-Kämppe, 2005). The DRP was determined by a molybdate blue method, using ascorbic acid as the reducing agent (Murphy & Riley, 1962) after filtration (pore size 0.45 µm before 1995, and 0.2 µm since 1995). Surface soil was sampled on the BZs to analyse the concentration of easily soluble phosphorus (P_{Ac}) by the method used in Finland (0.5 M NH₄-acetate–0.5 M acetic acid, pH 4.65; Vuorinen & Mäkitie, 1955).

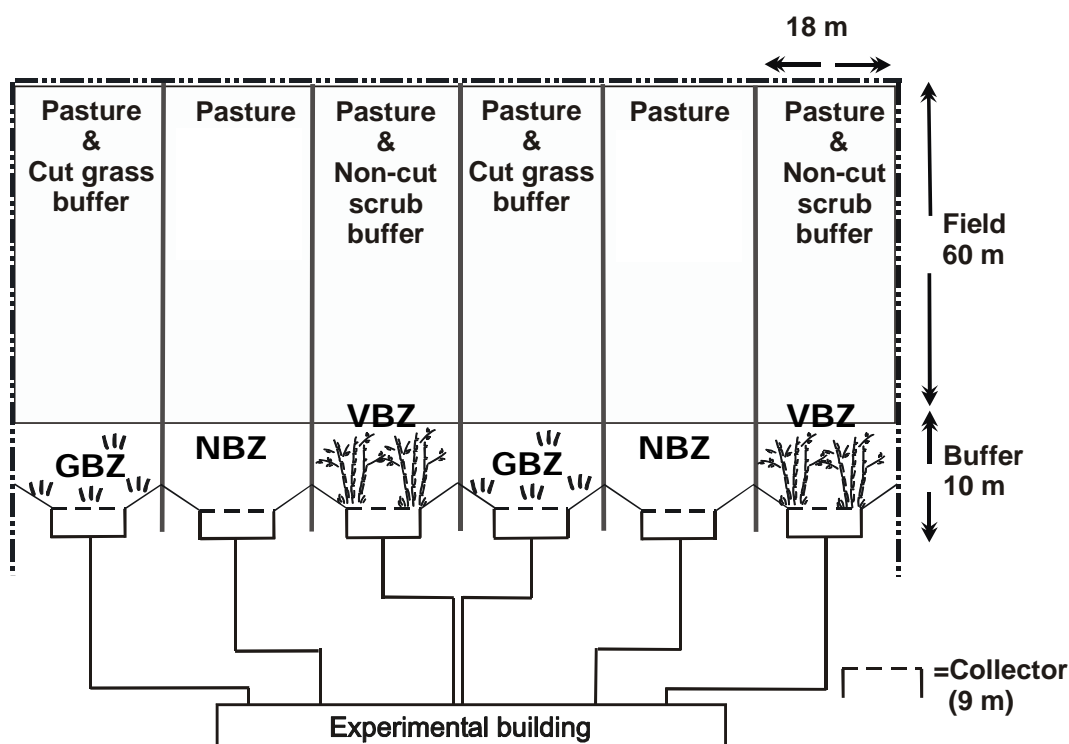


Figure 1. Schematic diagram of the experimental field in 2003–2005.

Results and Discussion

Surface runoff losses

The losses of eroded material and PP declined by half, and the decrease of TP loss was ca 40% in the surface runoff on the GBZs and VBZs compared with those on NBZs in 1992–2002 (Table 1). Instead, the DRP loss was 60% higher on the plots

with the VBZ than on the other treatments. The high DRP loss from the VBZs was most likely due to P leaching from the soil surface and high mass of decaying grass residue on the VBZ during spring runoff (Uusi-Kämpä, 2005; 2006). Also in laboratory experiments, the extraction of TP in plant leachates from the grass of the BZs was high (1.6–3.1 kg ha⁻¹) after three freeze-thaw-cycles, over 90% being as DRP (Uusi-Kämpä, 2007). Thus, at least a part of the high surface runoff DRP losses in spring might have been from the frozen and thawed plants on the VBZ.

On the pasture, the mean annual losses of eroded material and PP to surface runoff were significantly smaller than those on the conventionally tilled field (Table 1). The mean DRP loss was, however, the highest on the pasture. Extremely high DRP losses (0.4–0.9 kg ha⁻¹) were measured in spring runoff in 2003, after a warm and dry autumn. The mean concentrations of DRP were also rather high, over 1 mg L⁻¹, in spring runoff 2003 (Uusi-Kämpä, 2006). After killing the grass in Aug. 2005, high DRP loss (0.6 kg ha⁻¹) was measured the following spring. According to the first results from the direct drilling, there were no clear differences in erosion and nutrient losses among the treatments. The annual surface runoff losses in direct

Table 1. Mean (\pm difference of mean and minimum) annual precipitation, surface runoff, erosion and losses of total P, particle bound P and dissolved reactive P (DRP) on the conventionally tilled field, pasture and direct drilled field.

<i>Treatment</i> (n)‡	<i>Runoff</i> mm yr ⁻¹	<i>Erosion</i> t ha ⁻¹ yr ⁻¹	<i>Total P</i> kg ha ⁻¹ yr ⁻¹	<i>Particle P</i>	<i>DRP</i>
Conventional tillage with autumn ploughing, 1992–2002 (<i>precipitation 660 mm yr⁻¹</i>)					
NBZ (245)	160 \pm 20	1.3 \pm 0.5	1.3 \pm 0.5	1.2 \pm 0.5	0.16 \pm 0.02
GBZ (245)	130 \pm 20	0.6 \pm 0.09	0.8 \pm 0.1	0.6 \pm 0.1	0.16 \pm 0.03
VBZ (245)	140 \pm 20	0.5 \pm 0.1	0.8 \pm 0.08	0.5 \pm 0.07	0.26 \pm 0.02
Pasture, 13 May 2003–8 May 2006 (<i>precipitation 653 mm yr⁻¹</i>)					
NBZ (71)	130 \pm 20	0.26 \pm 0.06	0.9 \pm 0.1	0.3 \pm 0.07	0.59 \pm 0.08
GBZ (72)	120 \pm 20	0.24 \pm 0.03	0.8 \pm 0.03	0.3 \pm 0.03	0.51 \pm 0.01
VBZ (72)	110 \pm 4	0.23 \pm 0.003	0.7 \pm 0.05	0.3 \pm 0.06	0.41 \pm 0.01
Direct drilling, 9 May 2006–17 Apr. 2008 (<i>precipitation 674 mm yr⁻¹</i>)					
NBZ (28)	100 \pm 20	0.40 \pm 0.08	0.7 \pm 0.1	0.5 \pm 0.09	0.20 \pm 0.05
GBZ (28)	100 \pm 10	0.34 \pm 0.02	0.6 \pm 0.02	0.4 \pm 0.01	0.20 \pm 0.01
VBZ (28)	70 \pm 20	0.30 \pm 0.06	0.5 \pm 0.09	0.4 \pm 0.06	0.16 \pm 0.03

‡ Number of sampling dates in parenthesis.

drilling were as small as the losses on the plots with GBZ and VBZ in conventional tillage in 1992–2002 (Table 1). The study of direct drilling continues on the field.

Phosphorus in soil

In the beginning of the study (April 1992), the mean P_{Ac} was 6.8–8.8 mg L⁻¹ at a depth of 0–10 cm on the slope area of the experimental field (Figure 2). Later the P_{Ac} was measured from the surface soil (0–2 cm), and it was on the VBZ two times as high as on the NBZ and GBZ. On the VBZ, some DRP might also have leached from the surface soil. According to Sharpley *et al.* (1986) there is a significant linear relationship between the soil P content of the top 1-cm of surface soil and DRP concentrations in surface runoff from cropped and grassy watersheds. On the NBZ, the soil was fertilized in spring and ploughed in autumn. Due to ploughing the P_{Ac} in surface soil changed seasonally on the NBZ in 1992–2002 (Fig. 2).

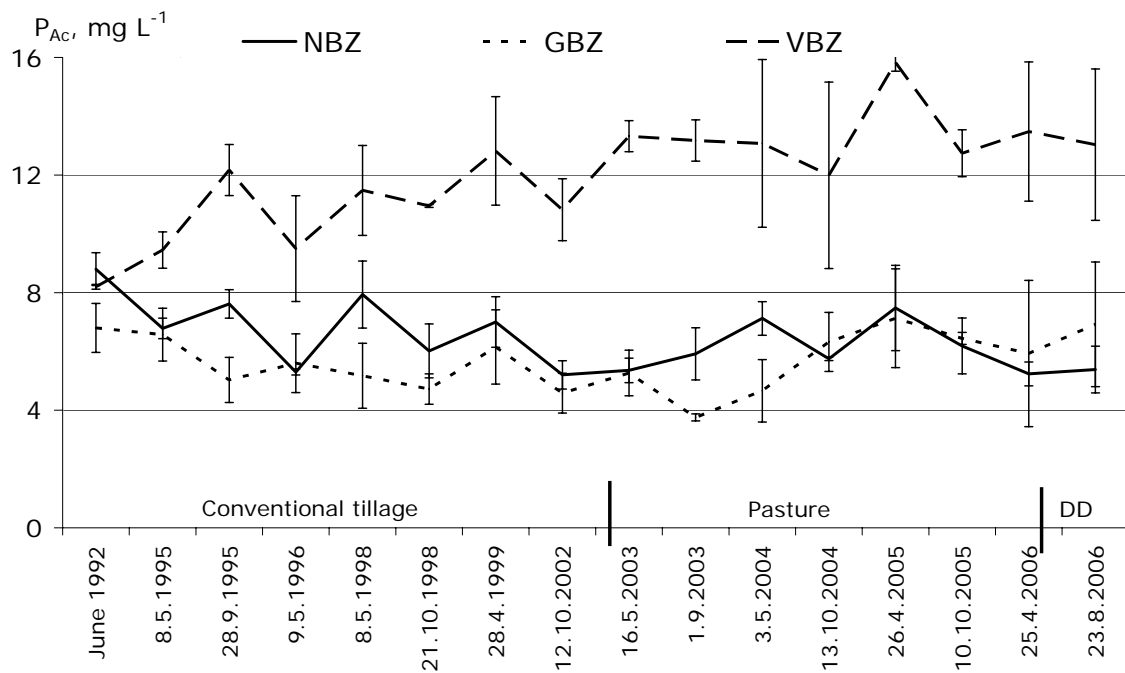


Figure 2. Mean (\pm difference of mean and minimum) concentration of easily available P (P_{Ac}) in the surface soil (0–2 cm) on the slope areas without a buffer zone (NBZ), and with a grass buffer zone (GBZ) and with a vegetated buffer zone (VBZ). The above source area and the slope of the NBZ were conventionally tilled, pastured, and direct drilled (DD) in 1992–2002, 2003–2005, and 2006 respectively. In June 1992, the soil was sampled from a depth of 0–10 cm.

Conclusions

The buffer zones seem to be effective to stop erosion and trap particle bound P in surface runoff from the autumn ploughed clay soil. On pastures, the buffers are not so important, if P fertiliser is not surface applied and the grazing intensity is not too high. However, the high DRP loss to surface runoff may be a real problem on grass fields in spring. The buffers are not able to uptake nutrients in early spring when the runoff is highest. Moreover, part of DRP probably leached from the surface soil and from frozen and thawed grass residue on the BZs. Therefore, innovations are needed for trapping DRP from surface runoff in spring. According to the first results in the direct drilling, the buffer zones are not as important as in the conventional tillage where the fields are normally bare in the winter season. Further results are needed to give recommendations for buffer zones on direct drilled fields.

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