COST Action 869

Mitigation options for nutrient reduction in surface water and groundwaters

WG3 - Mitigation options

Abstracts of the workshop

Mitigation options: framework, effectiveness, and interactions

27th - 29th November 2007

North Wyke, Devon, UK

Local organizers

Phil Haygarth and Linda Jewell

Updated version, see next page

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Updates when compared to printed version, distributed at workshop:

- **abstract Rubaek changed,**
- **abstract Haygarth added,**
- **abstract Sileika removed (presentation skipped),**
- **poster abstracts Bulmer, Freer, Fuentes, Hodgson, Van Bakel, and Van der Salm added.**

Contents

MEETING of COST 869 Working Group 3, Devon, UK,
27-29 November 2007

AGENDA

Session	Title
1	Introductions
2	Mitigation options: Special Cases
3	Field visit
4	Building a framework where different mitigation options fit in
5	Posters
6	Closing and conclusions

	Tuesday 27 November 2007
14:00 – 14.05	Welcome and some general announcements
	1. Introductions
14:05 – 14:35	HU - Peter Csathó Regulation the phosphorus turnover through the nitrate directive in the European Union: a shameful anachronism in the 21st Century
14:35 – 15:05	FI - Eila Turtola Finnish trends in P balances, soil test P, and other factors behind agricultural P load to surface waters during the Agri-Environmental Programmes
15:05 – 15.35	SE - Barbro Ulén Phosphorus from farmland to water in Sweden
15:35 – 16.00	*Tea and Coffee*
	2. Mitigation options: Special Cases
16:00 – 16:30	UK - John Quinton Mitigation options for phosphorus and sediment (MOPS): Overview and results of the first two years
16:30 – 17:00	BE - Charles Bielders Effects of destruction and burial dates of cover crops on runoff, erosion and P losses in a maize cropping system
17:00 – 17.30	FR - Chantal Gascuel Diagnosis and mitigation at different scales in France
17:30 – 17.40	DE - Ralph Meissner A plan of management possibilities to secure good ecological status of water resources – an essential basis to develop River Basin Management Plans [short presentation]
17:40 Closing	
19.00 – 20.30	*Dinner at hotel*
20.30 – 22.00	**Meeting Management Committee (in hotel)**

Wednesday 28 November

08. 30 – 11.30	**3. Visit Research Station**
11:30 – 12.00	*Tea and Coffee*
	2. *(Continued)* **Mitigation options: Special Cases**
12:00 – 12.30	IE – Karl Richards A review of diffuse agricultural pollution control in Ireland: recent research and current legislation
12.30 – 13.30	*Lunch*
	4. Building a framework where different mitigation options fit in
13:30 – 14.00	NL – Gert-Jan Noij Dutch Framework for P mitigation options and their cost-effectiveness
14:00 – 14.30	UK – Phil Haygarth Integrated approaches for mitigation control - one example from England and Wales
14:30 – 15.00	DK - Gitte Rubaek Danish efforts to mitigate phosphorus losses from agriculture to surface waters
15:00 – 15:30	*Tea and Coffee*
	4. Building a framework where different mitigation options fit in
15:30 – 15.45	NL – Wim Chardon Outcome of the inventory among COST partners regarding potential effective mitigation options in the EU in relation to the WFD
15:45 – 16.45	Discussion groups
16:45 – 17:30	Plenary session. Discussion of the outcome and overall conclusions
Evening	*Social Event*

Thursday 29 November

	2. *(Continued)* **Mitigation options: Special Cases**
09:00 – 09:30	DE - Klaus Isermann Protection spheres/goods and setting there aims/nutrient standards for C, N, P, S with special reference to the anthroposphere within the nutrition system and human health
09:30 – 10:00	UK – Marc Stutter The effects of mixed measures of best management practice and habitat restoration on stream water nutrients at a whole catchment scale (The Tarland catchment, NE Scotland)
10:00 – 10.30	CZ - Josef Hejzlar Phosphorus retention in semi-natural and modified reaches of agricultural streams
10.30 – 11.00	*Tea and Coffee*
11:00 – 12.00	**5. Poster session with short (5 min) explanation by the authors**
12.00 – 12.15	**6. Closing session** Conclusions of the meeting
12.15	*End of the meeting*

Abstracts of oral presentations - Presenting author, title page

Abstracts of poster presentations - First author, title page

ABSTRACTS OF ORAL

PRESENTATIONS

Regulating the phosphorus turnover through the nitrate directive in the European union: a shameful anachronism in the 21st century

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In spite of the fact that nitrogen behaves in the soil and in the environment sharply differently than phosphorus (i.e. excess nitrogen can move down in the soil profile quite freely and threatens predominantly the underground waters, while the majority of excess phosphorus is fixes in the plough layer and threatens the surface waters through erosion and surface runoff), the phosphorus issue is regulated in the European Union through the Nitrates Directive. Thus, the must of elaborating and implementing the EU Phosphates Directive is an inevitable, and urgent task. The aim of this presentation is to evaluate the nitrogen and phosphorus turnover in the EU in the first 15 years since the European Union passed the Nitrates Directive, aimed at protecting surface and subsurface waters in EU countries. It is therefore worth reviewing the progress made in recent years in achieving the aims of this major agricultural and environmental regulation. A comparison of changes in the nitrogen (N) and phosphorus (P) balances of the EU15 and NEU12 countries and in the P supplies of the soils over the last 15 years will be used for this purpose. Calculating P balances and evaluating the soil phosphorus status in the Central and Eastern European (CEE) countries was initiated in the frames of the COST 832 Action.

The negative NP balances and worsening NP status in the CEE countries, including those which have recently joined the EU (NEU12), may result in increasingly low yields and in economic and agronomic problems. These trends are in sharp contrast to past practices in some of the EU15 countries, where strongly positive NP balances and oversupplies with NP may lead to environmental and ecological threats.

Co-operation within the European Union should help to solve both the environmental threat facing the Western part of the community, and the agronomic and economic problems in the Central and Eastern part.

Improving the Nitrates Directive and forbidding derogations against the maximum 170 kg ha^{-1} N $year^{-1}$ through manure and slurry (i.e. in organic form) for the EU27 countries and administrative EU regions with the highest livestock densities is also a must for effective agro- environmental protection practice in the EU.

Finnish trends in P balances, soil test P and other factors behind agricultural P load to surface waters

Eila Turtola[1], Risto Uusitalo[1], Juha Grönroos[2], Riitta Lemola[1], Tapio Salo[1], Petri Ekholm[2], Markku Puustinen[2] and Katri Rankinen[2]

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Soil test P concentration has a major influence on the dissolved P concentration in runoff from agricultural soils. Thus, trends in soil test P partly determine the development of pollution potential of agricultural activities. We reviewed the changes in soil test P and P balances in Finnish agriculture and assessed the current development of P loss potential after two Agri-Environmental Programmes (AEP) since 1995. AEP has covered up to 95% of the cultivated field area and included restrictions of the P use in both chemical fertilizers and animal manures. Meanwhile, after Finland joined EU in 1995, the economic factors have also favoured lower use of commercial fertilizers. The average field balance of phosphorus in Finland has decreased from +35 kg ha^{-1} of the 1980s to about +8 kg P ha^{-1} today. As a consequence, the 50-yr upward trend in soil test P concentrations has probably levelled out in the late 1990s, as suggested by sampling of about 1600 fields and by a modelling exercise. Soil test P concentrations may also slowly decrease in the future, because they are currently at a level at which annual P fertilization is unlikely to give yield responses. Currently, soils that benefit from annual P applications are more often found in farms specialized in cereal production, whereas farms specialized in non-cereal plant production and animal production have higher soil test P concentrations. An imbalance in P cycling between plant (feed) and animal production is obvious. A major concern in the future will be the fate of manure P in those regions where animal production intensity is further increasing. AEP has also included optional measures to decrease erosion and particulate P losses, such as vegetative buffer zones, wetlands and reduced soil tillage. Currently about 20-25% of the field area in southern Finland is annually under reduced tillage, while the area under ploughing is around 60%. There are no nation-wide estimations on the efficiency of reduced tillage to cut erosion and P losses, but as compared with ploughing, plot experiments have shown a 10-60% reduction for erosion, with lower or even negative impacts on P losses. The potential of buffer zones and wetlands to reduce P losses has been tentatively estimated to reach a 10% reduction, at maximum, of the total agricultural load of P in Finland. Irrespective of AEP, economic pressures have contributed to doubling of the average size of the farms since 1995, with an increasing share of rented land. Such crucial management practices as liming and reconstructions of the subsurface drainage systems have been largely neglected on the rented land. This development includes risks for the structure of clayey fields in southern Finland with negative consequences on soil erosion and particulate P losses. Considering the current trends in agriculture it is not surprising that national monitoring of small- to medium-scale catchments did not show any clear changes in P losses from agriculture in 1990–2004.

Phosphorus from farmland to water in Sweden

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For a long time, research devoted to nitrogen (N) leaching and turnover in agricultural soil has been considerably more comprehensive than that into phosphorus (P) turnover, and losses and management in Sweden. Phosphorus is lost from agricultural land through being mobilized and transported away with running water. There are great variations in the amounts of P lost from agricultural land in different parts of the country as a result of differences in soils, soil hydrology and agricultural production. There are also large regional differences in the form in which the losses occur. Dissolved reactive phosphorus (DRP) can constitute 20-70% of total P in water. Drainage losses can make up between 10-70% or more of P transport. Long-term transport of total P in small agricultural streams in Scandinavia usually varies between 0.1-0.8 kg ha^{-1} yr^{-1}. In southern Sweden, phosphorus concentrations have been declining in recent years at a rate of around 2% per year (1993-2004)(Ulén & Fölster, 2007). To focus prevention efforts against P flow, a conditional d risk index for P has been drawn up in which each individual field is assessed (Djodjic & Bergström, 2005).

INTRODUCTION

From the beginning of the 1950s and up until the middle of the 1970s, large amounts of artificial fertiliser were applied to farmland to increase yields. In addition, the soil received farmyard manure relatively often without any consideration being given to its value as a phosphorus fertiliser. After 1975, the amount of artificial fertiliser used in Sweden decreased rapidly. In recent years the use of manure has also decreased with the decline in livestock farming. Total P fertilisation is now down at the same level as it was a hundred years ago. The P fertilisation in Sweden is generating a surplus of on average 2 kg P ha^{-1}. The value is highest in livestock-intensive areas, whereas in cereal growing areas without livestock there is often a deficit. However, net accumulation is small in relation to Western Europe and at the same level as several countries in Eastern Europe

In Sweden, an agronomic soil analysis is used to determine the concentration of dissolved phosphorus in the soil, based on extraction with acid ammonium lactate (P-AL) according to Egnér et al. (1960). This method is suitable for the relatively acidic Scandinavian soils and generally gives higher values than other extraction methods used in Western Europe and around the Baltic Sea (Neyroud & Lischer, 2003; Csato et al., 2007). This is due to calcium-bound P being dissolved out of soils with high lime content. The mean value of P-AL in Sweden is 106 mg P kg $soil^{-1}$ (Eriksson et al., 1997), which corresponds to the second highest (4) of five classes used to categorise available phosphorus in soil.

MITTIGATION OF P LOSSES

Infiltration of water into frozen soil is mainly governed by the soil structure and the water content of the soil at the time of freezing. Air-filled macropores in frozen soil can also pose a risk of phosphorus losses, since water with its content of dissolved or particle-bound P can be rapidly transported downwards in the soil. Ulén (1995) demonstrated that considerable leaching losses can occur in such conditions. A marked reduction in leaching losses of P can be achieved by incorporating fertiliser at the time of application (Djodjic et al., 2002).

The prevention of erosion demands systematic and often comprehensive efforts. However, it is important to take action in fields where erosion causes P losses, not just where erosion occurs, since erosion is not necessarily associated with losses of P. In actual fact, large P losses can occur even during periods with low rainfall intensity and small erosion losses. However, knowledge within this area needs to be improved and to encompass not only particle bound P but also P bound to colloidal material (Ulén, 2003, Ulén 2004).

There is often a greater accumulation of particles in a vegetation filter than of P. Several studies (e.g.Ulén 1997) mention that with vegetation filters in cold regions there is a risk of the plant material in the filter freezing. This can lead to increased losses of P since freezing bursts the cell membranes and releases the P in the plant cells, which is then carried away by runoff water. Increased P losses as a result of freezing of plant material has also been demonstrated in Swedish studies (e.g. Ulén & Kalisky, 2005; Torstensson et al., 2006).

A number of studies have shown that P losses are lower in tilled soil compared with undisturbed. However, there are also studies showing that soil tillage does not have this effect. In a Swedish study, this was explained by macropores in the topsoil being recreated by repeated freezing/thawing and the resultant fracturing of soil aggregates (Djodjic et al., 2002). Another explanation may be that soil tillage contributes to percolating water having a longer retention time in the P-rich topsoil layer, which means that leaching increases. However, in the subsoil the structure is relatively unaffected and the downward transport of P through macropores to the drain system can be rapid. One way to decrease leaching of P would be to promote rapid flow in the topsoil through e.g. breaking up the plough pan, while another would be to decrease the flow velocity in the subsoil through e.g. deep ploughing. Some studies have shown that P leaching decreases substantially after ploughing to greater depth in certain conditions, although this has not been tested in Sweden.

The disturbed backfill soil over a tile drain represents a good pathway for generating rapid P transport in the soil similar to the flow through macropores, especially in the first few years after drain installation. Based on the assumption that 2.5% of the soil volume in a newly tile-drained clay soil is made up of backfill (0.5 m wide pipe trench and 20 m drain spacing), it is obvious that the backfilling method has a great impact on e.g. P losses from drained arable soil. A method developed for clayey soils in Finland (the FOSTOP method, Nordkalk Oy Ab) involves incorporating burnt lime (CaO) with the backfill material in drains. The result is a stable and porous backfill that efficiently binds the phosphorus in percolating water. The lime filter drain, as the method is often known, thus acts as a mini chemical treatment plant. The lime requirement has been determined in trials to be 3-8% of soil wet weight. In addition to P removal, the lime filter drain can also lead to improved drainage in impervious clay soils and can thus contribute towards decreasing erosion. The average lifetime for the lime filter drain has been shown to exceed 10 years without any loss in treatment effect. In Sweden, the method has only been tested at one experimental site (Lindström & Ulén, 2003) and the long-term effects have not been monitored.

An alternative proposed in recent years is to limit drain runoff from tile-drained fields through controlled drainage, i.e. by raising the water level in the field (Wesström, 2002). A condition for this is that the field is relatively flat. However, the resulting reducing conditions that develop in the soil can lead to the release of iron phosphate compounds, which in turn leads to greater losses of DRP.

Another option to reduce the risk of P leaching is to grow crops such as lucerne, which due to their deep root system have the capacity to take up large amounts of phosphorus from the soil without any being added, a process usually referred to as mining. At harvest, the P is then removed from the field. However, the difficulties in establishing a dense lucerne crop can decrease the effect (Ulén & Mattsson, 2003). Perennial ley crops are generally better suited to mining than cereal crops and the practice works best on soils with high phosphorus levels.

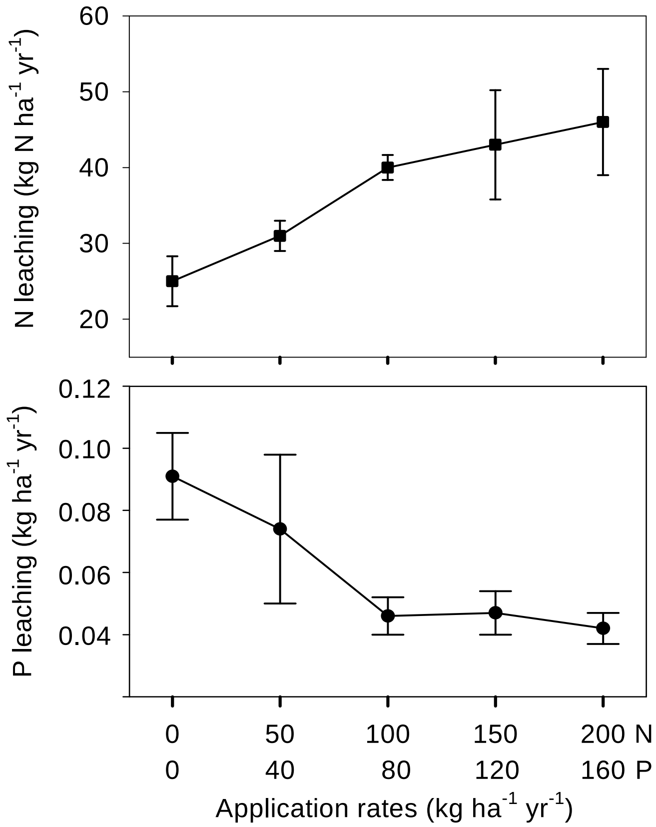

Fig. 1. Leaching of nitrogen and phosphorus with increasing doses of pig slurry on a sandy soil (source: Bergström & Kirchmann, 2006).

Large leaching losses of P are often associated with large phosphorus doses applied with manure and artificial fertiliser. However, this is not necessarily always the case. In a Swedish lysimeter study measuring phosphorus leaching from five soils that had received increasing doses of artificial fertiliser P since the 1950s, it was found that in three of these soils leaching tended to decrease with increasing phosphorus supply (Djodjic et al., 2004). The explanation given was that the ability of these soils to release P s varied and that the way P was transported through the profile was different in different soils. In another study, leaching of N and P was investigated in a sandy soil given increasing doses of manure over two years (Bergström & Kirchmann, 2006). As expected, N leaching increased as a result of higher doses of manure, but leaching of P decreased (Fig. 1). A P dose of 320 kg P ha^{-1} during the two-year period gave lower leaching than when no P was supplied. An explanation for this unexpected result could be that application of manure increases the pH in the topsoil, leading to the formation of relatively insoluble calcium phosphates and a decrease in leaching. However, it is impossible to confirm whether two years of manuring were sufficient to alter the binding conditions for phosphorus in the soil in the example cited. Nevertheless, it is obvious that the studies described above indicate that there is no unequivocal relationship between phosphorus application and P leaching.

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Mitigation options for phosphorus and sediment (MOPS): Overview and results of the first two years

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Losses of phosphorus (P) from agriculture are of particular concern, as agricultural systems traditionally have high inputs of P applied in fertilisers and manures to enhance productivity. Although there has been extensive research into effective treatments for reducing soil erosion from arable land, less is known about the effectiveness of mitigation options for reducing P losses. To address this research gap, the Defra funded MOPS (Mitigation Options for Phosphorus and Sediment) project (PE0206) investigates a range of treatments with potential for mitigating P losses from combinable crops on arable land. Field monitoring is being carried out over three field seasons on fifty-two unbounded hillslope-length plots at three field sites in the UK (Herefordshire, Staffordshire, Leicestershire) with contrasting soil types (silty clay loam, sandy loam, clay). At each site, trial mitigation options have been selected which are appropriate for each soil type. The treatments investigated include tramline disruption, crop residues, minimum tillage, contour cultivation, and the use of in-field vegetative barriers. Results from the first two field seasons show that P losses at all three sites are principally particulate (>76 %), hence control of erosion is important in mitigating losses of P from arable land. Tramlines are the main route of P and sediment transfer from arable fields, with losses of runoff, sediment and P from plots containing tramlines at least an order of magnitude higher than losses from plots without tramlines. Treatments which reduce runoff and erosion within tramlines have been found to be effective in reducing sediment and P losses. Disruption of tramlines using a ducksfoot tine consistently reduced runoff, sediment and P losses to levels comparable to non-tramline areas at two of the sites. Chopping and spreading straw, instead of baling and removing it also significantly reduced runoff, sediment and P losses from arable land, typically by 30-60 %. Both minimum tillage and cultivation on the contour reduced P losses compared to conventional tillage and up-and-down slope cultivation, and the use of vegetative barriers across the slope also appears to be effective as this reduces the slope length and promotes contour cultivation. Each treatment is assessed to determine the economic viability of the mitigation options selected. Results from the first year of the project showed little difference in yields between treatments, but differences in operating margins mean that minimum tillage and contour cultivation may be the most cost-effective mitigation options. The results from the final year of the project are expected to provide further support for the effectiveness of different treatments, and will also allow determination of the economic viability of different mitigation options in reducing sediment and P losses from arable land at field, farm and regional scales.

Effects of destruction and burial dates of cover crops on runoff, erosion and phosphorus losses in a maize cropping system

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Planting winter cover crops has been promoted in order to reduce soil losses. Although the reduction of soil losses during the winter period is well established, cover crops may possibly also improve soil structure after their burial, thereby reducing surface sealing, runoff and erosion, and consequently losses of sediment-bound and dissolved P during the subsequent Spring crop. The extent of this reduction in Winter will largely depend on the soil cover rate and the reduction during Spring on the amount of biomass produced by the cover crops and buried into the soil. The latter is affected by the dates of destruction of the cover crops. The objectives of this study were therefore to measure the impact of the date of destruction of winter cover crops on runoff, erosion and P losses in a maize cropping system.

Runoff, soil and P losses were measured by means of triplicate 90 m² runoff plots for 2 years during the winter period and the subsequent maize season on a loamy soil with an average 8 % slope (Nodebais) and on a sandy loam soil with an average 12 % slope (Bonlez). Two cover crop destruction dates (mid-march or mid-april) were evaluated and compared to control plots without winter cover crop. Bio-available P (Pbio) was estimated from the sum of labile (ammonium acetate-EDTA extractable) phosphorus and dissolved P.

During the 2004-2005 Winter period cover crops produced an average of 4.75 t biomass/ha, resulting in a significant reduction by more than 95 % of runoff, soil and Pbio loss compared to the control. In 2005-2006 cover crops produced 1.5 t/ha of biomass on average but runoff, erosion and Pbio losses were still reduced by 80 % on the sandy-loam site. Due to low intensity rainfall, the loamy site did not experience any runoff, erosion and Pbio losses during this period. There was no effect of cover crop management on runoff, soil and Pbio losses.
During the 2005 maize cropping season, previously covered plots of the loamy site showed up to 90 % reduction in runoff, soil loss and bio-available P compared to the control plots. The plots where cover crops had been destroyed in April showed a significant decrease of 50 % in runoff, erosion and Pbio losses compared to those were destruction took place in March, due to larger amounts of buried biomass (3 t/ha mid-March, 6.5 t/ha mid-April). This residual cover effect was not observed on the sandy loam site, in part because of less erosive rainfall at that site in 2005. In 2006, no residual cover effect was observed at any site. This may in part result from the lower biomass produced during the preceding winter.

Even at low rates of biomass and cover, cover crops are very effective at reducing losses of soil and bio-available P. When sufficient biomass is produced, a residual effect may in some cases be observed. This effect is larger as the amount of buried residue increases.

Diagnosis and mitigation at different scales in France

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The data over the last twenty years show that the level of phosphorus in soil is high, particularly in all the regions where intensive dairy farming exists. Monitoring soils and waters provides a good diagnosis of P pollution of the environment at the national scale. Western part of France is particularly concerned: the P storage and bio-availability in soil is always increasing up to now and induces a high risk of diffuse pollution. Regulations are going to be implemented at the regional scale, for each of French fluvial systems. The example of the Loire-Bretagne basin will be presented. However, the real lack of common usual knowledge about the phosphorus cycle in the environment by the water managers as well the lack of sharing the operational experiences has been considered as a brake for P mitigation. To overlap these difficulties, different initiatives were organized at national scale: two national symposiums have been organized last year and a written documentation will be next available.

The global regulations have to be emphasized by local regulations to better integrate local farming systems and variability of physical conditions. Two examples will be presented, one in French Brittany and another one in Alpen.

In Brittany, a holistic method is available to highlight and document objectively and the functions of the agricultural landscapes components facing to the main issues of the water quality (N, P, pesticide). Territ'eau framework carries out on farmers' fields, semi-natural areas or human infrastructures, which act as sources, sinks or buffers on water quality. This framework allows us to delimit active hydro-biochemical areas, defined by the three following characteristics: i) the dominant hydrological processes and their flow pathways ii) the mobility and persistence of each considered pollutant, and iii) the main elements of the agricultural landscape. These areas are delineated by analysing the flow connectivity from the stream to the croplands, by assessing the buffer functions of semi-natural areas according to their flow pathways. Hence, it allows us to identify functional semi-natural areas in terms of water quality, and assess their limits and functions; it helps in proposing different approaches for changing agricultural landscape, acting on agricultural practices or systems, and/or conserving or re-building semi-natural areas in controversial landscapes.

In Alpen, a non point pollution diagnosis applied at local scale (10 villages) has been elaborated. This diagnosis rests on a simplified description of P transfers. By this way indicators were used to study the links between these processes, the environment and the implemented control techniques. These indicators allow the end users to propose and improve the management system at field and catchment scale.

A review of diffuse agricultural pollution control in Ireland: recent research and current legislation.

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The importance of good water quality continues to be a national environmental priority. The latest national water quality report (Lucey *et al.*, 2007) has shown another slight improvement in surface water quality with 71% of river channel length classified as unpolluted. On the other hand groundwater quality continued to decline, with faecal coliforms recorded in 57% of all groundwater sources sampled, 25% exceeded 25 mg/l NO_3 and 2% exceeded 50 mg/l NO_3. Under the Water Framework Directive Ireland has identified that 45% of river water bodies and 37% of groundwater bodies are at risk from diffuse pollution and of not meeting the objectives of the Directive.

Historically, research in Ireland has focused on both nitrogen and phosphorus loss to water, but more recent research has started to consider pathogen transport as well. For base-flow dominated catchments with elevated soil P, TP losses of ~0.2 kg TP/ha/yr are typical, compared to 2 kg TP/ha/yr for hydrologically responsive catchments. P loss to water will only be reduced when P inputs are approximately balanced with outputs for fields and optimum STP for grassland production is attained.

In 2006, the national action plan under the Nitrates Directive was agreed and regulations were enacted to reduce agricultural N and P diffuse pollution. The action plan controls nutrient loss through nutrient management planning, setting prohibited periods for spreading and control of farmyard pollution. The effectiveness of the national action plan is being assessed by a new multidisciplinary research project through investigation of water quality and farming practices at the catchment scale. In addition, further diffuse pollution research is focusing on understanding the loss mechanisms, defining mitigation measures, using risk assessment and developing decision support tools for potential pollutants such as fecal coliforms, enteric pathogens, phosphorus and nitrogen from agricultural systems.

The effects of mixed measures of best management practice and habitat restoration on streamwater nutrients at catchment scales (Tarland catchment, NE Scotland)

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National mitigation measures in Scotland have been driven by GAEC (Good Agricultural and Environmental Condition) and the PEPFAA code (Preventing Environmental Pollution from Agricultural Activities). These strive for minimal maintenance in maintaining organic matter status, structure and guarding against soil erosion. Key measures include buffer strips to stop poaching and stream access by cattle, tillage and chemical, manure or slurry applications at stream margins. Vulnerable catchments are further protected by mandatory nutrient budgeting within designated Nitrate Vulnerable Zones. These measures will be reinforced from 2008 by the Scottish Government's set of national General Binding Rules, again including stream buffer zones, with additional regionally-targeted rules by 2012.

The Tarland Burn (NE Scotland) drains an area of relatively intensive agriculture (60% arable plus improved grassland) into the River Dee, a prime example of an oligotrophic river with species protected under Natura 2000. Water quality is an issue in such tributaries (mean annual SRP 18 µg/l and NO_3 3.8 mgN/l), but especially for the receiving waters and sensitive ecology in the main stem (SRP 1.7 µg/l and NO_3 0.4 mgN/l). Results on water quality changes over six years are reported for the Tarland Burn which has undergone mitigation measures and habitat improvements since 2000. Measures adopted have included fenced stream buffer strips, treatment of a major septic tank outflow, flooding control and improvements in public awareness of catchment issues.

Water quality at the catchment scale (52 km^2) has shown improvements in terms of suspended sediment (SS) concentrations and loads. Ninety percentile SS concentrations had decreased from 150 to 60 mg/l during 1999 to 2005, reflecting improvements in erosion at higher flows. Ninety percentile SRP concentrations have declined from 60 to 30 µgP/l during the same period, but there have been no reductions in NO_3 and increases in NH_4 concentrations. In exploring the processes behind these changes we compared control subcatchments with those where mitigation had occurred. Stream buffering and treatment of a point source had improved SS and SRP concentrations in a mesoscale subcatchment and this was linked to the return of *Salmonid* parr and reduced siltation of stream bed gravels. However, in a headwater where stream buffering alone had taken place there was no apparent improvements. Justification of buffer zones in the control of diffuse pollution is given by exploring changes in sediment and phosphorus concentrations over storms in an unbuffered headwater. Rapid increases in concentrations of SS and P forms in response to hydrograph rises (with strong clockwise hysteresis) showed that pollutants were very rapidly transferred to streams. Such responses suggested pollutant sources were near to, or in stream channels.

Dutch Framework for P mitigation options and their cost-effectiveness

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Meeting surface water quality goals for N and P in rural areas of the Netherlands requires site specific measures (SSM) in addition to the generic manure policy in force. For the efficient introduction of SSM their cost-effectiveness needs to be known. In the Netherlands there is an ongoing research project (2005-2010) to establish the effectiveness of unfertilized buffer strips. It comprises 5 field experiments to measure the effectiveness of unfertilized buffer strips under different circumstances (1), a model study for up-scaling (2), and a model study to estimate the cost-effectiveness of alternative SSM, including the costs of buffer strips (3).

With the effectiveness from 1 and 2, and the calculated costs from 3, we will be able to calculate cost-effectiveness of buffer strips by the year 2010. In the meantime the results from part 3 may be utilized for the selection of SSM for implementation or further research.

For comparison with buffer strips, we selected both source measures, hydrological measures and two types of constructed wetland ("end-of-pipe"), all tackling different emission sources and routes. The application of source measures was translated into farm management strategies, for which both costs and fertilizer rates were calculated with the farm models (BBPR, dairy) and MEBOT (arable). These fertilizer rates were input for the nutrient leaching model ANIMO. The hydrological model SWAP produces the hydrological input for ANIMO and calculates the effects of hydrological measures. The resulting average nutrient loads were calculated over a 15 year period, starting 7 years after implementation of the measure. The load reduction by constructed wetland was estimated on the basis of literature data and an estimation of expected input levels.

Both the methods used and available results will be presented.

Integrated approaches for mitigation control – one example from England and Wales

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In this paper we will present an approach to determine a set of common diffuse pollution mitigation options for phosphorus, nitrate, sediment and faecal indicator organisms and to be able to assess their cost and mitigation potential in a unified and integrated manner. The work has been used to help guide policy decisions towards packages of mitigation methods that might be used to make policy instruments for England and Wales. The approach of adopting mitigation and cost modelling frameworks for helping policy planners target priorities for mitigating diffuse water pollution is a useful 'top down' exercise and can yield useful information for planning priorities where and how best options might be most effectively targeted and for least cost but of greatest potential benefit. The approach also highlights potential diffuse water pollution 'trade-offs', and with future development could link to impacts on gaseous emissions. However, in conducting this policy relevant exercise, it is also evident that there is a notable absence of robust, locality-specific evidence for how mitigation methods work in the field under a range of conditions. We conclude that these approaches are required at the science policy interface and are a first step in the important activity of establishing what we know (and what we do not know) about the performance and cost (and affordability and likelihood of implementation). The future applied research agenda can in part be set to address the most sensitive uncertainties.

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Danish efforts to mitigate phosphorus losses from agriculture to surface waters

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In Denmark national regulation addressing nutrient losses to the aquatic environment was initiated in the 1980's. At that time, little was known about the agricultural contribution of P to surface waters. Regulation addressing agriculture, therefore, focused on nitrogen and the handling of manure. However, much of this regulation also had a significant impact on P.

The most recent Danish Action Plan for the aquatic environment addresses P surpluses in agriculture and the risk of P losses directly. The Action Plan requires a 50 % reduction in the P surplus, the establishment of 10 m buffer zones along streams and lakes and introduces a tax on feed phosphates.

As part of the Action Plan research is funded to investigate the reduction of the national P surplus and the development of effective mitigation options for rural landscapes. On one project a tool for identifying areas with a high risk of P losses as the basis for devising suitable mitigation options is presently being developed. This tool will also address the risk of nitrate leaching and describe environmental side effects and costs of the various mitigation options.

This paper presents: (1) an outline of the regulations implemented in Denmark and their impact on P surplus and P utilisation in Danish agriculture. (2) The mitigation options, which we presently work on as well as examples on how they are implemented in the abovementioned risk assessment tool.

The following report contains a study on 22 mitigation options:
Schou J.S., Kronvang, B., Birr-Pedersen, K., Jensen, P.L., Rubæk, G.H. Jørgensen, U. & Jacobsen, B. 2007.Virkemidler til realisering af målene i EUs Vandrammedirektiv. Udredning for udvalg nedsat af Finansministeriet og Miljøministeriet: Langsigtet indsats for bedre vandmiljø. Faglig rapport fra DMU, n0. 625, 132 p (in Danish with English summary). http://www2.dmu.dk/Pub/FR625_Final.pdf

Outcome of the inventory among COST partners regarding potential effective mitigation options in the EU in relation to the WFD

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At the beginning of COST 869, in October 2006, an inventory was made among the countries involved in the COST Action. A list was distributed with 88 mitigation options, which was originally made for the 4th International Phosphorus Workshop (2004) in Wageningen. It was based on inventories made for the UK, Sweden, Denmark and The Netherlands.

The list was roughly divided into 6 main categories of options for, respectively:
A. Reducing agricultural P,N input or increasing output.
B. Reducing (conversion to) soluble forms of P,N.
C. Reducing mobilisation of particulate forms of P,N.
D. Reducing P,N transport on field scale.
E. Reducing P,N transport in surface water.
F. Abating consequences of eutrophication in surface water.

The contact persons were asked to indicate for each option if experience is available in their country. This may vary from a literature research that has been done, via research on lab, plot, field or watershed scale, to the decision to make an option part of local, regional or national regulations [either voluntary, subsidised or mandatory]. It could also be indicated if an options is rejected, e.g., because it is considered unsustainable on the long-term, or was proven to be ineffective. Also, options that were not listed could be added.

Response was received from 22 of the 27 countries now involved in the Action.

Results of this inventory will be presented.

Protection spheres/goods and setting there aims/nutrient standards for C, N, P, S with special reference to the anthroposphere within the nutrition system and human health

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Anthropogenic sources account for about 60 to 80% of the C- (only ca. 3% for CO_2-C), N-, P- and S-fluxes involved (in-)directly both in global eutrophication, acidification as well as climate change, each enhancing mostly the other, and damaging actually more than 60% of the protection spheres like pedosphere, hydrosphere, atmosphere, lithosphere and biosphere and the anthroposphere within the nutrition system and human health especially in respect to food and water supply (4th UNEP-Report: Global Environment Outlook (GEO) Environment for Development / 25th October 2007).

Resulting from life cycle analysis (LCA´s) about 50 (20-80) % of these anthropogenic C-, N-, P-, S-fluxes and emissions are caused by the system nutrition of agriculture with plant and animal nutrition (production), human nutrition (consumption) and waste as well as waste water management (destruction, disposal), similar shares by use of (fossil) energy and industrial / trade activities mainly in the so called developed countries. Therefore there is a need to optimise sustainable use and management of the nutrients C, N, P and S in respect to environment (➔ Consistency), corresponding consumption (➔ Sufficiency) and production (➔ Efficiency), especially within the above mentioned nutrition system.

With a holistic approach protection aims / nutrient standards are set here as critical C, N, P, S levels and loads as well as for healthy human nutrition for all the above mentioned environmental spheres and anthroposphere, respectively, because they are a necessary prerequisite for cause oriented and sufficiently mitigation and adaptation options and measures done simultaneously with special reference to the nutrition system and land use. Corresponding actually integrated but future needed integrated (inter-)national legislation especially in respect to sustainable nutrition is shown.

Sufficiency in (especially animal) food and feed as well as in bio-energy consumption and only corresponding production leads especially in the developed and industrialized countries with their tremendous over-nutrition to ca. 70 (60-80) % of the needed emission reductions of reactive C, N, P, S, flanked by “only” ca. 30 (20-40%) reductions with technical measures.

A proposal was made for common activities in mitigation and adaptation as well as for research: “Land use, water management and environmental esp. climate change (in the EU-27): Assessment – Mitigation – Adaptation”.

Phosphorus retention in semi-natural and modified reaches of agricultural streams

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Improvement of retention in streams and riparian buffer zone is a potentially efficient measure to decrease export of phosphorus from agricultural catchments. A study was conducted with the aim to quantify P retention in different types of agricultural streams and to elucidate controlling mechanisms of P uptake. The study was carried out in the intensive arable land catchment of the Radimovicky stream in South Bohemia (49.442 N, 14.657 E). Soils in this catchment were cambisols on the syenite geological background with a bioavailable P concentration of ca 150 µg/g (Mehlich 3). Principal crops were cereals (winter and spring wheat and barley) and oil rape.

Two stream reaches were compared: (i) a semi-natural reach with ca 40 m wide, laggely water logged and uncultivated buffer zone and (ii) a modified reach with deepened, partly fortified channel and a tile-drained buffer zone that was maintained as a cropped meadow. Inputs and outputs of the these reaches were monitored in 2004-2006 by point sampling in ca 6 week intervals for analyses of basic P fractions (total P (P_{tot}), dissolved P, dissolved reactive P), total suspended solids, Fe, dissolved organic carbon, and ionic composition. In addition, the PO_4-P uptake parameters (uptake length and uptake rate) were measured in these reaches by addition of stable isotopes of orthophosphate and chloride and the fine, unconsolidated stream bed sediments were characterised by P sorption isotherms and by fractionation of P_{tot}, orthophosphate, Fe, and Al using the Psenner procedure (H_2O-buffered dithionate (BD)-$NaOH_{25°C}$ - HCl-$NaOH_{85°C}$).

The mean input concentrations of P_{tot} into both reaches were similar (ca 200 µg/l) but the retentions largely differed (~60% and ~30% in the semi-natural and the modified reach, respectively). The additional analyses also revealed significant differences between the reaches, especially in the P uptake rates, P uptake lengths, maximum P sorption capacity and P saturation of sediments, and fractional composition of P in sediment particles. Sorption of P on iron hydroxyoxides (FeOOH) was revealed as the key controlling process of phosphorus retention in the oxic conditions in the stream channel. The water logged conditions in the soils of the buffer zone promoted washing up dissolved Fe into streams hence increasing the binding capacity of the system for P.

ABSTRACTS OF

POSTER PAPERS

Controlled drainage: For all your water goals?

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Conventional drainage had been widely used in the Netherlands to improve the hydrological conditions for agricultural purposes. In this case, drains are placed above water level, and drainage water goes directly into the ditches. Due to the lowering of the groundwater level, nitrogen losses to the surface water will increase, since nitrate losses due to denitrification are reduced. However, phosphorus losses to the surface water will decrease, since P-rich surface layers become drier. Besides a higher risk on nitrogen losses, conventional drainage also can result in higher peak loads.

Deep controlled drainage has opportunities to reduce the negative effects of conventional drainage. Deep controlled drainage is a system of underwater drains where drain water will flow into a collector drain and subsequently into a sink. With the so-called 'Systeem van Iersel', the water level can be controlled using a pipe in the sink.

Prior to upcoming field work, a model analysis had been carried out. In this analysis, two reference situations (with and without pipe drains) were simulated with the models SWAP and ANIMO. Regional groundwater dynamics was simulated with SIMGRO.

The model analysis lead to the following conclusions:

- Compared with an undrained reference situation, conventional drainage results in a considerable lowering of the groundwater level, an increase of N-losses and a decrease of P-losses to the surface water. Deep controlled drainage results in a slight decrease of N-losses and a considerable decrease of P-losses.
- Changing from conventional drainage in the reference situation to controlled drainage results in a decrease of the N-losses to surface water, due to the higher groundwater level (more denitrification), but also to an increase of P-losses.
- Deep controlled drainage results in a decrease of N-losses and a slight increase of P-losses to surface water, when compared to conventional drainage.

Fieldwork is necessary to corroborate the model results.

Deep controlled drainage has good prospects for combined water quantity and quality goals. However, the effects of (deep) controlled drainage on N- and P-losses to surface water are in some scenarios conflicting. A decrease of N-losses goes hand-in-hand with an increase of P-losses, and vice-versa.

The choice of a drainage system (conventional or [deep] controlled) will depend on the regional water quantity and quality aims.

The survival of FIOs in soil, following dairy cattle slurry application to land by surface broadcasting and shallow injection

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The amended Bathing Water Directive (2006/7/EC) of February 2006 saw the introduction of more stringent microbial parameters for both inland and coastal waters. Two microbial parameters are now required to be examined; intestinal enterococci and *Escherichia coli* (FIOs). Approximately ninety million tonnes of livestock manures are recycled to agricultural land in the UK annually, which is a potential source of FIO export to surface waters.

The survival of FIOs within dairy cattle slurry, applied by broadcast and shallow injection was investigated at the plot scale. Soil core samples (2 cm depth) were taken and analysed for FIOs from fifteen 4 m^2 plots; 5 broadcast, 5 shallow injection, to which fresh slurry was applied at the rate of 45 m^3 per hectare and 5 controls (no slurry addition) during the summer.

The application method affected the survival rate of FIOs. *E.coli*, 84 days intestinal enterococci, 111 days when applied via shallow injection as compared to 50 days and 63 days, respectfully following broadcast application. Thus, FIOs can survive for extended periods following slurry application by shallow injection.

Phosphorus, sediment and colloid transfer from grassland – the GRASP project

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The objective of the project is to provide mechanistic and fundamental knowledge that contributes to the Defra programme through adopting a multidisciplinary team approach focused around three platform sites.

Specifically, the project will:

- Contribute fundamental knowledge to help budget losses
- Define new techniques for identification of colloids and sediment
- Improve mechanistic understanding of sediment, colloid and P transport
- Contribute to new models for understanding P transport through grassland soils

The poster gives an introduction to the GRASP project – a multi-discipline approach to understanding P, sediment and colloid transfers from grasslands.

It shows examples from:

- Plot scale erosion experiments
- Tracing sediment experiments using stable carbon isotopes and natural fluorescence
- Modelling of sediment and phosphorus
- Uncertainty evaluation of data and models using Generalised Likelihood Uncertainty Estimation (GLUE)
- Colloid and sediment characterisation using Flow Field-Flow Fractionation (FIFFF)

Knowing your stuff – Mitigation before application

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Slurry application to soil is a source of available phosphorus (P). Knowledge of P forms in slurry is a fundamental tool to understanding P dynamics in soil-slurry-water systems and the mechanisms responsible for the release of potentially available forms to water course over time. Indeed, water extractable P (WEP) has been correlated to runoff events in agricultural systems. Therefore, the identification of water 'extractable' total, inorganic and organic P in slurry is fundamental. This information can help identify the potential for slurry P release from soil and transport to water, so we can attempt mitigation before slurry application, through knowledge of how much and what type of P we will 'actually' apply.

That this 'prior' knowledge on WEP before slurry application is important is exemplified in a study which comprised ten fresh slurry samples collected from different farms in Devon (UK). The WEP was extracted according to Kleinman et al. (2006). Dry matter content varied between 1.2 and 12.0%, and the inorganic P in the WEP ranged from 3440 to 9813 mg kg^{-1} (average 5544 mg kg^{-1}). Within this context it is clear that slurry applications to agricultural land based on methods of applying a certain volume (e.g. 50 m^3) per area (ha) will provide slurries with different P leaching potential, as exemplified by the wide range of WEP contents in our study.

Acknowledgements
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Experimental determination of the effectiveness of unfertilized buffer strips in the Netherlands

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In the Netherlands we are investigating the effectiveness of unfertilized buffers trips along property boundaries in reducing the load of P (and N) towards the adjoining open water system. The study was initiated in response to an agreement made between the Netherlands and the European Union. In principle, Brussels wants buffers trips that are at least 5 m wide to be created along water ways, just as is now the case in other European countries. The Netherlands has doubts about the effectiveness of buffer strips in flat situations, but does not want to exclude the possibility of implementing the measure with an eye to the water quality targets specified in the EU water framework directive. The Netherlands has mainly permeable soils in a flat landscape, which has little surface run-off, or drained soils. This means that most of the discharge probably passes underneath the buffer zone. This certainly applies to plots of land with pipe drains. In order to take the effects of soil structure and hydrology into account, we make a distinction between six geohydrological situations. In each of these situations we have chosen an experimental site where we determine the load towards the adjoining ditch for a reference treatment and for a buffer strip treatment. The relative difference between the two measured loads then gives an estimate for the effectiveness at that site. Upscaling using (meta)models will give insight in possible locations in the Netherlands where the measure is useful and where not. We will present the chosen five locations, the general experimental set-up, and the first, preliminary results.

Assessing the impact of farm management practices on stream FIO loads using an evidence based approach

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Introduction of a revised European Union (EU) Bathing Waters Directive this year with more stringent standards, coupled with the implementation of the EU Water Framework Directive by 2015 is seeing the issues of bathing, surface and ground water quality being brought to the fore. While improvements in designated bathing waters meeting with mandatory bathing water quality regulation have been recorded because of tighter controls on point sources such as sewage treatment plants, non-compliance can still occur at designated bathing sites, which has been attributed, in part, to diffuse sources contributed from agricultural land. Research suggests that this is due to the mobilisation, transfer and successful delivery of microbes from land to water following the recycling of livestock manures to that land and from faeces deposited directly by grazing livestock. To determine the impact of a suite of farm management practices on microbial water quality (namely faecal indicator organisms [FIOs]) we are undertaking a detailed study of 10 farms that range from small hobby farms and tenant farms through to intensive dairies, in the Taw catchment, North Devon, South West England UK.

We have developed an expert-weighted risk-indexing approach to rank field and steading risk of FIO export (using source, transfer and connectivity drivers) coupled with detailed microbiological monitoring throughout distinctly different operationally active areas of the farm to identify risky farm practices and locations. This highlights FIO ‘hotspots’ of the farm environment that would benefit most from mitigation strategies (Phase II of the project following baseline data collection). Data collected on manure, land and animal management via a farmer survey also contributes to the risk profiling of each farm. Crucially, we aim to integrate an additional layer into our risk indexing tool to help identify the socio-economic drivers that may dictate farmer decision making and impact on the overall risk of FIOs being exported from those farms investigated. This paper focuses on the results from two distinct farm units, highlighting the results of the detailed microbiological monitoring and the subsequent integration of this evidence-based approach into the physically-based risk tool. The development of a relative risk tool, rather than a quantitative predictive model, that can assist farmers and land owners to prioritise land that is most ‘risky’ in terms of contributing bacterial contamination to watercourses will help focus mitigation efforts where they are likely to be most effective in terms of improving water quality.

Multipurpose wetlands for agricultural water protection – guidelines of wetland planning and construction

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INTRODUCTION

Constructed wetlands (CWs) are known to have an ability to retain nutrients and other harmful substances from the waters that flow through them. Usually, the main objective of is to decrease nitrogen (N) and phosphorus (P) loading, and hence eutrophication of surface waters. Wetlands can have also many advantages for rural landscape and ecological diversity of agricultural environment. When constructing wetlands for treating diffuse loading, combining also other interests in the planning in an early stage is essential for sustainable solutions.

The number of CWs as water protection measures is anticipated to grow in the near future in Finland. For this need, the latest scientific and experiential knowledge was compiled as renewed planning guidelines. In this project, the objective was to formulate and present detailed design and dimensioning guidelines of multipurpose-CWs for planners.

The knowledge included in the guidelines is based on the authors' 10-year experiences on CW research and planning as well as on intense co-operation with different interest groups.

CONTENT OF GUIDELINES

The characteristics of CWs have to be designed concerning environmental objectives, local conditions and constructing methods (excavating, damming etc). The nutrient-retaining processes in a CW largely depend on water residence time. Also the conditions defined by the form of different parts of the CW play a role. Hence, adequately dimensioned (by choice more than 2% of the above watershed) and multiform CWs are recommended. The latter recommendation refers to deep and shallow parts, vegetation zones, curved shorelines, gently sloping banks, spits of land, islets etc. The guidelines deal solely with agricultural multipurpose-CWs, which combine the water protection targets with several other objectives like improved landscape, increased biodiversity, flood management, recreational use and hunting. In the guidelines these issues are discussed and good planning solutions are presented.

CONCLUSION

By applying landscape design and ecological considerations in the early stage of CW planning, the technical demands of load reduction performance can be connected with many other benefits. The renewed CW planning guidelines take into account a wide variety of these aspects and will thus be an invaluable tool for the Finnish CW planners.

Soil, plant and environmental indicators to minimize phosphate inputs in permanent grasslands

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Phosphorus (P) is one of the essential nutrients for plant growth. However, P losses from over-fertilized grasslands especially in areas with high livestock density are still a major cause for eutrophication of surface waters. The overall aim of this project is to develop a set of soil, plant and environmental Indicators to propose strategies to limit P inputs into permanent grasslands and to reduce the risk of P losses to the hydrosphere.

The project is divided into three sections which address the effect of P inputs and soil properties on 1) availability of soil and manure phosphate to plants, 2) risk of phosphate losses from grassland soils, and 3) yield, botanical composition of grasslands and plant P status. In a companion project, a method to trace the fate of P in the soil / manure / plant / water system is being developed which is based on the measurement of the natural abundance of ^{18}O in the PO_4 groups ($\delta^{18}OP$).

Once this method is developed, it will be used to quantify the fraction of P in plants, grassland soils and water that is derived from animal manures. Therefore we will study three grassland sites used previously in long term experiments or surveys, which differ mainly in use intensity, fertilization, soil type, altitude and local climate. They are located at Watt / Reckenholz (extensive use), Verrieres (semi intensive use) and Lake Baldegg (intensive use).

The work will be carried out in collaboration with the Department of Earth Sciences of the ETH, the Agricultural Research Stations ART Reckenholz and ACW Changins, and the canton Luzern. This project contributes directly to the objectives of the working group 3 “Mitigation options” of the COST action 869.

Adsorption of glyphosate to Cambisols, Podzol and silica sand

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The glyphosate is one of the most applied organic herbicides with increasing importance nowadays. Glyphosate is a post-emergency non-selective broad spectrum herbicide extensively used in agriculture for the control of most annual and perennial plants. It controls weeds by inhibiting the synthesis of aromatic amino acids necessary for protein formation in susceptible plants. The sorption of glyphosate by soils occurs due to the inner sphere complex formation with metals of soil oxides, which are related to the soil phosphate adsorption capacity. Several binding mechanisms have been suggested for the sorption of this herbicide, such as: electrostatic bonds in extremely acid, hydrogen bonds with humic substances and, especially, covalent bonds with Fe and Al oxides.

The present study should contribute to answer the question if glyphosate binds to different soil types and how various iron oxides contribute to the binding mechanisms.

Batch adsorption experiments were conducted according to Part C 18 (EU, 2001) with three different soils and silica sand for a comparison:

- Soil originating from Wienerwald (Orthic Podzol, Bs, FAO classification 1994)
- Eurosoil 7 (E7) (Dystric Cambisol, Ah, FAO classification 1994)
- Soil originating from Phyra (Dysric Cambisol, Ah, FAO classification 1994)
- Silica sand (acid washed)

The substances were measured either as phosphorous (P) after filtration by ICP-OES or/and as single compounds with HPLC/FLD after post cloumn derivatisation with fluorescence detection (Pickering system).

The adsorption capacities of the two cambisols (Eurosoil (KD 188 – 299 l/kg) and Phyra (KD 13.8 – 29.3 l/kg)) were quite different and varied about one order of magnitude, although their Fe content was comparable. The Podzol (KD 467 – 519 l/kg) contained about 3 % soluble iron oxides and produced best adsorption results. The KD of silica sand was negligible. In the Wienerwald sample (Podzol) the main adsorption process seems to be based on iron oxides as the organic carbon content is quite low. Our data are in the range of those found in the literature; nevertheless the variations of the KD- values in different soils are significant and not only dependent of the Fe-content. A reduced sorption capacity could result in a leaching of glyphosate to groundwater.

Glyphosate can be adsorbed by the different substrates studied in different ways (e.g. Cambisols). Therefore, the use of glyphosate should be adapted to physico-chemical soil properties. The results in the literature show that iron oxides play an important role in the retention of glyphosate. In our study (data not shown) we could observe that from the investigated iron oxides (ferrihydrite, hematite and goethite) ferrihydrite had the highest impact on the adsorption process.

Mining soil phosphorous by zero P application: an effective method to reduce P loading to surface water?

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High soil P contents in agricultural soils in the Netherlands cause excessive leaching of P to surface waters. The reductions in P application rates in the present manure policy are not sufficient to reach standards resulting from the European WFD in 2015. Accordingly, additional measures have to be considered to further reduce P loading to surface water.

Greenhouse experiments showed that a rapid reduction in soluble P and readily available soil P can be obtained by zero P application (Koopmans et al., 2004). Field data confirming these findings were scarce thus far.

In 2002, a P-mining experiment started on four grasslands sites on sand (2 sites), peat and clay soils. The mining plots received no P and 300 kg mineral N ha^{-1} yr^{-1}. The grass is removed by mowing five to seven times a year. At the same sites the effects of different P surpluses (0-40 kg P_2O_5 ha^{-1} yr^{-1}) are studied from 1997 onwards, giving the opportunity of comparing the effect of mining with regular manure policy.

Mining soil phosphorus by zero P-application, over a period of four years, led to a strong (30-90%) reduction in both MRP and MUP concentration in the uppermost soil layer (0-5 cm). The reduction in concentrations declined with depth and changes were generally not significant in the deeper (up to 30 cm) soil layers. Mining also led to a decline in P pools in the soil solid phase. The largest decline was found in water extractable P, whereas reductions in more strongly bound P forms like oxalate extractable P and total-P were not yet significant (van der Salm et al., in prep).

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Influence of P-status and hydrology on phosphorous losses to surface waters on dairy farms in the Netherlands

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Introduction

The contribution of agriculture to the contamination of Dutch surface waters has increased from 43 % in 1985 to 57 % in 2002 (ref). Dairy farming is the largest producer of animal manure in the Netherlands (circa 75% of the total annual manure production). Information on nutrient budgets and leaching of nutrients from dairy farms was, however, limited. To mitigate this problem, monitoring programs were set-up at three dairy farms, namely one in the sandy area of the Netherlands, one in the peat-district and one on a river-clay soil. The three farms together represent the environmental conditions encountered in the Dutch dairy region. This study focuses on the losses of phosphorus from grazed grasslands on a clay soil a sandy soil and a peat soil, with different soil P-status and different hydrological pathways.

Experimental design

Phosphorous losses to ground- and surface waters were measured for a period of two to three years on a site with a heavy clay soil, a peat soil and a sandy soil. All sites were almost level and were draining on a dead-end ditch. At the end of each ditch a weir was placed with a flow meter connected to a sampling device for flow proportional sampling. The sandy site was well drained and drain-pipes were absent. About 3.5 m below the surface, a confining loam layer prevents exchange of water and solutes with deeper groundwater. The clay site was drained by tile-drains and trenches. The subsurface drains were located at a depth of 80 cm below the surface. The ditches were shallow (50 cm depth) and located at intervals of 46 m. Due to the low permeability of the heavy clay there was no seepage and groundwater recharge. The peat site has a man-made topsoil (0-40 cm) consisting of organic matter rich sandy clay. The subsoil consisted of woody peat. At 3 m below the soil surface a dense clay layer prevented extensive groundwater recharge. At the clay site the phosphorus losses to surface water were determined by flow proportional measurement of the discharge of trenches and drains. For sand and peat soil, the soil solution in the unsaturated zone was sampled using porous suction cups, which were placed in transects perpendicular to the ditches. Phosphate leaching fluxes at these sites were based on measured soil solution concentrations and simulated water fluxes. Surface run-off was assessed based on measurements using catchment plates and simple balance models for the peat soil (Van Beek et al., 2003) and was modelled for the sand soil (Torenbeek and Voskamp, 2003). At the clay site surface runoff was collected by the trenches, direct runoff form the field to the ditch was negligible (van der Salm et al., 2006, 2007).

Hydrological pathways, P saturation of the soils and P leaching losses.

The three sites differed considerably with respect to the main hydrological pathways. The clay site had a very low hydraulic conductivity and large part of the discharge took place by runoff or interflow through the upper soil layers to the trenches (Table 1). The peat and sand sites were better drained and most of the water was conducted through the soil matrix.

Table 1. Distribution of discharge to surface water and P sorption capacity, DPS and P sorption characteristics of the sites (0-40 cm) and P balance.

		Sand	Clay	Peat
Discharge to surface water (%) [1]	$Q_{Surface}$	8	67	12
	$Q_{shallow}$	53	32	4
	Q_{deep}	29	-	84
Al_{ox} (mmol/kg)		65	59	144
Fe_{ox} (mmol/kg)		8	172	209
Langmuir adsorption constant (K)		0.37	0.11	0.18
Maximum amount of P bound to Al and Fe (β) (-)		0.21	0.09	0.19
DPS (%)2		37	7	15
Phosphorus surplus (kg P/ha/yr)		20	21	14
Phosphorus surplus		2	3	5

1) $Q_{surface}$= Run-off, matrix flow (0-10 cm), trenches; $Q_{shallow}$ = Matrix flow (10-70 cm) and drains, Q_{deep} = matrix flow (> 70 cm). Due to differences in methodologies $Q_{sum} \neq 100$
2) DPS = $P_{ox}/(0.5*(Al+Fe_{ox}))$ for 0-40 cm depth

Phosphate binding capacity increased from sand to clay, resulting in a high degree of phosphate saturation in the sandy soil and a low phosphate saturation in the clay soil. Losses of P from the sandy site and the clay site were comparable although the DPS was much higher for the sandy site than for the clay site. Highest P losses were found at the peat site, which had an intermediate DPS. These differences in P losses can be explained by differences in sorption characteristics, differences in hydrological pathways and differences in the distribution of P within the soil profile between the sites. The sandy site was quite deeply drained and 84% of the water discharge is through deeper soil layers where the DPS was relatively low (Table 3). At the clay site 67% of the discharge was by means of drainage through trenches. This route leads to 75% of the P losses to surface water at this site and also a large part of the total P losses (60-80%) to surface water occurred as a response to incidental heavy rainfall following manure application in early spring (Van der Salm et al., 2006). The peat site had an intermediate position with a somewhat higher DPS and drainage through deeper soil layers (Tables 3 and 5). This intermediate position contributes to the high P losses observed at the peat soil. Another reason for the high losses from the peat soil is the release of P from eutrophic layers in the peat, contributing to about 50% of the total discharge.

A rough estimate of the impact of a reduction on manure application on the leaching was made using the Langmuir isotherms and the sorption characteristics of the sites (van Beek et al., submitted). Changes in P surpluses had the largest impact on P leaching on the sandy soil, followed by peat soil and finally the clay soil. This sequence is strongly influenced by the fraction of reversible bound P which decreased from sand to clay.

Conclusions

P losses were strongly determined by the hydrologic pathways in combination with the DPS and adsorption characteristics. Relatively high losses were found at the clay site, despite the low DPS, due to the important role of trenches and the resulting shallow drainage of the site. The highest losses were found at the peat site due to a combination of DPS, an intermediate sorption constant, shallow drainage and presence of eutrophic peat layers. Reducing P inputs as measure to reduce N and P leaching to surface water is likely to be most effective on sandy soils, but for clay and peat soil hydrological conditions and release of P from eutrophic peat layers hamper the effectiveness of such measures. For these soils additional measures should be considered.

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