MTT SCIENCE 10

Novel methods for reducing agricultural nutrient loading and eutrophication

Meeting of Cost 869

14–16 June, Jokioinen, Finland

Eila Turtola, Petri Ekholm and Wim Chardon (eds.)

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Working Groups 2 and 3

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Preface

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In many intensively cultivated areas, surface and ground waters suffer from eutrophication and deterioration of the water quality. To improve the environmental protection actions of agriculture, EU countries have adopted common legislation, such as the Nitrate Directive and the Water Framework Directive, which set limits to the use of manure and aim at good ecological state of waters by 2015, respectively. Moreover, different voluntary measures and environmental schemes are being supported financially by EU and national governments to reduce agricultural nutrient loading and eutrophication, for instance by optimizing phosphorus (P) and nitrogen (N) fertilization, controlling erosion and promoting the establishment of buffer zones and wetlands.

Yet, good ecological state appears to be unattainable in many agriculturally loaded water bodies in the near future. Former accumulation of nutrients in soils and sediments retards the recovery of waters, implementation of environmentally friendly measures may be inadequate, or the measures themselves are inefficient. There is an obvious need for novel methods and new techniques that speed up the load reduction and the recovery of different types of water bodies and that could be easily adopted by farmers and put into practice by other stakeholders in the river basins.

The aim of this workshop, held at MTT Agrifood Research in June 2010, is to discuss novel methods for reducing agricultural nutrient losses and alleviating their effects in water bodies. The novel methods may include:

- chemical amendments to reduce soil loss or to immobilize P in soils or in wetlands;
- filter systems to remove P from field runoff;
- removal of N from runoff waters by fixation to innovative materials;
- use of sediment traps;
- capturing P in sediments.

Targeted and cost-effective use of such methods requires that we recognise the sources and transport routes of nutrients, critical steps in the load generating processes and the magnitude of responses in the rivers, lakes and coastal waters suffering from eutrophication. Moreover, the limitations, possible risks and side-effects must be evaluated.

This issue of MTT Science gathers together the abstracts of oral and poster presentations held in the workshop. We hope that the workshop will succeed in triggering scientific discussion on the development, needs, application, limitations and mechanisms of new methods directed to fields and management practices responsible for the highest environmental risks. Ideally, adaptation of such measures, together with traditional water protection, would speed up the recovery of waters and allow better recycling of nutrients in the agricultural system.

The workshop forms part of the COST 869 Action (Mitigation options for nutrient reduction in surface water and groundwaters) and is additionally financed by MTT Agrifood Research Finland, Finnish Environment Institute, the Finnish Ministry of Environment, Yara Suomi Oy and Sachtleben Pigments Ltd.

Tiivistelmä

Eila Turtola

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Maatalouden vesistökuormituksen vähentämiseen on sitouduttu sekä Suomessa että monissa muissa maissa, joiden vesistöt ovat rehevöityneet intensiivisen viljelyn ja kotieläintalouden seurauksena. Lannoituksen säätäminen, jyrkkien rinteiden suojavyöhykkeet, syysmuokkauksesta luopuminen ja laajaperäinen nurmiviljely ovat keinoja pienentää liuenneen fosforin, eroosioaineksen ja nitraattitypen kuormitusta. Maatalouden ravinnekiertojen korjaaminen vaatii edelleen perusteellisia muutoksia kotieläinten lannan käsittelyyn ja käyttöön. Samaan aikaan lämpimät ja sateiset talvikaudet lisäävät peltomaiden eroosioriskiä ja myös typen huuhtoutumista, ellei maaperän eroosiokestävyyttä ja toisaalta typpitaloutta pystytä vastaavasti parantamaan. Vesistöissä puolestaan sisäinen kuormitus voi hidastaa hyvän tilan saavuttamista.

Perinteisten maatalouden vesiensuojelumenetelmien potentiaalinen vaikuttavuus on huomattava, jos ympäristöohjelmat ja teknologian kehitys tukevat tavoitteiden saavuttamista. Esimerkiksi Suomessa on arvioitu, että fosforilannoituksen vähentäminen viljelykasvien tarpeen mukaiseksi voisi pienentää liuenneen fosforin kuormitusta kymmeniä prosentteja nykytasosta. Jos tiukka fosforikuuri aloitettaisiin nyt, em. tulokseen päästäisiin yli kahdenkymmenen vuoden päästä. Koska perinteiset toimenpiteet vaikuttavat hitaasti, niiden rinnalle on ryhdytty kehittämään uusia menetelmiä puuttua entistä suoremmin ja tehokkaammin ravinnekuormitukseen. Tällöin tavoitteena voi olla (1) pitää ravinteet tai maahiukkaset tiukemmin kiinni maassa, (2) puhdistaa valumavesiä tai (3) sitoa ravinteita vesistössä aktiivisen kierron ulkopuolelle.

Nyt käsillä oleva MTT Science -lehden numero koostuu esitelmien ja postereiden tiivistelmistä, jotka liittyivät Jokioisissa 14.–16.6. 2010 pidettyyn seminaariin 'Novel methods for reducing agricultural nutrient loading and eutrophication'. Tiivistelmät antavat läpileikkauksen yllä mainittuihin tavoitteisiin tähtäävästä, eri puolilla maailmaa tehtävästä tutkimuksesta. Mukana on laboratoriotutkimuksia erilaisten materiaalien kyvystä sitoa ravinteita tai parantaa maan eroosiokestävyyttä, ja monissa tapauksissa tutkijat ovat jo ehtineet testaamaan tehoa myös pelloilla, kosteikoissa tai vesistöissä. Mitä intensiivisemmästä ja potentiaalisesti kalliimmasta menetelmästä on kyse, sitä todennäköisemmin sitä sovellettaisiin vain kaikkein kuormittavimmissa (tai vaikeimmin kunnostettavissa) kohteissa. Toisaalta uudet keksinnöt ja menetelmien kehittyminen saattavat tuottaa myös ratkaisuja, joita voidaan soveltaa laajasti.

Vaikka uusilla menetelmillä pyritään ennen kaikkea saavuttamaan vesistöjen hyvä ekologinen tila, tarjoutuu samalla mahdollisuus ottaa ravinteita talteen ja palauttaa niitä kasvien käyttöön, tai maaperän laatu voi parantua kestävämmän rakenteen myötä.

Vesiensuojelun haasteet ovat eri alueilla samantyyppisiä huolimatta vaihtelevista luonnonoloista tai eroista ravinteiden sidontaan tarvittavien materiaalien saatavuudessa. Seminaarin tarkoituksena on edistää tiedonvaihtoa ja yhteistyötä tällä kehittyvällä tutkimusalalla. Seminaarin rahoitukseen ovat osallistuneet COST 869 (Mitigation options for nutrient reduction in surface water and groundwaters), Maa- ja elintarviketalouden tutkimuskeskus, Suomen ympäristökeskus, Ympäristöministeriö, Yara Suomi Oy ja Sachtleben Pigments Ltd.

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Session 1: Novel methods – innovations, experiences, prospects

Amendments to control phosphorus mobility

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Phosphorus (P) contamination of surface and ground waters is a worldwide environmental concern. Repeated applications of fertilizers, animal manures, and other P-sources can increase P concentrations in soils, increase the threat of off-site P losses, and degrade water quality. The problem is especially severe where: 1) The native soil P retention capacity is small, or has been significantly compromised (P saturation index PSI > 0.25), 2) Connectivity distances (depth to groundwater, distance to surface water) are short, and/or 3) Highly sensitive water bodies (low tolerance for additional P) are threatened. The conditions coexist in several areas world-wide (e.g., agricultural coastal plain operations) and are widespread in Florida. Accordingly, there is a long history of efforts to reduce off-site losses of P and to control soluble P in water bodies, collectively known as best management practices (BMPs). The practices can be categorized into methods that: 1) Reduce P inputs, 2) Reduce P solubility, 3) Increase P retention, and 4) Remove P before it reaches sensitive water bodies.

Reducing inputs to soils and waters includes limiting P-source additions to better match crop needs based on soil test values, actual plant status (e.g., tissue P concentrations), and reasonable yield expectations - components of Nutrient Management Plans (NMPs). Keeping animals, soils, and P-containing wastes out of streams and considering all sources of P and the overall system management - components of Comprehensive Nutrient Management Plans (CNMPs). Such actions are logical, widely practiced, and useful, but are often inadequate to sufficiently decrease water body P concentrations. Failure is especially obvious when excessive legacy (previously added P that is soil or sediment-bound) P is involved, and the practices typically have slow remediation potential. Water body P concentrations can remain unacceptably high even decades after widespread P reduction efforts begin.

The other BMPs can also be only partially successful, but are amenable to augmentation with various amendments and are the subject of my presentation. Summaries of amendments use in Florida to control P mobility are available in a recent report (Wanielista et al., 2009) and in two extension publications (Agyin-Birikorang et al., 2009) [copies of the publications are available on the workshop website]. I will review the basis and effectiveness of several practices, focusing on the use of metal salts and drinking water treatment residuals (WTRs), and various strategies of amendment use.

Reducing P solubility in soils and waters with amendments can be an effective management practice. Soil pH can be altered to minimize P solubility, but requires recurring maintenance of the desired pH, lest precipitated P compounds dissolve over time as the soil returns to its native pH. Likely more useful is precipitation/sorption removal of P from water before the water is applied, or in receiving water bodies. Alum [$Al_2(SO_4)_3$] has a long history of successful use in lakes, storm water retention basins and constructed wetlands. One of the earliest records of lake treatment was in Lake Långsjön in Sweden. Sometimes, alum treatment is combined with polymer additions if the water source is runoff containing abundant sediment-associated P. Basic mechanisms of P removal include precipitation and adsorption and enmeshment of P in $Al(OH)_3$ flocculants. Alum addition, and subsequent floc formation, can also be used in storm water retention areas and constructed wetlands to bind P that tends to diffuse into the water column above the sediments.

Adding alum (or other Al, Fe, or Ca sources) to animal manures and sewage sludge prior to land application can dramatically reduce soluble P concentrations in the source and reduce P off-site losses.

Amendments of various types can increase P retention in soils/sediments and control P solubility. Precipitation of P can be encouraged with Ca-based or Fe/Al-based amendments (including metal salts) carefully selected to be compatible with natural soil conditions. Drinking water treatment residuals (WTRs) can be especially useful and can be preferable over other "waste amendments", e.g., coal combustion by-products, cement kiln dust, bauxite "red mud", because most WTRs contain minimal contaminants of concern, e.g., trace elements and excess salinity.

Approaches centered on removing P from water escaping soil before the water-borne P reaches a significant water body include storm water treatment areas, natural and constructed wetlands and buffer (riparian) zones. The natural capacity of the systems to retain P can be augmented with metal salts, amendments, and polymers. Most experience is with surface flow retardation and treatment, but permeable reactive barriers filled with adsorbent or immobilizing agents are thought useful to treat ground water before it joins surface drains and surface waters.

We have the greatest experience and success using WTRs, and specifically Al-based WTRs, to control P mobility. Effectiveness is strongly related to reactive Al-oxide content (not total Al content) and to internal (micro) porosity. Immobilization of P is by high-energy retention in micropores (not surface precipitation) and is stable long-term as long as the solid's integrity is maintained. Immobilized P can be encouraged to form in high-P soils, organic sources of P, and in barriers to water movement. The amendment is effective at reducing P in runoff, leaching, and (we hope) in flowing ground water. Use of Al-WTR in permeable reactive barriers is an area of active research.

Issues related to Al-WTR use include determining a rate that maintains sufficient crop-available P while minimizing off-site P losses; human, animal, and agronomic concerns (especially with Al and trace elements); overly conservative, or no WTR-specific, regulations; limited WTR supplies; and failure of current P Indices to account for WTR benefit.

The literature contains numerous reports of amendment use to control P mobility, but a reader must be cautious. The choice of amendment or treatment technique is complex and depends on several variables. One must understand not only the nature of the P-source, but reactions and loss mechanisms expected in a particular system. Importantly, be watchful of approaches that actually make the situation worse and understand how to correctly judge success. I will review some "lessons learned" with amendment use in Florida.

References

Agyin-Birikorang, S., O'Connor, G.A., Obreza, T.A. 2009. Are alum-based drinking water treatment residuals safe for land application? Extension letter SL 299 Univ. of Florida, 8 pp.

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Methods for reducing agricultural nutrient loading and eutrophication: The New Zealand story

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In New Zealand, water quality is good compared with international standards. Trend analysis of water quality data, however, shows that over recent years, water quality has declined, particularly in lowland streams and rivers, related to the expansion and intensification of pastoral agriculture (Ballantine and Davies-Colley, 2009). The New Zealand dairy industry has established a number of environmental goals, including the reduction of nitrogen (N) and phosphorus (P) losses from land by 50% for N, and by between 50 and 80% for P (depending on soil type) over the next decade (Dairy Environment Review Group, 2006). To assist farmers to reduce nutrient losses from land and achieve the targets outlined, innovative methods are being tested throughout the country by various research providers, examples of which include:

- Tree bark to reduce nutrients in dairy and piggery farm effluents,
- Constructed farm wetlands to reduce nutrients in subsurface drainage water,
- Iron slag socks to reduce phosphorus concentrations in drains and streamwater
- Tephra to adsorb phosphorus from dairy farm drainage water in mole drainage systems.
- Use of soil amendments to reduce dissolved phosphorus concentrations in wetlands
- Natural zeolite filters to reduce nutrient export from constructed farm wetlands
- Amended zeolite products to adsorb nutrients from water
- Capping materials to lock phosphorus into lake sediments e.g. Phoslock.

In this presentation I aim to present an overview of research undertaken in New Zealand to reduce nutrient loads to freshwater from agriculture and eutrophication and outline the main techniques being tested.

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Ballantine D.J., Davies-Colley R.J. 2009. Water quality trends at National River Water Quality Network sites for 1989-2007. http://www.mfe.govt.nz/publications/water/water-quality-trends-1989-2007/index.html Ministry for the Environment, Wellington, 2009, pp. 43.

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Session 2: Potential of phosphorus and nitrogen binding materials

Testing phosphorus sorbing materials - results and questions about criteria

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In The Netherlands, it was long attempted to reduce the loss of phosphorus (P) to surface water only via general measures: lowering the amount of P in animal feed, reducing the amount of manure that can be applied, a ban on manure application in winter, etc. This has led to a gradual decrease in P content in surface water (Chardon and Schoumans, 2007), but on too many locations this remained too high. Therefore, innovative remediation practices are being developed that should address agricultural P loss to waters in the short term. Trapping P on its way to surface water via barriers or filters could be such a practice.

For binding P, we tested iron hydroxide (ferrihydrite) produced by oxidizing Fe^{2+} in anaerobic groundwater, pumped up for the production of drinking water. The ferrihydrite was either available as a sludge (with 33% Fe) or as a coating on filter sand (with 20% Fe).

In a batch experiment the sludge showed a very high affinity for P. However, the coating of the sand was not stable during shaking, so the coated sand could not be tested in a batch experiment.

In a column experiment we tested the coated sand and a mixture of 1, 5 and 10% sludge with resp. 99, 95 and 90% of pure sand; this gave an Fe-content of the mixtures of resp. 0.33, 1.65 and 3.3%. This was percolated with a solution of 4 mg ortho-P L^{-1} at ca. 19 pore volumes a day. As expected, breakthrough was strongly, and negatively, correlated with the amount of Fe present in the column. In the near future, also granulated ferrihydrite will be tested.

Results will be presented, and the applicability of sludge, coated sand and granulated products will be discussed. Especially the hydraulic conductivity of pure products and mixtures will be addressed. Also, the methods for testing materials in the laboratory will be discussed, e.g. influence of initial concentrations used and kinetic aspects.

Reference

Chardon, W.J., Schoumans, O.F. 2007. Soil texture effects on the transport of phosphorus from agricultural land in river deltas of Northern Belgium, The Netherlands and North-West Germany. Soil Use Manage. 23 (Suppl. 1), 16-24

Phosphate retention/solubilization characteristics of industrially produced Ca–Fe oxide granules

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We studied in laboratory phosphorus (P) retention and solubilization characteristics of industrially produced granules containing calsium (Ca) and iron (Fe). At least 85% retention efficiency was obtained in 5 minute contact with 1 mg P l^{-1} solution, and equally high P retention in leaching tests when granules were placed on the bottom of soil columns.

In a flow-through system fed with 50 mg P l^{-1} solution, the granules showed retention capacity of 7 g P kg^{-1} for a coarse (2–5 mm) size fraction and more than 16 g P kg^{-1} for a fine (< 2 mm) size fraction. About 20% of the P retained by P-saturated granules was solubilised when extracted sequentially with water (twice), with anion and cation exchange resin mixture, and with buffered dithionite solution (pH 6.9, Eh less than –300 mV). During a 6-month anoxic incubation, concentrations of dissolved Fe and P in water increased somewhat, but remained lower than for a soil sample used as control. Solubilization of P was partly pH-dependant, suggesting that phosphate in P-saturated granules was in part precipitated as, or adsorbed to, Ca-associations. Phosphate solubilized at neutral pH but low redox potential suggests that phosphate was also adsorbed by Fe hydroxides.

When P-saturated granules were immersed for 16 days in an oligotrophic lake, 60% of the total granule mass was lost. The mass loss comprised of element losses of > 80% for Ca, but no loss of metal elements, and about 25% loss of the P bound by P-saturated granules. It seems that even though Ca-associations initially played a significant role in P retention by the granules, the metal hydroxide component of the granules had captured P during dissolution of Ca-associations. Field studies are started in 2010 to test the granules as a medium for P retention in wetlands and edge-of-field permeable reactive barriers.

Nanostructured Vermiculite – A new material for recycling ammonium from different types of polluted matters

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We present an original patented technology that involves modifications applied to the crystalline lattice of the natural mineral vermiculite. This modification occurs at the nanolevel that varies from 0.4 – 0.7 nm up to hundreds of nm, in terms of the cell size and clusters of the crystals, respectively. The present project aims to obtain a brand-new, high-tech geomaterial GS-1, which can be used as an efficient filter and immobilizer of ammonium ion (NH_4^+) from variable polluting matters (waters, soils, excrements, etc). A secondary product, ammonium-doped modified geomaterial termed herein GS-2, can be obtained during operations related to cleansing of the polluted environment. GS-2 thus becomes an ecologically sound fertilizer for long-term period use and a soil conditioner. All the methods and products related to this development are novel, environmentally friendly and concerned with recycling.

The geomaterial GS-1 is able to absorb up to 4.7 wt% of NH_4^+ into the A-site of its crystal lattice over a short time span. Such absorption is selective since other cations hardly get absorbed though they can have a similar size and charge. Such selectivity opens various prospects for the use of GS-1 as a unique NH_4^+ absorber for various polluted environments. Our material has been efficiently tested on waste water from a biogas plant, human urine, combustion experiments (fox excrements), industrial chimneys, excrements from farms etc. Moreover, the ammonium-doped secondary geomaterial GS-2 was tested as a fertilizer in greenhouse experiments with seedlings. After five months, the weight of the plants that had grown in a substrate containing geomaterial GS-2 was 10 times the weight of plants growing in the reference substrate. More longer and representative tests are currently in progress to establish the ideal proportions of both geomaterials for their best efficiency.

These test results together with latest marketing research are currently used for a commercialization project in Europe. The unique aspect of GS-1 for reduction of polluting NH_4^+ and its reuse as a fertilizer (GS-2) for increased growth has very significant business potential.

Session 3: Practical results for runoff, buffer zones and wetlands with new measures

Evaluation of chemical amendments to control soluble phosphorus losses from dairy cattle slurry

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It is estimated that agriculture accounts for 38% of all pollution in Ireland's waterways. In recent years, there have been improvements in water quality in Ireland. The number of rivers in Ireland with good river status increased from 67% in 1997 to 71.4% in 2008. However, more work is needed in order to ensure that Ireland meets the targets set by the Water Framework Directive. This directive requires that all Irish rivers will achieve at least 'good status' by 2015. In fresh water environments, algal growth is phosphorus (P)-limited. An increase in soluble P concentration in surface water runoff, resulting from land application of dairy cattle slurry, may result in eutrophication of rivers and fresh water lakes. The aim of this study is to identify chemicals with the potential to reduce P and suspended sediment (SS) loss from agricultural grassland arising from the land application of dairy cattle slurry.

The objective of this work is to examine – at laboratory scale - the effect of chemical amendments on dissolved reactive phosphorus (DRP) and total phosphorus (TP) loss from grassland following land spreading of dairy cattle slurry. A laboratory flume was built to accommodate undisturbed grassed soil samples. Three treatments were examined in the rainfall simulator: (i) dairy cattle slurry (control); (ii) alum (1.11:1 Al: TP stoichiometric rate); and (iii) lime (10:1 Ca: TP), each applied at a rate equivalent to 26 kg TP/ha. Lime addition reduced the DRP mean flow-weighted concentration by 53% during Rainfall 1, 70% during Rainfall 2, and by 85% during Rainfall 3. Alum was best at reducing SS loss from the flume, lowering it by 87%, 91% and 81% in the 3 successive rainfall events, compared to 80%, 84% and 74% with lime.

A preliminary study on buffer zones amended with P-binding compounds

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Although vegetated buffer zones (BZs) along water courses decrease losses of eroded soil particles and total phosphorus (TP) through field surface runoff, they appear ineffective in reducing dissolved reactive phosphorus (DRP) losses from boreal clayey soils. After soil freezing and thawing in spring, DRP losses can be considerable and they may even increase on BZs (Uusi-Kämppä and Jauhiainen 2010). To improve DRP retention, we added Fe and Ca containing compounds to the surface of BZs: gypsum ($CaSO_4$ x $2H_2O$), Fe-gypsum, ground calcium carbonate ($CaCO_3$) or granulated ferric sulphate (Ferix-3).

Altogether 40 undisturbed surface soil columns (depth 7 cm, Ø=24 cm) were cored from two BZ sites located on clay soils at Jokioinen and Pöytyä, SW Finland, in November 2008. Phosphorus status in surface soil (0–2 cm), estimated with extraction using acid NH_4-acetate (pH 4.65), was 'fair' (6.4 mg L^{-1}) and 'excessive' (47 mg L^{-1}) at Jokioinen and Pöytyä, respectively. Gypsum (6 t ha^{-1}), Fe-gypsum (8.5 t ha^{-1}), $CaCO_3$ (3.3 t ha^{-1}) or Ferix-3 (0.67 t ha^{-1}) was spread on surface of four replicate soil samples, whereas eight samples served as untreated controls. Simulated rainfall (5 mm h^{-1}) was applied indoors to presaturated samples. After that, the soil samples were frozen (1–2 months), thawed (20 h, +6°C) and a second simulated rainfall was applied. A third rainfall was given after yet another freeze-thaw cycle. During each rainfall simulation, surface runoff was collected and analysed for DRP and TP.

Freezing and thawing increased the DRP concentration of control treatment up to 13-fold. For the samples treated with Fe and Ca compounds, the removal efficiency for DRP was increased in the order: gypsum<$CaCO_3$<<Ferix-3<Fe-gypsum. Both Ferix-3 and Fe-gypsum retained 74–85% of DRP and 47–64% of TP, compared to the control, whereas gypsum and $CaCO_3$ were not effective in the retention.

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Structure liming and omitting ploughing as measures to reduce agricultural nutrient loading to surface waters

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High losses of soil and total phosphorus (TP) have been shown to occur from tine-cultivated and mouldboard-ploughed soils in clay soil areas, especially from soils with a weak soil structure in Scandinavia. Structure liming with burnt lime (CaO) causes an immediate reaction between CaO and clay. Adding CaO at a rate of 5 t ha^{-1} to a marine clay soil south of Stockholm doubled aggregate stability, expressed as readily dispersed clay (RDC). A two-year plot experiment at the same site revealed a clear reduction in TP leaching via tile drains, mainly in the form of particulate phosphorus (PP), after structure liming at the same rate. Overall, TP leaching declined significantly from 0.22 to 0.085 kg t^{-1} year $^{-1}$ related to harvested amount of barley. Omitting ploughing and only cultivating in autumn did not decrease TP losses, but reduced nitrate-nitrogen (NO_3-N) losses at the site in the second year.

Omitting ploughing in autumn and continuous crop cover are generally used to control soil erosion In one example, estimated particulate P (PP) losses from a tile-drained, heavy clay soil in SW Sweden were 2 kg ha^{-1} in wet winters, but undersown green manure or undisturbed stubble reduced these losses by on average 42% over 4 years. In Norway, ploughing and shallow cultivation of sloping fields in spring instead of ploughing in autumn has been shown to reduce particle transport by up to 89% on soils with very high erodibility. Particle erosion from clay soils has been estimated to be reduced by 79% by direct drilling in spring compared with autumn ploughing. However, the results regarding the effect of reduced tillage during autumn on losses of dissolved reactive P (DRP) are contradictory, indicating that erosion control measures should be further evaluated for fields with a low erosion risk.

Phosphate adsorption on different filter materials

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A study of some Norwegian constructed wetlands in arable catchments showed that the average phosphorus (P) retention varied from 21-44% (Braskerud 2001). In catchments with vulnerable water bodies it is of interest to improve P retention in the constructed wetlands by including P adsorbing filters in the end of the wetland. Construction of filters at the outlet of tile drains is also a possible mitigation option. P retention in filters is expected to be a combined effect of retention of soil particles that are too small for sedimentation in the wetland and adsorption of dissolved P. Here, results from a laboratory study of adsorption of phosphate to four different materials of interest for use as filters in constructed wetlands are presented.

The filter materials tested were Maxit Filtralite P, Kemira CFH-12, crushed lime stone and coral sand. In Kemira CFH-12, Fe is the active component (ferric hydroxide granules), whereas in the other three Ca is the active component. The laboratory experiment was performed with four different phosphate concentrations in the range from 50 to 500 µg P/L, three different contact times (30 min, 2h and 6h) and with 1 g filter material to 30 ml solution.

The ferric hydroxide granules were superior to the other filter materials. At 30 min contact time and 500 µg P/L, 88% of P was adsorbed, whereas at 6 h contact time 99% of P was adsorbed. Crushed lime stone adsorbed less than 20% of P in the 500 µg P/L solution. Filtralite P and coral sand showed quite similar ability to adsorb P. At 30 min contact time and 500 µg P/L 35-50% of P was adsorbed, whereas at 6 h contact time 78-90% of P was adsorbed.

Reference

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Constructed wetland to mitigate P losses from hotspots in agricultural areas

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Most constructed wetlands (CWs) in Sweden have been designed to retain nitrogen (N) and not phosphorus (P), which has resulted in limited knowledge about their effectiveness as P traps. A designed CW for P retention was built in August 2009 at an agricultural site in central Sweden. A catchment characterisation demonstrated that a horse paddock close to the wetland substantially increased the risk for high P loads to the CW. Extracted P in an acid ammonium lactate solution from topsoil samples was at some areas more than 500 mg P-AL kg soil^{-1}. Simultaneously, the degree of P saturation in the same soil extracts was locally high. Ten years flow-weighted averages of total phosphorus (TP) and total nitrogen (TN) in subsurface run-off water were 0.5 and 6.3 mg L^{-1}, respectively.

The CW consisted of a one meter deep sedimentation basin with the length of 27 m, and two shallow (0.3 m) vegetation filters with a total length of 72 m. The CW was formed as a curved long-narrow opening of the culvert and the surface area was rather small (0.28% of the 35-ha catchment). Flow proportional water samples were analysed every fortnight and continuous water flow was measured at both the wetland inlet and outlet. Both particulate bound phosphorus (PP) and dissolved reactive phosphorus (DRP) retention were estimated. During spring flood, high frequency water samples were collected as it is a critical period for P loss from agricultural areas in Sweden. Sedimentation traps showed an average gross sedimentation rate of 4.2 g d.w. month^{-1} in the sedimentation basin and 0.8 g d.w. month^{-1} in the first vegetation filter. This indicates that most of the particles and P was trapped closer to the inlet.

Winter-time nutrient load is challenging long-term water protection measures - urgent need for new tools

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Lake *Säkylän Pyhäjärvi* (SW Finland) is an example of a large and shallow lake suffering from eutrophication. During the last 20 years the quality and general usability of water in Lake Pyhäjärvi have shown considerable variation driven by both a variety of human activities and climate-related factors such as wet and dry years. The lake has been thoroughly studied for decades and has been the object of comprehensive restoration activities both in the catchment and in the lake since the 1990s. Lake Pyhäjärvi has been the target of an intensive restoration programme since 1995 when the Pyhäjärvi Protection Fund (PPF) was created by local municipalities, private industries and local associations to act in collaboration with regional environmental and agricultural authorities. Since 1995, nearly all farmers in the catchment have committed to the Finnish Agri-environmental program to implement basic water protection measures. In addition, such intensive catchment management practices as buffer zones, sedimentation ponds, and wetlands have been introduced. New innovative treatment methods such as filter ditches and sand filters were also constructed and tested for their ability to remove phosphorus (P) from runoff waters. PPF has also been active in promoting waste water treatment in the rural catchment.

Currently, restoration work is facing new challenge: increased winter time nutrient load from the catchment. P load was especially high in winters 2006/2007 and 2008/2009. Most of the water protection measures (wetlands, buffering stripes, filter systems) work insufficiently in winter flood situations. Thus, new technical solutions should be developed for both flood management and nutrient removal in winter time. Also, environmentally friendly cultivation practices should be developed and implemented.

Possible solution for viable land use with environmentally sound agricultural production in the Koppány valley area, Hungary

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The research work is along the Koppány River near Somogyacsa, Törökkoppány and Somogydöröcske villages in the watershed of the Nagy (Big) Koppány stream, Hungary. The underdeveloped area is designated by local rural development community as an experimental area for agro-ecological development. A continuous ecological deterioration is the typical characteristics of the target area and similarities can be found in other rural Hungarian watersheds and Central/Eastern Europe with similar geo-physical and socio-economic characteristics.

We introduce the agricultural structure of the area and related pedological and socio-economical problems. The local rural development community (Vox Valley Development Association) coordinating the 2007-2013 rural development funds of EU in the area decided to demonstrate the possible actions which help the formation of a sustainable agro-ecological system in an area. We also introduce the possible solutions based on these funds, e.g. introduction of agro-ecological schemes, sustainable close-to-nature fishponds, animal husbandry focusing of native Hungarian breeds and plant production focusing on herbal species, shrubs and trees, all in order to keep local population and cultural heritage in place, reduce pollution in surface waters and reduce soil and nutrient loss.

Apart from the short overview of the main factors leading to the present situation this paper concentrates on proposals which will help the evolution of a sustainable eco-social system by increasing biodiversity, decreasing the further fragmentation of habitats, offering alternative income sources for local residents based on the protection and flexible handling of former and present agri-cultural heritage. The basic of this research activity is a landscape ecological approach that starts with the examination of basic natural features from geology to birds and ends with a complex package of possible solutions.

Assessing the potential for using constructed wetlands as mitigation options for phosphorus and sediment within UK agriculture

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The Mitigation Options for Phosphorus and Sediment (MOPS) projects explore practical methods to reduce diffuse pollution from UK agriculture. Previous research undertaken within MOPS has demonstrated that the use of in-field mitigation options (e.g. reduced tillage) can be effective at reducing surface runoff, sediment and nutrient loss. However, pollutants can still be lost from hillslopes unchecked via subsurface flow pathways, which may transfer high nutrient loads downstream. Current research within MOPS is therefore investigating edge-of-field mitigation approaches, which can tackle both surface and subsurface pathways where they discharge into ditches and streams.

MOPS has created seven new constructed wetlands at the edge of agricultural fields, and is now assessing their functioning and effectiveness as diffuse pollution mitigation options. The constructed wetlands, located on different farm and soil types, have been built to three different designs and sizes suited to UK landscapes. Sediment and nutrient load reductions and wetland effectiveness are determined through continuous monitoring of discharge and turbidity and storm water sampling for sediment and nutrients at wetland inlets and outlets. Sediment and nutrient accumulation will also be assessed by annual topographic surveys and sediment sampling, and tracer experiments will be carried out in the course of the project in order to understand water and sediment residence times.

The use of constructed wetlands to trap sediment and nutrients is new to the UK, but is well established elsewhere, particularly in Scandinavia. The project builds on this research, and has a number of novel factors including assessment of multiple pollutants and pathways and pollution swapping, and the consideration of the economic and social aspects of these mitigation options. Here we present the initial results, including novel high-resolution data from the first monitored events.

Does gypsum reduce phosphorus losses in an agricultural catchment?

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Many inland and coastal water bodies in Finland fail to achieve the good ecological state demanded by the Water Framework Directive by 2015, unless nutrient loading from agriculture is drastically reduced. Novel remedies may provide a means by which nutrient losses from arable land to surface waters can be effectively reduced particularly at high risk sites. The use of gypsum as a soil amendment dates back to ancient Greeks but its use for phosphorus (P)-control is relatively new. In the ongoing TraP project, gypsum is broadcasted on soil surface and the effect of this measure on P losses from arable land is evaluated using laboratory and field studies and modeling. The gypsum originates from fertilizer plant using Finnish igneous apatite free of Cd and radioactivity.

The study area, Nummenpää catchment (2.4 km^2, 41% fields), is located in southern Finland. The fields are mainly on clayey soils and the dominant plants include spring cereals and cabbage. Gypsum was spread (4.1 t ha^{-1}) on 91% of the field area in autumn 2008. Runoff quantity was monitored by a V-notch weir and runoff quality manually and with the aid of automatic sensors (YSI 600, SCAN spectrolyser) before, during and after the gypsum amendment. Turbidity measured by the sensors correlated well with the concentrations of particulate P as analysed in the laboratory. In addition, sensor-measured electric conductivity correlated with sulphate concentration in runoff.

Soil analyses showed that conductivity and sulphate concentrations increased significantly in the plough layer after the gypsum amendment, but pH and the concentrations of P, K, Mg and Ca were not affected. When normalized by the changes in runoff volume, the loss of particulate P was some 60% lower after the gypsum amendment. Dissolved P was also reduced, although the scatter in the results was higher. To reliably single out the effect of gypsum from other contributing factors, the monitoring at the site should be continued.

Based on the estimated sulphate flux, a maximum of 30% of gypsum was leached within the first year after application. That about 70% of gypsum remained in the soil, suggests that desired effect may still continue. The elevated sulphate losses may pose a risk of enhanced benthic release of P in sulphate-poor lakes, which may restrict the potential application areas to catchments discharging into sea, which is inherently rich in sulphate.

Session 4: More about catchments: measures on critical source areas

Shortfall of P budged in Orlík reservoir – statistical tryout among culprits with sparse data

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Orlík reservoir, the largest one in Czech Republic, is intensively affected by eutrophfication. Concerted effort of main authorities in past few years resulted in aspiration with "simple" goal: restore attractiveness of popular site for regional tourism. Today intense cyanobacterial blooms disable bathing and limit boating at upper part of reservoir. Of course, at the beginning of the project precise phosphorus (P) sources apportionment according to their impact on summer algal growth is needed. Then thresholds will be set up below which individual sources/groups should be decreased. Finally, restoration measures can be sought and realized.

Preliminary synthesis has implied rough imbalance between P sources in watershed and total influx to reservoir. Nearly 75% of P influx have "unknown" origin. Nevertheless, main sources (most of point sources and load from agricultural land) are measured quite precisely. Erosion and widespread fishponds are now most suspected sources of uncertainty. Moreover, because calculation is based on monthly sampling, it is possible that resulting influx is overestimated in part. Here we decided to search for any "fast and cheap" approach independent to model processing at the same time (SIMCAT).

Whole basin was fragmented into five sub-watersheds. In addition to total area they differ considerably in characteristics such as: land use (proportion of arable land, area of ponds or forestry), hydrology (mean discharge, flow-duration curve and retention time) and habitation (ratio of sewerage, treated wastewater and population density). All these factors represent specific pollution sources as indirect markers. We will statistically discriminate variability according these markers. We presume correlation matrix of possible culprits and their share at uncertainty of annual load can focus our attention. Detail inspection of three years discharge data (Q_d values) will exclude if discrepancy is caused by inadequate influence of extreme values.

Reservoir characteristics: dam is 91 m high at crest, total volume 0.7 km^3, surface area 27 km^2, watershed area 12.106 km^2 of which 35% in arable land, 0.64 10^6 inhabitants, Q_a = 82.5 m^3 s^{-1}, theoretical retention time 100 days. Bottom outlet.

Sources, transport, and eutrophication potential of phosphorus in the catchment of drinking water reservoir Římov, Czech Republic

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Římov Reservoir is a dimictic, deep-valley reservoir (volume, 34 10^6 m^3; surface area, 2,1 km^2; max. depth, 43 m; mean water residence time, 0.25 yr) in an upland area of South Bohemia (48.833N, 14.667E). Its water quality suffers from symptoms of eutrophication caused by excessive loads of phosphorus (P). Land use of the catchment (area, 489 km^2) include forestry (51%), agriculture (arable land, 22%; grassland, 24%), urbanization (2%; mean population density, 35 persons per km^2), and fish ponds (1%). The aim of our study was to investigate the point and diffuse P sources in the catchment, determine the composition of dissolved and particulate P forms in the particular sources, and evaluate the amount and forms of P that were permanently retained in the reservoir bottom sediments by its major binding counterparts, i.e. Fe and Al hydroxides.

The study evidenced that judging the eutrophication potential based on the total P export from particular sources can lead to biased results. Namely, the point source discharges of municipal wastewaters and the fish pond effluents represented only ca 22 and 3% of the total catchment P sources, respectively, nevertheless, they overweighed all other sources in the eutrophication effect as they delivered most of P into the reservoir in bioavailable forms (orthophosphate and/or phytoplankton biomass) and also were the primary cause of increased concentrations of P in the reservoir inflow during the summer period. These two source types also showed a low (Fe+Al)/P molar ratio (less than 5) while the runoff from forest and agriculture areas had this ratio above 15, which indicates that P from the municipal wastewaters and fish pond effluents might be more easily recycled in the reservoir aquatic ecosystem without being entrapped in particles and made unavailable by combining with these metals. Also the sediment particles in the forest and farmland streams showed low phosphorus saturation index (PSI) values (less than 10%) while the particles in streams loaded with municipal wastewaters had the PSI values much larger (over 30%). The analysis of P fractions in a dated sediment core from the reservoir lacustrine part showed a higher P concentrations and PSI values compared to particles delivered into the reservoir from the catchment with the inflow, indicating stable and permanent retention of P in the reservoir bottom deposits.

In conclusion, this study demonstrated that the improvement of eutrophication problems should be directed mainly to more efficient purification of P from municipal wastewaters and to the reduction of P concentration in fish pond effluents.

Evaluation of critical source areas to reduce nutrient loading from agriculture in river basins in Saxony/Germany

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We modelled sediment and nutrient (N, P) input in water bodies of the Federal State of Saxony (Germany) using the simulation tool „Stoffbilanz". Future scenarios were developed for the cultivation of energy crops with a share of up to 30% of arable land. Results are an important contribution to elucidate the current and future situation of N and P loads of groundwater and surface water. Funding was provided by the Saxonian Agency for Environment, Agriculture and Geology responsible for water quality in scope of the Water Framework Directive.

The model calculates N leaching from the soil zone based on input, output and turnover of N. Turnover processes for cropland are simulated in the "Stoffbilanz" model by using indicators for mineralization and immobilization of N. C:N ratio, mean annual temperature, crop specific management practice, and contents of humus, clay, calcium carbonate and rock fragments.

Sediment and particle bound phosphorus inputs are calculated using the concept of "area connectivity". GIS functions are used to delineate areas with high hydraulic connectivity to river network. The likelihood of connectivity is computed, considering the distance to watercourse, transport capacity of surface runoff and sedimentation of soil in landscape. Sediment and particle bound P inputs in the watercourse were calculated according to the concept of sediment delivery ratio, which was adapted to regional scale.

Critical source areas and driving forces of N and P inputs are analysed, considering sources and sinks at regional scale. Landscape properties, management practice and spatial distribution of crops (food crops, energy crops, short rotation coppice) were found to be the most important factors controlling loading of groundwater and surface water for all scenarios.

Reduction of groundwater pollution by nitrate-nitrogen with agrotechnical measures

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The largest reservoir of high-quality drinking ground water in Slovak Republic is situated in the Žitný Ostrov (the Rye Island) region. This region belongs to the Danubian lowland where the Quaternary deposit with thickness up to 350 m creates ideal conditions for water accumulation. Considering that these areas are also the areas with the most intensive crop production in our Republic, it is necessary to look for all available ways of protection these water resources from the pollution of nitrate-nitrogen (NO_3-N) as well (e.g. restriction or limitation of some agricultural activities in these areas).

One of the possible ways how to reduce penetration of NO_3-N to groundwater is also the systematic exploitation of different agriculture systems of soil use in concrete area on regulation of water-nitrate regime of soil (cover-protection layer of groundwater).

A few years research in the protection area of water resource Borovce, district Piešťany, deals with influence of different factors on distribution of moisture and content of NO_3-N in soil profile up to the depth of 3 m. The factors are: two different crop rotations, biological (A1) and cereal (A2), two different fertilization variants, manure fertilization (B1) and straw fertilization + NPK (B2) and two different ways of soil cultivation, conventional cultivation (C1) and protective cultivation (C2).

Results of these experiments inter alia showed that the crop rotation had the highest influence on the moisture profile. On the other hand, the influence of examined fertilization variants on the change of moisture was the smallest.

From the point of view of groundwater protection on this specific area, the best combination of variants was A1 B1 C2, i.e. biological crop rotation fertilized by manure and using protective cultivation.

Balancing emission reduction measures and ecological water quality benefits; the river Dommel case

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The river Dommel (the Netherlands) suffers from urban and rural inputs of organic wastes and nutrients. As a result, good ecological conditions as demanded by the EWD are yet far from reached and substantial investments are necessary to improve the water quality. Local governments and waterboards more and more demand an optimization of the cost-benefit ratio, when designing catchment management plans.

A two-year project is started to link ecological water quality to specific regional pressures by intensive monitoring and modeling. The main idea is to shift from emission reduction targets (as an objective itself) to vulnerability and resilience of the aquatic ecosystem. The projected result is insight in the most efficient and cost-effective measures, both emission reductions and management options. Moreover, the feasibility of implementing the measures and regulations is enlarged by the early involvement of all parties in this project (local government, waterboard, scientists, consultancies). This presentation will show the set up of the project and some preliminary results.

Session 5:
Remedies in water bodies

What to do with extra electrons – how combating eutrophication may affect mineralization pathways

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Life on earth is based on redox-reactions *i.e.* transport of electrons in versatile metabolic reactions. In microbial metabolism organic carbon – serving the energy source for heterotrophic life – is the electron donor, whereas oxygen, nitrate, manganese and iron oxides and sulphate act as external electron acceptors. Eutrophication increases the amount of organic matter and its mineralization increases the flow of electrons to inorganic counterparts *i.e.* electron acceptors. As to the consequences of eutrophication, it is not insignificant where the electrons flow *i.e.* by which pathway organic carbon is mineralized in aquatic systems.

The pathway of electrons is dependent on the quantity and quality of organic matter as well as on the quantity and availability of electron acceptors present in specific system. Mineralization through oxygen can be considered favorable. However, in eutrophic aquatic systems the consumption of oxygen easily exceeds its transport to deep water layers giving rise to anoxic mineralization processes some of which can be considered favorable, too. For example nitrate reduction *i.e.* denitrification leads to formation of N_2. However, unfavorable processes may also emerge: iron reduction leads to release of both Fe and Fe-bound P and sulphate reduction forms toxic H_2S gas capable to reduce efficiently Fe oxides leading to blocking of Fe cycling. Methane formation, in turn, increases its release to atmosphere.

Considering eutrophication control remedies, there is also a need to assess the effects of measures on the fluxes of electron acceptors to understand the consequences of the measures. Some of the measures may affect the flux of electron acceptors, which may have an adverse or positive impact on the mineralization processes in recipient system. In this paper the above mechanisms are demonstrated against a set of current water protection measures, such as artificial oxygenation and erosion control.

Application of Lanthanum-modified bentonite and flocculent reduces eutrophication in a lake

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Eutrophication control in lakes often consists of a reduction of the external loading of nutrients in combination with in-lake measures. Flock and Lock is a novel technique to reduce the internal loading of phosphorus in lakes. It combines the application of a flocculent, in this research Iron-III-chloride ($FeCl_3$), with the application of a Lanthanum-modified bentonite clay product, commercially known as Phoslock®. The flocculent precipitates phosphorus and particles (like algae cells) from the water body (Flock). The Lanthanum-modified bentonite caps the sediment and binds the phosphorus that escapes from the sediment and from precipitates (Lock).

The effectiveness of Flock and Lock is being studied in a whole-lake application. This application was carried out in May 2009 in Lake De Kuil (the Netherlands). This lake has an area of 7 hectares and a maximum depth of 8 meters. The lake includes a bathing area and used to have a poor water quality due to frequent blooms of Cyanobacteria. In the application 4.3 tons of Iron-III-chloride and 41.5 tons of Lanthanum-modified bentonite were applied. To compensate for the acidification, which was caused by the use of Iron-III-chloride, 0.2 tons of Calciumhydroxide powder ($Ca(OH)_2$) was added.

Prior to the application a bloom of Aphanizomenon appeared in Lake De Kuil and transparency was low. Within a few days after the application the cyanobacterial bloom disappeared, the transparency increased and the concentration of phosphorus decreased. During the summer of 2009 cyanobacterial blooms did not occur again, the transparency remained high, the phosphorus concentrations remained low and the macrophytes increased. During the winter of 2009-2010 the lake was covered with ice for over two months. In early spring 2010 water quality remained good.

The research will be continued during 2010 and 2011 and is sponsored by the Dutch Ministry of Economic Affairs, the Province Noord-Brabant and the waterboards Brabantse Delta, De Dommel and Aa en Maas.

Using Phoslock® to control cyanobacteria in a shallow eutrophic Scottish reservoir- ecological responses across multiple trophic levels

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The ecology of many shallow lakes has been detrimentally affected by elevated phosphorus (P) and nitrogen enrichment as a result of human activity. This process is known as cultural eutrophication and often leads to a loss of biodiversity, increased operational costs for water companies and expensive lake remediation work. As such, eutrophication management is one of the biggest challenges facing aquatic ecologists; a fact that is recognised within European environmental policy (e.g. WFD and Habitats Directive).

When nutrient inputs are reduced at source, chemical and ecological recovery can be delayed for decades as a result of internal P loading. This problem is most pronounced in water bodies with a low flushing rate and may exist indefinitely in water bodies with no natural outflow. It is, therefore, essential that methods for the control of internal loading are examined and trialled at the whole lake scale.

We report on the use of a lanthanum-modified bentonite clay (Phoslock®) to control problem cyanobacteria blooms by disrupting internal P release in a shallow hydrologically isolated reservoir (Clatto Reservoir, Dundee). This talk will use Clatto Reservoir as a case study to (1) describe the current Phoslock® dose estimate and application methodologies, (2) discuss the physicochemical responses in the water column following an application of Phoslock® and (3) assess the ecological (macrophytes, benthic algae, benthic macroinvertebrates and phytoplankton) responses during a 1 year period of post-application monitoring.

Using Phoslock® to control cyanobacteria in a shallow eutrophic Scottish reservoir - assessing its impact on sediment phosphorus pools

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Clatto Reservoir (Dundee, Scotland) is a shallow man-made water-body with a history of cyanobacteria blooms. It receives limited surface run-off from the catchment, being predominately rain water fed, so sediments are the main source of phosphorus (P). In March 2009, 24 tonnes of Phoslock® were applied to the reservoir to reduce internal P loading and, accordingly, cyanobacteria standing stock.

P in sediments is present in various pools. Seasonal changes in physicochemical and biological processes can trigger the release of P from such pools (i.e. anoxia, pH changes or microbial mineralisation); consequently P is either exchanged into unsaturated pools or released to the overlaying water-column. Individual water-body characteristics, for example, bathymetry and fetch, cause those processes also to vary spatially. Understanding these temporal as well as spatial dynamics in sediment P fluxes and drivers of P release is important to efficiently manage internal loading.

In order to evaluate the role of Phoslock® in internal load management three key questions were addressed: i) what is the spatial distribution of Phoslock® following a common application, ii) how does Phoslock® affect P pools, and iii) when does Phoslock® alter P pools? To answer these questions four sediment cores were taken before (2 days) and after (28 days) the application. The top ten centimetres of each core were sectioned into two centimetre slices and P pools and elemental composition of each slice were determined. Initial results show that Phoslock® is not competing with existing P pools and that a commonly conducted application leads to an increase in Phoslock® concentrations up to a sediment depth of 10cm. Application timing will be discussed in order to enhance the efficacy of Phoslock® in internal load management.

Poster Session: Novel methods for reducing agricultural nutrient loading and eutrophication

Release of P from soil and suspended solids to assess the real risk of eutrophication

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Fertilization, in the long term, can affect the amount of phosphorus (P) compared to the crop needs and modify the soil P saturation. These factors can lead to P losses from soil to waters, especially via runoff and as particulate P causing eutrophication. To evaluate the effect of agronomic practices on P losses and on its bioavailability, soil samples (0-30 cm) from a middle term experiment have been selected. The field experiment is based since 1992 on maize cropping systems with different fertilizer applications: mineral, as NPK and PK, and organic, as manure (M) and slurry (S). A water dispersion test (DESPRAL), that simulates the surface runoff, has been applied to soil samples in order to obtain the amount of total dispersed solids and the main forms of that can be P lost. To assess the exchanging rate and the real availability of P bound to dispersed particles, chemical sequential extraction and isotopic exchange kinetics on soil and relative dispersed solids have been applied.

In the M system the bulk soil was almost P saturated and exchanged less P, but in the relative suspended solid a quite larger P exchangeability occurred in the short time, involving not only the most labile P forms but also the HCl-extractable fraction, considered more un-labile. The dispersed solids from S or PK systems had a similar behaviour, while in NPK ones the P exchangeability involved only the more labile P forms, also in the longer term.

From these results, it appeared that the real risk of eutrophication is linked to the amount of P that becomes available to algae rather than to the total amount reaching the water bodies and that the impact of the particulate P on water quality may be not easily deduced by P behaviour in soil.

Can phosphate solubilising bacteria be of use on phosphate saturated soils?

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Due to decades of excess phosphorus (P) fertilization in Flanders, most acid sandy soils became P saturated. This saturation implies that farmers in these areas are bounded to very strict P fertilization rules. The bulk of the (excessive amount of) P in the soil is strongly adsorbed and not directly available for plant uptake. Therefore, it is necessary to look for a way to make the P more available to the crop, even in these P saturated soils. Phosphate solubilising bacteria (PSB) transform unavailable P into plant available forms, and could thus proof to be very useful even in P saturated soils under severe fertilization restrictions. The goal of this research is to investigate the survival and performance of PSB in conditions of high total P content in soil.

Five PSB species, namely three Bacillus and two Pseudomonas species, where selected. Firstly they were tested on different media with different amounts of insoluble phosphate, to check their survival and their P solubilising potential under completely controlled conditions. Then the bacteria will be brought in a more realistic environment, namely in quartz sand with a nutrient solution that supplies all nutrients to the bacteria except P. The P will be provided in an insoluble form as $FePO_4$, $AlPO_4$ or $CaPO_4$. In a next step, the bacteria will be inoculated in P saturated soil under controlled conditions, to test their P solubilising capacities under these specific conditions, and crop P uptake will be monitored simultaneously.

Gypsum effects on soil characteristics and phosphorus sorption

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Effects of gypsum use as soil amendment to enhance phosphorus (P) trapping by agricultural soils were indentified in laboratory and field conditions. Fine textured clay of pH 6 and low-medium P status (PAAc 9.6 mg/l) was treated in laboratory by 0, 2, 4, 6 and 8 g/l gypsum and kept close to saturation in 0.5-litre pots perforated at bottom. After 4-week incubation the soils were watered and percolation water was analyzed. As anticipated from previous studies, turbidity and concentration of dissolved phosphorus were decreased along with elevated electrical conductivity. Accordingly, under field conditions the soil treated by gypsum (0, 2, 4, and 6 ton/ha) showed better aggregated stability and infiltration capacity in wheat cropping by both direct drill or minimum tillage. Improved aggregate stability is most probably the main reason for detected decrease of turbidity and particulate P load by gypsum.

To understand more closely why gypsum controls also dissolved P leaching, adsorption/desorption isotherms of P for soils amended by different gypsum rates were determined with Q/I-plot technique at a soil-to-solution ratio of 1:50 using P additions of 0, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8, 1.0 and 1.5 mg l^{-1} by KH_2PO_4. The suspensions were shaken for one hour, allowed to stand for 22 hours, shaken for 15 minutes and centrifuged. The suspensions were filtered (Nuclepore polycarbonate, 0.2 mm) and determined for phosphate by the molybdenum blue method. Net adsorption or desorption was calculated from the difference in the P concentration in the solution before and after the equilibration. A modification of the Freundlich adsorption equation was used to calculate equilibrium P concentrations (EPC). The paper gives the primary results on the modified Q/I plots by gypsum. The results clearly indicate increased dissolved P adsorption by gypsum, most efficiently at gypsum rate 4 g/l soil. The used gypsum originated from Siilinjärvi phosphogypsum (see the abstract of Ekholm et al on page 26).

Phosphorus dynamics and retention in non-point source wetlands in southern Sweden

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Data from seven constructed wetlands receiving runoff from agricultural catchments in the south of Sweden are investigated with respect to water quality in general and phosphorus (P) dynamics in particular. The seven wetlands differ in size (0.23–2 ha), design, land use and catchment characteristics. Wetland to catchment area varies between 0.06% and 2%, and the soil types in the catchments range from mixed sand to heavy clay with various proportion of agricultural land use (35–100%). The hydraulic load varies between 7 and 684 m $year^{-1}$, which reflect the different geographical and hydrological conditions.

The data series cover 2–9 years in the respective wetlands with continuous flow measurements and time or flow-proportional water samples for the time period covered. The aim of the study is to quantify wetland retention of P from agricultural catchments, and to identify factors that can explain differences in specific and relative P retention in the wetlands.

The relationship between water flow and seasonal variations of P concentrations in wetland inflows and outflows are analyzed for both dissolved and total P. Furthermore, differences in P concentrations are related to catchment characteristics, e.g. area, land use, soil types, amount of rural wastewater discharges, to identify possible landscape factors that affect stream transport of P and P retention in constructed wetlands.

This investigation will provide a better understanding of factors affecting P retention in created wetlands, with further implications for wetland research and monitoring. Furthermore, the results can assist when formulating models for P removal in wetlands receiving non-point source runoff.

Sustainable phosphorus remediation and recycling technologies in the landscape

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The quality goals of the European Water Framework Directive require a substantial reduction of diffuse phosphorus (P) loads from farmland in Denmark. Due to decades of surplus P additions with manure and fertilizers, the source of today's P losses is accumulated soil P, now posing a long-term risk. Mitigating agricultural P losses is particularly challenging, as critical losses are only a small fraction of actual soil P contents and not directly related to fertilizer P input. General regulations to reduce fertilizer P inputs have so far been ineffective. Tile drains and ditches connect fields to receiving waters and act as subsurface highways for both soluble and particulate P and nitrogen (N), but efficient mitigation options are lacking.

A newly launched research project "Sustainable Phosphorus Remediation and Recycling Technologies in the Landscape, SUPREME-TECH" (2010-2015) funded by the Danish Strategic Research Council, aims at developing cost-effective filter technologies targeting P-retention and N-removal in agricultural subsurface drainage. Filter technologies will be developed by (i) identifying the best performing filter substrates for retaining and transforming nutrients under highly variable flow regimes and nutrient loads, and by (ii) exploring technical solutions for field scale implementations of the filter technologies. Various designated natural and industrial filter substrates will be investigated for their suitability as filter substrates according to hydrological performance, P-retention efficiency and N-removal capacity. Based on their suitability selected filter substrates will be investigated in full scale experimental systems. The project studies different approaches of implementing the filter technologies including drainage well or drainage pipe filters, ditch filters as well as surface-flow and sub-surface flow constructed wetlands. The project also addresses the suitability of filter substrates for retaining other micro-pollutants as well as the potential for recycling P-saturated filter substrates as soil amendments. The project includes modelling of filter systems to provide design parameters and optimize filter performance, and analysis of the cost-effectiveness of implementing filter technologies in landscapes compared to other mitigation options. The project (www.Supreme-Tech.dk) is a collaboration between University of Aarhus and Copenhagen, five international universities and 15 participating industries.

Modelling of the effects of phosphorus load in Iisalmi Route

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The effect of changing external load the phosphorus (P) content in lake waters is poorly understood. Basic mass balance models have been used since 1970s to predict the concentrations as a function of external load. However, the retention of P in the lake chains, typical in most parts of Finland, is poorly understood. The aim of this study was to develop a model that can be used to predict the P content of lakes in Iisalmi Route caused by external loads of P. The model can also be used in the decision-making process of water protection.

The model involved two different steady-state models and was created with the Microsoft Excel program. In the model the Iisalmi Route up to the Lake North-Kallavesi were divided to 11 subdistricts. The data for the model was collected from the Hertta system and VEPS system which are maintained by the Finnish Environment Institute. After the model had been created it was calibrated and tested. The testing showed that the model was reliable.

The model was used to simulate the targets presented in the water protection guidelines to year 2015 and to change external P load and flow rate when predicting the changes of P content in lakes. Using the targets of the guidelines the P contents were decreased 10-22 % in different subdistricts. Results indicated that model works better with lakes that have lower level of eutrophication. In future the model will be developed to include the actions of the water protection for different loading sectors, especially for agriculture.

Erosion mapping with Light Detection and Ranging (LIDAR) and RUSLE – method testing at experimental plots and farmers' fields

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In southern Finland abundant of clayey soils, erosion carries major part of phosphorus load to water bodies. The purpose of this poster is to demonstrate present study intended to draw maps of soil erosion risk by using RUSLE (Revised Universal Soil Loss Equation) and field parcels situated both on experimental fields of MTT (Kotkanoja and Lintupaju) and on private farms.

The first uncalibrated model uses only three factors of RUSLE: 1) Length Slope factor (LS) that was evaluated from 1-m resolutions of LIDAR based Digital Elevation Model, 2) Erosion factor (K) that was evaluated from 1:4000 scale soil maps by using K-values that were taken from earlier studies done with ICECREAM model (Finnish heavy clay soils seem to be vulnerable to dispersion erosion, but the values used by earlier models might not consider the phenomena; therefore new K-values should be evaluated), 3) The cover factor (C) is based on the concept of deviation from a standard; in this study only the standard value (pasture) was used.

The first erosion maps of field parcels on private farms have been delivered to farmers in south-western Finland by "TEHO" project and feedback from the farmers will be used in the model development. After the basic calibration against data from experimental fields of MTT the changes caused by the cultivation measures (P-factor) and rainfall (R) are adapted to the model. The final objective is to estimate the erosion risk of fields (t/ha/year) for whole Finland and show calibrated results on the map. The calibrated model could also be utilized when creating a national phosphorus index. The project is financed by the foundation of the Central Union of Agricultural Producers and Forest Owners (MTK-säätiö) and the Ministry of Agriculture and Forestry.

Potential phosphorus and arsenic release in dispersed particulate form from Bangladesh rice fields

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In Bangladesh, rice cultivation covers nearly 75% of the agricultural surface. In the dry season, paddy fields are irrigated with groundwater, often polluted with arsenic (As), phosphorus (P), iron and other elements. The most affected zones belong to the Ganges Floodplain (GF) and Meghna Floodplain (MF) soil series. Irrigation causes a continuative input of As and P in soils, although mineral fertilizers remain the main P source. Soils can lose important amounts of As and P in solution or in particulate form especially during monsoon season. The potential transfer of P from Bangladesh soils to waters has received scant attention and the potential As transfer associated to dispersed particles is generally not considered. In the present work soil samples representative of the GF and MF series were characterized and the potential transfer of P and As with dispersed particles was evaluated using a simple water dispersion test (DESPRAL).

The GF soils are calcareous, with silt-loam to silty clay texture, while MS soils are noncalcareous with mainly silt-loam texture. Nearly 30% of the < 20 µm total granulometric fraction was water-dispersible in the MF soils and 20% in the GF soils. The average total soil P did not differ between the two series, while total As was higher in the GF soils. However, soluble P and dispersible P and As were higher in the MF compared with GF soils, as well as P and As Enrichment Factors (PEF, AsEF) in the < 20 µm dispersible fraction. The PEF and AsEF were respectively 1.5 and 2.6 in the MF soils and 1.2 and 1.8 in the GF soils. These results, considering the important raining events in the monsoon season, suggest particulate dispersion as one of major possible processes for P and As transfer from soil to surface waters, especially in the Meghna Floodplain soils.

Reduction of phosphorus load from critical source areas using a ferric sulphate dozer

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Exercise areas and milking stations have been identified as hot-spots of phosphorus (P) losses in many animal farms. In farm surveys we repeatedly measure excessive soil P concentrations in surface layer (0–2 cm) of these sites, e.g. paddocks that are affected by excrements. In rainfall simulations these soils have given very high concentrations (up to tens of milligrams per litre) of dissolved reactive P (DRP) in runoff water. As a remediation solution for such small areas that are saturated with P, we tested treatment of runoff water using a ferric sulphate dozer (Närvänen et al., 2008).

The dozer consists of cone-shaped polyester netting that is attached to the bottom of a container filled with granular ferric sulphate. The shape of the netting ensures that when water level rises, a larger volume of the cone is immersed in runoff and more ferric sulphate is dissolved. Thus, chemical dissolution is regulated by the flow. In our test site, the ferric sulphate dozer was placed in a channel leading to a sedimentation pond that had a sand filter wall at the outlet. The chemical treatment that was performed during one calendar year showed reductions of DRP and total P in runoff by 95% and 81%, respectively. For high-P waters draining from small areas, the construction and running costs of this type of treatment are reasonably low.

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Gypsum effects on percolated water characteristics at various soil P status

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Recently, the use of gypsum, i.e calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$), has shown significant potential to decrease turbidity (NTU) or particulate phosphorus (PP) discharge in Finnish agricultural soils. Effects of the soil amendment on dissolved phosphorus (DRP) losses have also been detected. The focus of this paper is on DRP in percolate waters from soils having similar texture and pH but varying soil P-indices.

The test soils, originating from same catchment and owning similar barley cropping history at minimum tillage in the past 10 years, were sampled from 7 different locations to 0–10 cm depths after harvest. Soil P-indices close to 5, 10, 15, 20, 40 mg/l soil were analyzed by acid ammonium acetate (AAC), indicating medium (10–15 mg/l) and high (20-40 mg/l) soil P status. These soils were treated by mixing 2 g gypsum (moisture 18% v/v) per 0.5 liter soil and kept close to saturation in plastic pots of 10 cm height, perforated at bottom. After 2 or 5 days incubation, 150 ml water was applied to the soils. The percolated water was analyzed for DPR, NTU, electrical conductivity (EC) and sulphate (SO_4^{2-}).

Without gypsum, DPR (mg/l, y) depended on soil P_{AAC} (mg/l, x) typically by y=0.0127x-0.0232 (R^2 0.85). The gypsum treatment corresponding 4 ton/ha, however, changed this relationship to y=0.0084x-0.583 (R^2 0.90), indicating significant change in DPR concentrations at high soil P-status. Also NTU was remarkably decreased by gypsum but independently on soil P. Similarly, EC and SO_4^{2-} increased by gypsum.

Accordingly, the gypsum application has potential to control P leaching from soils of high P status in the intermediate period when high soil P indices are being driven lower. Because gypsum use as soil amendment is, according to other studies, easily applicable to farm management practices and does not harm crop growth, the measure would allow normal cultivation during P mining of most risky high P soils.

Characterization and strategies for the control of eutrophication in the Furnas watershed (Azores – Portugal)

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Furnas watershed has a total area of 1,150 ha, 68% of which is used for pasture production for grazing of milking caws and beef production (average stocking rates vary between 1.5 and 1.7) and 32% is forest land (*Cryptomeria japonica*). Soils are originated from volcanic pyroclastic materials (fine ash and cinders) that are weakly weathered, and are generally classified at the Great Group level (Soil Taxonomy) as Typic Udivitrands. Average annual fertilization rates are: 62 kg N/ha and 68 kg of P_2O_5/ha. Fertilizer K is not usually applied because the soil parent material is, in general, very rich in this element.

The eutrophication process, identified in this watershed for the last twenty years, has been attributed to the high application rates of P fertilizers which, in conjunction with the low P retention capability of the soils, the slope pattern of the landscape and the high average annual rainfall (2,500 mm), tend to favour the P mobilization and transport to the water body, mostly in runoff. It is now well accepted that soil testing, when properly conducted, can be an essential and vital component of the risk assessment process for soil phosphorus movement from agricultural soils as a causative factor in the eutrophication of surface waters. Soil test data (Olsen method) from two different surveys, conducted in 2006 and 2008, consistently indicate high and very high P values, for most of the pasture soil samples, significantly higher than values from the forest soils in the Furnas watershed.

The degree of phosphorus saturation (DPS) approach, relating the P sorbed at a certain moment in the soil to its maximum P sorption capacity, has been used as an additional component of the risk assessment process and its correlation to P Olsen data was highly significant ($R^2 = 0.82$).

As part of a management plan being implemented, the regional government of the Azores has decided to initiate the negotiations with private owners for the acquisition of 200 ha of pasture lands of the upper part of the watershed to be forested with endemic species and thus leading, in the medium to long term, to a more favourable nutrient balance and better control of the eutrophication process in the Furnas watershed.

Protection of hill lakes through erosion control works

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Soil erosion has a great impact on reservoirs, owing to sedimentation and degradation of water quality. Erosion and sediment effluence are compared between a watershed with erosion control works and same watershed without erosion control works. The comparative analysis of these two situations set of some conclusions.

The erosion can be reduced under acceptable limits; a proper cultivation structure mixed with erosion crop system reduced erosion and sediment effluence; a good erosion control works capitalized efficiently rainfall, surface runoff is reduced; an adequate reclamation of outlet network reduces gully erosion; ensemble of land reclamation (cultivation structure, erosion crop system, erosion control works on outlet network) reduces erosion and sediment effluence with 23%.

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Surface Runoff Simulator (SIMU) hastens the research on phosphorus losses from grassland

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In Finland most important grass production areas are located on areas that have severe winter conditions, soil frost and snow cover that affect the runoff patterns. Surface waters of these areas suffer from dissolved phosphorus (P) pollution originated from intensive dairy farming. To study the effects of different treatments and changing winter conditions on surface runoff, we developed a device called Surface runoff Simulator (SIMU). The aim of this study was to determine the accuracy of the device and to evaluate its practical value in surface runoff research.

The experimental treatments are randomized on small grass plots during growing season. At the end of the growing season, the top soil (0-5 cm) from each plot is lifted by a turf grass cutter and frozen. Then the grass mats are placed individually on the sloping SIMU devices and covered with snow. Infrared heaters are used to melt the snow and the melt water is collected. Many factors are completely adjustable: the treatments on the field, the slope of the grass mat, the duration of melting period and the amount of snow that produces the surface runoff. The treatments in this experiment were control, 20 t of slurry ha^{-1}, 40 t slurry ha^{-1}, 20 t slurry + 3 t fine lime ha^{-1} and 40 t slurry + 3 t fine lime ha^{-1} and there were four replicates of each. Soil samples were taken before the runoff experiment and analysed for water extractable P (1:60). The amount of melted snow was equal to 71 mm of water.

The results of the experiment (Table 1) were realistic when compared to results from the experiments on field scales (Turtola and Kemppainen 1998). The procedure found differences in total P and dissolved Ca concentrations and tendency in dissolved P concentration although water extractable P in soil was the same for all treatments. It seemed that 20 t slurry ha^{-1} had no effect on concentration of total or dissolved P but 40 t slurry ha^{-1} increased clearly the concentration of total P. Even though the measuring of the runoff for dissolved P seems to be quite scale independent, the processes operating on small scale are still different than on field scale (Cornish *et al.* 2002). Thus, the SIMU is more reliable for measuring the differences between the treatments. SIMU is a useful tool when estimating the effects of climate change on P losses from grassland as it is economical, easy to use, fast and adjustable.

Table 1. The soil and the runoff water concentrations in SIMU experiment.

	Soil of the grass mats	Runoff water from the grass mats					
	Water extractable P mg l^{-1} (1:60)	Total P mg l^{-1}	*SE*	Dissolved P mg l^{-1}	*SE*	Dissolved Ca mg l^{-1}	*SE*
Untreated	11.0	0.38	0.045	0.26	0.049	11.3	1.41
Slurry 20 t	10.6	0.36	0.021	0.27	0.021	14.2	1.96
Slurry 40 t	11.7	0.45	0.034	0.32	0.038	10.3	1.41
Slurry 20 t+Ca 3 t	11.7	0.35	0.034	0.26	0.031	15.6	1.61
Slurry 40 t+Ca 3 t	11.1	0.48	0.024	0.37	0.005	15.0	2.19
tr *P* values	0.52	0.005		0.078		0.005	

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Acidification as a controlling factor for the content of active forms of nutrients in soil

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The effects of soil acidification on the content of nutrients in active form (NH_4-N, NO_3-N, PO_4-P, Ca^{2+}, Mg^{2+}, Zn^{2+}) in soil was studied in a laboratory experiment. The soil samples were taken from four different soils. The experimental unit was 250 g of soil samples. Different values of pH (pH: 3.5 – 7.5) were simulated by the addition of NaOH and HCl, as well as by maintaining a 60% full water volume for six months. After incubation, single-time nutrients extraction was carried out by a one-hour agitation of the soil material with redistilled water, at a ratio of 1 to 10 (soil to water). The soil-water mixture was filtered under pressure, and the contents of NH_4-N, NO_3-N, PO_4-P, K^+, Ca^{2+}, Mg^{2+} and Zn^{2+} were measured in the received solution.

The assumption was that the active form of nutrient is most sensitive for leaching in the case of adequate water flow through the soil profile. The content of NO_3-N in the soil was decreased significantly as acidification increased. In contrast, the content of NH_4-N was increased at the same time. It was probably connected with the limitation of nitrification efficiency (Haynes and Swift 1986, Robson and Abbott 1989). The maximum contents of NH_4-N, K^+, Ca^+, Mg^+ and Zn^+, were extracted from pH 3.5 treatments; however, minimum contents were extracted from pH 7.5 treatments. There is probably the mechanism of exchangeable cations (NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Zn^{2+}) displacing from sorption complex by H^+ and Al^{3+} ions (Goulding and Blake 1988, Hartikainen 1996). The highest content of PO_4-P in the soil was noticed in pH 6 and 7 treatments; and was probably caused by phosphorus immobilisation to insoluble compounds at pH 5.5 above. (Addiscott and Thomas 2000).

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Agricultural practice and nitrogen leaching in a field experiment: Risk analyses using the NLEAP model

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Intensification (tillage, fertilizer application, plant growing, irrigation) of the natural conditions of Fluvisol creates conditions for more intensive water movement through the soil profile and migration of nutrients. Monitoring results showed that groundwater has neutral to alkaline reaction, which does not exceed the maximum permissible pH value 8.5. Nitrate concentrations depend on fluctuation of groundwater table due to capillary upraising of nitrate at depth below 2,00 from the geological profile. Considerably high fluctuation of groundwater table was observed during the monitoring period. Maximum and minimum levels of the groundwater followed the seasonal distribution of the precipitation typical for the region.

Nitrate content in the groundwater was influenced by the reduced anthropogenic loading with fertilizers and a decreasing trend in nitrate concentration could be seen during several years in the end of the monitoring period (1972–2004) when nitrate concentrations were around and below the maximum permissible limit. The highest nitrate concentrations were measured during spring-summer months.

As a general conclusion, a certain effect of the anthropogenic loading was observed on the chemical composition of groundwater on the studied soil. In order to prevent pollution by agricultural practices it is necessary to maintain a deficit in nitrogen balance and irrigation management has to be done in a way to insure low drainage flow and nitrogen in the irrigation water has to be accounted for in the cycle of nutrients. The tests of NLEAP model showed good agreement between measured and simulated output parameters. The information of leached nitrogen could be used as predictive tool for the risk analyses in vulnerable regions.

Assessing the effect of constructed wetlands on non-point source nitrogen removal

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The Swedish E.P.A. has estimated that the 6000 ha wetlands that will be constructed in agricultural landscapes by 2012 will reduce the load to the Baltic Sea by 450 tonnes of nitrogen (N) (NV 2008). It has been suggested that with stricter guidelines for wetland location and design, the nitrogen removal per hectare of wetland could be substantially increased. This paper presents results obtained from a scenario analysis of the N load reduction that could be achieved if 6000 ha constructed wetlands would be constructed with improved guidelines.

Four different scenario simulations were run with a combination of two different assumptions regarding nitrogen load (% agricultural land in catchment) and removal rate constant. Transport calculations were based on nutrient loss estimations made in PLC 5 using the hydrological model HBV-NP (catchments of about 250 – 400 km^2), and wetland N removal was calculated according to the method used by Arheimer and Wittgren (2002) and Tonderski et al. (2005). Minimum and maxium removal rate constants were estimated from data obtained from Swedish wetland monitoring programs.

It was estimated that a maximum load reduction of 1200 tonnes N could be achieved with 6000 ha new wetlands, with large regional differences. The results are compared with a recent estimate of 110 tonnes N and 9 tonnes phosphorus (P) transport reduction resulting from 4135 ha existing wetlands constructed with subsidies in Sweden (Brandt et al. 2009). In both cases, the calculations are sensitive to assumptions regarding catchment size and nutrient loss as well as wetland removal effectiveness. A more detailed analysis of the relative effect of different assumptions is presented in this paper.

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Rainfall simulations of Jokioinen clay soils amended with gypsum to decrease soil losses and associated P transfer

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The bulk of phosphorus (P) loss is in annually tilled non-calcareous clay soils typically associated with soil losses. To decrease dispersion and off-site transport of soil matter, we amended two clayey fields with gypsum (6 tn ha^{-1}) that is obtained as a by-product of phosphoric acid manufacturing at Yara Siilinjärvi plant (East Finland); unamended plots and plots that received ground limestone (the same Ca application as with gypsum) were used as control treatments. The fields were cropped with spring-sown wheat and tilled either to about 10 or 20 cm depth in the autumn. Soil cores with 15 or 30 cm in diameter were retrieved for indoor rainfall simulations at intervals. The 15 cm diameter soil cores (4 of the 5 planned samplings analyzed to this date) were used for surface runoff generation (bottom plugged), whereas percolation water was collected from the 30 cm soil cores (1 of the 2 planned samplings analyzed).

As for surface runoff, gypsum application decreased particle mobilization from the uppermost surface soils, and also dissolved P concentrations in runoff as compared to the control treatments, but the effect of gypsum on the uppermost soil appeared to be fading one year (with 630 mm rainfall) after the amendment. In percolation water for which one set of soil cores (sampled 7 month after applications) have been analyzed, gypsum radically decreased turbidity, particulate P, and also dissolved P concentrations. At the same time, cation leaching and electrical conductivity of percolation water increased. Gypsum amendment didn't affect the harvested crop yields or nutrient uptake, except for hampering Se uptake by wheat (one crop year analyzed). Our results concerning lower soil losses after gypsum application were in agreement with the data from the simultaneous catchment study on gypsum effects on discharge quality (see the abstract of Ekholm et al. on page 26).

Nutrient transport from different subsurface drainage systems on clay soil

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The aim of this study is to find out how filter material and drain spacing of improved subsurface drainage affect crop production and nutrient load in both drainage waters and surface runoff. In the method I gravel is used as an envelope and the drain spacing is 8 m. In the method II very thin textile (<1 mm) is used as an envelope and drain spacing is 6 m. The research is carried out on a field at Jokioinen in south-western Finland. The soil is heavy clay and the mean slope is 1%. The existing tile drainage pipes were laid in 1954 using 16 m spacing and an average depth of 1 m. The size of the field is 6 ha and it consists of 3 field sections each with a separate drainage system. In the summer of 2008, the additional drainage systems were built into two of the field sections using the methods I and II. The third one was left as a control plot.

Volume and quality of subsurface and surface waters from each field section were measured. Concentrations of total phosphorus, dissolved orthophosphate, total nitrogen, ammonium nitrate, nitrate nitrogen and solid substances were determined from the water samples. Furthermore, depth of groundwater table, soil moisture and crop yield were also measured on several points within each field section. Physical and chemical soil properties were also determined from each field section.

In the paper runoff, nutrient load and crop yield from the calibration and testing periods are presented. The feasibility of the two drainage methods is evaluated from the point of view of crop production and nutrient loading to surface waters.

Applying on-line monitoring for quantification of diffuse load

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The load calculations of nutrients and suspended solids transported by streams and rivers are usually based on single water samples, models or discharge/concentration rating curves. Water quality changes are very rapid especially in small watercourses. Therefore, sporadic sampling is inadequate for determination of quality variation, resulting in significant errors in load calculations. New monitoring techniques that can measure high suspended solids and nutrient concentrations at frequent intervals are therefore needed.

High resolution water quality data collected by automatic sensors (YSI 600 and SCAN Spectrolyser) were used to determine the suspended solids (SS), phosphorus (P) and nitrogen (N) load from agricultural, clayey catchments of different size in the region of Lepsämänjoki River in southern Finland. Automated monitoring stations measured turbidity, nitrate nitrogen (NO_3-N concentration, electric conductivity, water temperature and water level in every 5 to 60 minutes. Data from the sensors were collected with the data loggers. Loggers were equipped with transmitters using GSM mobile phone network to automatically send the data measured into the server. Continuous turbidity data was calibrated to total phosphorus (TP), particulate phosphorus (PP) and SS concentrations by using regression analysis. Data from the nitrate sensor was calibrated to (NO_3-N) and total nitrogen (TN) concentrations on the basis of laboratory analyses. The discharge was measured indirectly on the basis of stage-discharge relation for each measurement location or with measuring weir. Results of load calculations based on single samples and on-line water quality data were compared to estimate the advantage of the continuous monitoring.

With high resolution on-line data collected from agricultural watersheds it is possible to reliably estimate the total load and to detect even the minor changes in water quality. It is, for instance, possible to investigate the influences of certain agricultural practices applied in the catchment. The method has been used successfully for example to investigate the effects of gypsum amendment on P fluxes and erosion in a small agricultural catchment in southern Finland.

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