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RETENTION OF AGRICULTURAL SURFACE RUNOFF IN A COLD-CLIMATE VEGETATIVE BUFFER ZONE – EFFECT OF VEGETATION AND SEASON

Vegetasjonssoner i jordbrukslandskapet som rensetiltak for overflateavrenning – Effekt av ulik vegetasjon og årstider

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Abstract

This paper presents an investigation of three vegetative buffer zones (BZ) (10 x 5 m) treating agricultural surface runoff. The experimental full scale BZs were located at Mørdre in south-east Norway. The average retention capacity in BZs (entire experimental period) with only grass and with trees and grass was respectively 33 and 46 % for suspended solids, 34 and 48 % for organic carbon, 23 and 34 % for total P, 28 and 38 % for PO_4^{3}-P, 16 and 31 % for total N, –11 and –2 % for NO_3-N and 7 and 28 % for NH_4-N. With a few exceptions, there was no difference in retention efficiency (%) between the summer and the winter season. Similarly, there was in general no difference with regard to retention efficiency between the two BZs covered with trees and grass and the BZ covered with grass only. The infiltration capacity in the BZs with trees and grass was not significantly different from the BZ with grass only. Nevertheless, due to better infiltration capacity and increased retention efficiency in the root zone, BZs with trees is recommended. For sedimentation to occur, a dense grass cover is crucial as well, thus sparsely planted trees are recommended.

Key words – vegetative buffer zone, agricultural runoff, vegetation cover, cold temperate areas

Sammendrag

Artikkelen presenterer et fullskalaforsøk der renseeffekten i vegetasjonssoner (10 x 5 m) for overflateavrenning er blitt studert. Forsøksanlegget var lokalisert på Mørdre sørøst i Norge. Den gjennomsnittlige renseevnen i vegetasjonssonene (hele forsøksperioden) med henholdsvis bare gress samt med gress og trær var 33 og 46 % for suspendert materiale, 34 og 48 % for organisk materiale, 23 og 34 % for total P, 28 og 38 % for PO_4^{3}-P, 16 og 31 % for total N, –11 og –2 % for NO_3-N samt 7 og 28 % for NH_4-N. Med noen få unntak var det ingen forskjell med hensyn på renseevnen i vegetasjonssonene mellom sommer- og vinterhalvåret. Likeledes var det generelt ingen forskjell med hensyn på renseevne mellom de to vegetasjonssonene med trær og gress og sonen dekket med bare gress. Infiltrasjonskapasiteten var heller ikke significant forskjellig mellom sonen med gress og de to sonene med trær og gress. På grunn av bedre infiltrasjonskapasitet og økt renseevne i rotsonen er likevel vegetasjonssoner med trær anbefalt. Da et tett gressdekke er viktig for sedimentering av suspendert materiale, anbefales det spredt plantede trær.

1 Introduction

Increased intensity in modern agriculture combined with removal of natural buffer systems such as wetlands, small streams and vegetative buffer zones (BZs) along streams, has led to erosion and loss of nutrients from agricultural areas to the watercourses. The result is that runoff and diffuse pollution from agricultural areas constitutes one of the major anthropogenic sources of both nitrogen (N), phosphorus (P) and sediment inputs to surface waters (Borgvang and Tjomsland, 2001; Kronvang et al., 2005; Lyche Solheim et al., 2001). Today the concentration of N and P in inland and coastal waters is in many cases so high that many rivers, lakes and estuaries are impacted to such an extent that a good ecological quality cannot be obtained (Conley et al., 2002; Jeppesen et al., 2003). With increased focus on eutrophication and algae blooms in lakes and rivers, large efforts have been made to find measures aimed at reducing the runoff of nutrients and sediments. Responses in the form of best-management practices such as restrictions on manure spreading, reduced use of fertilizer and reduced tillage during non-growing seasons are necessary but often insufficient measures. In addition there is a widespread reintroduction of buffer systems in the landscape to reduce agricultural nutrient and sediment losses, both at source areas and along different pathways. Vegetative buffer zones along creeks and rivers are one type of buffer system, which is becoming more and more widespread in the modern agricultural landscape (Dillaha et al., 1989; Syversen, 2002a; Uusi-Kämmpä et al., 2000; Vought et al., 1994).

Vegetative BZs are in this case defined as natural vegetation zones between agricultural areas and watercourses. They may be covered with grass or grass in combination with trees. The retention efficiency of BZs depends on local conditions such as climate, soil type, and topography. It also depends on the crop-management of the cultivated areas, i.e., ploughed versus reduced tillage (Uusi-Kampaa, 2008). In addition, design criteria of the buffer zone such as width and vegetation type affect the retention efficiency (Haycock and Pinay, 1993; Sabater et al., 2003; Syversen, 2002a and 2005). In BZs several retention processes interact: deposition of sediments and sediment-bound nutrients, infiltration, sorption of nutrients, uptake of nutrients in the vegetation and microbial degradation. In addition to function as buffers against agricultural runoff, vegetative BZs increase the stability of river banks, increase the biological diversity in the agricultural landscape and function as corridors for wild animals.

Studies investigating the retention efficiency of BZs have mainly been carried out in areas that are climatically different from the cold temperate areas in Norway (e.g., Blanco-Canqui et al., 2006; Borin et al., 2005; Dillaha et al., 1989; Dorioz et al., 2006; Liu et al., 2008; Magette et al., 1989; Osborne and Kovacic, 1993). It was therefore a need to examine the retention efficiency of BZs in Norway where the influence of cold winters and snow melting periods could be included. In southern Norway and other Nordic countries surface runoff and erosion has been documented to be highest during the winter and especially during the snowmelt period (Ahlström and Bergman, 1990; Fiener and Auerswald, 2005; Grønsten et al., 2007; Lundekvam and Skøien, 1998; Syversen, 2002a; Øygarden, 2000). The focus of the field studies in BZs in Norway has so far been on retention processes for P in surface runoff during both summer and winter seasons. The design criteria studied have been the width and the slope of the BZ, the amount of surface runoff entering the BZ and type of vegetation (Syversen et al., 2001; Syversen 2002a, b; 2005).

Vegetation has great impact on retention processes in a BZ. Vegetation with a high stem density will increase the hydraulic roughness and thereby reduce the sediment-carrying capacity of the water entering the BZ. The soil structure tends to be better developed in areas with permanent vegetation, which increases the infiltration capacity. Wooded riparian soils have particularly good infiltration capacities (Lyons et al., 2000). In Norway, the difference in retention efficiency in different types of vegetation has so far only been studied in short-term experiments. More information regarding the effect of type of vegetation on the retention of nutrients and sediments in cold temperate climate was therefore needed, and a project devoted to this topic was started in 2003 at a field research site in south-eastern Norway. This article reports the results from field experiments taking place between 2003 and 2007 (only the first half of the year 2007), where the retention efficiency in BZs of suspended solids and nutrients in surface runoff has been studied.

2 Material and methods

2.1 Field site

The field site Mørdre was established in 1990 about 70 km northeast of Oslo, Norway. The study area was situated at a hillside with an average slope of 14 %. The topsoil (0–10 cm depth) was characterised as leveled silty clay with 44 % clay, 51 % silt, 5 % sand and 1.5 % organic matter. The study area consisted of an upper part with cultivated areas (CA1–CA4, 10 m x 45 m) and a lower part with BZs (BZ1, BZ2 and BZ4, 10 m x 5 m) (figure 1). Below one of the cultivated areas (CA3), there was no BZ, and this area is referred to as the reference field.

In 2003, trees (Aspen, *Populus tremula*) were planted in two of the BZs (BZ1 and BZ4, figure 1). Five trees were planted in each BZ (about 1 tree/10 m^2). The diameter of the trunks was 14–16 cm (measured 1 m above the roots) and the trees were about 4 m tall when planted. The vegetation in the BZs consisted otherwise of various local grass and herbs.

The cultivated areas (CA1–CA4) were sown with barley in May 2004, oat in May 2005 and again barley in May 2006. The cultivated areas were added fertilizer and pesticides, and harrowed during the fall. Every cultivated area and corresponding BZ were surrounded by a low plastic fence (20 cm above the surface and 10 cm into the soil), separating each area from its neighbour areas in order to minimize transport of water from one area to another.

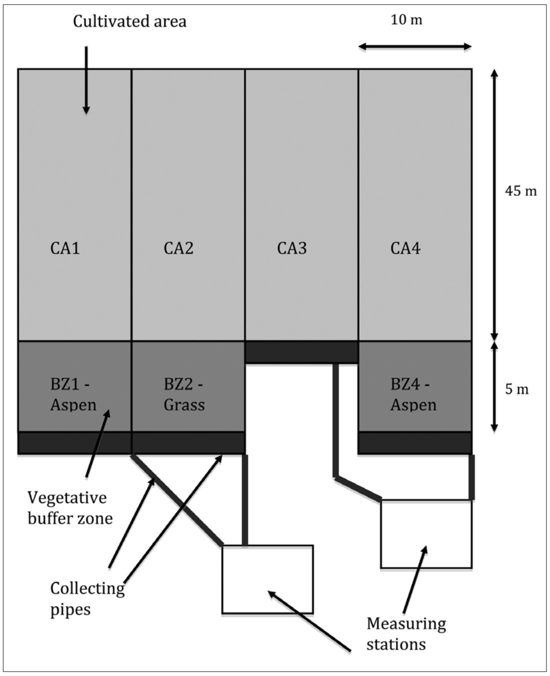

Figure 1. *Presentation of the field site at Mørdre with the four cultivated areas (CA1– CA4) and the three buffer zones (BZ1, BZ2 and BZ4).*

2.2 Water samples

The surface water from the BZs and the reference field were collected in pipes and led to a tipping bucket system inside a measuring station (figure 1). The tipping number was registered on a data logger and discharges were calculated. Volume proportional mixed samples were taken after every runoff event or as frequently as one or two times a day during the snow-melting period. The water samples were analysed for suspended solids (SS), organic carbon (orgC), total nitrogen (totN), nitrate (NO_3^-), ammonium (NH_4^+), total phosphorus (totP) and phosphate (PO_4^{3-}). The water samples were analysed according to Norwegian standards (NS): SS and orgC (NS 4733), totP (NS 4725), PO_4^{3-}-P (NS 4724), totN (NS 4743), NO_3^--N and NH_4^+-N (Traacs auto analyser).

2.3 Calculation of retention efficiency

The retention efficiency of the BZ was calculated as the difference between the amount of nutrients and suspended solids in the water into and out of the BZ. The amounts were calculated by multiplying concentrations of suspended solids and nutrients with the amount of surface runoff, summed over a runoff event. The water samples from the reference field represent the inlet sample to the BZs, while the water samples from the BZs represent the outlet samples. Despite equal area, soil type and slope for the four cultivated fields (CA1-CA4), the runoff from these areas differed. Thus in order to use the water samples from the reference field as input values to the BZs, a correction was needed. Runoff from the four cultivated areas was thus compared in the period of June 2003 to August 2004. The correlation between runoff from the areas CA1, CA2 and CA4 and runoff from the reference field CA3 differed for small and large runoff episodes. Thus two sets of linear regression models will be used to calculate runoff into the BZs:

$$QCA1 = 0.625 * QCA3 - 0.305,\ R^2 = 0.9937,\ \text{runoff episodes} > 5\ \text{mm}$$

$$QCA1 = 0.412 * QCA3 + 0.083,\ R^2 = 0.9007,\ \text{runoff episodes} < 5\ \text{mm}$$

$$QCA2 = 0.361 * QCA3 - 0.252,\ R^2 = 0.9944,\ \text{runoff episodes} > 2\ \text{mm}$$

$$QCA2 = 0.230 * QCA3 + 0.028,\ R^2 = 0.6290,\ \text{runoff episodes} < 2\ \text{mm}$$

$$QCA4 = 0.527 * QCA3 + 0.060,\ R^2 = 0.9952,\ \text{runoff episodes} > 3\ \text{mm}$$

$$QCA4 = 0.363 * QCA3 + 0.109,\ R^2 = 0.6921,\ \text{runoff episodes} < 3\ \text{mm}$$

QCA3 represents the measured runoff out of the reference field CA3, while QCA1, QCA2 and QCA4 represent the calculated runoff into the bufferzones BZ1, BZ2 and BZ4. The summer period referred to in this article lasts from May throughout October and the winter period lasts from November throughout April.

2.4 Calculation of infiltration

The infiltration within the BZ was calculated as the difference between the calculated runoff into the BZ and the measured runoff out of the BZ.

2.5 Statistical analysis

Statistical analysis (*t*-test, ANOVA and Tukey-Kramer at $P < 0.05$) was carried out. The *t*-test was used to find significant differences in the removal efficiency of the various chemical parameters with regard to seasons. ANOVA and Tukey-Kramer were used to find significant differences in the removal efficiency of the various chemical parameters with regard to type of vegetation in the BZs. The statistical program used was JMP5 (The Statistical Discovery Software, SAS Institute Inc., USA).

3 Results

3.1 Precipitation and surface runoff

The yearly average temperature for the nearby weather station Vandsemb was 5.2, 5.4, 5.8 and 5.8 °C for the years 2003–2006, respectively (normal temperature for 1961–1990 was 4,2 °C). The yearly total precipitation at the weather station Vandsemb was 722, 789, 679 and 921 mm for the years 2003–2006, respectively (yearly total precipitation for 1961–1990 was 670 mm).

During the experimental period, about 60 % of the yearly precipitation fell during the summer period (May to October), while 60 to 93 % of the yearly surface runoff took place during wintertime (November to April). In general, 13 to 62 % of the precipitation during wintertime turned into surface runoff, while the corresponding numbers for the summer season was 0.2 to 10 %.

3.2 Concentration of suspended solids and nutrients in surface runoff from cultivated areas

The concentration of suspended solids, PO_4^{3}-P and particulate P (defined as the difference between total P and PO_4^{3}-P) in the surface runoff from the reference field (CA3) for each runoff episode is presented in figure 2a, c and e. The total amount of these compounds lost from the reference field (CA3) for each runoff episode is presented in figure 2b, d and f. The total amount of each compound is equal to the concentration in the runoff multiplied with the amount of runoff. As figure 2a and b shows, there were more runoff episodes during the examined winter periods than during the summer periods. However, runoff episodes with high concentration of suspended solids were observed both during the summer and the winter seasons. Actually, the highest concentration of suspended solids in the runoff was measured during the summer of 2004 (6600 mg/l). The highest amount of suspended solids lost during one runoff episode was measured during the winter of 2005/2006 (39 kg). The concentration of organic carbon in the runoff as well as the amount of organic carbon lost from CA3 for each runoff episode followed the same pattern as for suspended solids, but the numbers were lower (results not presented). The highest concentration of organic carbon measured in the runoff from CA3 was 460 mg/l (summer 2004), while the highest amount of organic carbon lost from CA3 during one runoff episode was measured to be 3 kg (winter 2005/2006).

The runoff of PO_4^{3}-P and particulate P from CA3 also varied a lot, and high concentrations in the runoff was measured both during the winter and the summer seasons. During previous field experiments at the same site, particulate P was found to be the main P-compound in the runoff. Due to Syversen (1997) as much as 89 % of total P in the runoff occurred as particulate P. In the field experiment presented in this article, substantial amounts of total P in the runoff occurred as PO_4^{3}-P (figure 2c-f). During the first years with field experiments at the site, the soil was not cultivated. During this experimental period, however, the areas were used for cultivating grains and fertilizers were added. This could have led to an increase in the runoff of PO_4^{3}-P.

Nitrogen in the runoff from CA3 was mainly present as NO_3-N and organic N (defined as the difference between total N and NO_3-N and NH_4-N) (figure 3a–d). The concentration of NH_4-N in the runoff was negligible (results not presented). The highest concentrations of NO_3-N in the runoff were measured during the summer period, up to 30 mg/l during the summer of 2006. High concentrations of NO_3-N in the runoff during summer were probably due to use of fertilizers. High concentrations of organic N in the runoff were measured both during the summer and the winter seasons. The concentration of organic N in the runoff as well as the loss of organic N, were closely related to the concentration and loss of suspended solids (figure 2a–b and figure 3c–d).

3.3 Retention within the BZs based on runoff episodes

Figure 4 and figure 5 present the amount of suspended solids, organic carbon, total P, PO_4^{3}-P, total N, NO_3-N, NH_4-N, respectively, retained within the BZs for each runoff episode. Each point at the graph represents one runoff episode. Negative values represent a net loss from the BZ during a specific runoff episode.

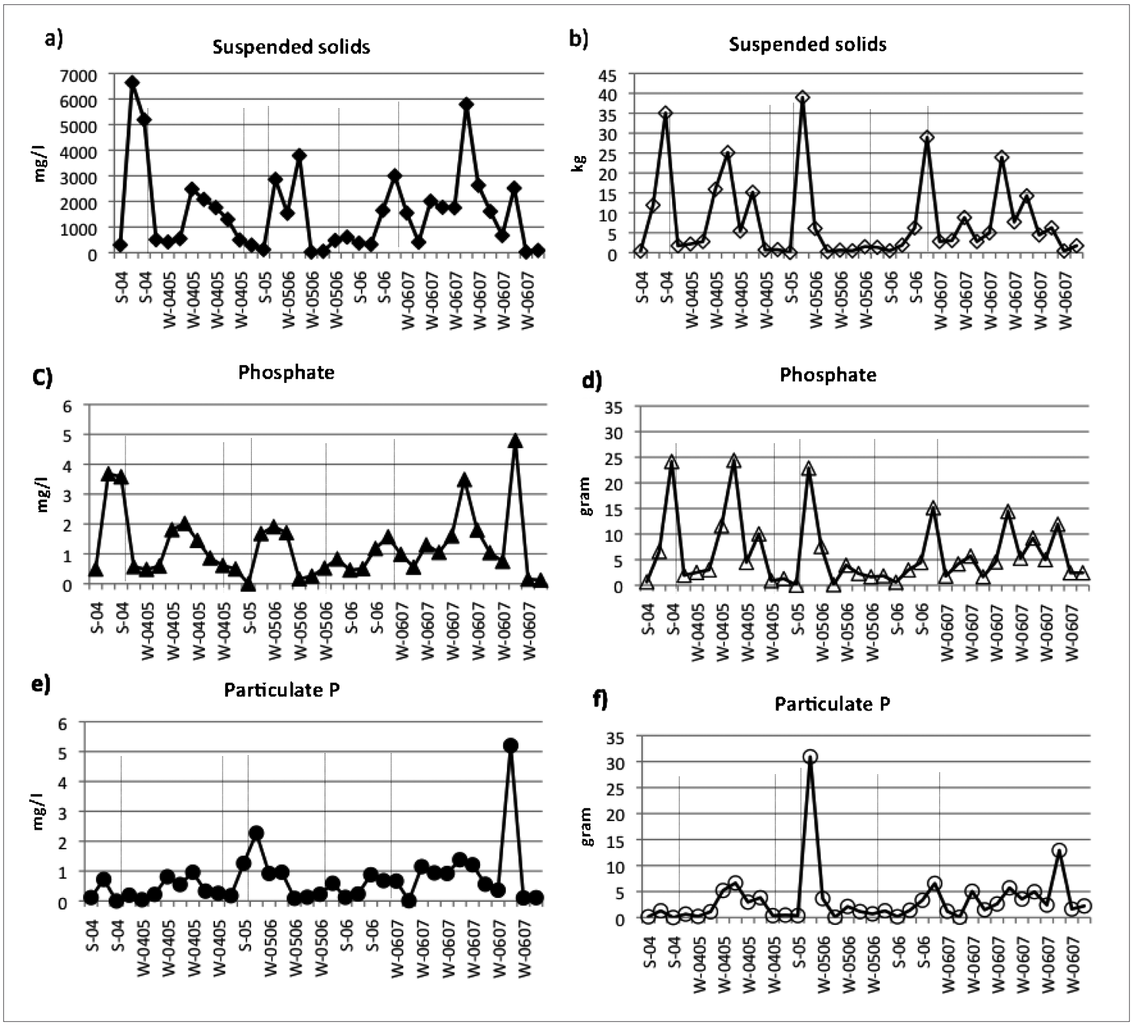

Figure 2. *Runoff of suspended solids (a and b), PO_4^{3}-P (c and d) and particulate P (e and f) from the reference field (CA3) during the entire experimental period, where each point at the graph represents one runoff episode. Each parameter is presented both as the concentration (mg/l) in the runoff as well as the total amount (g or kg) lost from CA3 per runoff episode. The dotted vertical lines divide the graph into summer (S) and winter (W) periods.*

The runoff episodes show considerably variation with regard to retention of suspended solids and nutrients. There is a high retention during some runoff episodes, almost no retention during some episodes and loss of suspended solids and nutrients during some episodes. It is only during a few runoff episodes that the net loss of suspended solids is of any significance. Runoff episodes with high retention occur both during summer and winter, this is valid for both suspended solids and nutrients. The maximum amount retained/lost within one runoff episode is 18 kg (winter) /–7 kg (winter) suspended solids, 1,3 kg (winter) /–0,8 kg (winter) organic carbon, 19 g (winter) / –3 g (summer) total P, 11 g (summer) / –2 g (summer) PO_4^{3}-P, 34 g (summer) / –12 g (summer) total N, 34 g (summer) / –9 g (summer) NO_3-N, 5 g (summer) / –0,5 g (winter) NH_4-N.

During the entire experimental period, each BZ had a total retention of suspended solids between 100 and 88 kg. The total amount of organic carbon retained within each BZ was between 6,7 and 6,2 kg (table 1). The total retention of total N was greater than the total retention of total P, 170 to 227 g versus 84 to 77 g for each BZ, respectively (table 1). Regarding the soluble nutrients, the total retention was highest for PO_4^{3}-P,

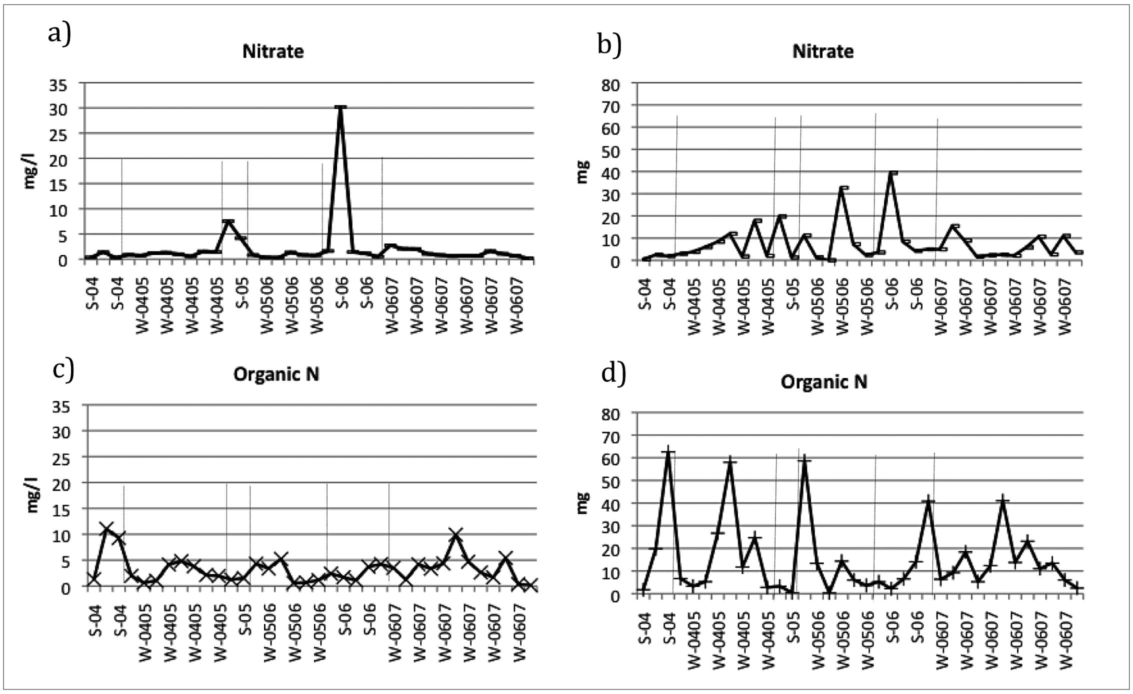

Figure 3. *Runoff of NO_3-N (a and b) and organic N (c and d) from the reference field (CA3) during the entire experimental period, where each point at the graph represents one runoff episode. Each parameter is presented both as the concentration (mg/l) in the runoff as well as the total amount (g) lost from CA3 per runoff episode. The dotted vertical lines divide the graph into summer (S) and winter (W) periods.*

while the total net loss was highest for NO_3-N (table 1). Ammonium and PO_4^{3-} adsorb to clay particles already settled in the BZ, while NO_3^- does not adsorb to particles and is easily washed out of the BZ.

3.4 Retention efficiency – average

The yearly average retention efficiency of the BZs varied substantially (figure 6). This clearly shows how important it is to have a sufficiently long time series. Runoff episodes with low retention or net loss of suspended solids and nutrients caused low retention efficiency during some years. According to figure 6, the retention efficiency of NO_3-N and NH_4-N showed highest variation.

3.5 Retention efficiency – summer versus winter

The average retention efficiency (%) during the summer compared to the winter is presented in table 2. The two first columns of the table present all data, and except for total P, no significant difference between the summer and the winter periods with regard to any of the parameters are seen. For total P, the retention was significantly higher during wintertime compared to summertime. The next two columns compare the retention efficiency during the winter and summer periods for the BZ with only grass (BZ2). No significant difference between the summer- and winter period was found for any

Table 1. *The net amount of suspended solids and nutrients retained within (positive numbers) and lost from (negative numbers) the BZs at Mørdre throughout the entire experimental period.*

		SS kg	orgC g	totP g	PO_4^{3}-P g	totN g	NO_3-N g	NH_4-N g
BZ2	Retention	100	6664	84	65	170	27	10
Grass	Loss	–12	–1313	–2	–1	–15	–28	–2
BZ1 and BZ4 (average)	Retention	88	6190	77	64	227	65	17
Grass with few trees	Loss	–2	–115	–4	–2	–18	–35	–1

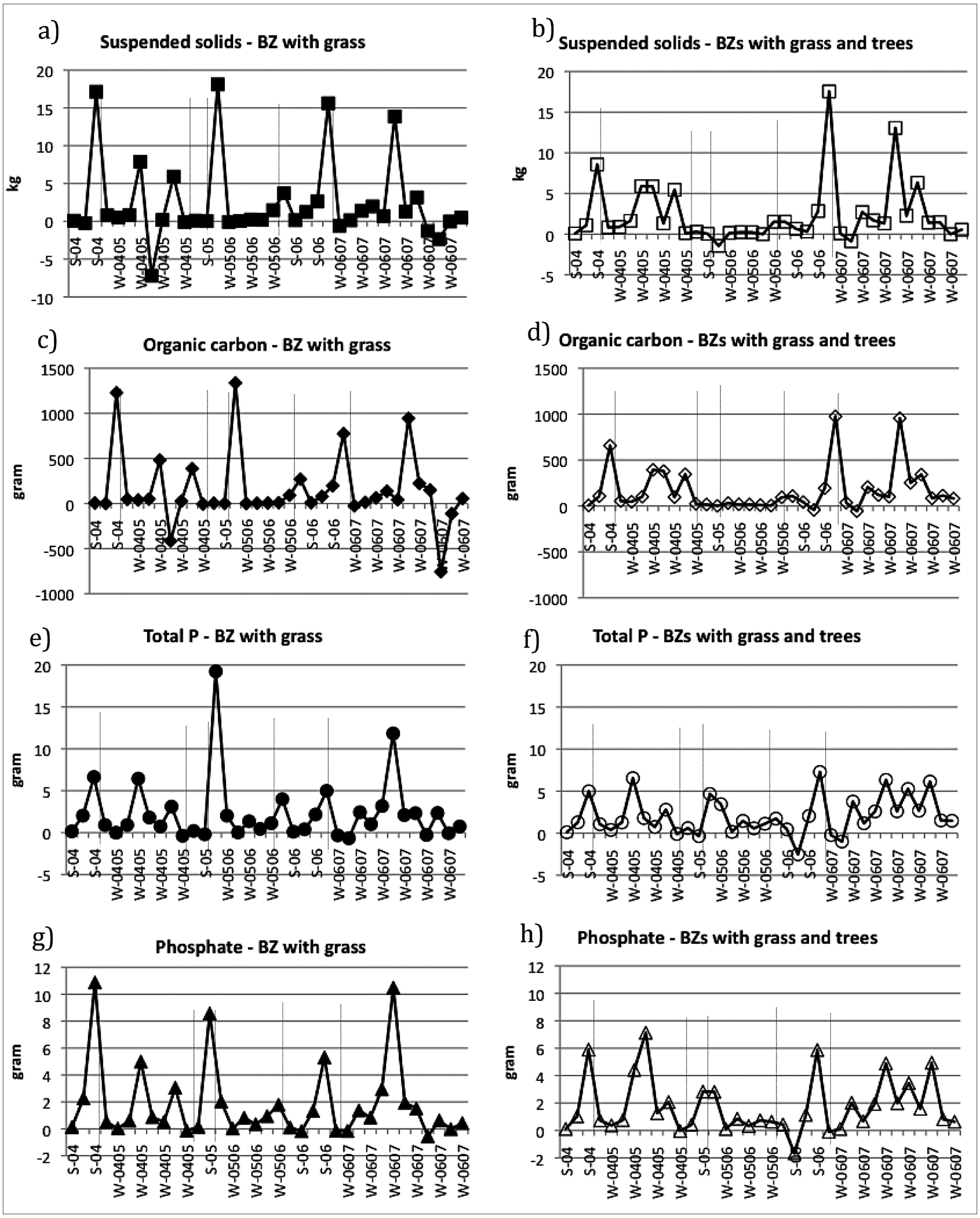

Figure 4. *Retention/loss of suspended solids (kg) as well as organic carbon, total P and PO_4^{3}-P (g) in/from the buffer zones during the entire experimental period, where each point at the graph represents one runoff episode. The results for BZ2 (grass) is presented in a, c, e and g, while the results (average) for BZ1and BZ4 (grass and trees) is presented in b, d, f and h. Positive numbers indicate retention within the BZ, while negative numbers indicate loss from the BZ. The dotted vertical lines divide the graph into summer (S) and winter (W) periods.*

Table 2. *Average retention (%) of suspended solids and nutrients for the summer and winter periods. Negative numbers indicate loss of suspended solids and nutrients from the BZs.*

	All data (BZ1, BZ2 and BZ4)		BZ2 (grass)		BZ1 and BZ4 (grass with few trees)	
	Summer	Winter	Summer	Winter	Summer	Winter
SS	57^{A}	38^{A}	61^{A}	27^{A}	55^{A}	43^{A}
orgC	46^{A}	36^{A}	49^{A}	12^{A}	44^{A}	48^{A}
totP	11^{B}	34^{A}	24^{A}	23^{A}	4^{B}	40^{A}
PO_4^{3}-P	24^{A}	37^{A}	33^{A}	28^{A}	19^{B}	41^{A}
totN	16^{A}	28^{A}	29^{A}	14^{A}	9^{B}	35^{A}
NO_3-N	4^{A}	-6^{A}	23^{A}	-17^{A}	-6^{A}	-1^{A}
NH_4-N	27^{A}	19^{A}	27^{A}	2^{A}	27^{A}	28^{A}

Different letters for the summer and winter periods indicate that the retention (%) for a given compound was significantly different. Similar letters indicate no significant difference.

of the parameters. The last two columns of table 2 compare the summer and winter period for the two BZs with trees and grass (BZ1 and BZ4). In this case there was a significantly higher retention of total P, PO_4^{3}-P and total N during wintertime compared to summertime.

Due to greater density of the vegetation and uptake of nutrients in the vegetation during summertime, higher retention efficiency was expected for this season. For total P, high retention efficiency during winter may, however, be explained with a high runoff intensity, which detach larger particles from the soil, which are more easily settled in the BZs (Syversen, 2003).

3.6 Retention efficiency – BZ with grass versus BZs with grass and trees

The average retention capacity in the BZs (entire experimental period) with grass only and with trees and grass was respectively 33 and 46 % for suspended solids, 34 and 48 % for organic carbon, 23 and 34 % for total P, 28 and 38 % for PO_4^{3}-P, 16 and 31 % for total N, –11 and –2 % for NO_3-N and 7 and 28 % for NH_4-N. The retention capacity is highest for suspended solids and organic carbon, second best for total P and PO_4^{3}-P and lowest retention capacity was found for the nitrogen compounds.

In general, the retention efficiency (%) was not significantly different for the two types of BZs. There were some exceptions, however. During winter time, there was a significantly lower retention efficiency of total P, total N and NH_4-N in the BZ with only grass compared to one or both of the BZs with trees and grass (table 3). When data from both the summer and winter periods are regarded together, there was also a significantly lower retention efficiency of NH_4-N in BZ2 with grass compared to BZ4 with trees and grass.

Table 3. *Average retention (%) of suspended solids and nutrients for the three BZs. Negative numbers indicate loss of suspended solids and nutrients from the BZs.*

	All data			Summer			Winter		
	BZ1 (trees and grass)	BZ4 (trees and grass)	BZ2 (grass)	BZ1 (trees and grass)	BZ4 (trees and grass)	BZ2 (grass)	BZ1 (trees and grass)	BZ4 (trees and grass)	BZ2 (grass)
SS	48^{A}	43^{A}	33^{A}	61^{A}	50^{A}	61^{A}	45^{A}	42^{A}	27^{A}
orgC	49^{A}	46^{A}	34^{A}	49^{A}	39^{A}	49^{A}	49^{A}	48^{A}	31^{A}
totP	33^{A}	35^{A}	23^{A}	9^{A}	$-0{,}3^{A}$	24^{A}	38^{AB}	42^{A}	23^{B}
PO_4^{3}-P	39^{A}	37^{A}	28^{A}	32^{A}	7^{A}	33^{A}	41^{A}	35^{A}	34^{A}
totN	32^{A}	30^{A}	16^{A}	23^{A}	$-4{,}5^{A}$	29^{A}	33^{A}	37^{A}	14^{B}
NO_3-N	11^{A}	-14^{A}	-11^{A}	24^{A}	-35^{A}	23^{A}	8^{A}	-9^{A}	-17^{A}
NH_4-N	22^{AB}	34^{A}	7^{B}	23^{A}	31^{A}	27^{A}	22^{AB}	34^{A}	2^{B}

Different letters indicate that the retention efficiency (%) for a given chemical component is significantly different between the BZs. Similar letters indicate no significant difference.

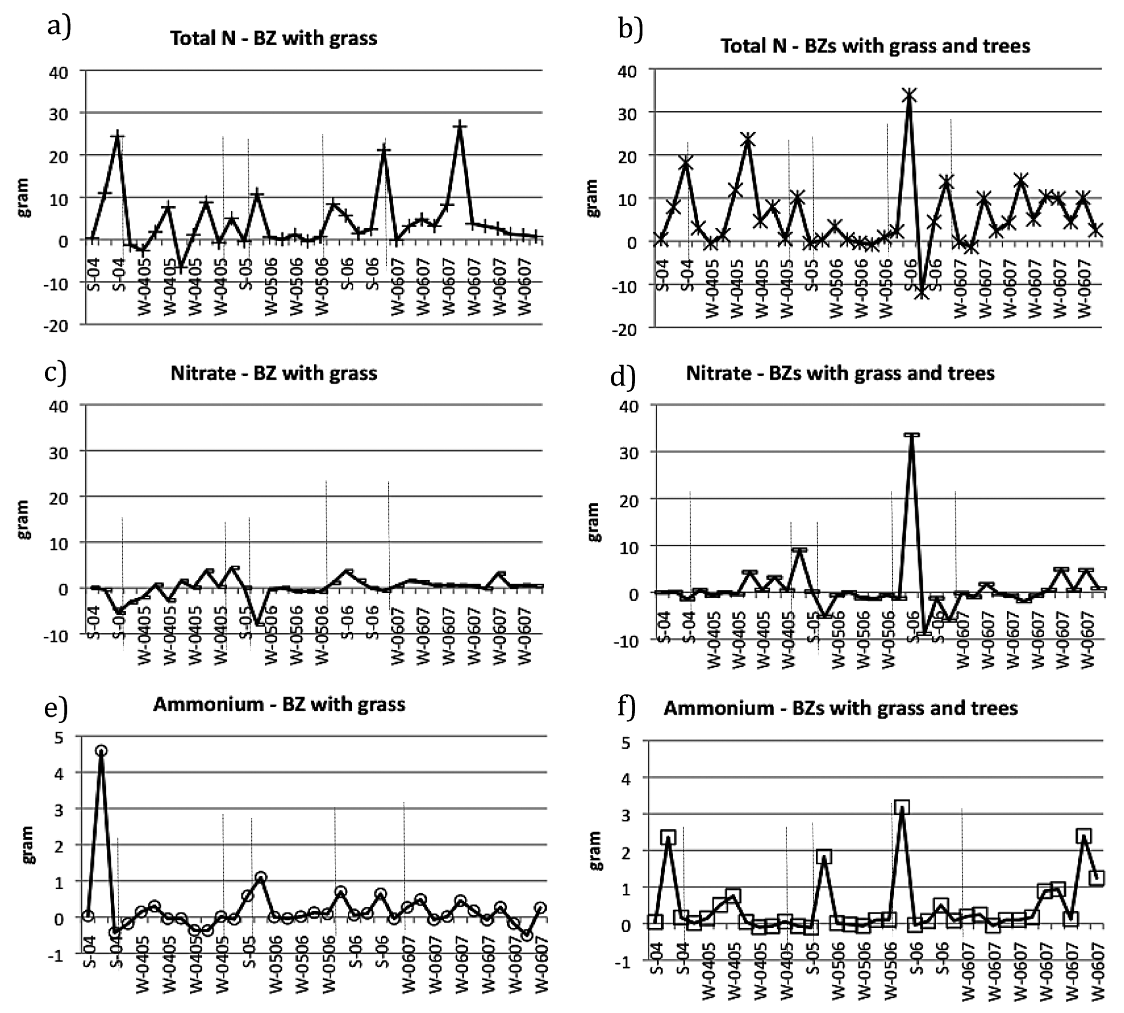

Figure 5. *Retention/loss of total N, NO_3-N and NH_4-N (g) in/from the buffer zones during the entire experimental period, where each point at the graph represents one runoff episode. The results for BZ2 (grass) is presented in a, c and e, while the results (average) for BZ1and BZ4 (grass and trees) is presented in b, d and f. Positive numbers indicate retention within the BZ, while negative numbers indicate loss from the BZ. The dotted vertical lines divide the graph into summer (S) and winter (W) periods.*

3.7 Infiltration

The infiltration capacity within the BZs varies substantially between the runoff episodes. Given as percentage of the surface runoff, the infiltration varies between 0 and 100 %.

The infiltration capacity in the BZs with trees and grass was not significantly different from the BZ with only grass. This was valid whether all the data was regarded together or if the summer- and winter season was treated separately (table 4). There was not found any difference between the summer and winter season with regard to infiltration (table 5).

Table 4. *Average infiltration (%) in the three buffer zones. Infiltration is defined as the percentage of the surface runoff from the cultivated area that infiltrates within the BZ during one surface runoff episode.*

	BZ1 (trees and grass)	BZ4 (trees and grass)	BZ2 (grass)
All data	29^A	18^A	31^A
Summer	22^A	19^A	14^A
Winter	30^A	18^A	34^A

Different letters indicate that the infiltration is significantly different between the three BZs. Similar letters indicate no significant difference.

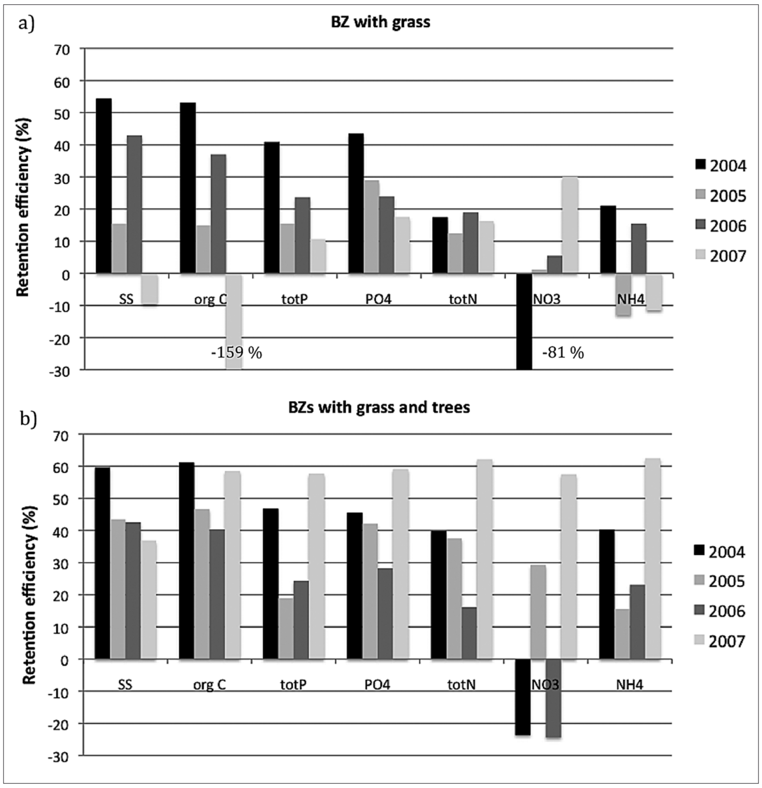

Figure 6. *Yearly average retention efficiency (%) for the buffer zone with grass (BZ2), and the two buffer zones with trees and grass (BZ1 and BZ4) (average). For the year 2004 only the autumn is considered, while for the year 2007, only the winter and the snowmelting period in spring are considered.*

4 Discussion and conclusions

The presented results from the field experiments at Mørdre during the period of 2004–2007 suggest that the retention efficiency in vegetative BZs receiving surface runoff is not improved by planting some sparsely separated trees compared to keeping the zone covered with only grass.

Sedimentation and infiltration in the BZ are the two most important retention mechanisms when it comes to surface runoff. The physical process of sedimentation has for instance, been shown to account for P retention rates of 128 kg P ha^{-1} yr^{-1} (Hoffmann et al., 2009). Thus for trees to have a positive effect on the retention efficiency in a BZ, either the sedimentation rate or the infiltration rate should be improved. It is most reasonable to believe that a deep and extensive root system will increase the infiltration rate of the soil in the BZ. The reason that the BZs with trees did not have a higher infiltration capacity than the BZ with grass in the presented study from Mørdre, could be that the trees at the site need longer timer in order to develop an extensive root system, or that the vegetation was too sparse to develop an extensive root system.

Previous field studies focusing on BZs with different vegetation have shown that BZs covered with forest have a high infiltration capacity (Lyons et al., 2000). In a previous field experiment in Norway consisting of short trials with surface runoff, it was reported about higher retention of suspended solids and total N in a forest covered BZ compared to a grass covered BZ (Syversen, 2005). This was explained with a high infiltration capacity in the moss that covered the ground in the forest. Regarding total P (which occurred mainly as dissolved

Table 5. *Average infiltration (%) during the summer and winter seasons. Infiltration is defined as the percentage of the surface runoff from the cultivated area that infiltrates within the BZ during one surface runoff episode.*

	Summer	Winter
All data	18^{A}	28^{A}
BZ2 (grass)	18^{A}	32^{A}
BZ1&BZ4 (trees and grass)	19^{A}	18^{A}

Different letters indicate that the infiltration is significantly different between the summer and winter season. Similar letters indicate no significant difference.

P), there was no difference in the retention between BZs with grass and BZs with trees (Syversen, 2005). Lowrance and Sheridan (2005) suggest that a combination of a managed forest and a grass BZ is an effective system for retaining nutrients and particles. Results from Schoonover et al. (2004) suggest that both giant cane and forest vegetation are good candidates to incorporate into riparian buffer zones in southern Illinois as well as in other regions with similar climatic and physiographic conditions.

In a previous lysimeter experiment with columns (length: 0.5 m; radius: 0.5 m) planted with either trees or grass, the retention capacity of the root zone of a BZ was studied (Søvik and Syversen, 2008). The soil in the columns with trees had better retention efficiency then the soil in the columns with only grass. The results from the column experiment might be due to a better uptake of nutrients in trees compared to grass. Haycock and Pinay (1993) found a better retention of NO_3^- in the groundwater below a BZ with trees than below a BZ with grass. Contrary results, i.e., more NO_3^- removed in the groundwater below a BZ with grass than below a BZ with trees has been reported by Groffman et al. (1991), Lowrance et al. (1995) and Schnabel et al. (1996). In the experiments of Lowrance et al. (1995), relatively young trees may have led to low denitrification rates in the soil below the forest covered area.

Thus the presence of trees in vegetative BZs has, in most cases of the investigations reported above, a positive effect on the retention capacity of the zone. The water percolating through the root zone of a BZ with trees will in most cases be better cleaned than the water percolating through a root zone of a BZ covered with only grass. It is, however, important to also keep a dense vegetation of grass in the BZs, in order for an efficient sedimentation process to occur. Therefore trees in BZs should be planted with an adequate distance. A vegetation cover including trees will also improve the other ecological functions of BZs such as improved landscape esthetics, improved shade conditions in watercourses and shelter for animals leading to increased biodiversity.

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