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Critical evaluation of options for reducing phosphorus loss from agriculture

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Wageningen, The Netherlands

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Contents

Background and introduction

The role of phosphorus (P) in eutrophication of surface water has long been recognized. Negative effects of eutrophication include: reduced biodiversity of aquatic ecosystems and surface water quality, and algal blooms that restrict the use of surface waters for recreation and drinking water production. Algal toxic substances have caused fish kills and animal and human diseases in the past. Reduction of phosphorus input to surface waters is thus necessary, mostly starting with diminishing industrial losses, precipitating P in sewage water treatment plants and increasing the number of households that are connected with sewerage systems. Due to these reductions the relative contribution of agriculture to total P input to aquatic systems increases to 50 or even 90 % in many watersheds.

In Europe, the Water Framework Directive will force authorities of watersheds to improve the ecological status of the water. For many waterways this implicates a further reduction of nutrient inputs. It is foreseen that this has especially a large impact for phosphorus.

The need for reducing P loss from agriculture is thus clear, and studies to find the main locations where P loss starts and on transfer routes to rivers and lakes have received much attention recently. Research on reducing P loss is also expanding, and many different options are proposed and tested (and sometimes rejected) under different soil, crop and environmental conditions. Thus, there is a strong need for a critical evaluation of these options, in order to reduce further research where little benefit is likely and to expand research on options that have proven to be successful.

In the past, International Phosphorus Workshops (1995 Wexford, 1998 Antrim, 2001 Plymouth) have greatly contributed to increase our knowledge about the relation between agriculture and P losses, and about transfer of P from soil to water. The 4th International Phosphorus Workshop is aimed to be a platform for evaluating the effectiveness, under varying conditions, of different types of options for reducing P losses from fields, and the transport of P in, or effects of P on surface waters.

Source orientated options, like a (drastic) reduction of P input to agriculture, or prevention of P transport from agricultural fields, may be considered to be most effective for avoiding unwanted effects. However, when considerable amounts of P have accumulated in the soil in the past, a reduction in P loss may take (much) time. Therefore, also ("end-of-pipe") options for reducing P transport in surface water and for abating consequences of eutrophication in surface water are discussed. Furthermore, discussions will include aspects like the effectiveness of options for different forms of P (inorganic, organic, and particulate), economic aspects, and interaction with the nitrogen cycle.

Wim Chardon

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VI

Organisation

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VIII

PROGRAMME

Day 1 – Monday 16th August

All lectures, on all days, will be in WICC, room: Ir. Haakzaal

[Name of speakers in **bold**]

08.00 Registration
08.30 Introduction, Prof. W. **van Vierssen**, Director of the Environmental Sciences Group of Wageningen
       University and Research Centre

Risk assessment
08.45 **Heathwaite**, A.L., A.N. Sharpley, A.R. Melland, and C.J.P. Gourley
       Risk assessment methodologies (invited paper)
09.15 **Humphrey**, R.L., and P.J.A. Withers
       Field-scale risk assessment of phosphorus and sediment loss from agricultural land to water:
       Targeting mitigation options for the Water Framework Directive
09.35 **Quinton**, J.N., and J. Freer
       A semi-distributed approach for assessing the potential of mitigation measures for reducing the risk of
       phosphorus sources connecting with surface water bodies
09.55 Quin, B.F., J.D. **Blennerhassett**, G.S. MacLaren, and M.R. Hart
       Farm environment risk-assessment maps – bridging the gap between regional oversight and
       individual farm risk management

10.15 RECESS

10.45 **Foy**, R.H., A.N. Sharpley, and O. Oenema
       Interaction between nitrogen and phosphorus losses at watershed scales: Compromise or conflict?
       (invited paper)
11.15 **Isermann**, K., and R. Isermann
       Healthy human nutrition as the most important source-oriented option for reducing also phosphorus
       loss from agriculture – exemplary shown for Germany
11.35 Sharma, N.C., and S.V. **Sahi**
       Strategy for phosphate phytoremediation
11.55 Questions and discussion

12.10 LUNCH

Catchment / landscape scale
13.00 **Haygarth**, P.M.
       Importance of 'incidental' phosphorus losses at different scales (invited paper)
13.30 Doherty, C., P. **Jordan**, and G. McCartney
       Defining and mitigating against multi-source nutrient transfer at the catchment scale
13.50 **Cox**, J.W., and D.R. Smith
       Erosion and phosphorus mobility from agricultural catchments (invited paper)
14.20 **Bechmann**, M.E., and N. Vagstad
       Mitigating phosphorus losses from agricultural areas in Norway
14.40 **Cornish**, P.S.
       Prioritising locations, industries and abatement actions for environmental improvement in a
       heterogeneous watershed
15.00 **Kronvang**, B., M.E. Bechmann, H. Behrendt, G.H. Rubæk, and O.F. Schoumans
       River basin management plans for the European Water Framework Directive (invited paper)
15.30 Questions and discussion

15.45 POSTER SESSION (tea and coffee will be served in poster room)
       Authors are asked to be present near their poster until at least 16.45.

18.00 ADJOURN

Day 2 – Tuesday 17th August

08.30 **Chardon**, W.J., and G.F. Koopmans
    Phosphorus accumulation in Dutch soils: History, policies and options
09.00 **van der Zee**, S.E.A.T.M., W.J. Chardon, G.F. Koopmans, and O.F. Schoumans
    An indicator for phosphate saturation of soils
09.30 **Schoumans**, O.F., and R. van den Berg
    Evaluation of manure policy and its environmental impacts in The Netherlands
10.00 **Mulleneers**, E.A.J., and B.J.M. Crijns
    Phosphate regulation in the Dutch manure policy

10.20 RECESS

10.50 **Hendriks**, R.F.A., and C.L. van Beek
    Diffuse sources of phosphorus loading of surface waters in Dutch peat pasture areas
11.20 **Verloop**, J., H.F.M. Aarts, H. van Keulen, and J. Oenema
    Experiences with zero surplus P management and mining P on dairy farming system De Marke;
    strategies, effects on productivity and soil processes
11.50 Questions and discussion

12.05 LUNCH

13.15 EXCURSION

By bus to National Park "De Hoge Veluwe" and the Kröller Müller Museum
For more information see website: www.hogeveluwe.nl and www.kmm.nl.

13.45 Arrival in National Park, visit the Park and/or the Museum on a free bicycle
17.30 Depart to Wageningen (from the restaurant in the centre of the Park)
18.30 Conference Dinner in Restaurant "De Blauwe Kamer"
21.30 Depart of bus 1, back to hotels in Wageningen
22.00 Depart of bus 2

From websites:
National Park De Hoge Veluwe is one of the Netherlands' oldest and largest national parks. It consists of no less than 5,500 hectares of woodland, heathland, lakes and driftsand. Together with the Kröller-Müller Museum and the sculpture garden it offers a unique combination of nature, art and architecture.
De Hoge Veluwe is a park where visitors can still find plenty of space and peace, and where you can walk undisturbed for hours, or cycle using one of the free white bicycles. It is home to many endangered plant and animal species. Have you ever come face to face with a red deer, moufflon or roe deer? It can happen at De Hoge Veluwe! Alongside peace and space, there is also a lot to do in the Park. To protect the peacefulness, the activities are concentrated in the central area of the park.

The Kröller-Müller Museum was designed by a Belgian architect, Henry van de Velde in 1937-38. Constructed in light brown brick, the design and layout is in line with Helene Kröller-Müller's ideas of bringing art and nature together so that each should enhance each other. The Kröller-Müller collection's main emphasis is on work of the late 19th and 20th centuries and its fame rests principally on its 280 paintings and drawings by van Gogh mainly from his stays in The Hague, Brabant, Paris, and Provence ("Bridge at Arles"). Other painters represented are George Serat, Pablo Picasso, Fernand Léger and Piet Mondriaan.

The Kröller-Müller Museum has one of the largest sculpture gardens in Europe. The Sculpture Garden laid out in 1961 also reflects Helene Kröller-Müller's conception of a symbiosis between art, architecture and nature. It is filled with many modern pieces including Jacques Lipchitz, Claes Oldenburg, Henry Moore, Jean Debuffet, Auguste Rodin, and Barbara Hepworth.

Day 3 – Wednesday 18th August (morning)

Manure and Biosolids

08.30 **Jongbloed,** A.W., and H. Valk
Alteration of phosphorus content in diets for livestock: Impact on animal performance and health, and the environment (invited paper)

09.00 **Maguire**, R.O., B.C. Joern, Z. Dou, J.T. Sims, and J.T. Brake
Phosphorus forms and mobility due to manipulating phosphorus in animal feed (invited paper)

09.30 **Dao**, Thanh H., J.B. Reeves, and H. Zhang
Reducing the mobilization of organic phosphorus in dairy wastewaters: Chemistry and role of active and intermediate pools

09.50 **He**, Z., Z. Senwo, R. Mankolo, and C.W. Honeycutt
Distribution of phosphorus species in poultry litter characterized by sequential fractionation coupled with phosphatase hydrolysis

10.10 **Poulsen**, H.D., C.D. Børgesen, G.H. Rubæk, G.J. Heckrath, J. Sehested, T. Dalgaard, J.F. Hansen, and A. Kyllingsbæk
Scenarios for phosphorus accumulation in soil in relation to livestock intensity and feeding practice

10.30 RECESS

11.00 Basta, N.T., E.A. **Dayton**, J.M. Novak, P.A. Moore, and D.W. Watts
Immobilization of phosphorus in soil and manure using Al-based treatments and byproducts (invited paper)

11.30 **Moore**, P.A., Jr., D.R. Edwards, and T.C. Daniel
Long-term effects of alum-treated poultry litter on soil chemistry, nutrient runoff and crop production: Is this treatment sustainable?

11.50 **Staats**, K.E., and D.L. Sparks
Molecular-scale determination of P speciation in alum amended poultry litter

12.10 **Sims**, J.T., F.J. Coale, J. White, A.L. Shober, R.O. Maguire, and C.J. Penn
Biosolids effects on phosphorus in soils and runoff: Environmental policy implications

12.30 Questions and discussion

12.45 LUNCH

Day 3 – Wednesday 18th August (afternoon)

Field issues / measurements
13.45 Betson, M.J., E.I. Lord, and P.S. **Davison**
Modelling the effect of crop canopy development and associated management practice on erosion and phosphorus loss
14.05 **Lundekvam**, H.E.
Effects of cultivation systems on P-losses through surface and drain runoff in south-eastern Norway
14.25 **Shand**, C.A., G. Coutts, J. Eubeler, and J.A. Chudek
Redistribution of phosphorus in grazed ecosystems
14.45 **Styles**, D., I. Donohue, and C. Coxon
Relating agronomic soil test P and soil type data to soluble P loss risk in Ireland: Implications of drying soil samples
15.05 **Tujaka**, A., and S. Gosek
The effect of long-term fertilization on the migration and balance of phosphorus

15.25 RECESS

15.55 **Tunney**, H.
Phosphorus and potassium concentrations in overland flow water from grassland plots
16.15 **Watson**, C.J., R.V. Smith, and E. Chisholm
The effects of soil phosphorus status on phosphorus losses to surface runoff and land drainage water
16.35 **Zhang**, T.Q., C.F. Drury, C.S. Tan, W.D. Reynolds, and C. Fox
Long-term changes in soil phosphorus forms and phosphorus losses in subsurface flow: Environmental evaluation of various cropping systems

Costs / economics
16.55 Annett, J.A., R.V. Smith, C. **Jordan**, W.G. Hutchinson, and C. Glass
Costs and benefits of reducing phosphorus inputs to surface waters
17.15 **Collentine**, D.
Phase-in of nonpoint sources in a Transferable Discharge Permit (TDP) system for water quality management
17.35 Questions and discussion

17.50 ADJOURN

Day 4 – Thursday 19th August

Please note the early start at 8 am!

Catchment / landscape scale
08.00 **Kaffka**, S.R.
   Managing phosphorus pollution at the landscape scale in the Upper Klamath Basin of Oregon and California
08.20 Andersson, L., B. Arheimer, M. Larsson, J. Olsson, C. Pers, J. **Rosberg**, K. Tonderski, and B. Ulén
   Integrated modelling of phosphorus fluxes at the catchment scale
08.40 **Kronvang**, B., C.C. Hoffmann, A. Laubel, I.K. Andersen, M.L. Pedersen, L.M. Svendsen, S.E. Larsen, and H.E. Andersen
   Revitalizing the natural phosphorus storage in river basins: Danish experiences from restoring lowland rivers and floodplains
09.00 **Øygarden**, L., and M.E. Bechmann
   Paired catchment comparison of measures to reduce phosphorus losses in Norway
09.20 **Walker**, F., and E. Bazen
   A GIS approach to identifying non-point source phosphorus pollution in an East Tennessee watershed

09.40 RECESS

Surface water
10.00 **Braskerud**, B.C., K. Tonderski, and B. Wedding
   A role for sedimentation ponds and constructed wetlands? (invited paper)
10.30 **Boers**, P.C.M., and L. van Liere
   Methods to abate eutrophication symptoms in lakes (invited paper)
11.00 Bakker, D., and J. **de Klein**
   Phosphorus retention in freshwaters in the Netherlands: Comparing a mass-balance and flow-path approach
11.20 **Chambers**, P.A., and M. Guy
   Defining the concentration of phosphorus causing impairment of a Canadian river
11.40 **Lehtoranta**, J., P. Ekholm, K. Lukkari, M. Leivuori, H. Pitkänen, and H. Hartikainen
   Phosphorus retention in an agriculturally loaded estuary
12.00 **Meissner**, R., H. Rupp, and P. Leinweber
   Impact of land use change and re-wetting on phosphorus concentration in surface water - results and trends of a German case study

12.20 General discussion and conclusions

13.00 LUNCH

14.00 END OF WORKSHOP

XIV

List of abstracts of oral contributions

XVIII

List of abstracts of poster papers

XX

Abstracts of oral contributions

Integrated Modelling of Phosphorus Fluxes at the Catchment Scale

L. Andersson[1], B. Arheimer[1], M. Larsson[2], J. Olsson[1], C. Pers[1], J. Rosberg[1], K. Tonderski[3], and B. Ulén[2]

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[2] Swedish University of Agricultural Sciences (SLU), Department of Soil Sciences, Division of Water Quality Management, P.O. Box 7072, SE-750 07 Uppsala, Sweden
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A phosphorus (P) transport and retention model (HBV-P) operating at the catchment scale has been developed for simulating P fluxes throughout river systems as well as apportionment of P sources. The model has been developed to facilitate for example calculation of the effect of nutrient reduction scenarios (e.g. changed agricultural practices, buffer zones, and constructed wetlands). Sub-models handling phosphorus input such as agricultural leaching, lake and river/river bank processes are integrated in the catchment model. Agricultural leaching estimates are based on the ICECREAM model, which is a field scale model that has been further developed by including macro pore flow to tile drains. Up scaling of sediment transport and surface runoff from agricultural land are made in a GIS-environment. Retention processes in rivers and lakes have been included, and also routines for stream bank erosion, buffer zones and wetlands. Also, diffuse leaching from forests and urban areas, and emissions from point sources are included. HBV-P is based on the hydrological model HBV, which is a dynamic semi-distributed rainfall-runoff model that uses a daily time-step. Examples from model application in the Rönne river basin are shown, including scenarios of various remedies.

Costs and Benefits of Reducing Phosphorus Inputs to Surface Waters

J.A. Annett[1], R.V. Smith[2], C. Jordan[2], W.G. Hutchinson[1] and C. Glass[1]

[1] Department of Agricultural and Food Economics, School of Agriculture and Food Science, The Queen's University of Belfast, Newforge Lane, Belfast, BT9 5PX, UK
[2] Agriculture, Food and Environmental Science Division, Department of Agriculture and Rural Development, Newforge Lane, Belfast, BT9 5PX, UK

Eutrophication of marine and freshwaters is an increasing problem in Northern Ireland (NI) with the main cause being a combination of point and diffuse sources of phosphorus (P) from agriculture, industry and human sewage. An interdisciplinary research project has provided detailed budgets of P loads from all major sources to freshwaters, together with costs for a range of P reduction strategies. These costs were compared with the financial benefits of reducing eutrophication derived from resource costs and the contingent valuation method.

The first aim of the study was to establish a total P budget for all P inputs to surface and coastal waters in NI. To calculate the diffuse agricultural contribution, export coefficients were used. These had been derived for total P by multiple regression of P loads against CORINE land cover classes for 30 sub-catchments of two major rivers in NI McGuckin et al., 1999) GIS was employed to determine total P losses for these land use types for the whole land cover of NI. By this method, it was determined that 1130 tonnes of total P are exported annually from agriculture to inland and coastal waters. In addition there are other diffuse contributions from urban streets and surfaces, moorland, forests and peat bogs, which total 165 tonnes of P annually. The human contribution to the overall P budget was divided into households connected to mains sewer, households connected to septic tanks, and industrial discharges. These contributions were calculated to be 945, 118 and 40 tonnes P yr^{-1}, respectively. Rainfall falling directly on surface waters contributes 28 tonnes P yr^{-1} to the overall budget of 2174 tonnes P yr^{-1}. Agriculture, which accounts for 80% of land use, is the largest contributor with some 48% of all P exports to inland and coastal waters. However, as a large proportion of the effluent from wastewater treatment works discharges directly to sea or estuary, the agriculture contribution to inland waters is increased to 58%.

The costs and effectiveness of a number of policies and reduction methods was then considered in the context of the P budget to establish both the level of reduction achievable and the costs of different methods and combinations of methods. Reductions through both source and transport controls were taken into account. Source controls included good nutrient management being adopted on all farms; P removal at additional waste water treatment plants; P removal from direct industrial discharges; voluntary or statutory controls on the use of detergents containing P; changes to the P content of animal feedstuffs; and taxation of the P content of chemical fertiliser. Transport controls included riparian buffer strips and changes in riparian land uses and management; the setting of total daily or annual maximum loads for catchments; and the development of nutrient trading schemes to provide an incentive for reduction. An estimate of the total reduction achievable through a combination of all feasible methods, was derived, and is in the order of 50% of the overall discharges to all waters. Significant reductions of 72% of inputs may be achieved through a combination of measures to reduce human-derived P whilst reductions in the agricultural contribution are more modest at some 25% of inputs to water. Costs for each method of reduction were derived in the form of cost per kilogram of P removed per annum. Some methods entailed no resource cost as they involved a reduced financial outlay. These included some methods of reducing the P content of animal feeds and a reduction in the use of chemical fertilisers with a P content where soil tests identify an Olsen P index of 2 or above. Other methods, such as P removal from waste water treatment works of 10,000 population equivalents, have costs of £6.54 per kg of P removed, whilst some methods have high initial costs e.g. fenced buffer strips on riparian improved grassland at £754 per kg of P removed. The annual cost of environmental damage caused by freshwater eutrophication in England and Wales has been calculated to be between £75.0 and £114.3 million (Pretty et al, 2001). These economic damage costs applied to NI amount to £26 million yr-1 for agriculture. Reducing nutrient inputs will reduce these costs, and will also realise the benefits to the population of Northern Ireland of having an improved environment. A contingent valuation survey of 700 households was recently undertaken to identify these benefits for two different scenarios of P reduction. The sample design for the study ensured an equal probability for each household in Northern Ireland to be chosen for the study. Reduction scenario 1 relates to arresting further decline in water quality and scenario 2 to actions that secure a return to good ecological water quality. Preliminary results from the study estimate that the mean willingness to pay for the 'arrest decline' option was £10.74 per household, whilst the mean willingness to pay for a return to good ecological water quality status throughout NI was £15.37 per household.

References
McGuckin, S.O., C. Jordan, and R.V. Smith. 1999. Deriving phosphorus export coefficients for CORINE land cover types. Water Sci. Technol. 39:47-53.
Pretty, J.N., C.F. Mason, D.B. Nedwell, and R.E. Hine. 2001. A preliminary assessment of the environmental damage costs of the eutrophication of fresh waters in England and Wales. Environment Agency.

Phosphorus Retention in Freshwaters in The Netherlands; Comparing a Mass-Balance and Flow-Path Approach

D. Bakker, and J. de Klein

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Introduction

Freshwaters in the Netherlands receive substantial amounts of nutrients from both point and diffuse sources. These nutrient loads induce great problems in downstream standing waters (lakes and coastal zones). However not all of the loads to ditches and streams will eventually be discharged to the lakes. Part of the nutrients will be retained in the catchment during downstream transport. This is a highly variable process and is generally referred to as 'nutrient retention'. Lake water conditions can be improved by reducing nutrient loads to surface waters. To evaluate these measures understanding and quantification of the retention process is of great importance. Retention is often estimated indirectly as a remaining item in a mass-balance. This usually does not give information on underlying processes and mechanisms.

Aim and method of the research

In this study we quantified phosphorus (P) retention (and also nitrogen; not presented here) at the national scale by combining a mass-balance and a more mechanistic flow-path approach. General objective was a) to study the total retention in freshwaters and its annual variation, b) to relate calculated retention to surface water conditions in the sub-regions, and thus estimating potential retention in different types of surface waters. We set up annual mass-balances of 1990 to 2000 using measured river loads (both import and export) and the total diffuse and point sources.

For the flow-path approach we defined 17 sub-regions based on the major catchments in the Netherlands. All these regions are interconnected. The upstream regions receive transboundary river loads and internal sources; the downstream regions receive phosphorus from upstream regions and internal sources and finally they export phosphorus to the North Sea. For every sub-region total length (ditches, streams, small rivers) or total area (large rivers, lakes) is determined using detailed GIS-maps. Retention factors are estimated for all freshwater types and thus total retention in each sub-region

Results

Annual P-retention (%) is presented in Fig. 1. P-retention ranges from 20 to 60% using the mass-balance and 34-55 % in the flow-path approach. Variation between the years is strongly correlated with annual precipitation surplus. Estimates of retention fractions for different water types are presented in Table 1. Sensitivity analysis shows that total retention is mostly determined by retention fraction in rivers.

Fig. **1**. Annual P-retention (% of total input) calculated with both methods.

Table 1. Estimated retention fractions per freshwater type.

Type	Dimension	P-retention (%)	N-retention (%)
Gullies	<1 m width	0.18	0.44
Ditches	1-6 m width	0.18	0.44
Streams	>6 m width	0.40	0.29
Large Rivers		0.25	0.23
Lakes		0.31	0.15

Immobilization of Phosphorus in Soil and Manure Using Al-Based Treatments and Byproducts

N.T. Basta[1], E.A. Dayton[1], J.M. Novak[2], P.A. Moore[3], and D.W. Watts[2]

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[2] USDA-ARS-CPRC, Florence, SC, USA
[3] USDA-ARS, University of Arkansas, Fayetteville, AR, USA

Introduction

Research has shown that Al-based materials (drinking water treatment residuals, WTR and aluminum sulfate,alum) can be utilized effectively to reduce P solubility and P transport to surface or ground water. Several best management practices (BMPs) have been proposed to utilize WTR. One is to surface apply WTR to remove dissolved P from agricultural runoff water. Another beneficial use of WTR is to incorporate it into soil to reduce P solubility and prevent P leaching. Beneficial use of Al-based materials has also been extended to reducing P solubility in organic soil amendments such as manure or biosolids by co-blending with WTR or alum. Long term studies initiated in 1995, have been conducted to compare P leaching between alum treated and untreated poultry litter.

Materials and Methods

Six Al-based WTR were used to examine potential application strategies to reduce P solubility (transport) in soil and organic soil ammendments. A simulated rainfall study was used to determine reductions in runoff P as a result of WTR applications of 0, 5, 10, or 20 Mg ha^{-1}. WTR were incorporated into a soil with a high soil P-test (Mehlich III P, 315 mg kg^{-1}) at 0, 1, 2.5, or 5 % and incubated for 21 days. WTR were co-blended with a biosolid and a poultry litter at 0, 10, 25, 50, or 75 % (by weight) and incubated for 90 days.

Results and Conclusions

Mean runoff P reduction ranged from 0, 18.4, 36.3, and 66.6 % for 0, 5, 10, or 20 Mg ha^{-1} WTR applications, respectively. When WTR was incorporated into a soil (Mehlich III P, 315 mg kg^{-1}), mean Mehlich III extractable P reduction ranged from 0, 10.2, 19.1, 34.7, and 54.7 % and mean 0.01 M CaCl$_2$ extractable P, reductions from 0, 63.7, 78.2, 84.8. and 91.0 % for 0, 1, 2.5, or 5 % WTR applications, respectively. When WTR was co-blended with a biosolid mean Mehlich III extractable P reduction ranged from 0, 51.3, 65.3, 79.0, and 87.1 %, and mean 0.01 M CaCl$_2$ extractable P reduction from 0, 39.3, 63.9, 77.0, and 85.5 % for 0, 10, 25, 50 and 75 % WTR application, respectively. When WTR was co-blended with a chicken litter mean Mehlich III extractable P reduction ranged from 0, 32.7, 64.3, 80.6, and 87.6 %, and mean 0.01 M CaCl$_2$ extractable P reduction from 0, 62.7, 87.9, 93.6, and 93.9 % for 0, 10, 25, 50 and 75 % WTR application, respectively. Long term studies with alum-treated poultry litter showed runoff P reductions of 70% when compared with untreated litter.

Mitigating Phosphorus Losses from Agricultural Areas in Norway

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Introduction

Reduction of the phosphorus (P) losses from agriculture has been a priority issue in Norway since the last 20 years. Local and nation wide action programs have been supported by extensive research and monitoring activities aiming at identifying cost-efficient measures and abatement strategies to reduce in particular the soil erosion and the diffuse P losses. These 20 years of experiences may prove very useful for the implementation of the river basin management plans linked to the EC Water Framework Directive.

Considerable variability in phosphorus losses

Phosphorus losses from agricultural areas show great spatial and temporal variability across gradients in climate, soils, topography, land use and management practices in Norway. The variability is exemplified by the range in mean P losses measured in small catchments, varying from less than 0.5 to more than 5 kg P ha^{-1} yr^{-1}. Meanwhile, the losses may vary with a factor of 20 between individual years, the largest range in catchments where soil erosion represents the major P loss process. Differences in precipitation, erosion risk and livestock density are some important factors determining the level of P losses from agricultural areas, whereas the annual variations are largely dependent on the autumn and winter weather conditions. The documentation of the actual P losses, their trends, variations and causes, has been an important basis for the design of mitigation strategies and related policy instruments.

Policy instruments and implementation of measures

The research community has worked closely together with government organisations in order to develop cost efficient measures and strategies to enhance the implementation of measures. Already in 1985, the national authorities introduced the National Action Plan against Agricultural Pollution (1985-1988), which in the late 1980s resulted in practical measures and increased political interest. During the 1980s as well as in the early 1990s, several economic and legal instruments were introduced to reduce the P losses from agricultural activities. This was combined with a substantial strengthening of the extension services together with information and education activities directed towards the farmers communities. The government interventions have been continuously upgraded and adjusted to present day, resulting in a variety of measures with widespread implementation throughout the country.

The JOVA-programme

This presentation will focus on the results obtained in the Norwegian Agricultural Environmental Monitoring Program (JOVA), which includes information for 1-2 decades on the on-farm implementation of measures at fields scale and the P losses at catchment scale. The program has a nation-wide network of monitoring stations with different length of time-series from 4 to 15 years. Components of the results from this program have been published earlier (e.g. Bechmann and Våje, 1999; Vagstad et al., 2001) while this presentation will cover the nationwide perspective, focusing on implementation of measures.

References

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Modelling the Effect of Crop Canopy Development and Associated Management Practice on Erosion and Phosphorus Loss

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One of the principal drivers for the detachment of soil particles, and hence particulate bound phosphorus (P), is the kinetic energy (KE) of rainfall impact (Morgan, 2001). However this impact may be reduced by the presence of a plant canopy, such as a growing crop, or by crop residues. During a typical crop cycle the period of greatest exposure of the soil surface occurs from just before sowing of the crop where a finely tilled seedbed is present, until moderate crop cover is achieved. The risk of erosion is greatly enhanced if this period of vulnerability coincides with periods when surface runoff is likely (rewetted soils; heavy rainfall). Therefore management decisions concerning the sowing dates, types of crop and potential mitigation practice (such as the use of post harvest plant residues for soil cover) can be critically important in preventing soil erosion and consequent P loss.

These factors have been incorporated in the conceptual design of the Phosphorus and Sediment Yield CHaracterisation In Catchments (PSYCHIC) model that has been developed for the UK, through the use of monthly crop-specific cover values. The values are derived both from models of crop growth, such as EPIC (Williams et al., 1990), CERES (Jones et al., 1984) and the MORECS system (Hough et al., 1996), and through knowledge of management practice. These values (examples illustrated in Table 1 for crop cover only) have been combined with a relationship between KE and monthly total rainfall and number of rain days, derived by Davison et al., (2004), and the KE from leaf drainage using the relation with plant height proposed by Brant (1990). Additional adjustments have been developed for the degree of cover provided by trash. Estimates of the effect of crop cover and surface roughness on surface runoff are then used to determine sediment and P transport. The combination provides estimates of soil detachment and movement which incorporate process-based functions and management practice while having minimal data requirements.

Table 1. Proportion of surface cover per month for selected crops in the UK.

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Winter wheat	0.39	0.39	0.45	0.83	0.96	0.99	0.99	0.96	0.00	0.26	0.26	0.39
Spring barley	0.00	0.00	0.10	0.63	0.92	0.99	0.99	0.99	0.00	0.00	0.00	0.00
Potatoes	0.00	0.00	0.10	0.63	0.92	0.97	0.98	0.98	0.50	0.20	0.00	0.00
Sugar beet	0.00	0.00	0.10	0.63	0.92	0.97	0.98	0.98	0.98	0.98	0.59	0.29
Forage maize	0.00	0.00	0.10	0.63	0.92	0.97	0.98	0.98	0.50	0.20	0.00	0.00
Permanent grass	0.96	0.97	0.98	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.96
Temporary grass	0.85	0.85	0.87	0.96	0.98	0.99	0.99	0.98	0.78	0.82	0.82	0.85

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Methods to Abate Eutrophication Symptoms in Lakes

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Excessive loading of phosphorus (P) may lead to eutrophication problems in lakes, such as excessive algal growth, loss of biodiversity, growth of toxic blue-green algae. These problems received substantial attention of the water managers during the last decades.

The obvious way to combat these problems is to reduce the P loading to the lake. This approach, however, usually does not have the desired results. The main reason is that due to a number of feedback processes in the ecological system the shift from the clear water system dominated by aquatic macrophytes to the turbid water system dominated by algae takes place at substantially higher P loadings than the shift back. In practice this means that a very large reduction of the P load is required to combat eutrophication symptoms.

The last 20 years substantial efforts were put in attempts to find alternative techniques to combat eutrophication symptoms. Some of these techniques are aimed at decreasing the availability of phosphorus for algal growth, e.g. by dredging of P-rich sediments or inactivation of P in the sediments by adding P-binding agents. Another group of techniques tries to influence one or more of the feedback processes that stabilise the algae dominated state. These techniques, commonly referred to as biomanipulation, have now evolved to more or less standard techniques in water quality management and are supported by a vast amount of scientific literature and manuals for water managers.

The core of these techniques is a drastic reduction of the fish stock in a lake. The fish stock is responsible for a number of feedback processes that stabilise the turbid water state:

- fish, and especially the young of the year, predate heavily on zooplankton. Zooplankton grazes on algae and reduction of the fish stock may increase the grazing pressure on algae
- some fish species, such as the bream commonly dominating the fish community in temperate shallow lakes, stir up the bottom sediment while searching for food. This increases the turbidity of the water and reduces the possibilities for colonisation by macrophytes. The presence of macrophytes in shallow lakes are generally believed to have an important stabilising factor for the clear water state, amongst others by competition with the algae for nutrients, serving as refuge for zooplankton and enhancement of the loss of algae from the water column by sedimentation.

In this presentation the theoretical principles of the ecological lake restoration techniques will be explained with the emphasis on the feedback processes that stabilise either the turbid algal dominated state or the clear macrophyte dominated state. The working of the techniques will be illustrated using the results of a number of lake restoration case studies in shallow temperate lakes.

A Role for Sedimentation Ponds and Constructed Wetlands?

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Introduction

Loss of soil particles and nutrients from arable land may harm streams and lakes. Constructed wetlands (CWs) and ponds in small arable streams are used as a supplement to best management practice on arable fields. CWs are shallow (less than 0.5 m) and vegetated, while ponds are often deeper than 1 m, and have less vegetation in the water column. Internationally, the use of this type of technology is regarded as an efficient, and often the only applicable, measure for reduction of diffuse pollution in streams. Moreover, it includes a possibility for increased biodiversity in well-drained agricultural landscapes. This paper focuses on factors that influence the retention of phosphorus in CWs and ponds receiving water from agricultural catchments. Examples are mainly taken from Norway and Sweden.

Factors affecting P-retention

Normally, a large surface area versus catchment area is recommended to achieve good results, e.g., US recommendations is a ratio of 1-5 %. A large surface area influences the retention, because the hydraulic loading rate (HLR; $m^3 d^{-1}$) decreases. However, in many European countries it is impossible to set aside such large areas for CWs and ponds. Despite the fact that several models predict little retention of phosphorus in small CWs, CWs and ponds of approximately 0.06 – 0.4 % of the watershed area have been constructed. The average HLR for seven investigated CWs and ponds varied from 0.2 to 1.8 $m d^{-1}$, which equals retention times from 3.6 days to less than 10 hours. Still the average total P (unfiltered)-retention of several years was 10 - 44 %. We observed increased P-retention under storm runoff situations, due to increased erosion of coarse particles and aggregates with high settling velocity. In this respect, the CWs and ponds performed best when they were most needed.

Results have shown that the relative retention usually increases as the ratio CW or pond surface area to catchment surface area, increases. However, factors within the catchment, which influence the P-loss and the form of P that enters the CWs and ponds, may be more important for the performance. Such factors may be: P-content of the soil, soil texture, agricultural practice (e.g., cereal or dairy production), topography and the ratio agriculture land : forest or urban settlements.

Design

Design of CWs and ponds is important to optimise the retention processes. The most important processes are (i) sedimentation of particle-P, (ii) P-binding to particles and sediment, and (iii) P-incorporation in biological tissue. A number of factors should be considered when designing measures for P retention. Often the *topography* influence the lay out, and from an aesthetical point of view the form should be organic or look natural. To obtain a high hydraulic efficiency, structures inside the CWs and ponds can be created to spread the water. *Increasing depth* is a means to increase water retention time. Observed retention of P, however, did not increase with depth. A possible reason is that the settling distance of particle-P (TP>0.45) is longer in deeper zones and that *vegetation cover* mitigates resuspension of sediments under storm runoff situations. As a result, CWs often performed better than ponds for particle-P. The sorption behaviour of phosphorus is redox-sensitive, and sorbed phosphorus may be remobilized in periods with low redox potential, e.g. low flow periods. High HLRs may, counteract this by creating an oxidized layer on the sediment surface as long as water flows through. Deep areas, however, may be cut off from O_2-rich water due to stratification of the water, and little leakage of excess O_2 through roots due to little vegetation. Wind may bring O_2 to bottom sediments, however, resuspension of sediment and a release of P may also be a result. *Vegetation in the water* or as *plants for wind protection on land* may prevent wind turbulence.

Future research

Retention of dissolved-P in the studied Norwegian and Swedish CWs and ponds is usually low (RP<0.45). However, our sampling systems (volume and time proportional composite sampling) may have influenced this fraction. Future research aims to increase the retention of this P-fraction, e.g. through the use of mineral or organic filters.

Another focus for further studies is the effect of ageing. As CWs and ponds receive P-rich water over the years, the P-binding capacity in the sediment may be saturated. In areas with some erosion, binding sites are renewed. For low erosion areas the P-content in the sediment may increase, with a net P-leakage from the CWs and ponds as a result.

Defining the Concentration of Phosphorus Causing Impairment of a Canadian River

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Anthropogenic inputs of phosphorus (P) to aquatic ecosystems can result in excessive aquatic plant growth, depletion of oxygen, and deleterious changes in abundance and diversity of aquatic invertebrates and fish (Smith 2003). Whereas sufficient understanding of effects of nutrient inputs on lake ecology has permitted development of nutrient guidelines for protecting lake water quality, limited information on the relationship between P concentration and ecological consequences in lotic systems has hampered development of nutrient guidelines for streams and rivers. Yet small streams are typically the water body most intimately connected with agricultural land. This study presents an approach for setting P guidelines for lotic systems based on analysis of long-term data from reference sites and experiments conducted *in situ* to determine P concentrations associated with increased algal abundance.

The Wapiti River in northern Alberta, Canada arises in the Rocky Mountains and traverses coniferous forest and aspen parkland, before crossing open prairie now cultivated for wheat, oats and barley and, ultimately, a small urban centre (population ~ 37 000) discharging secondarily-treated wastewater from a sewage treatment plant and pulp mill. Analysis of long-term (1989-2000) data from the Wapiti River showed median nutrient concentrations at reference sites were 2 µg/L total dissolved P (range: detection limit to 62 µg/L), 7 µg/L N as NO_2+NO_3 (range: detection limit to 310 µg/L), and 5 µg/L N as total ammonia (range: detection limit to 270 µg/L). Downstream of the agricultural and urban inflows, median nutrient concentrations were 19 µg/L total dissolved P, 34 µg/L N as NO_2+NO_3, and 40 µg/L N as total ammonia. *In situ* bioassays to determine the response of attached algae to added nutrients (Scrimgeour and Chambers, 1997) measurement of river-water and algal tissue nutrients (Kahlert, 1998), and analysis of activity of an algal enzyme produced under low-P conditions (i.e., alkaline phosphatase; Healey and Hendzel, 1979) showed attached algal growth was constrained by insufficient N, P or both in reference reaches but nutrient limitation was alleviated downstream of the urban centre. Empirical models relating algal abundance to nutrient concentrations and other stressors (river discharge, turbidity) showed, for the Wapiti River, periphyton biomass was a predictable function of P and other stressors (r^2=0.62 for all data and r^2=0.76 for autumn data).

Our results showed P guidelines for protection of streams and rivers from eutrophication could be developed based on analysis of water chemistry data from reference and exposed sites, and experiments to quantify effects of added nutrients on attached algae. This approach is scientifically defensible and sensitive to the ecosystem and geographic region in question. In the case of the Wapiti River, very low nutrient concentrations (<4 µg/L TDP and <65 µg/L N as nitrate, nitrite and ammonia) must be maintained to prevent a change in river nutrient status.

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Phosphorus Accumulation in Dutch Soils: History, Policies and Options

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History

The main soil types in The Netherlands are fertile clay and peat soils and less fertile sandy soils. In the past, on the unfertile sandy soils poor farmers lived on small farms, with mixed farming (arable land + animals). After 1950, on these soils landless animal production started to developed, as a result of the Common Agricultural Policy of the European Union (EU) on increasing agricultural productivity, the availability of cheap feed imported via Rotterdam harbour to support the livestock population, and improved animal disease control and manure storage facilities enabling high livestock densities. The increase in the number of animals, and of phosphorus (P) in the manure produced, caused an excessive surplus of phosphorus (P). From data on im- and export of P, the average P surplus of agricultural land in The Netherlands (i.e., the difference between total import of P entering the country and total export of P leaving the country), can be calculated on a hectare basis. Table 1 shows a large increase of the average P surplus in the period between 1950 and 1980. This led to environmental concern and already in 1970, agricultural researchers warned for negative consequences the high P surplus might have for the quality of surface waters on the longer term (de la Lande Cremer, 1970). From 1980 onwards, the average P surplus decreased, due to various policies of the Dutch government. Nevertheless, the surplus remains highest within Europe (Steén, 1997).

Table 1. Surplus of P import over export in The Netherlands (kg P ha^{-1} agricultural land)

Year	1950	1960	1970	1980	1990	1995	2000	2003
Surplus	26	30	37	43	40	35	34	26

Policy

Within the Dutch policy aimed at reducing the impact of manure on the environment, different stages can be distinguished (Henkens and van Keulen, 2001):

1984-1990 *Stabilization of manure production*. The main goal was the prevention of further expansion of the pig and poultry sectors; the growth rate of both sectors decreased indeed.

1990-1997 *Reduction of mineral burden by setting limits to the use of P in animal manure*. Limits were set for the application of P via animal manure, that decreased with time (kg P ha^{-1} yr^{-1}, 1991→2002): arable land 55→35 kg, grassland 110→35 kg, and maize 87→35.

1998-2005 *Mineral Accounting System (MINAS)*. This system regulates the use and production of both nitrogen (N) and P on farm level. Above a levy-free amount a fee has to be paid on the surplus. However, in 2003, the MINAS system was rejected by the Court of Justice of the EU, so after 2005 an alternative policy will be introduced.

2006- *Limits to total N and P use*. A limit will be set to total use of P in manure and mineral fertilizer. After 2015, input must be balanced with offtake.

As shown in Table 1, different policies were succesfull in reducing the natural surplus of P. However, an average P-surplus remained. Over the period 1950-2003, a cumulative surplus can be calculated of 1834 kg P ha^{-1} (average 36 kg P ha^{-1} yr^{-1}). As a consequence, the surface of agricultural land with a P status ample sufficient or high has strongly increased, especially on sandy soils in the East and South of The Netherlands where poultry and pig industry is concentrated. For the year 1999, it was estimated that 28% of the agricultural soils in the Netherlands had a P status high, implicating that no further P application is needed (RIVM, 2004).

Options

Besides the regulations mentioned above, reducing the excretion of P when growing pigs was very successful (see abstract Jongbloed and Valk, this volume). On a national scale, relevance of P export was small, but is increasing. Recently it was stated (RIVM, 2004): *"There is a strong need for cost-effective and well-tested measures to prevent or combat eutrophication of streams, as diffuse phosphate pollution from the historical burden of agricultural fields will continue for many decades whatever manure policy the Netherlands will carry out."*

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Phase-in of Nonpoint Sources in a Transferable Discharge Permit (TDP) System for Water Quality Management

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There has been overwhelming interest in addressing water quality issues through the use of economic instruments. Much of this attention has focused on the cost efficiencies offered by Transferable Discharge Permit (TDP) systems. Unfortunately, the attempts to start up permit markets which are able to exploit abatement cost differences between sources have not met with the success expected. Two of the reasons for the lack of success that have been taken up in analysis of these programs have been the problem of transaction costs and in the case of non-point sources (NPS), undefined property rights.

The composite market design is a proposal for a TDP system which specifically includes agricultural non-pointsource (NPS) dischargers and addresses both property rights and transaction cost problems. The composite market consists of a set of three interrelated markets, two primary markets and one secondary market, which represent three different types of market functions. The first of these is a market for discharge reduction credits. The second market is an offset market. The third market, the secondary market, is an exchange for discharge permits where discharge sources and other actors can engage directly in the market transfer of permits. When the composite market is fully mature, the total number of permits issued represents a cap on discharges allowed in the catchment.

The primary advantage of a composite market over other TDP systems is that it minimizes transaction costs incurred by dischargers in their search for information to be used in the evaluation of abatement measures and assigns limited property rights to discharges. Therefore, this market system design supports the potential of a TDP program to lower total abatement costs and promote the development of abatement technology. The composite market builds on model generated discharge reduction quantities from non-point sources that serve as *fiat* values for establishing limited property rights to discharges. The design guarantees that there will be sufficient liquidity in both primary markets to ensure that the market price signal conveys accurate information to market actors for evaluation of possible abatement measures. The secondary market provides added flexibility to market actors, additional price information and the opportunity to realize economic rents based on private information. Finally, the composite market system may be phased-in over time, an aspect which facilitates implementation.

The first step to implementation of a composite market scheme is the estimation of the supply curve for abatement measures in the catchment area. Estimation is performed by combining costs with modeled loss reductions from selected Best Management Practices (BMPs) and then using this information to estimate the supply curve for abatement which in turn can then be used to set permit prices. Since an initial estimation can be adjusted as new information becomes available, the first estimation doesn't need to be comprehensive. This facilitates the use of partial information in the scheme and justifies making preliminary estimates of abatement costs. The Rönneå catchment in southern Sweden is used as a pilot study area for making this type of estimate. Costs for existing measures that reduce nutrient losses from farmland (catch crops and spring planting) are based on existing programs financed by the Swedish Agricultural Board. In addition, measures that are not currently eligible for support but that could be of interest are also included in the study.

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Prioritising Locations, Industries and Abatement Actions for Environmental Improvement in a Heterogeneous Watershed

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Sources of pollution in catchments with heterogeneous land uses are difficult to quantify, and therefore it is difficult to prioritise land uses for abatement action or to predict the catchment-scale outcomes of remedial action. This paper draws together research over 10 years to quantify nutrient exports from rural industries in the Sydney Basin, which is within the Hawkesbury-Nepean catchment and includes much of the city of Sydney and major rural industries. The aims were to develop sufficient understanding of mobilisation and transport processes to devise farm and watershed-scale management plans, and to develop a methodology for prioritising abatement actions.

Monitoring water quality, discharge and land management over 2.5 years in 'nested' locations in a sub-watershed provided estimates of nutrient export coefficients (Baginska et al., 1998) and data for model calibration (Baginska et al., 2003). Phosphorus exports from dairy pasture and intensive horticulture (vegetable farms) were high: about 5 and 15 kg/ha.yr, with soluble phosphorus (P) dominating dairy runoff and particulate P the market gardens. Additional research provided further insight into the management factors leading to high P export loads (Hollinger et al., 2001; Cornish and Hollinger, unpublished) and scale effects (Cornish et al., 2002).

Nutrient budgets for both intensive horticulture and dairy farms reveal that imbalances between inputs and outputs drive high P runoff; hence there is a need to reduce P loading at source. However, soils in many agricultural systems are already loaded with P, and interventions are needed to reduce mobilisation and delivery to streams. Mobilisation in runoff will be reduced through better irrigation (intensive horticulture and dairy) and effluent management (dairy) and erosion control (intensive horticulture). Filter strips and farm dams may manage P in the transport pathway, although such sinks can also behave as sources (Cornish et al., 1997).

An export coefficient model in a GIS framework satisfactorily prioritised industries and abatement actions and provided the foundation for a pilot nutrient-offset trading scheme (McNamara and Cornish, in press). Better management at source requires extension to focus on helping farmers to better understand plant nutritional requirements and fertiliser management, and to implement improved irrigation methods and management approaches, including deficit irrigation. Simple approaches to farm planning, already used by farmers, should be extended to the identification of risk areas and the use of flow pathway interventions (eg filter strips) to help reduce P exports. This requires practical strategies, rather than sophisticated approaches that are inaccessible to farmers. Research on predictive tools to manage P runoff should be directed at understanding the relationship between soil P and P concentrations in runoff and to better prediction of the effects of scale.

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Erosion and Phosphorus Mobility from Agricultural Catchments

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The full impact of diffuse sources of phosphorus (P) from agricultural lands, particularly the movement of particulate (>0.45 μm) P in surface runoff of eroded soil material, was discovered after point sources of P to streams were largely removed by legislation. Management aimed at minimising erosion, to minimise P loss, was introduced (such as no till cropping), and buffer strips (rows of vegetation placed at strategic points between the source and the river) were planted. In some regions in Australia, this management was effective in reducing particulate P in runoff to streams whereas in others, stream P levels continued to increase. The reason for this was partly explained by Fleming and Cox (2001), who determined the relative importance of particulate P in runoff from agricultural catchments in South Australia. They showed that dissolved P in runoff was consistently high throughout the year. In contrast, particulate P dominated flows at the start of the season when the loam over clay soils had minimal vegetation and were vulnerable to erosion. Increased rainfall intensity later in the growing season, when pastures were established, did not significantly increase particulate P. While conservation tillage practices can lead to increased soluble P losses, resulting from surface application of fertilizers (McIsaac et al., 1995), particulate P fractions represent 3 to 40 times more P than the soluble fractions from cropland (Bundy et al., 2001). Particulate P dominates flow from the parts of the landscape where easily erodible (dispersive) sodic soils form (Cox et al., 2002). These are usually waterlogged (seepage areas) within the catchment and it has been found that an order of magnitude more P and sediment is lost under seepage conditions compared to drainage conditions (Zheng et al., 2004). Cox et al. (2000) found that P, in the particulate form, could move through clay subsoils within macropores and the amount of P mobilised was controlled by the "residence time". Kirkby et al. (1997) found that P loss was influenced by the wetness of the soil. P in drainage from wet soil cores was significantly less than P lost through dry soils. However, soils that are saturated for long periods of time tend to have more P loss potential than well-drained soils (Baxter et al., 2002), as ferric phosphate minerals can be reduced to ferrous phosphates, which are more soluble, thus more susceptible to losses via runoff.

Thus it was shown that to reduce P loss to groundwater, streams or surface water storages across the agricultural regions of southern Australia, management must not only concentrate on reducing erosion at the start of the growing season. Management must include stabilising sodic soils, keep them from becoming saturated, and increase the residence time of P, thereby allowing mineral and organic fractions time to sorb P. Currently soil chemical amendments, which can bind P to soil, are being trialled. These include red mud (a by-product of bauxite mining) (e.g. Summers et al., 1993), polyacrylamides (e.g. Lentz et al., 1998) and most recently calcium amendments and polydadmac (Churchman *pers. comm.*), which have had varying success.

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Reducing the Mobilization of Organic Phosphorus in Dairy Wastewaters: Chemistry and Role of Active and Intermediate Pools

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Information is needed on organic phosphorus contribution to the sources and sinks of dissolved phosphorus (PO_4–P) in the soil–manure–water system because complexed P forms can be mobilized to alter solution-phase dissolved P concentrations. The high variability of manure dissolved P concentrations increases the risk of over-application of nutrients and dissolved P offsite discharges. A series of experiments were conducted with the objectives of characterizing the forms that are water-desorbable as they occur on working farms and confined animal feeding operations. Development of a novel measurement of P pools of active and intermediate bioactivity may contribute to efforts to identify mechanisms controlling the distribution of component P and the development of targeted manure management practices.

In samples (n= 107) of dairy manure collected across the northeastern region of the USA, a phytase-hydrolyzable phosphorus (PHP) fraction was found native to ruminant animal manure, in addition to water-extractable P (WEP) that varied considerably between sampling locations (40 to 8630 mg kg^{-1}). A large P fraction was readily hydrolyzable by exogenous phytases and an additional 28.4 ± 9.4 % of total P was released as orthophosphate over and above the level of WEP. Sources of the dissolved P are comprised of complexed inorganic and organic compounds that include phytate (IP6). Counterions such as Na^+, Ca^{2+}, Al^{3+}, and Fe^{3+} and cation to IP6-P mole ratios were found to influence the enzymatic dephosphorylation of organic P. Dephosphorylation of IP6 by *Aspergillus ficuum* (Reichardt) Henn. phytase EC 3.1.3.8 decreased by up to 50 ± 3.6 as Ca^{2+} levels increased and Ca^{2+} to IP6-P mole ratios reached 6:6. Polyanionic IP6 has a high affinity for Al^{3+} and Fe^{3+} and dephosphorylation was reduced by 27 and 32% at a cation to IP6-P mole ratio of 1:6 for Al^{3+} and Fe^{3+}, respectively, while reaching more than 99% at a mole ratio of 6:6. Therefore, the enzyme-hydrolyzable P fraction in manure can be significantly underestimated because complexed PHP was not susceptible to dephosphorylation by the phytases. By the same token, reduction in mobilization and biological dephosphorylation of inositol phosphates may be achieved with a judicious choice of the type and quantity of polyvalent counterions and the control of exogenous enzymatic activity.

A modified fractionation method was developed to characterize water-desorbable inorganic and organic P coordinatively associated with polyvalent cations. The fractionation conditions are mild and its simplicity may increase the practicality of widespread composition characterization and P bioavailability measurements in animal manure and the development of mitigation practices to reduce mobilization of bioactive organic P.

Table 1. Selected properties of 107 manure samples collected from dairy farms across the NE USA.

Statistical parameter	Total solids	pH	EC	Water-extractable P	Total P
	g L^{-1}		(dS m^{-1})	(mg kg^{-1})	(mg kg^{-1})
Mean	91	8.0	22.2	1870	11836
Standard deviation	48	0.8	10.1	1740	5018
Median	89	8.2	20.6	1396	10883

Table 2. Effect of counterion associated with phytate (IP6) on hydrolysis and PO_4 release in dairy manure.

Cation to P mole ratio	Ca^{2+}		Al^{3+}		Fe^{3+}	
	-------------------------------------- PO_4-P (mM) --------------------------------------					
No added IP6	0.272	b	0.224	d	0.188	d
Na-IP6	1.325	a	1.429	a	1.347	a
1:6	1.325	a	1.086	b	1.012	b
3:6	1.343	a	0.369	c	0.368	c
6:6	1.367	a	0.270	d	0.156	d

Treatment means within column followed by same letter are not significantly different according to Duncan's multiple range test at the 0.05 probability level.

Defining and Mitigating Against Multi-Source Nutrient Transfer at the Catchment Scale.

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Mitigating against phosphorus transfer at the catchment scale under the terms of the European Union Water Framework Directive will be a challenge to catchment stakeholders. Sources will have to be properly defined, and risk assessed, including critical areas of diffuse pollution, large scale point sources and scattered rural point sources. Mitigation of multiple sources of phosphorus (P) transfer, following definition, will possibly include altered farm management and the termination of point sources.

In the border counties of Northern Ireland and the Republic of Ireland grassland agriculture predominates on poorly drained drumlin soils that are prone to fast run-off flow paths. This area has a history of excessive P fertiliser additions resulting in surplus soil P concentrations that are vulnerable to acute transfer in hydrologically active areas. The majority of the total annual P load that is delivered to standing waters from rivers in the region is associated with acute storm discharges interacting with these soils. Rivers, however, are also impacted by chronic rural point sources from a high, unsewered rural population density that result in high P concentrations at low flows.

In the Blackwater Catchment Scheme - Water Framework Directive Initiative*, a project in the cross-border Blackwater River catchment, definition and mitigation will be demonstrated in three 5 km^2 catchments that are impacted by acute and chronic P transfer. A further evaluation phase will be undertaken to assess the success of the mitigation measures including reductions in P transfer at the catchment scale, the impacts on farm business performance and the ability of cross-border jurisdictions to manage water quality issues in International River Basin Districts.

* Approved EU Interreg IIIA Priority 2 Measure 2 (Environmental Protection and Management) Project (subject to economic appraisal).

Interaction between Nitrogen and Phosphorus Losses at Catchment Scales: Compromise or Conflict?

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On the basis that nitrogen (N) is the limiting nutrient in marine waters and phosphorus (P) in fresh waters, it is commonly assumed that nitrate controls are applicable to catchments draining into eutrophic coastal waters while P controls are required only for the catchments of freshwater systems. There are however extensive examples of N limitation in fresh waters and of P limitation in marine waters. This blurring of the limiting nutrient distinction between marine and freshwater systems has influenced case law within the European Community area, so that measures to control nitrate loss from agriculture are now required in the catchment areas of eutrophic fresh waters. This raises a number of questions. 1) Could lower nitrate inputs have any beneficial impact on the trophic status of fresh waters? 2) Are there inherent conflicts in controlling both nitrate and P losses, as measures that lower nitrate loss exacerbate P losses or vice versa? 3) Finally, to what extent are the current legal controls for nitrate effective in controlling P losses to water?

The utility of P controls is justified by the successful restoration of many lakes. There is a lack of examples of ecological improvement that followed lowering of nitrate exports, although this can be attributed to the paucity of case studies where nitrate inputs to lakes have been lowered. The capacity of certain bloom forming blue-green algae to fix N offers a means by which primary production can overcome N limitation. More controversially, there is evidence that lowering nitrate inputs enhances P release from the sediment, as the presence of nitrate suppresses the microbial reduction of Fe^{3+} and so lowers the associated release of iron bound P from lake sediments. The observed N limitation in many eutrophic lakes may reflect an enhanced denitrification potential that results from greater amounts of organic carbon from primary production that is stimulated by high P loadings.

With respect to the second question, it is recognised that there are different source and hydrologic pathways for nitrate and P. The dominant nitrate loss pathway is leaching through the soil profile, whereas losses of P are attributed to the mobilisation of P at or close to the soil surface so that soil type and texture have major influences on potential loss. Measures to control P loss focus on limiting surface losses, whereas N control strategies focus primarily on the placement and timing of N applications to minimise nitrate loss from the root zone. There is experimental evidence that reduced tillage techniques, which reduce total P (TP) loss can enhance nitrate and dissolved P loss. The environmental benefits of a trade-off between lower TP but enhanced dissolved P remain unclear and very likely site-specific. Also, controlled drainage to increase denitrification and decrease nitrate leaching can increase P mobility and leaching in wet soils with high P status, as occurs in lowlands of The Netherlands and Delaware. While transport potentials for N and P differ, protocols for assessing source risk factors based on the timing and placement of fertiliser and manures are similar for each nutrient.

This leads to the final issue, as to whether legally based controls for nitrate may be effective for P? There remains little hard evidence at the catchment scale on which to make a judgement. Published data from rivers in Western Europe shows no downward trend in nitrate concentrations following the introduction of the Nitrates Directive (ND) but dissolved P concentrations have declined, although this is usually attributed to point source controls on P. The importance of base flow as a source of nitrate could mean that the time-scale of response of nitrate will be slow, as has been compliance with the ND. The European model for the ND action programme (AP), sets a farm stocking rate limit of 170kg N/ha which will lower animal numbers, notably in dairy, poultry and pig sectors that rely on imported feedstuffs. This may be expected to reduce the risk of P loss from manure applications. Current AP measures that forbid or restrict winter application of manures should also have clear benefits for lowering P losses. Capping stocking rates has, notably in the Netherlands, offered a framework in which imported feed stuffs can be substituted for feed grown on farms so that the P surplus can be eliminated. In this regard, the simple measure of a stocking rate limit presents an opportunity for a more sustainable use of nutrients, both N and P, which can avoid the creation of large surpluses and so lower the risk of loss to water.

Importance of 'Incidental' Phosphorus Losses at Different Scales

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'Incidental' is a term used to describe phosphorus (P) mobilisation that occurs when rain and runoff interact directly with fresh applications of P to the soil surface, such as those from fertiliser, manure or excreta (Haygarth and Jarvis, 1999; Withers et al., 2003). 'Incidentals' involve pools of P that are conceptually distinct from those mobilised from the soil itself, although from the time of application, freshly applied P undergoes an equilibration with soil P pools; this means that there is a relatively small and diminishing time period for incidental mobilisation to occur. Incidentals are therefore characterised by high rates of export over a short period of time, where loads can be as high as a few kg P per hectare equivalent during a short runoff event, perhaps lasting only a few hours or days, but nonetheless having loads that are similar to the magnitude of loads otherwise determined over a whole year (Preedy et al., 2001). Despite their apparent significance, uncertainty exists because evidence for 'incidentals' has been mostly focussed on mechanistic studies at the fine spatial scale, using plot studies.

In theoretical terms, the two components of incidental losses are (1) 'significant' fresh P inputs (SFI) and (2) 'efficient' hydrological connection (EHC). 'Significant' inputs are defined as those that are of sufficient quantity to make an impact in the measured P concentration response in a chemo/hydrograph, determined at the given scale of focus (see Haygarth et al., 2004 for a discussion of how these may be 'measured'). These may be characterised in two theoretical extremes, the first being as spatially heterogeneous high intensity P input (e.g. a manure heap or failed P storage facility) that makes an impact because of the intensity of the P application and persists because it has little opportunity for equilibration with soil P. The second theoretical extreme will be an input that is spatially homogenously distributed (e.g. slurry or fertiliser spreading) that makes an impact because the large land area covered increases its likelihood of spatial coincidence with 'efficient' hydrological connection. 'Efficient' hydrological connection is defined as P transport via a low resistance pathway that has a low potential for buffering P in transport (e.g. a macropore, a drain, overland flow, or a channel) and may be activated or enhanced with provision of high hydrological energy, e.g. high rainfall or runoff. Like SFIs, EHC may be theoretically either heterogeneous (e.g. a macropore or a drainage conduit) or relatively homogeneous (e.g. sheet wash across a hill slope or piston flow through free draining soil) in space. Both SFI and EHC are highly spatially and temporally variable and depend on the given scale of focus.

This raises the importance of the concept of 'delivery'; this describes the linkage of P from the spatial and temporal point of SFI to the point of channelised flow. Clearly some SFIs may never become mobilised as incidentals because they become quickly incorporated into soil P pools. For those that are mobilised, during delivery, the extent, nature and dynamics of interactions between soluble and particulate P in water and colloids/sediments play a critical role. A new project has recently been funded by the UK government (Defra) that aims to explore and define concepts of P delivery and some of the concepts initially raised by this project will be reported in this paper (Heathwaite et al., 2003).

The conclusion is that incidental losses can be significant at all scales. However, in practice the likelihood of observing them becomes less likely as the progression from small to large scale increases, since the two controlling factors, SFIs coupled with EHC become decreasingly likely with increasing scale.

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Distribution of Phosphorus Species in Poultry Litter Characterized by Sequential Fractionation Coupled with Phosphatase Hydrolysis

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The chemical composition of phosphorus (P) in manure significantly impacts its transport and potential bioavailability. Increased knowledge of manure P chemistry is therefore required to optimize recycling of manure P and minimize the adverse environmental effects of animal manure application to cropland. In this study, the distribution of P forms in 15 poultry litters was investigated with sequential fractionation coupled with orthophosphate-releasing enzymatic hydrolysis. Manures were first sequentially fractionated into H_2O-soluble, $NaHCO_3$-soluble, NaOH-soluble P, and HCl-soluble P. Fractions were then incubated in 100 mM sodium acetate (pH 5.0) with 1) potato acid phosphatase, 2) potato acid phosphatase and nuclease P1, and 3) both enzymes plus wheat germ acid phosphatase to identify and quantify simple labile monoester P, nucleotide P, and phytate (*myo*-inositol hexakisphosphate)-like P, respectively.

The majority of P in the 15 poultry litters was distributed in H_2O and HCl fractions (about 30%, and 40% of total manure P, respectively). In contrast, $NaHCO_3$ and NaOH fractions contained only 10-20% of total manure P. However, P species in these fractions were different. Inorganic P accounted for 80% of P in H_2O fractions, and 70% of P in $NaHCO_3$ fractions. Only 5-15% of P in the two fractions was enzymatically hydrolysable organic P. In NaOH and HCl fractions, 50 to 90% of P was present in organic forms. Among them, 40-70% was phytate-like P and 10-30% was simple monoester P. Findings in this study indicate that poultry litter contained similar amounts of easily bioavailable P (H_2O- and $NaHCO_3$- extracted inorganic P and hydrolyzable organic P) and stable P (NaOH- and HCl-extracted P). These properties must be considered when developing sustainable P management practice for poultry litter.

Risk Assessment Methodologies

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This presentation will evaluate a range of risk assessment methodologies that have been developed in a number of countries to better manage the environmental risk of phosphorus (P) loss from diffuse agricultural sources to receiving waters. Many of the approaches have as their root the critical source areas concept (e.g. Heathwaite et al., 2000) implicit in the Phosphorus Index (e.g. Heathwaite et al., 2003c; Sharpley et al., 2003). This concept identifies 'hotspots' of risk in the landscape where high source inputs and high hydrological connectivity coincide. Many variations on the original index (Lemunyon and Gilbert, 1993) now exist, but whereas the source inputs are relatively easy to identify and evaluate, transport controls on P losses from field to catchment scale remain difficult to account for in the simple matrix approach. Here we will present a number of examples of risk assessment methodologies of varying degrees of sophistication.

In the UK, risk assessment tools range in scale from field scale indices (e.g. Hughes et al., 2001), to hillslope models (e.g. the NERM - Nutrient Export Risk Matrix, Heathwaite et al., 2003b) to simple catchment models such as the Phosphorus Indicators Tool (Heathwaite et al., 2003b) and distributed nutrient models (e.g. Whitehead et al., in press). We will critically evaluate how they may be used to provide of the relative risk and likely success of targeted remedial options to reduce P loss from agriculture.

Research in the US has focused on refining various components of the P Index to meet local climate, soils, land use practices, environmental issues, and stakeholder interests (Sharpley et al., 2003). To facilitate this, regional working groups have been active in coordinated research and extension efforts to ensure consistency in terms of risk predictions and associated management recommendations assigned by Indices across state regulatory boundaries. Research is also being conducted at a national level to obtain data to more rigorously support the various factors and coefficients used in the P Index. Current work includes developing (i) simplified RUSLE calculations of erosion by greater use of existing soil survey data bases, and (ii) universal test of water extractable P in amendments (manure and sludges) for use by commercial and state run agricultural analysis laboratories. At the same time, a concerted catchment scale effort is underway to compare P Index-assessed risk with observed losses of P, and to support the assumption that Index-based management changes will decrease P export and lead to catchment sensitive farming.

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Diffuse Sources of Phosphorus Loading of Surface Waters in Dutch Peat Pasture Areas

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Introduction

In Dutch peat pasture areas the majority of the surface waters is highly eutrophic. In view of the European Water Framework Directive remedial measures to lower nutrient concentrations are required. However, implementation of adequate measures is complicated because contributions of different sources to nutrient loading of surface waters are often unknown. At present, diffuse sources are the main contributors of P to surface water, since point sources are largely renovated. Generally, leaching of fertilizers is considered to be the dominant diffuse source. However, also the peat soil itself, often rich in P, and, in some locations, P-rich upward seepage may contribute substantially to the P loading of surface waters. Therefore, the objective of this paper was to quantify the contributions of different P sources to the P loading of the surface water in Dutch peat pasture areas.

Materials and methods

For three typical Dutch peat pasture areas P loading of the surface water and the contribution of the three main sources of P, viz. *fertilization* (including manure and cattle droppings), *peat soil* (mineralization of peat and leaching out of P-rich peat layers) and *upward seepage*, were quantified. For the polders Bergambacht and Rozendaal, both with upward seepage, calculations were executed on a regional scale with a calibrated and validated, dynamic mechanistic simulation model (Hendriks, 2003), consisting of the hydrological FLOCR model linked with the nutrient leaching ANIMO model (Hendriks et al., 1999). Model simulations were performed for the period 1950-1998 with real(istic) data on meteorology and fertilization levels. For the Vlietpolder, without upward seepage, measurements at field scale were carried out on P discharge, mineralization of soil organic matter, composition of the soil solution and fertilizer application for 2 years (Sept. 2000 - Sept. 2002). The contributions of the different sources were quantified on basis of the measurements using a simple balance model (van Beek et al., 2004).

Results, discussion and conclusions

For all three peat pasture areas fertilization is the smallest source of P loading of surface water (Table 1). In Bergambacht and Rozendaal upward seepage is the dominant source of P loading. In the Vlietpolder the peat soil is the largest source, contributing more than twice as much to the P loading as fertilization. In Bergambacht the ratio between the two sources peat soil and fertilization is 1.5, while in Rozendaal this ratio is a little more than one. The percentage of fertilizers leached to the surface water is about equal for Bergambacht and Rozendaal, but is twice as high for the Vlietpolder. This discrepancy may be caused by differences in model approach, but also by differences in hydrological and soil conditions, and composition of fertilizers.

The results suggest that ending of the fertilization in peat pasture areas may decrease P loading of surface water with at most 20-30%. Because of the high storage capacity for P in peat soils this effect will be reached only in the long term (decades). In areas with P-rich upward seepage, raising of the drainage level can contribute to decreasing the P loading. For this purpose, solid knowledge of the hydrological conditions is required.

Table 1. P fertilization, P loading of surface water, contribution of three sources to P loading of surface water and percentage of fertilizers leached to surface water, for three peat polders in The Netherlands.

Polder	P fertilization (kg P ha^{-1} a^{-1})	P loading (kg P ha^{-1} a^{-1})	Contribution of sources (%)			% of fertilizers leached
			fertilizers	peat soil	seepage	
Bergambacht[1]	37	3.2	20	30	50	1.7
Rozendaal[1]	59	3.0	28	32	40	1.4
Vlietpolder	41	4.3 *(4.0-4.6)*[2]	31 *(11-51)*	69 *(49-89)*	–	3.3 *(1.1-5.7)*

[1] results of the last simulation year

[2] *(min.-max.)* range due to ranges in measurements; results for the Vlietpolder are recalculated from van Beek et al. (2004)

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Field-scale Risk Assessment of Phosphorus and Sediment Loss from Agricultural Land to Water: Targeting Mitigation Options for the Water Framework Directive

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Diffuse phosphorus (P) loss from agricultural land is a key contributor to ecological water quality problems, for example eutrophication, and as such, has been heavily targeted by the European Water Framework Directive. This comprehensive and pivotal piece of legislation includes ecological status as a key indicator of good water quality and dictates that all member states must achieve 'good status' by 2015. In order to meet this challenging milestone, known water quality problems, in particular those associated with diffuse pollution, must be targeted with appropriate land management mitigation measures that will not only work, but that can be implemented with minimum disruption to the agricultural community.

To this end, a field scale risk assessment methodology was developed for P loss from UK agricultural land. The risk assessment aims to identify the risk of P mobilisation within the field and subsequently, the risk of P delivery to a watercourse. It is similar in approach to the P loss risk index. A holistic approach has been taken, by combining inherent landscape characteristics with actual farm management practices. It includes a comprehensive range of site-specific risk factors, along with different potential hydrological flow pathways. Each factor is assessed *in-situ* and ranked semi-quantitatively to produce an overall risk score. An alternative approach involving a decision tree, for more rapid site risk identification, was also developed. Mitigation options are then suggested, tailored to local needs.

The two approaches have been trialed on 30 farms throughout the Avon and Wye river catchments in England, both priority areas for the Water Framework Directive. Results are presented and implications for the successful implementation of mitigation measures are discussed. The risk index acts as a stand-alone, low-tech tool for farm advisors, in addition to supporting catchment scale decision support systems such as PSYCHIC (Phosphorus and Sediment Yield Characterisation in Catchments).

Healthy Human Nutrition as the Most Important Source-Oriented Option for Reducing also Phosphorus Loss from Agriculture Exemplary Shown for Germany

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In spite of about 80% of the C, N, P, S emissions of the total nutrition system agriculture, human nutrition and waste as well as waste water management are in agriculture and off them also about 80% are caused (in-)directly by animal production starting point and a prerequisite for all mitigation options and strategies is not the production of feed and food of the agricultural sector but as the most important socio-economic factor the healthy human nutrition especially with animal food. The reference values for the average healthy dietary intake/consumption of energy, protein and fat of 2100 kcal, 53g and 70g $\cdot$capita$^{-1}\cdot$d^{-1} with shares of animal food of about 20, 40 and 50% respectively and those values for net meat consumption of 64 g $\cdot$capita$^{-1}\cdot$d^{-1} represent the maximum of a tolerable animal production of the corresponding capita specific animal stock of 50 kg live weight (LW) $\cdot$capita$^{-1}\cdot$yr^{-1}.This is equivalent to 0.1 animal units (AU) per capita and year with a maximal tolerable density of 1,0 AU$\cdot$ha^{-1} with nutrients supplyable aa^{-1} resulting from long-term field trials in Western Europe The impacts of both, actual unhealthy and future healthy human nutrition, on the P input into the waste water sector and on the P balance of agriculture is shown in Table 1.

Tab. 1: Impacts of (un-)healthy human nutrition in Germany on the P balance of the total system nutrition with agriculture, human nutrition as well as waste and waste water management

[Agricultural Area (aa): 16.2 Mio ha; Total area (TA): 35.7 Mio ha.; Capita: 82.2 Mio ≡5.1 ha aa^{-1}]

H U M A N N U T R I T I O N		A G R I C U L T U R E						
Situations	**W A S T E W A T E R**	**Animal Units (AU)** (1 AU ≡500 kg LW)		**P – Farm balance (kgP · ha aa^{-1} · yr^{-1})**				
	Dietary P intake ≡Excretion: [kg· capita^{-1}· yr^{-1}]	**Absolute [Mio AU]**	**Relative [AU ·capita^{-1}]**	**Input**	**Output = Input** **Saled products**			**Surplus**
					Plant	**Animal**	**Total**	
1. Actually (1993) unhealthy overnutrition with energy, esp. animal protein and fat (DGE 2000/2001)	0.460 [100] ≡kg·aa^{-1}·yr^{-1}: 2,33 [13]	20.1[1] [100]	0.24[1] ≡ 20 kg LW	17.9[1] [100] [100]	5.3[1] [100]	2.6[1] [100]	7.9[1] [100]	10.0[1] [100] Soil: 8.8 Surface water: 1.20
2. Future (2015) healthy need oriented and realistic nutrition (Sustainability)	0.444 [96] ≡kg·aa^{-1}·yr^{-1}: 2.25 [34]	8.2 [41]	0.10 ≡50 kg LW	6.6 [37] [100]	4.0 [75]	1.1 [41]	5.1 [65]	1.5 [15] Soil: > 1.32 Surface water: < 0.18 [2]

[1] P balances of 2000;   [2] Corresponds to the critical levels: 100µg TP/l ; agriculture: 50µg TP/l and the critical loads: 300 g TP·ha TA^{-1}· yr^{-1}; Agriculture: 180 g TP ha aa^{-1} · yr^{-1} of LAWA I / II (1998)

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Healthy compared with unhealthy human nutrition has nearly no effect on the P excretion and on the P input into the waste water sector, but enormous impacts for a future sustainable P balance of agriculture: In this way optimised consumption and corresponding production of animal food and feed reduce the animal stock of -59%, the P input and surplus with potential P loss of -63% and -85% respectively. Simultaneously P removal/recycling from sewage and bio compost is more than doubled from 1.7 to 4.0 kg P· ha aa^{-1}·yr^{-1}.

Conclusions

The ecological component "consistency" of sustainable nutrition can therefore nearly be achieved by mitigation measures safeguarding its social component "sufficiency" -mostly cost-saving and cost-effective. These proposed mitigation measures of a sustainable human life style should be flanked by individual technical mitigation measures in "small steps". Also shown on this workshop aiming to reduce not only the emissions of P but also simultaneously those of C, N and S sufficiently. In this respect there is a need for N-, P- and C-directives also as parts of a future reformed and integrated EU-Water Framework Directive (WFD 2000). These measures should be accompanied by adequate prices for biomass products and especially for food and feed guaranteed also by foreign trade protection. This contrasts to the directive (EG) No. 1782/2003 (Cross compliance and modulation) from 29th September 2003. The products must not necessarily be cheap but worth their prices to meet the economical, environmental and social needs. These instruments and measures for a sustainable human nutrition shown here, are essential parts for the scenarios and prognoses dealing with the sustainable nutrient management in the Danube River Basin of the EU-RP-5-Program "daNUbs"(2/2001-1/2005)[EVK1-CT-2000-00051].

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Alteration of Phosphorus Content in Diets for Livestock: Impact on Animal Performance and Health, and the Environment

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The input of phosphorus (P) by means of feeds and inorganic fertilizers often exceeds the output in milk and meat on most intensive dairy, pig and poultry farms. The manure produced is mostly also applied on these farms, and if not balanced with crop requirement, the excess may lead to run-off and accumulation in the soil, resulting finally in leaching of P in ground and surface waters. This may result in exceeding the maximal allowable standards for the concentration of P in these waters. Therefore, new legislations have been enforced, that limit the use of animal manure and inorganic fertilizers per hectare of land, or the number of animal units per hectare in some countries (Jongbloed and Lenis, 1998).

In this paper, the essential role of P for maintenance and production performance is described. Furthermore, the impact of more intensive production systems on the environment is outlined. Several examples are presented concerning the input-output balance for P under different conditions (Jongbloed et al., 2000). This paper describes for P, how diets for dairy cows, pigs and poultry can be altered without compromising animal health and performance, with simultaneously enhanced P utilization and lowered P excretion. Also, the consequences of diet alteration on the form of P in manure is discussed. Essential is that the availability or digestibility of P in forages, raw materials and mineral supplements for ruminants, pigs and poultry are known together with the required amount for optimal production. Also, there should be a proper ratio between P and other minerals due to negative interactions among minerals, which lead to reduced absorbability or utilization of P. In addition, current P evaluation systems in some countries, and the recommended P levels in the feeds are compared (Valk et al., 2000). The benefits of using supplementary microbial phytase in feeds for pigs and poultry on animal performance and P excretion are outlined. Consequences of lowered P supplies are discussed with regard to animal welfare and health (Valk and Sebek, 1999). Finally, it is shown that as a result of the environmentally-related research in the Netherlands, diet formulation in practice has been altered and that the excretion of P per growing-finishing pig has more than halved in the last 30 years.

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Managing Phosphorus Pollution at the Landscape Scale in the Upper Klamath Basin of Oregon and California

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The Upper Klamath Basin (UKB) is a high desert region straddling the California-Oregon border east of the Cascade Range. Irrigation and other agricultural practices in the region may result in impaired surface water quality, reducing its use for wildlife and fish in neighboring national wildlife refuges that receive drainage water from farms, and in the Klamath River, which drains the region. By 2004, target total maximum daily loads (TMDLs) for nutrients must be established for the Klamath River. To investigate the relationships among agricultural practices and surface water quality in the UKB, a multi-year (1995-2000) reconnaissance survey of surface water and agricultural tile drain locations was conducted, focusing on total dissolved solids, nitrogen, and phosphorus concentrations and mass transfers. Data was collected at 18 surface and 10 tile drain locations every ten days during the irrigation season (March through October) and one or two times a month during the remainder of the year. Water samples were analyzed for P, N, temperature, pH and electrical conductivity (EC_w), a total dissolved solids or salinity. Detailed climate and water balance data were available over a multi-decade time interval. Most surface water transfers are measured or estimated from pump operation. These data were used together with concentrations derived from sampling to estimate transfers of salts and nutrients within the UKB.

The salt content of surface waters increased nearly threefold as water moved through the watershed. Mean EC_w levels in water entering the region were 250 :S cm^{-1}, while water sampled at the main irrigation drain increased to 600 :S cm^{-1} over the sample period and to 700 :S cm^{-1} by the time water reentered the Klamath River. The EC_w values observed in subsurface tile drains were higher on average than in input and other surface waters in the region (2,500 :S cm^{-1}). Temperature and pH values in tile drains were lower than surface water values and do not influence them. For total P (TP), input waters averaged approximately 0.27 mg L^{-1} for the years reported. Water leaving the farmed area increased to 0.33 mg L^{-1}. TP increased further to 0.40 mg L^{-1} a the end of the Klamath Straits Drain, where water entered the Klamath River. The overall increase in P concentration in surface waters was much less than for salt, suggesting that processes other than simple enrichment are occurring, particularly those associated with the exchange of sedimentary P and aquatic plant species. Total N increased from 2.3 mg L^{-1} to 4.0 mg L^{-1} over the same pathway. Atomic ratios (TN:TP) of surface water samples remain constant at approximately 10:1 throughout the system, suggesting that the amount of small particulate matter in surface waters affects the values observed. Sediment transfer is influenced in part by the agitation of surface water as it passes through canals, pumps and weirs. The average TP value in tile drains beneath farm fields was 0.34 mg L^{-1}. While average TP values in subsurface tile drains were not different from those found at the main surface drain outlets, the range in values was large (0.1 to 0.8 mg L^{-1}), and a larger amount was in the soluble fraction. Similarly, high NO_3-N values were observed in tile drains, leading to the inference that some N and P from fertilizer and soil organic matter is lost in drainage. Calculations suggest that reduced fertilizer use can help bring P inputs and outputs into balance in local farming systems. This may reduce any avoidable losses of P. But surface waters entering the region are already enriched with N and P. It seems unlikely, however, that reducing N and P losses from farming, if possible, would influence surface water quality sufficiently to make them significantly less eutrophic. Wetland sediments, soils high in organic matter, and nutrients contained in water introduced for irrigation provide effectively non-limiting amounts of nutrients for aquatic plant growth.

Calculations demonstrate that wetland management and farming practices in the southern portion of the UKB currently result in the net removal of nutrients from the waters diverted for irrigation on a yearly basis, compared to allowing the same amount of water to simply flow down the river unused. However, large errors of estimation for the amounts of water transferred, large year to year climate variation, combined with smaller errors associated with sampling and sample estimation suggest that TMDLs may not be an effective or efficient policy for reducing nutrients in return flows to the Klamath River. Seasonal recycling of some drainage water for irrigation would reduce the amount of nutrients returned to the river on a yearly basis more effectively and efficiently.

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River Basin Management Plans for the European Water Framework Directive

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During the last decade more emphasis has been directed to the losses of phosphorus (P) from diffuse sources as the influence of phosphorus from point sources has decreased considerably in most countries due to improvement of waste water treatment (Pieterse et al., 2003). Thus, phosphorus losses from agricultural areas are in many European river basins the main P-source to rivers, lakes, reservoirs and coastal waters (Table 1), where excess P-inputs due to algal growth are often the main cause for not fulfilling a good ecological quality (Conley et al., 2002).

Table 1. Model estimated (MONERIS) contribution of agricultural total P-losses to total P emissions to surface water within major European River Basins (according to Behrendt, 2004).

River Basin	Catchment area (km^2)	Mean annual runoff (mm)	Population density (inh/km^2)	Total P-export from river basin (kg P/ha)	Total P emission to surface waters (kg P/ha)	Total P loss from agriculture (kg P/ha)
Elbe	148,270	159	185	0.36	0.81	0.36 (44%)
Rhine	185,300	430	423	1.06	1.28	0.27 (21%)
Danube	802,888	269	388	0.27	0.84	0.36 (43%)
Odra	118,148	149	42	0.38	1.09	0.19 (17%)
Po	73,761	681	33	1.06	1.41	0.27 (19%)

The P-loss from agricultural areas in River Basins arises from the contribution of dissolved and particulate P losses to surface water via different pathways (soil erosion and surface runoff, bank erosion, leaching, tile drainage water, etc. A quantification of the importance of P-pathways for agricultural P-losses to surface waters in Denmark is shown in Table 2.

Table 2. Estimated contribution of different phosphorus pathways to agricultural total P-losses in Denmark.

River Basin	Soil erosion and surface runoff	Wind erosion	Bank erosion	Leaching to tile drains on mineral soils	Leaching to tile drains on organic soils	Upper groundwater	Total
Estimated annual P-loss (tonnes yr^{-1})	7-35	5-15	275-645	55-200	30-225	< 60	432-1180

The newly adopted EU Water Framework Directive (WFD) aims at protecting different water bodies by performing pressure/impact analysis, introducing monitoring programmes, setting ecological reference targets and developing River Basin Management Plans before 2009. The mitigation measures adopted for reducing phosphorus loss from agricultural land can be grouped into two main classes (general measures and specific measures in P-loss risk areas). Furthermore, mitigation measures can be sub-divided into 4 main categories according to their way of functioning: i) Changes in agricultural practises; ii) land use changes; iii) changes in environmental management; iv) regulation of agricultural production. The adoption of management measures in River Basins demands that catchment managers are able to quantify the importance of different P-pathways, map P-risk areas with a certain spatial resolution and can estimate the effect of various management measures for changes in P-losses.

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Revitalizing the Natural Phosphorus Storage in River Basins: Danish Experiences from Restoring Lowland Rivers and Floodplains

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During the last decade more emphasis has been paid to the fluxes of suspended sediment and associated phosphorus (P) through freshwater drainage systems (e.g. Meade, 1995). This is mainly because of severe eutrophication effects in rivers, lakes, reservoirs and coastal waters observed throughout the world. In particular, the ability of P to be bound to particulate matter means that the flux can be highly discontinuous, with periods of suspension and transport alternating with periods of sedimentation and rest (Svendsen et al., 1995). Overbank storage has been shown to be an important natural sink for suspended sediment and associated P in river systems (Walling and He, 1994). In many river systems overbank flooding is, however, prevented due to the regulation of watercourses for various purposes as drainage of agricultural areas, ship traffic, dams and reservoirs, etc. In Denmark, more than 1000 river restoration projects have been completed during the last 2 decades and a number of these projects involved restoring the natural hydrologic contact between a river and its floodplain (Table 1).

Table 1. River restoration projects conducted in Denmark involving re-meandering and increased inundation of the floodplain during the last two decades.

Restoration projects	Before 1990	1990-1994	1995-1998
Re-meandering involving inundation of the floodplain	5	14	25

In 1998, the Action Plan on the Aquatic Environment II was passed by the Danish Parliament including the re-establishment of 16,000 hectares of wetlands. In March 2004, 30 projects encompassing 1,871 ha have been established and a total of 128 projects have passed through a preliminary investigation. A large number of these projects include restoration of the natural form of rivers and allows for natural flooding of adjacent meadows. Monitoring programmes were established for a few of the accomplished river restoration projects in Denmark during the last 2 decades. Experience gained from river restoration projects and results from an experimental research site have increased our knowledge on the importance of flooding in lowland river systems for water, sediment and nutrient exchange and retention processes between the river and floodplain. Experiences on phosphorus storage through depositional processes have been gathered through in-situ measurements by sediment traps, applying mass-balances and using radioactive tracers (e.g. [137]Cs) to quantify longer-term sediment deposition rates on floodplains. Our results indicate that large amounts of sediment, organic matter and phosphorus can be deposited on the floodplain during short term inundation periods (Table 2). The experiences gathered in Denmark on river-floodplain restoration will be presented and the importance of applying this management measure in river basins under the EU Water Framework Directive as a mean to increase natural phosphorus storage will be discussed.

Table 2. Average deposition rates of sediment, organic matter and particulate phosphorus during each of three overbank flood events measured on a ca. 5000 m^2 floodplain.

	Measuring period	Sediment (g DW m^{-2})	Organic matter (g DW m^{-2})	Particulate phosphorus (g P m^{-2})
1. Overbank flooding	24 Nov. - 2 Dec.	254	70	1.18
2. Overbank flooding	11 Jan. - 20 Jan.	1205	198	3.75
3. Overbank flooding	21 Jan. - 9 Feb.	3002	360	6.50

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Phosphorus Retention in an Agriculturally Loaded Estuary

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Most of the riverine P-flux from Finland to the Baltic Sea originates from agricultural activities, crop cultivation in particular. Since the fate (i.e. distribution, settling and sediment reactions) of this P-load in the receiving water is largely unknown, its potential eutrophying effect is also difficult to estimate. Bulk of the P-load from arable land consists of particulate P, i.e. P bound to eroded soil particles. Particulate P may form a significant source of algal-available P, especially if P bound to reducible Fe is included in the ultimately available P-pool (Uusitalo and Turtola 2003, Uusitalo et al., 2003). Some of the P bound to reducible Fe-forms (e.g. poorly crystalline Fe-(hydr)oxides) remains inactive under oxic conditions – and will thus be omitted by algal assays – but may become mobile in anoxic marine sediments. The mobilization can be attributed to two microbiologically mediated processes: (1) Fe(III) oxide reduction and (2) hydrogen sulphide (H_2S) formation, the latter giving rise to the more or less complete reduction of Fe(III) aggregates to Fe(II) sulphides.

Our objective was to study the pools of Fe-bound P in river water and in estuarine sediment in order to examine the role of this P in the total pool of potentially algal-available P in the agriculturally loaded Paimionjoki estuary (SW Finland). Our data was derived from the measurement of the flux and settling of riverine P in the estuary and the from bottom sediment studies, including pore water analyses and P-fractionations.

The higher average tot-P concentration in the surface sediment (1.5 mg g–1 DM) than in the settling matter (1.1 mg g–1 DM) indicated that P is enriched in the estuarial surface sediment. In the estuarial sediment, the pore water concentrations of dissolved Fe were high, whereas those of dissolved P were low. By contrast, the opposite was true for the open sea sites (high P, low Fe). The result supports the hypothesis that there is sufficiently dissolved Fe(II) in the estuarine sediment for the formation of Fe(III) oxide layer in the oxic top sediments, which – in turn – prevents the upwards diffusing DIP entering the above water. Such a sediment layer is often absent in the open sea, resulting in high internal P-fluxes. The tentative results obtained using the P-fractionation scheme of Jensen and Thamdrup (1993) suggests that the P-pools extracted with buffered dithionite (BD-P), i.e. P bound to reducible Fe, is indeed higher in the estuarial surface sediment (0–10 cm) than in the open sea. These results indicate a good sediment P-retention ability in the Paimionjoki estuary, where relatively good oxygen conditions prevail in the near-bottom water. The practical implication is that the eutrophying potential of agricultural P-loading may be overestimated by laboratory experiments in which a P-carrying sample is reduced by dithionite.

The good sediment P-retention may be attributed e.g. to (1) turbulent and well-aerated conditions in the estuary and (2) high amount of Fe (originating from eroded soil) able to bind P. Under such conditions, organic matter is largely mineralized aerobically or using electron acceptors such as NO_3 (Mn) and Fe rather than SO_4^{2-}, which decreases the formation of Fe sulphides, unable to capture P.

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Effects of Cultivation Systems on P-losses through Surface and Drain Runoff in South-eastern Norway.

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Introduction and methods

Five USLE-plot sites measuring surface runoff (all) and drain runoff (two) have been running since 1987 (1), 1990 (2), 1992 (2). Results including 1995 have been reported earlier (Lundekvam, 1998). Here the period 1992-99 will be focused. The plots are 21-68 m long, with slopes around 13%, and soil types: A) levelled silty clay loam, B) clay and C) loam with high aggregate stability. The top soil contained from 800-1100 mg total phosphorus (P)/kg of dry soil. Yearly fertilizing was about 100 kg N and 19 kg P/ha resulting in a yearly P-surplus of about 6-10 kg P/ha depending on yield. Mostly spring grain have been grown under tillage systems like ploughing autumn (standard), harrowing autumn, no till autumn (ploughing or harrowing spring), removal or no removal of straw. Also winter wheat and meadow have been included.

Results

Comparing soil types using the standard autumn ploughing system the following yearly average results for surface runoff (mm), soil loss (kg/ha), total P loss (g/ha), suspended solids (mg/l), P concentration (μg/l), and the ratio P concentration (μg/l) over suspended solids (mg/l)) were obtained: Soil type A: 226, 3310, 3850, 1465, 1704, 1.16, soil type B: 120, 940, 1130, 778, 940, 1.21, soil type C: 82, 120, 273, 146, 332, 2.26.

Thus the artificially levelled soil type A with low organic matter content and low aggregate stability was clearly most erodable, had highest surface runoff and lost most total P. A high correlation between concentration of total P (Y in μg/l) and suspended solids (X in mg/l) was obtained, resulting in the following equations. Material before 1996: Y=184+0.972 X, material 1992-99: Y=223+1.033 X. The equations are based on average values for several years for each site and treatment. Even though similar, the regression coefficient has increased significantly probably reflecting an increase in soil P that for 10 years could be 4 to 15% depending on fertilizing, soil type, P loss, yield and tillage.

The regression equations between total P and suspended solids in runoff water have a high constant term indicating that the soil particles may be richer in P at low erosion levels and that dissolved P may contribute more to total P. Both factors are likely. Because of the high constant term it also follows that measures that reduce soil-losses will be less efficient in reducing losses of P, especially if erosion levels are low. This is reflected in the measurements comparing no till autumn with ploughing autumn where the following reductions for the three soil types were found: A: soil loss 86%, P loss 74 %, B: soil loss 83 %, P loss 71%, C: soil loss 60%, P loss 20%. Since small and P-rich particles and dissolved P both may stay long in water bodies and also may have a high biological effect, it turns out that the effects of erosion reducing measures on eutrophication will be even smaller than the effects on reducing total P. Still it will be sensible to reduce erosion, especially on soils with moderate to high erosion risk. Plant, plant residues, fertilizer and manure left on top of the soil will be an extra P source and therefore contribute to relatively high P-losses compared to soil losses on systems like: direct drilling, spring tillage with no tillage in autumn or shallow tillage systems (harrowing). Permanent grassland will be extra vulnerable to such losses, because there is no incorporation of plant residues nor fertilizer or manure. This is reflected in the ratios total-P/suspended solids (Y/X): meadow (6-12), harrowing spring (1.8-5.8), ploughing spring (2-4), harrowing autumn (1.4-3,4), ploughing autumn (1.03-2.26). However, a major part of ratios could be explained by the equations given above and different P-content in soil.

For drain water a relation between total P (Y μg/l) and suspended solids (X mg/l) was found to be Y=35.5+1.23*X, thus with a lower constant term and higher regression coefficient than for surface water. For drain water the yearly average results considering runoff (mm), soil loss (kg/ha), P-loss (g/ha), suspended solids (mg/l), concentration of total P (μg/l), ratio total P/suspended solids were the following: soil type A: 210, 1040, 1300, 495, 620, 1.25, soil type C: 292, 37.4, 144, 12.7,49, 3.9. Thus drain water may contribute significantly to soil and P-losses especially on erodable soils. Tillage was found to affect soil and P-losses also in drain water, caused by preferential flow.

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Phosphorus Forms and Mobility due to Manipulating Phosphorus in Animal Feed

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Strategies to Reduce the Phosphorus Concentration in Animal Feeds

Intensification of animal agriculture has led to the production of more P in manure than is required in local crops. Concerns over excessive losses of P from manured soils have now led to interest in manipulating animal diets to lower P concentrations in diets, and subsequently P excretion in manure, while sustaining animal production. Phosphorus in animal diets comes from the P present in basic feed ingredients and from mineral P supplementation. There are two main strategies for lowering P concentrations in animal diets: (i) reducing P over-feeding, which is a common practice (often called insurance feeding or safety margin), and (ii) increasing the bioavailability of feed P and improving P utilization efficiency by the animals. Reducing the over-feeding of P can apply to all animal species, while increasing the digestibility of P applies mostly to monogastric animals (swine and poultry) that lack the ability to digest the phytate-P that makes up about two thirds of the P in corn and soybean meal. Reducing over-feeding of P involves clearly identifying critical levels of P for all species and then formulating feeds as closely as possible to these recommendations. As animals age, they generally require less P as their bone development matures. Increasing the number of feeding phases, with a lowering of the P concentration in each successive phase as the animals mature, can also reduce over-feeding of P. To increase the utilization of P fed to monogastrics there are several strategies that include, (a) adding the enzyme phytase to increase digestion of phytate-P, (b) adding citric acid to lower gut pH and increase the effectiveness of phytase, (c) Adding vitamin D_3 or its derivatives to increase uptake of P from the gut, and (d) breeding of high available P (low phytate-P) crops for animal feeds.

Impact of Diet Modification on Phosphorus in Manures and Losses in Runoff

Using currently available diet modification strategies, total P concentration in manure can be decreased by 40 % for poultry, 50 % for swine and 30 % for dairy cattle (CAST, 2002). For dairy cattle fed with diets containing a lower amount of P, not only is total faecal P decreased but more importantly the decrease is mostly in the water soluble fraction (Dou et al., 2002). Reducing the overfeeding of P in poultry diets will reduce the P concentration and solubility in manures generated (CAST, 2002; Maguire et al., 2004). However, for monogastric animals, the use of the feed additive phytase has raised some concern due to its effect on the solubility of P in manure, as changes in manure soluble P may affect soluble P losses in runoff. Most of the literature shows that phytase in diets does not increase the concentration of soluble P in manures generated (Baxter et al., 2003; Maguire et al., 2004). However, in a broiler study, Vadas et al. (2004) found that phytase formulation in the diet increased soluble P in litters, although this did not translate into significantly greater soluble P losses in runoff. More research on the impact of phytase is needed to clarify the situation.

Concerns over soluble P losses following manure applications are generally short-term as soluble P additions usually affect only the first runoff event (Maguire et al., 2004). Over the long-term total P application controls changes in soil test P that, in turn, exerts a strong influence on P losses in runoff. Diet modification can be used to decrease P surpluses and hence soil test P increases, therefore diet modification can go a long way towards decreasing P losses from manure-amended soils.

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Impact of Land Use Change and Re-wetting on Phosphorus Concentration in Surface Water – Results and Trends of a German Case Study

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Introduction

Fen soil cultivation in North-eastern Germany resulted in severe peat degradation; therefore present and future management is aimed to restore degraded sites by re-wetting. However, little is known about the impact of different fen-preserving land management schemes on the redox and phosphorus (P) dynamics in soil and adjacent surface water. A few studies indicated that elevated water tables due to re-wetting can result in a mobilization of P and its transport to adjoining ground and surface waters as observed in the Droemling fen area, Germany (Meissner et al., 2003) and at other sites (Heathwaite, 1990; Hacin et al., 2001).

Methods

We investigated effects of re-wetting on the concentration of soluble reactive P (SRP) in surface water of the main drainage channel of the Droemling, the Ohre river. Our aim was to evaluate the trend of SRP in the Ohre river and relate it to land use changes in the catchment. For this purpose we used a set of water quality data collected by the Environmental Protection Office of Saxony/Anhalt from the Ohre river at Satuelle gauging point. Long-term series of data are required for the time-series analysis of element concentration. In the present study, the time series 1996 – 2002 was suited for statistical trend analysis. Water quality data of the Ohre river were evaluated statistically on the basis of the 10th and 90th percentiles of discharge. This methodology allows an initial estimation of land-use change and re-wetting effects at the catchment scale.

Results

SRP concentration in the Ohre river at Satuelle significantly increased between 1996 and 2002. The increased SRP contents in the Ohre river probably to a certain extent resulted from land-use change and partial re-wetting in the Droemling water catchment. Trend calculations for the period 1996 - 2002 were used to pre-estimate the range of SRP-concentration in the Ohre river for the next 6 years period presumed the calculated trend is continuing. Recently, about 3.5 per cent of the total area of the Droemling fen area is used extensively or re-wetted. Presumed the proportion of extensively used and re-wetted area will remain around 3.5 per cent, an average SRP concentration of about 40 μg L^{-1} can be expected for 2009. This means an increasing by about 33%. For a **scenario calculation** we hypothesized that the slope of the current trend line corresponds to the proportion of extensively used and re-wetted area. In **Scenario I** we assume that the proportion of extensively used and re-wetted area will be raised up to 10 per cent of the whole area within the next 6 years (moderate re-wetting). This would result in an average SRP concentration of about 80 μg L^{-1} in 2009. In the extreme **Scenario II** we assume that 30 per cent of the whole area will be extensively used and re-wetted within the next 6 years. In this case an average SRP concentration of about 170 μg L^{-1} can be forecasted for 2009. Scenario II can be regarded as a worst case, but the risk of surface water pollution with P becomes obvious. However, the magnitude of order is correct since comparatively high average SRP concentrations of 190 μg L^{-1} were measured already in 2002 in surface water adjacent to an experimental site, which was re-wetted since 1993.

Conclusions

A decision support system was developed for the Droemling area to safeguard surface water quality in co-operation with regional stakeholders (Magdeburg Water Plant, Natural Park Administration Droemling). It may assist conflict mitigation strategies and provides a long-term perspective for the re-wetting process in this region. The decision support system demands continuous monitoring of water quality data. It may give support to stakeholders to iterate the management plans and other options to avoid costs and at the same time to steer the process for ecosystem renewal.

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Long-term Effects of Alum-treated Poultry Litter on Soil Chemistry, Nutrient Runoff and Crop Production: Is this Treatment Sustainable?

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Introduction

Phosphorus (P) is normally the limiting nutrient for eutrophication in freshwater systems. In areas where large numbers of poultry are produced, such as NW Arkansas in the USA, non-point source P pollution can be a problem. One potential solution to this problem is the addition of aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$), commonly referred to as alum, to the manure. Alum additions reduce P solubility in the manure (Moore and Miller, 1994), which has been shown to lower P runoff from small plots by as much as 87% (Shreve et al., 1995) and from small watersheds by 75% (Moore et al., 1999, 2000). The objectives of this study were to evaluate the effects of normal poultry litter, alum-treated litter, and ammonium nitrate on: (1) soil chemistry, (2) nutrient runoff, and forage production.

Materials and Methods

A long-term (20 year) study was initiated in April, 1995 on 52 small (3.05 x 1.52 m) plots cropped to tall fescue (*Festuca arundinacea Schreb.*). There were 13 treatments (unfertilized control, four rates of normal litter, four rates of alum-treated litter and four rates of NH_4NO_3) in a randomized block design. All fertilizers were broadcast applied annually in the spring (April or May). Litter application rates were 0, 2.24, 4.49, 6.73, and 8.98 Mg ha^{-1} (0, 1, 2, 3, and 4 tons acre^{-1}); NH_4NO_3 rates were 65, 130, 195 and 260 kg N ha^{-1} and were based on the amount of N applied with alum-treated litter. Soil pH, water soluble P, Mehlich III P, and exchangeable Al at the 0-5 cm depth were monitored annually. During year 7 soil samples were taken with depth.

Results

Ammonium nitrate applications resulted in reductions in soil pH beginning in year 3. This reduction in pH in soils fertilized with NH_4NO_3 caused exchangeable Al values to increase from less than 1 mg Al/kg soil in year 2 to over 100 mg Al/kg soil in year 7 for many of the ammonium nitrate plots. In contrast, normal and alum-treated litter resulted in an increase in soil pH, which decreased exchangeable Al when compared to unfertilized controls. Severe yield reductions were observed with NH_4NO_3 beginning in year 6, which were due to high levels of acidity and exchangeable Al. Fescue yields were highest with alum-treated litter. Cumulative yields with alum-treated litter were 6 and 16% higher than with normal litter and ammonium nitrate, respectively. Aluminum uptake was typically not affected by fertilizer type, but was occasionally higher with the higher rates of ammonium nitrate. Soluble and total Al concentrations in runoff were not affected by fertilizer type. During year 7 Mehlich III P was found to be higher at the surface 0-5 cm in plots fertilized with alum-treated litter compared to normal litter. We hypothesized this was due to more P leaching with normal litter. Soil profile samples confirmed this; significantly more P (both water soluble and Mehlich III extractable P) was found at greater depths in plots fertilized with normal litter, compared to alum-treated litter, indicating that alum additions greatly reduced P leaching. Alum additions have reduced P runoff by 75% in a companion study started the same year on paired watersheds.

Conclusions

After 9 years of annual applications alum-treated litter resulted in significantly less P runoff and leaching than normal litter. Whereas ammonium nitrate applications resulted in soil acidity and Al toxicity in forage, the use of alum-treated litter did not affect exchangeable Al, Al runoff and/or Al uptake by plants. Cumulative tall fescue yields were higher with alum-treated litter than normal litter or ammonium nitrate. These data indicate that alum-treated litter is a more sustainable fertilizer source than normal poultry litter and/or ammonium nitrate.

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Paired Catchment Comparison of Measures to Reduce Phosphorus Losses in Norway

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Introduction

In the 1980s a comprehensive effort was made to reduce pollution from agriculture in Norway by establishing a program called "Action plan against agricultural pollution". Within this program a set of paired catchments, each pair comprising one catchment with traditional management (reference) and one catchment with intensive supervision on all available best management practices (BMP) including increased subsidies for some measures. Together with this research, an information campaign was going on involving most of the active Norwegian farmers. Though this study on paired catchments were carried out in 1985-1988, results have only been presented nationally as a whole. Internationally, results have only been presented from specialised studies e.g. Øygarden (2000). This extended abstract summarises the results on phosphorus (P) from the paired catchment study.

Materials and methods

Four regions in Norway were included in this study in 1985-1988. In Akershus, Hedmark, Rogaland and Nord-Trøndelag regions, sites were representing areas of intensive cereal production; mixed farming, intensive livestock production and mixed production, respectively. Each region had a paired catchment as reference and one BMP catchment. The BMPs included nutrient management planning, increasing areas of no-till, improving soil structure, and reducing concentrated runoff of surface water. In Akershus the focus was on soil erosion and reduced tillage, whereas in Rogaland the nutrient management (livestock farming) had the main focus. Farming practices were recorded and water discharge, losses of soil and nutrients from the catchments were monitored.

Table 1. Paired catchments comprising reference and BMP management.

Region	Size (km^2)		Dominating production	Precipitation (mm)	Soil	Soil P status (P-AL-class)	
	Ref.	BMP				Ref.	BMP
Akershus	1.5	2.5	Cereal	825	Silty clay	2-3	2-3
Hedmark	0.6	3,1	Mixed	563	Silty sand	2-4	2-4
Rogaland	2.0	1.1	Milk	1150	Silty sand	2-4	1-4
Nord-Trøndelag	1.7	1.7	Mixed	1000	Silty clay loam	2-4	1-4

Results and discussion

The general information campaign influenced farmers in the reference catchments as well as in the BMP catchments. There was a general decrease in P application during the monitoring period. In the Akershus and Hedmark catchments there were significant decreases in area of autumn ploughing during the study period. In the Rogaland study there was a significant decrease in spreading of manure in autumn and winter.

The significant influence of weather conditions on losses of total P obliterates the effect of implemented measures. However, in the Akershus study the difference between the reference and the BMP catchments showed a clear effect of measures at catchment scale.

Conclusion

Owing to the intensive information campaign, BMPs were implemented in both the reference and the BMP catchments and hence, differences in P losses between the catchments were less than expected. However, effects of measures on P losses were proved in some of the paired catchments.

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Scenarios for Phosphorus Accumulation in Soil in Relation to Livestock Production Intensity and Feeding Practice

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Phosphorus (P) is an essential nutrient in livestock and crop production. Utilization of P in dairy cows and pigs is low (Valk et al., 2000; Poulsen, 2000), and the excretion of P may cause excessive accumulation of P in soils receiving manure thereby increasing the potential for P loss to water. Phosphorus accumulation in soils depends amongst others on livestock density, type and category of animal, feeding practice, crop rotation and P yields in the given area. By improving our basic knowledge on the animals' physiological P need and by improved P utilisation in feed, it is possible to reduce P excretion from dairy cows and pigs through changes in feeding practice. In Denmark, these options are being pursued to reduce P accumulation in agricultural soils as part of a comprehensive action plan for the aquatic environment (Poulsen and Rubæk, 2004). We therefore estimated the effect of livestock production intensity and changes in feeding practices on P accumulation in soils for three different types of farms (a farm with sows raising piglets to weaning at 4 weeks of age, a farm raising pigs from weaning to slaughter at 102 kg, and a dairy farm). Low, medium and high intensity of livestock production, defined by the number of animals per hectare arable land, were included, and relevant crop rotations and plans for the use of manure and fertilizer P were defined for each scenario. The net P accumulation in soil between 1985 and 2025 was calculated for each scenario. The effect of changed feeding practice was included in the scenarios from 2002. An example for pig production is presented in Table 1.

Table 1. The effect of extensive, medium and intensive livestock production and changing feeding practise on the accumulation of total P in the top soil. Livestock production: Extensive 2.6, medium 4.3, and intensive 6.0 sows incl. piglets to weaning per hectare. Concentration of total P in top soil was estimated at 525 mg kg^{-1} soil in 1985.

Sows and piglet production	Change in total P in top soil from 1985 to 2002, %	Feeding practise improved	Change in total P in top soil from 2002 to 2025, %
Extensive	10	Yes	-3
Extensive	10	No	1
Medium	22	Yes	5
Medium	22	No	10
Intensive	36	Yes	13
Intensive	36	No	19

By improving feeding practice in extensive sows and piglet production, the soil P pool decreased. In the other scenarios, the P contents in soils increased, even with improved feeding regimes. In the scenario with intensive production (6 sows per hectare), P accumulation in the top soil will increase by 13% between 2002 and 2025 even if the feeding regime is changed. The scenarios on pigs from weaning to slaughter and dairy cows showed almost the same pattern (data not shown). The P accumulation in the scenarios simulating intensive production without dietary changes corresponded to total soil P contents of 811 and 749 mg P per kg top soil for slaughter pigs and dairy cows in 2025, respectively.

In addition to the changed feeding practise, the implementation of an alternative fertilization strategy was also studied in the scenarios. Adjusting P application to crop need by reducing or omitting fertilizer P, the soil P pool would further decrease, remain unchanged or increase at a lower rate from 2002 to 2025 according to the livestock production intensity.

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Farm Environment Risk-Assessment Maps – Bridging the Gap Between Regional Oversight and Individual Farm Risk Management

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Introduction

Growing awareness of environmental issues, particularly those related to the farming industry have lead to calls for a more sustainable approach to agricultural management practices where losses of nutrients such as phosphorus (P) and nitrogen (N) to the surrounding environment are minimised.

In New Zealand, Regional Councils are charged with the job of ensuring that environmental pollution is minimised and that the requirements of the Resource Management Act (1991) are met. This includes ensuring that all practical steps are taken to maintain water quality. Point-source industrial and domestic wastewater contamination were the first priority. Now attention is being focussed on nutrient and bacterial enrichment from agricultural land.

The Councils options in this respect are limited to, for example, punishment for specific incidents, the setting of nutrient usage limits in Regional Plans, and supporting the use of Best Management Practices and nutrient budgeting.

To assist farmers in the management of nutrient and bacterial loss on their individual farms, Summit-Quinphos, with the assistance of the National Institute of Water and Atmospheric Research (NIWA) have developed what it calls Farm Environment Risk Assessment Maps (FERAMs).

FERAM Models

FERAMs consist of three maps which present the risk of P run-off, nitrate leaching and faecal bacterial run-off in a colour coded scale ranging from dark blue for low risk through to dark red for high risk. The models used to produce the maps are generated in a GIS environment where knowledge of scientific principles of water movement, sediment transport and nutrient and bacterial transport mechanisms as well as site specific information such as soil type, rainfall intensity and soil Olsen P levels are combined.

The information in the FERAMs can be used to identify areas of high risk of loss and the factors contributing to this high risk and can therefore be used to assess appropriate farm management practices to reduce this risk. Examples of management strategies (where P loss is the risk), include the use of riparian buffer zones, the use of reactive phosphate rock (RPR), which has been shown to reduce the loss of fertiliser P in surface runoff compared to soluble forms of P fertiliser, and grazing management strategies which minimise sediment loss.

Originally the FERAMs were designed to be used only at an individual farm scale, allowing the farmer to identify the areas of high risk within their farm and make appropriate management changes in these areas. However, recent improvements in software, and advances in digital mapping technology, have resulted in a powerful new computer-based mapping tool. With this tool, Summit-Quinphos field consultants are now able to present information on a regional or catchment basis. Patterns of topography, rainfall intensity and soil types with high potential risk of nutrient loss can be easily identified.

These maps can be queried and interrogated, allowing field staff to quickly "zoom-in" from the regional or catchment scale to individual farms. Individual farms within high-risk areas can be easily located using the digital aerial photographs database, allowing for detailed visualisation at an individual farm level.

By seeing the farm in a regional or catchment context, farmers can grasp far more easily the need to control nutrient and bacterial loss from each and every farm. They are then, in our experience, far more amenable to consider alternative fertiliser and management strategies, designed by their field consultant, to help ensure both the profitability and environmental sustainability of their farming operation.

Conclusion

The contribution of agriculture to declining water quality requires changes in farming practices to be made in order to ensure a halt to this continuing degradation. The authors believe that FERAMs are a valuable tool which help identify areas where changes are most urgently needed, and allow the farmer to see where they fit in within a regional or catchment context. With modification of the input factors as required, the FERAM approach should have the potential for international application.

A Semi-distributed Approach for Assessing the Potential of Mitigation Measures for Reducing the Risk of Phosphorus Sources Connecting with Surface Water Bodies

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The risk of phosphorus (P) reaching streams and surface water bodies associated with overland flow and sediment, where it can cause pollution, is a combination of a source connecting with a sink. While this has been recognised in the literature, few models explicitly take account of the delivery of material to water bodies and how this relates to the source material. In this paper we present a new approach whereby the sources of material reaching the stream are calculated using semi-distributed functions, enabling delivery maps to be produced of high and low risk areas. We do this by characterising the individual flow pathways using a multiflow algorithm and using soil and land use information to characterise the source. Soluble phosphorus is generated using a simple empirical relationship between soil P test values and soluble P; sediment associated P is mobilised by using a simple erosion model. The proportion of P is then routed through the landscape and a memory is retained of the contributions of individual pixels to the delivered phosphorus. The impact of buffer placement on the contribution of P to surface waters is demonstrated using data from two research catchments.

Evaluation of Manure Policy and its Environmental Impacts in The Netherlands

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Within the present national and European context the results of this evaluation point out that the Dutch manure policy has reached a decisive stage. The high nitrate concentrations in groundwater decreased substantially, but exceeding of the European standard of 50 mg/l persists on soils sensitive to nitrate leaching. The nitrogen surpluses will have to go down by several tens of kg/ha before the nitrate standard will be reached.

Although the agricultural sector managed to bring down the phosphorus surpluses by 30% since 1997, soils are still accumulating phosphorus, and leaching of phosphorus did not decrease. The policy goals of MINAS, the loss standards for nitrogen and phosphorus, were achieved. However, the underlying environmental goal, a tight balance between nutrient application and crop removal, was not reached. The manure contracting system did not have any limiting effect on manure production, because the dairy farmers had to contract only 85% of the nitrogen production in manure. The system of Manure production ceilings was very effective as it prevented the large and economically vital farms to increase their livestock numbers.

In October 2003 MINAS was rejected by the European court of justice as a proper implementation of the Nitrate Directive. Hereafter the Dutch government decided to abandon MINAS in 2006, and the Manure contracting system in 2005. In 2006 the Netherlands will adopt a manure policy based on application standards instead of standards for mineral losses. The new manure policy, including application limits for nitrogen in manure and fertilisers as required by the Nitrate Directive, will set tighter limits to the use of nitrogen and phosphorus than the present MINAS.

Redistribution of Phosphorus in Grazed Ecosystems

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Introduction

Through grazing, trampling and defecation large herbivores affect nutrient flows, vegetation community dynamics and the response of associated fauna in grazed ecosystems. For the construction of models which describe the consequences of the differential redistribution of sheep faeces and urine, both within and between vegetation communities, new information is required in relation to the composition of sheep faeces and its effect on soil solution chemistry. Much of the phosphorus ingested by sheep is returned to the soil, almost entirely in faeces and faecal patches represent areas where phosphorous and carbon are recycled (Williams and Haynes, 1995). Our paper investigates the influence of sheep faeces on soil solution chemistry over a 6-month period. Using ^{31}P-NMR we additionally studied the composition of the faeces residues that remained on the surface.

Sheep faeces

Faeces were collected from sheep grazing on a grass clover pasture on an improved, freely-drained, humus-iron podzol. The chemical composition of the sheep faeces was determined by ashing freeze-dried sub-samples, extracting the ash with HCl, and analysing the solution using ICP optical emission spectroscopy. The sheep faeces contained 1.3 % P.

Plot experiment

Fresh faeces were applied to the soil in late summer using a randomised block design within a fenced enclosure. Individual blocks (1.2 × 1.2 m) contained nine faecal patches or equivalent controls. There were six treated and 6 control blocks. The faeces (150 g fresh) were applied to a circular area of diameter 150 mm, typical of the natural patch sizes. At intervals over a 6-month period, intact soil cores (80-mm diameter, 50-mm deep) were taken, along with those from untreated controls. The grass and any remaining faecal residues were removed by cutting. The cores were placed in polycarbonate centrifuge cells and the gravimetric moisture content of the cores adjusted to 95% of maximum field capacity by applying water to the surface. The cores were incubated at field temperature for a period of 16 h after which time, soil solution was obtained by centrifugation (1000 g). The soil solution was filtered (0.45 μm) and analysed from total P, molybdate reactive P, DOC and other elements. There were significant increases ($p < 0.05$) in the concentrations of P fractions and other elements compared to untreated controls.

^{31}P NMR

Information on the phosphorus composition of sheep faeces and the effect of weathering on the soil surface was obtained directly on solid samples using ^{31}P-NMR with a Varian/Chemagnetics CMX300 LITE instrument and magic angle spinning (6 kHz). The spectra (cross-polarised) clearly showed two main forms of phosphorus with well resolved resonances at 6.0 and 1.0 ppm: sidebands (33 and -32 ppm) were present only for the resonance at 1 ppm. The freeze-dried faeces were extracted with 0.25 M NaOH/0.05 M EDTA and the NMR spectra of the solution was determined with a Bruker DPX300 spectrometer. The spectra were dominated by a sharp resonance with a chemical shift (6.4), characteristic of inorganic orthophosphate but there were additional resonances around 5.6, 5.2, 0.2, and - 4.0 ppm, whose intensities changed because of weathering.

Comparison with sheep urine

Sheep urine is nitrogen rich and contains little phosphorus. The urea in sheep urine is rapidly hydrolysed in contact with soil resulting in an increase in the pH of the soil solution and desorption of organic- and inorganic-P from soil surfaces. The paper will further elucidate the differences between faeces effects and urine effects (Shand et al., 2002) on soil solution chemistry.

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Strategy for Phosphate Phytoremediation

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Introduction

Indiscriminate application of poultry litter and other manures in farmlands has caused non-point source of phosphorus (P) pollution at many locations in the U.S. and elsewhere. While problems with eutrophication are long standing (Daniel et al. 1998), reports of *Pfisteria piscicida* emergence in waterways in Mid-Atlantic U.S. pose a potential human health concern (Burkholder et al. 2002). One potential solution to the problem of P movement is the practice of growing crops that can accumulate high amounts of phosphate (Pi) from soil and, at the same time, generate enormous biomass. Viewed in this perspective, phytoremediation can be an attractive technology to apply in the P-prone areas. There are several reports of hyperaccumulator plants aiding to the phytoremediation of heavy metals, but the ability of plants to assist in the remediation of P remains scarcely known so far (Delorme et al. 2000; Sharma et al. 2004). The objective of this study was to screen crops (grass and vegetable) for their potential to accumulate Pi in their aerial parts. Our strategy also includes genomic analysis of a potential plant (*Lolium multiflorum*) for identification of phosphate transporter gene regulating the accelerated uptake and transport.

Materials and Methods

Seedlings of grass, beans, cucumbers and other vegetable crops were planted in pots containing soil with KH2PO4 (2.5 g/kg soil) and grown till flowering in green house. After harvest, roots and shoots were assayed for P contents using ICP-MS (Sharma et al. 2004). Expression analysis of Pi transporters in Gulf ryegrass was carried out as described by Muchhal and Raghothama (1999). Pi transporter gene (ZmPT2) from maize was used as a heterologus probe.

The c DNA library was prepared with the poly A+ RNA from Pi starved plants for 11 days, using commercially available lambda ZAP kit.

Results

Among the grasses, Marshall and Gulf ryegrass (Lolium multiflorum) demonstrated high potential (>2% shoot DW) in solution culture (Sharma et al. 2004). In pot experiments, these grasses, again, accumulated more P in their aerial parts, on manipulation in the mode of planting. Among the vegetable crops, some cucurbits showed P accumulation up to 1% DW.

Preliminary northern analysis did not show hybridization with one of the maize Pi transporter probes. Further analysis using other Pi transporter probes are continuing.The unamplified primary cDNA library had a complexity of 3x106 pfu/ml. After one round of amplification the complexity of library reached over a billion pfu/ml.

Conclusion

It is believed that with manipulation in cultural conditions, such as soil pH, temperature and microbial inoculation, selected crops can be used to remove excess P from soil and water bodies. Identification and characterization of Pi transporter genes will ultimately help in genetic engineering of plants/crops suitable for phytoremediation of polluted P rich soils.

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Biosolids Effects on Phosphorus in Soils and Runoff: Environmental Policy Implications

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Introduction

Water quality concerns have caused many U.S. states to pass laws or establish guidelines that restrict manure applications based on phosphorus (P) (Coale et al., 2002). The widespread changes in P management for manures have brought attention to the need for similar approaches for the land application of biosolids. Most states regulate the agricultural use of biosolids in accordance with federal rules that follow the standard, long-term approach used with animal manures, requiring biosolids to be applied at a rate that is equal to or less than the agronomic N rate for the crops to be grown (Shober and Sims, 2002). Recent research suggests that some of the factors that lead to the more restrictive approaches now used for animal manure P also apply to biosolids. Stehouwer et al., (2000) reported that biosolids applied to meet the N requirements for corn added from 93 to 294 kg P ha^{-1}, much more than is removed in harvested corn grain (~25 kg P ha^{-1}) which could lead to the buildup of P in soils and increase the risk of P loss to water. Some research, however, has shown that the risk of P loss to water is lower with biosolids than manures. This has been attributed either to the lower solubility of biosolids P, relative to manure and fertilizer P, due to the chemical amendments added at some wastewater treatment plants or to organic matter added in biosolids which improves soil structure and reduces soil erosion (Penn and Sims, 2002; Withers et al., 2001). We have conducted 5 years of laboratory and field research to determine if there are fundamental differences in the forms of soil P or the physical properties of biosolids-amended soils that mitigate the risk of P loss and require a different approach to P management than is needed for manures and fertilizers. This presentation reviews that research and its relationship to emerging environmental policies for biosolids P in the USA.

Materials and Methods

Laboratory studies were initially conducted to evaluate the effect of biosolids type on forms and solubility of P in soils of the Mid-Atlantic USA. These studies led to rainfall simulation experiments that compared soil P with P lost in runoff, using runoff boxes and a 3-year field study at two locations. Other studies compared soil P forms and desorption in fields and setback areas from a range of farms where biosolids had been used for crop production.

Results and Conclusions

Our research, at all scales, has consistently shown that soils amended with certain types of biosolids, such as those treated with metal salts, have lower soluble P concentrations and produce lower P concentrations in runoff than most manures and fertilizers. Results of these studies have been combined with data from >900 field scale P Site Index evaluations to assess the impact of assigning different risks of P loss to biosolids compared to manures. Environmental policy-makers in the mid-Atlantic and other states are now debating whether or not to assign lower risk to land-applied biosolids than animal manures. We present, based on our data and other studies, a framework that could be used to asses the risk of P loss and guide improved P when biosolids are used by agriculture.

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Molecular-Scale Determination of P Speciation in Alum Amended Poultry Litter

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Introduction

Alum ($Al_2(SO_4)_3$ has been added to decrease soluble P in PL (Moore and Miller, 1994). While alum amended litter (Al-lit) releases significantly less P to runoff and leachate, the P retention mechanism is not fully understood. Hunger et al. (2004) and Peak et al. (2002) have provided direct observations of P speciation in these systems, using nuclear magnetic resonance (NMR) and x-ray absorption near edge structure (XANES) spectroscopy. Both studies showed the importance of aluminium surfaces as P sinks in alum amended PL. In combination with macroscopic techniques, these molecular-scale approaches can provide in-depth P speciation and distribution information about these heterogeneous samples. Sequential extractions have been routinely used to describe the distribution of P in mineral soils. These tools indirectly suggest how, and to what, P is bound. The method of Hedley et al. (1982) is one of the most widely used P fractionation schemes for soils. In this procedure, biologically available inorganic P (P_i); weakly sorbed P; P chemi-sorbed to Al and iron Fe; and apatite-like materials (Ca-bound P) are removed in four separate steps. However, there is no direct evidence that these P associations are the ones exploited during the extractions. Soil P fractionation procedures have been applied to PL which likely contains a much larger proportion of organic components than soils. So, organic P compounds and P bound to carbon based materials need to be considered.

The first objective of this study was to understand how alum treatment of PL alters the distribution of P. Secondly, we aimed to elucidate the chemical nature of the P removed with each extraction step, through the use of a direct, molecular-scale technique. In doing so, information on the use of alum as a best management practice will be provided. Also, a better understanding of a widely used extraction technique will be gained.

Materials and Methods

Sequential extractions were performed on several alum-amended and unamended PL samples provided by Dr. J. T. Sims. The method from Dou et al. (2000), a modification of the Hedley, was used. Briefly, a 0.3 g subsample of each PL was extracted with 30ml of DI water, 0.5 M $NaHCO_3$, 0.1 M NaOH, and 1 M HCl, respectively. Samples were shaken for 1 h, followed by centrifugation, the extracts were filtered, and immediately analyzed for Al, Ca, Fe and P by ICP-AES. Following each step of the extraction, one replicate was freeze dried and stored for XANES analysis at beamline X-19A of the National Synchrotron Light Source at Brookhaven National Lab (Upton, NY, USA). Multiple scans were collected, in fluorescence mode, from 50 eV below to 50 eV above the P K-edge. Data reduction was conducted with WinXAS 3.0 and principal component analysis completed using software designed by Matthew Marcus (beamline 10.3.2. of the Advanced Light Source, Berkely, CA, USA).

Results and Discussion

The extract analysis shows that HCl removes the largest proportion of total extractable P in all samples (from 40-60%). The Al-lit samples showed larger NaOH-extractable P compared to the control samples, which reinforces that this fraction is metal bound. In addition, the unamended samples had elevated water-extractable P. Aluminium was mainly extracted in the NaOH extraction and Ca was removed during the HCl extraction, as expected. However, the proportion of Fe in the HCl extracts was much higher than in the NaOH extracts (75% verses 12-15%). So the acid extraction may be removing P bound to Fe surfaces better than NaOH.

Fitting our standards to three principle components in a target transformation, we found that aluminium complexes and organic P compounds best fit our Al lit extraction samples (had the lowest SPOIL values). For the control samples, spectra of calcium and sodium salts were among the best fits. While further data analysis is needed to differentiate between individual extractions, we do see that there is an overall difference in P speciation between the two treatments.

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Relating Agronomic Soil Test P and Soil Type Data to Soluble P Loss Risk in Ireland: Implications of Drying Soil Samples

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Introduction

Understanding the relationship between soil phosphorus (P) status and potential P desorption is of critical importance for the prediction and management of diffuse P losses. Much work has been done on defining these relationships within specific soil types, but usually relies on data based on analyses of P desorption from dried soil samples. Phosphorus desorption has been found to increase substantially after sample drying (Bartlett and James, 1980; Turner and Haygarth, 2001). In Ireland, a large nation-wide database of agronomic soil test P (STP) data exists in the form of Morgan P concentrations. Previous work by Daly et al. (2002) attempted to use these and mapped soil type data, in conjunction with P desorption indices derived from laboratory analyses of dried soils, to predict stream molybdate-reactive P (MRP) concentrations on a subcatchment scale. In this study, we look at the effect of sample drying on soil-type-specific STP - P desorption relationships, and its implications for ranking soluble P loss risk across a range of subcatchment typologies using mapped STP and soil type data.

Methods

Thirty-four soil samples were collected from a range of land uses and soil types across the 859 km^2 Mask catchment in the west of Ireland. Samples were divided into sub-samples which were either maintained at their sampled moisture status and at 4°C, or air-dried according to standard practice. Both moist and dried samples were analysed for readily desorbable P (Pw) and longer term desorbable P by the iron-oxide strip test method (Pfeo). Dried soil samples were analysed for a range of general soil characteristics and various measures of STP, and also P sorption. Soils were divided into groups based on the organic matter (OM) content classification system used by Daly et al. (2002), and P desorption characteristics were compared between groups. Resulting P desorption indices were then applied to maps of Morgan P and soil type for the Mask catchment in order to rank subcatchments for soluble P loss risk. These rankings were then compared with mean subcatchment soluble P concentrations (MRP and total dissolved P: TDP) obtained from bi-weekly sampling of all the major catchment streams.

Results and discussion

Both methods of P desorption were strongly correlated with one another (r = 0.97***), and Morgan P proved to be a strong predictor of moist sample P desorption (r^2 = 0.76*** and 0.81*** for Pw and Pfeo respectively). Inclusion of OM content as a negative predictor in multiple regression analyses with Morgan P proved significant, increasing r^2 values to 0.83*** and 0.87*** respectively. There were insufficient data to detect differences in P desorption/Morgan P ratios between mineral soil groups, but Mann-Whitney U tests found significant differences between peat and mineral soil groups (U = 4*** for both Pw and Pfeo) in moist samples. For dried samples, differences were significant for Pfeo (U = 36*) but not for Pw (U = 90). Based on mean moist sample P desorption/Morgan P ratio data, peat soil desorption at a given Morgan P concentration was 0.26 and 0.27 times mineral soil desorption for Pw and Pfeo respectively. From these data, a simple subcatchment P desorption index (PDI) was devised:

$$PDI = m(Pm) + 0.27p(Pm)$$

where m and p are the proportion of the subcatchment accounted for by, respectively, mineral and peat soils, and Pm is the average catchment soil Morgan P in mg L^{-1}. Application of this model to maps of soil type and Morgan P for the Mask catchment resulted in significant correlations (Spearman Rank; *df* = 12) with mean stream concentrations of both MRP and TDP (r_s = 0.64* and 0.54*, respectively). When Morgan P alone, or peat/mineral P desorption ratios derived from dried sample analyses, were used, the index was not significantly correlated with stream MRP or TDP concentrations. Thus, differential soil-type desorption appears to be an important driver of soluble P loss risk, and this effect is obscured by the standard practice of sample drying prior to soil P desorption analyses.

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The Effect of Long-Term Fertilization on the Migration and Balance of Phosphorus

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Introduction

Long-term phosphorus fertilization can ensure plant nutrient requirements, neutralize the reduction of P stock in soils but can also lead to the modification of soil fertility and productivity by itself. The element being not availed by plants can leach to deeper soil layers and surface water causing eutrophication (Sharpley and Withers, 1994, Siegenthaler and Steuffer, 1991). Towards the need for the sustainable management of plant nutrients, which found response in EU countries throughout the EU Nitrogen Directive enforcement and EU Phosphorus Directive preparation, we carried out research on the determination of phosphorus migration in soil profiles based on the P balance after long-term fertilization.

Materials and Methods

A long-term experiment (1973-1999) was carried out in micro plots $1m^2$ in area filled with light soil on middle loam. Four objects treated yearly with cattle slurry during 1973-1989 received the following doses of slurry (S1-S4): 25, 50, 100 and 200 $m^3 \cdot ha^{-1}$. Four different mineral fertilizer treatments (M1-M4) were also studied, with half of NPK rates applied as slurry. In 1990-1999 the after-effect was investigated. In 2000 plots were dismantled and the soil was sampled in the surface and sub-surface layers. The content of available phosphorus was determined according to the Egner-DL method, in all treatments and soil profiles. The P balance was calculated as the difference between P input via fertilizers and P removal with crop yields.

Results

Table 1. The available phosphorus content (Egner-DL) in surface and sub-surface soil layers

Treatment	mg P·kg⁻¹ in layers		
	0-25 cm	25-50 cm	total
S-1	27.5	15.3	42.8
S-2	34.9	17.4	52.3
S-3	42.3	25.3	67.6
S-4	79.4	38.8	118.2
M-1	28.8	17.0	45.8
M-2	38.4	18.7	57.1
M-3	53.6	22.7	76.3
M-4	94.6	26.2	120.8

Table 2. The P-balance (direct and residual effect of fertilization) in kg P·ha⁻¹

Treatments	Fertilization*		Uptake*		Balance*	
	1973-1989	1990-1999	1973-1989	1990-1999	1973-1989	1990-1999
S-1	19.6	9.5	22.3	16.8	-2.7	-7.3
S-2	39.2	12.8	31.1	18.7	+8.1	-5.9
S-3	78.4	16.1	38.1	20.1	+40.3	-4.0
S-4	156.7	19.4	48.4	28.4	+108.4	-9.1
M-1	10.9	9.5	19.5	17.0	-8.6	-7.5
M-2	21.8	12.8	25.5	19.0	-3.7	-6.1
M-3	42.3	16.1	25.3	19.8	+17.0	-3.7
M-4	79.5	19.4	28.4	23.5	+51.1	-4.2

*- yearly average

Conclusions

1. The highest contents of phosphorus were found in treatments fertilized with the highest doses of P, both for slurry and mineral fertilizers, in the 0-25 cm soil layer, whereas a lower amount of available phosphorus was found in the 25-50 cm soil layer, irrespective of the form and rate of P application.
2. A direct effect of fertilization was the high increase of the phosphorus balance, particularly in case of treatments fertilized with the highest rates of cattle slurry.
3. Research on the after-effect of fertilization shows that the balance of phosphorus was slightly negative, below 10 kg·P ha⁻¹, independent of the form and rate of fertilization.

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Phosphorus and Potassium Concentrations in Overland Flow Water from Grassland Plots

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There is now considerable information on phosphorus (P) loss from grassland; however, there is little information on potassium (K) loss in overland flow from grassland. This paper describes the P and K concentrations in overland flow water from six instrumented grassland plots at Johnstown Castle from autumn 2000 to spring 2001.

Field plots were hydrologically isolated to measure N, P and K loss in overland between October 2000 and March 2001 (Tunney and O'Donnell, 2002; Tunney et al., 2003). Overland flow was measured at 5-min intervals and flow proportional water samples were collected, during overland flow events, using Sigma 900 samplers. Results from six field plots (0.47 to 1.45 ha each) are presented. The plots were on three sites in three areas of the Teagasc Johnstown Castle farm (each about 1.5 km apart); two plots in the Warren (1&2), one in the Cowlands (3) and three in the Dairy (4, 5&6). The plots at the Dairy (cows) and the Cowlands (beef) were intensively farmed (>2.5 LU ha^{-1}). The plots at the Warren (beef) were previously extensively grazed (<2.0 LU ha^{-1}) or cut for silage. The Warren plots were cut and the other plots were grazed in 2000. Fertiliser was applied according to Teagasc advice, however, plot 1 received no P and the plot 3 received high P (30 kg P ha for the past 30 years). The soils were derived from Irish Sea drift, the Dairy was mainly brown earth and the others were gley soils. The water samples collected from the six plots were treated as six separate sets of data and also as a single set. MS Excel was used for statistical analyses.

A total of 2467 flow proportional water samples were collected during the study period (520, 499, 382, 250, 415 and 401 from plots 1 to 6 respectively). There was a statistically significant relationship (P<0.01) between total reactive P (TRP) and K for all plots combined and for plots 2 to 6 individually. The relationship was not significant for plot 1, which had the lowest TRP levels. There was not a statistically significant correlation between soil test P and soil test K for the six plots. The potassium concentrations in overland flow water were generally of the order of 10 to 20 times higher than the TRP concentrations. The mean concentrations of TRP and K in overland flow and soil test P and K for the six plots are summarised in Table1.

Table 1. Mean TRP and K (mg l^{-1}) in overland flow water, correlation between TRP and K (R^2) and soil P and K (mg l^{-1} soil) for the six plots.

Plot	1	2	3	4	5	6
TRP	0.06	0.11	1.23	0.27	0.39	0.68
K	1.34	0.82	8.07	6.68	7.02	9.37
R^2	0.004	0.30	0.61	0.21	0.54	0.72
Soil P	3.5	4.8	17.9	4.5	7.0	7.2
Soil K	75	73	92	123	131	104

The results indicate a significant relationship between TRP and K loss in overland flow at 5 of the 6 plots. It is not clear why this relationship exists. In addition it was found that there was not a statistically significant relationship between TRP and iron (iron binds P in the soil) or total N or nitrate N (there is a high use of fertiliser N on farm land) in overland flow water from these plots during the period of this study. It appears that there is some chemical or other reason why TRP and K move together in overland flow water. It is interesting that the relationship between TRP and K exists on these plots despite wide variations in TRP and K concentrations. There is need for further work to explain why this relationship exists and if it may offer possibilities for amelioration of P loss from grassland fields to water.

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An Indicator for Phosphate Saturation of Soils

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Introduction

To adequately deal with the hazard of phosphate leaching from fields in agricultural use to ground water, it is essential to take into account the sorption of phosphate by soil. Phosphate sorption significantly retards leaching and limits concentrations in solution that may control runoff losses to surface water. In view of the large livestock densities in the highly developed Dutch agriculture, the total area that was suspected to pose a hazard of phosphate leaching on the short to intermediate term was large. For this reason, an indicator for the hazard of phosphate leaching was sought with sufficient soil chemical basis to be generally applicable for Dutch soils, as well as being accessible with routine laboratory analysis.

Background of the phosphate saturation indicator

The majority of Dutch soils are noncalcareous and moreover, the intensive livestock breeding is concentrated on the Dutch sandy soils, with pH-values predominantly below 5-6. In such sandy soils, it has been established that the reaction of phosphate is predominantly with amorphous fractions of Fe and Al. Furthermore, the effect of other parameters that affect P-sorption is secondary to that of the amorphous Fe and Al fractions. Hence, a robust indicator α is obtained by the ratio of oxalate extractable P over oxalate extractable sum of Fe and Al oxides, where the oxalate extraction mainly involves amorphous oxides. The rate of growth of the indicator is strongly dependent of a.o. the concentration.

Regarding the indicator, it is important to recognize that the sorption of phosphate with amorphous oxides is due to different processes that differ with regard to their kinetics and reversibility. Besides a rapid adsorption, which is well reversible and follows the Langmuir equation, we can distinguish a process called diffusion-precipitation and which has slower kinetics and is less reversible. It is necessary, though, to observe that this distinction into two processes is made for operational ease rather than based on rigorous soil chemical theory. We anticipate that in reality, the transition between surface adsorption and diffusion-precipitation is gradual (Van der Zee, 1988, Koopmans et al., 2004). Nevertheless, due to the pragmatically distinguished adsorption and diffusion-precipitation reactions, the indicator α can be separated in a part attributed to adsorption (β), and a part attributed to diffusion-precipitation (γ), where β is about one half of γ. This distinction is important, because the limited reversibility of the precipitated quantity largely affects the leaching risks.

Phosphate leaching

The risk of P-leaching depends on the quantity of P present in soil that can desorb, and the capacity of the subsoil to intercept this quantity on its way to ground water. This concept was the basis for developing a second indicator that is related with the phosphate saturation of the soil profile. Based on fundamental understanding of the P-transport process in a soil profile, this profile phosphate saturation indicator could be attributed a critical value. Major, yet implicit, ingredients in this value were the phosphate concentrations in the P-saturated topsoil and the concentration that is expected to lead to surface water eutrophication under Dutch conditions. Furthermore, a number of simplifications were made, that may be limited with regard to their validity.

The presentation

In this presentation, the main line of thought in the development of a phosphate saturation indicator is presented. Additionally, major simplifications, assumptions, applications, and recent challenges to this approach are discussed. We show that the indicator has a broad range of validity, which is certainly not limited to Dutch, or to sandy soils, and has been used in several other countries for anticipating adverse effects of P-loading of soils and regulating P-balances. Nevertheless, its limitations need to be recognized, to prevent inappropriate use.

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Experiences with Zero Surplus P Management and Mining P on Dairy Farming System De Marke; Strategies, Effects on Productivity and Soil Processes

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Nitrogen (N) and phosphorous (P) are indispensable inputs for the sustainability of agriculture. The use of both inputs has increased dramatically in recent decades, but so have nutrient losses. Dairy farming has its share in the problems of N and P losses to ground water particularly in soils that are susceptible to leaching in regions with high animal densities. The coherence of intensive dairy production, high N and P-inputs, low utilization and high levels of N and P-leaching is particularly evident in the light sandy soils in the Eastern and Southern part of the Netherlands. In research project De Marke possibilities are examined to realize a production system that is sustainable both from an environmental and economical point of view. A sustainable system was designed, implemented in practice on farm scale and tested. National environmental standards for the concentration of nitrate (50 mg NO_3 l^{-1}) and phosphate (0.15 mg P l^{-1}) in ground water were used as boundary conditions for system development. These boundary conditions have to be met without reducing milk production intensity below the national average of 11900 kg ha^{-1} or exporting slurry.

The maximal acceptable P-concentration in ground water complies with a net P-rate to the soil of less then 1 kg ha^{-1} yr^{-1} and a zero P-surplus (defined as the difference between inputs to the soil by application of manure, fertilizers, atmospheric deposition and discharge by crops harvest). Thus, a manure application strategy was set up to realize a zero P-surplus whereas in common practice average P-rates to the soil are 48 kg P_2O_5 ha^{-1} yr^{-1}. Since the implementation of the 'De Marke management' in 1993, the responses of crop production, availability of phosphate in the soil and P-flows within the whole farming system as well as losses to the environment are monitored. This monitoring program enabled to answer the main issue of the P-related aspects in the research: do crop productivity and P-availability decrease when a zero P-surplus strategy is implemented and maintained for several years? Furthermore on a plot of De Marke long term field experiments where carried out with P-rates equal to halve the rate that is required to achieve a P-balance and with zero P-inputs. Also in this experiments crop productivity and P-availability indicators were monitored; this contribution gives an overview of the results. Attention is paid to the sustainability of the zero surplus strategy on the long term, both from an agricultural and environmental perspective.

A GIS Approach to Identifying Non-Point Source Phosphorus Pollution in an East Tennessee Watershed

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The identification and quantification of non-point sources of pollution on a watershed scale is an important step in developing implementation strategies to reduce the sources and loading of phosphorus into surface waters. The Integrated Pollution Source Identification (IPSI) system is a geographic information systems (GIS) approach developed by the Tennessee Valley Authority (TVA). The IPSI approach assigns different land use classes to fields identified from low altitude, colour, infrared photographs. Estimates of potential sources and loads of non-point source pollutants are made from assigning different RUSLE (Revised Universal Soil Loss Equation) factors to the different land-use classifications.

The Pond Creek watershed (TN06010202013) in the Upper Tennessee Basin of Eastern Tennessee is a small predominantly agricultural watershed covering about 9,432 hectares. Pond Creek is listed on the state's 303(d) list of impaired streams in Tennessee for pathogens and nutrients. Agriculture in the Pond Creek watershed is typical of the pasture based beef cow-calf and dairy systems in the Southeastern United States and is suspected to be responsible for much of the water quality impairments. Analysis of the watershed using IPSI suggested that overgrazed, poor and fair pastures, as well as arable crops with low residue cover are significant contributors to the sediment and phosphorus loads in Pond Creek. Since early 2003, agricultural extension efforts in the watershed have been directed toward pasture improvements (fertility, weed and herd management).

Evaluating economic tradeoffs among the list of best management practices (BMPs) could shed new light on the benefits that each practice offers in relation to reaching water quality goals and reducing phosphorus loads to the watershed. The increasing environmental problems and policy debates surrounding beef and dairy pasture operations have centered on the implementation of buffer strips, fencing cattle out of rivers/streams, cattle crossings, and alternative watering systems to name a few. While these BMPs appear costly to install, in some circumstances they may provide economic benefits to offset the lost profits from alternative uses. Learning how to better manage pasture land and manure nutrient application has become important to both researchers and public alike. Producers were surveyed in the Pond Creek watershed to better understand farm level decision making. Economic evaluation of buffer strip adoption versus improved pasture on farm profitability was conducted for this area. The collection of data from previous field level research on buffer strip and improved pasture effectiveness to reduce nutrient runoff has been the main focus of this research.

Initial results show that improvements in pasture management will not only reduce the amount of soil erosion coming from pastures but will increase the ability of the pastures to trap and retain the phosphorus associated with sediments and manure solids. Unlike many other BMPs recommended for livestock on pastures (i.e., fencing, riparian buffers and alternative water systems) the economics of pasture improvement through increases in pasture quantity and quality is more attractive to farmers.

The Effects of Soil Phosphorus Status on Phosphorus Losses to Surface Runoff and Land Drainage Water

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Introduction

Diffuse losses of phosphorus (P) from agricultural land to surface water have been increasing in recent years leading to increased eutrophication of Northern Ireland's surface waters (Watson and Foy, 2001). The aim of the current experiment is to assess the relationship between soil P status and P losses in surface runoff and land drainage water from grazed grassland swards. This information is important in developing a sustainable P management policy for agriculture.

Methods

Grassland plots (each 0.2 ha) received 0, 10, 20, 40 or 80 kg P ha^{-1} yr^{-1} applied as triple superphosphate (46% P_2O_5) in six equal applications from March 2000. All plots received the same inputs of N (250 kg N ha^{-1} yr^{-1}), potassium and sulphur. Plots were grazed by beef steers from April to October to maintain a constant sward height of 7 cms. Plots were hydrologically isolated and artificially drained to v-notch weirs with flow proportional monitoring of drainage water. Surface runoff collectors were installed across the width of the plots at the lowest point and were connected to portable water samplers (ISCO, Inc). Soluble reactive P (SRP) was determined on 0.45 μm membrane filtered water samples by the method of Murphy and Riley (1962). Soil samples (0-75 mm) were air-dried, sieved and analysed for 'Olsen' extractable inorganic P (Olsen-P).

Results

The average Olsen-P status of the plots in February 2000 was 14.7 mg l^{-1}. In February 2004 the Olsen-P status of the plots receiving 0, 10, 20, 40 and 80 kg P ha^{-1} yr^{-1} had increased to 16, 17, 24, 29 and 48 mg l^{-1}, respectively. Annual flow weighted mean concentrations of SRP in land drainage were highly variable from year to year. As SRP concentration data showed a significant positive skewness together with kurtosis, median values were measured because they are a superior measure of central tendancy than mean values and are resistant to the effects of outliers. Median values of SRP in land drainage from the plots receiving 40 and 80 kg P ha^{-1} yr^{-1} in 2002/03 showed significant increases compared with those measured in 2000/01. From March 2003 to February 2004 median values of SRP in land drainage were higher from the plots receiving P fertiliser (31.5 – 46.5 μg P l^{-1}) compared to the zero P control (24.5 μg P l^{-1}). However, there was no consistent relationship with the Olsen-P status of the different plots.

From March 2002 to February 2003 there was 1045 mm rainfall and 64 surface runoff events giving a total volume (average for plots) of 439,000 litres per plot. The surface runoff collectors intercepted 34% of the hydrologically effective rainfall. March 2003 to February 2004 was considerably drier with 679 mm rainfall and only 14 runoff events giving a total runoff volume (average for plots) of 36,600 litres per plot. This was equivalent to less than 6% of the hydrologically effective rainfall. The annual mean SRP concentrations in surface runoff varied from year to year and from March 2003 – February 2004 were 287, 341, 463, 536 and 2383 μg P l^{-1} from the plots receiving 0, 10, 20, 40 and 80 kg P ha^{-1}, respectively. The high mean concentration of SRP from the plot receiving 80 kg P ha^{-1} was due to a surface runoff event on 4 May 2003, which occurred 2 days after fertiliser application. This resulted in a maximum SRP concentration of 21,500 μg P l^{-1}. The contribution of surface runoff to total P loss was lower than that from land drainage from the plot receiving the low P application rate (10 kg P ha^{-1}). However, at high P application rates, total P loss in surface runoff well exceeded that observed in land drainage. For example, for the plot receiving 80 kg P ha^{-1}yr^{-1}, total P lost in surface runoff for 2002/03 was 1.74 kg P ha^{-1} yr^{-1} compared to 1.06 kg P ha^{-1} yr^{-1} from land drainage.

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Long-term Changes in Soil Phosphorus Forms and Phosphorus Losses in Subsurface Flow: Environmental Evaluation of Various Cropping Systems

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Introduction

Knowledge on contribution of various cropping systems to soil phosphorus (P) losses is essential to selection/design the best management practices which are both agricultural sustainable and environmentally friend. This is especially important in high P soils which pose great threat on water quality. There are 50 to 75% of agricultural soils in eastern Canada have been deemed having high or excessive soil test P levels (PPI/PPIC/FAR. 2002). A number of cropping systems, such as grassland (strip) and crop rotation with legumes, are believed being capable of improving water quality through reducing surface runoff/erosion losses and recycling soil residual nutrients from previous crops. On the other hand, it is also noted that crop rotation improves soil structure, soil moisture reservation, and earthworm population, which consequently improve soil macroporosity and subsurface. Recent researches have found that subsurface flow is a major pathway contributing to soil P losses to water ways, especially in flat and/or fine-textured soils (Zhang et al, 2002). Our objectives were to evaluate the effects of long-term cropping systems and fertilization practices on changes in soil P forms in comparison with the virgin soils and soil P losses in tile drainage water (sub-surface flow), and to determinate the environmental consequence of various cropping systems in a Brookston clay loam soil in eastern Canada.

Materials and Methods

Field studies were conducted for three years (2001-2003) in long-term experimental plots initiated in 1959. Long-term treatments include three cropping systems (continuous corn: CC, continuous bluegrass: CB, and crop rotation of corn-oats-alfalfa-alfalfa: CR) and two fertilization regimes (with and without fertilization). Plots have been consistently managed since 1959. Tile drainage water samples were year-round continuously collected and flow volume monitored using a computerized auto-sampling system from 2001 to 2003. Water samples were analyzed for dissolve inorganic (DIP) and organic P (DOP) and particulate P (PP). Soils were sampled from each plot and the adjacent forest site to form a base for the evaluation of long-term effects of cropping systems and fertilization on soil P. Soil P was fractionated into various inorganic (Pi) and organic P (Po) forms using the modified Hedley's procedure (Hedley et al, 1982).

Results and Discussions

Under virgin forest, soil P was predominated by stable P, followed by moderately stable Pi and moderately labile Po. Consistent cropping without fertilization reduced all forms of soil P relative to virgin forest; i.e. labile P and moderately labile P by 60-76% and moderately stable and stable P by 30-39%. Consistent cropping with fertilization reduced all forms of Po, in the order of CC>CR>>CB, but increased labile and moderately Pi in the order of CB>>CC>CR. Moderately stable Pi increased with fertilization in CC and decreased in RC and CB. Our study shows that all forms of soil P are in a dynamic system, of which the transformation pathways may depend on the balance of soil P input vs. output. Cultivation of virgin soil causes losses of soil Po, which may not be remedied by fertilization. Unfertilized CC and CB had similar flow-weighted mean P concentrations (FWMPC) of 0.043, 0.035 and 0.19 mg P L^{-1} for DIP, DOP and PP, respectively, while the corresponding concentrations under unfertilized RC were greater by 6 %, 25 % and 14 % , respectively. Fertilization increased FWMPC of DIP, DOP and PP in tile water by an average of 375 %, 393 % and 75 %, respectively, relative to no fertilization. For both fertilizations, FWMPC of DIP and DOP followed the order CB >> RC > CC, while the reverse order occurred for PP. The total annual soil P losses in tile water were 226-1253 g P ha^{-1} for the unfertilized treatments, and 96-611% greater for the fertilized treatments. Total annual P loss followed the order of CB >> RC > CC, which was the same as that of the total tile discharge volume, regardless of fertilization. The leaching losses of soil P can be strongly influenced by cropping systems and fertilization. The role of grass sod and crop rotation in prevention of soil nutrient losses should be re-evaluated. Relationships between soil P forms and P losses are discussed.

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Abstracts of poster papers

Sulphur Coating Diammonium Phosphate Fertiliser to Reduce Incidental Phosphorus Losses to the Surrounding Environment

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Introduction

Phosphorus (P) is one of the most important mineral nutrients in agricultural systems and, along with nitrogen (N) is generally added in the largest quantities as fertiliser. Phosphorus and N are also the main contributors to eutrophication effects such as algal blooms and unwanted weed growth in most fresh water ecosystems. To maintain or improve water quality, non-point sources of pollution of these nutrients must be minimised or reduced.

It is now recognised that incidental losses from soluble P fertiliser sources can, in many circumstances, contribute a large percentage of annual total P losses from agricultural watersheds. Diammonium phosphate (DAP) fertiliser has been shown to be one of the larger contributors towards P run-off in these situations. It has become a very widely used fertiliser source due to its relatively high N and P content and cost effectiveness. This combination of increasing use and high P runoff risk mean that it is important to develop methods to reduce its susceptibility to runoff.

One such method developed is to coat DAP with a slurry of sulphur (S) finely ground in water. Additional drier S can be easily added to the slurry if required agronomically.

Methods and Results

Three prototypes of S coated DAP fertiliser as well as straight DAP were applied to a runoff trial where simulated rainfall was applied to ready lawn and the run-off collected and analysed.

The results showed that DAP coated with dry-ground S, using a little S slurry as a binder (DAP/S1), actually resulted in more P run-off than straight DAP. This was probably because (1) the exterior coating of the DAP had been softened by the water, and (2) the dry-ground S used was too coarse to protect the DAP from the initial effects of the overland water flow. DAP coated with wet-ground S slurry (DAP/S2 and DAP/S3) and either undried (S2) and especially air-dried (S3) reduced the amount of P lost from the plots from the equivalent of 1.6 kg P/ha of fertiliser with straight DAP to 1.3 and 0.9 kg P/ha respectively. DAP/S3 became the prototype for the product hereafter referred to as "PRO-DAP".

A laboratory technique was then developed to screen alternative products for their susceptibility to run-off. The technique involved rinsing a set volume of water through fertiliser granules placed on gauze over the top of a sand bed. The gauze and remaining fertiliser was then removed and the sand rinsed to wash any remaining P into the filtrate. The filtrate was then analysed for total P and an assessment of the amount of P fertiliser lost was calculated. Analysis of the filtrate showed that P loss from the PRO-DAP was approximately 40% less than that from the DAP treatment, in agreement with the field trial indicating that the method was useful in pre-screening products.

A field trial was conducted at Queens University, Belfast, Northern Ireland where a rainfall simulator was used to investigate P concentrations in run-off from DAP, PRO-DAP and reactive phosphate rock (RPR) fertilisers.

Reductions in P run-off using PRO-DAP were similar to those found in the preliminary trials, in terms of reducing losses of P in run-off from agricultural soils soon after P fertiliser addition. Total P concentrations in the run-off were 41.8, 22.3, 4.0 and 3.5 µg/ml for the DAP, PRO-DAP, RPR and control treatments respectively one day after fertiliser application. The low loss from the RPR fertiliser was similar to that found in other New Zealand research.

Conclusion

The combination of the results from the demonstration run-off trial, the laboratory leaching technique and the field trial all suggest that PRO-DAP has the potential to significantly reduce incidental P losses in run-off compared to straight DAP fertiliser, thereby minimising potential non-point source pollution and helping to protect the environment. Further work is being conducted to determine whether, as expected, nitrate leaching from DAP is also reduced by converting DAP to PRO-DAP.

Relationships between Phosphorus Desorption and Exchangeability in Swiss Agricultural Soils

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The amounts and the rates of potential phosphate (P) release from the soil's solid phase to the solution can be assessed by a number of methodologies, including desorption or isotopic exchange experiments. The aim of this study is to understand the relationships between desorbable and isotopically exchangeable P in Swiss cultivated soils. Using a flow-through reactor, continuous P desorption is promoted in unlabelled and ^{33}P-labelled soils. Preliminary results on one soil show that for 2 weeks the rates of desorption of stable and radioactive P are comparable, suggesting that P release is constantly supplied by a pool of isotopically exchangeable P. The parameters that describe the kinetics of isotopic exchange vary with increasing desorption time. For a given time, the measured amounts of desorbed P are different from modeled isotopically exchangeable P, the former being initially lower and then higher. These three points will be addressed after expanding the number of tested soils and the desorption time to at least one month.

Comparison of Methods of Determination of Organic Phosphorus in Soils

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Introduction

Organic phosphorus (P) contents in soils differ due to their pedogenesis and their agricultural use. Soils which have been enriched with P from animal manure normally show a relative low content of organically bound P. However, soils without residues of P from manure have a higher content of organic P (40-70%). Soils with a poor agronomic rating of the P status tend to have the highest organic P content. Presently, the policy in the Netherlands is to balance P inputs with P outputs on farm level and to reduce high soil P status. From long term measurement of changes in soil P status under conditions of a negative P balance, it was found that water soluble P hardly declined, even at high initial rating of soil P status. Apparently, soils are able to buffer changes in water soluble P. This buffering capacity is attributed to (slowly) reversible bound inorganic P and to organic P. The contributions of both pools of soil P by either desorption or mineralisation is currently investigated. In order to assess the contribution of organic P, different methods of determination were compared. Methods of organic P determination can be classified in sequential and parallel methods.

Sequential methods require a number of extractions with a range of extractants and are therefore time consuming. Parallel methods consist of the determination of total P and inorganic P and are less time consuming. In all cases organic P is calculated as the difference between total P minus the (total of) inorganic P. Methods were compared by means of standard addition of potassium phytate, and are given in Table 1. Soil samples were taken from quartz sand, peat, sandy soil and marine clay, of arable land and grassland.

Table 1. Analytical methods used

Method	Reagents	Reference
Total P	$H_2SO_4/H_2O_2/Se$	Novozamsky et al. (1984)
	HNO_3/HCl	NEN 6465
	HNO_3/H_2SO_4	NEN 5768
Organic P	6 M H_2SO_4	Rubeak and Sibbesen (1993)
	0.5 M H_2SO_4	Kuo (1996)
	5% HCl	Lepelaar and Schoumans (1999)
	0.25 M NaOH – 0.05 M Na_2-EDTA	Bowman and Moir (1993)

Results

- Total P content and recovery of potassium phytate depended of method used, soil type and total P content.
- Organic P contents depended of method used. Correlation between methods was poor.

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Is Phosphorous Fertilization Necessary for Watermelon Production on High Phosphorous Soils on Maryland's Eastern Shore?

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Excess nutrient loading continues to create water quality problems in the Chesapeake Bay Watershed. Nutrient management restrictions (Maryland Department of Agriculture, 2001) implemented to limit excess phosphorus (P) application have caused concerns regarding crop yield and quality. A three year study was conducted to determine if a high yield of quality watermelon (*Citullus lanatus*) can be produced with a reduced P fertilizer level and the use of a preceding cover crop on high P soils of the Eastern Shore of Maryland. Watermelon was planted on Norfolk Loamy-Sand soils (fine loamy, siliceous, thermic type kandiudults*)* in a split plot design, with four replications. The main plot treatments were cover crops and the sub plot treatments were five different P fertilizer rates ranging from 0 to 60 kg P ha^{-1}, at 15 kg increments. All P treated and untreated post harvest surface (0-20 cm) and sub surface (20-40 cm) soil samples were tested "excessive" for soil-test P. The addition of P-fertilizer to these soils was unnecessary for the production of high yield of quality watermelons. This result is in agreement with a study concurrently conducted on sweet corn in the same area (Geleta et al., in press). In two of three sites, the use of a preceding cover crop increased watermelon yields and fruit size significantly. Our results suggest that use of a rye cover crop and a reduction in P-fertilizer input could have a positive environmental impact by reducing the risk of P over-loading without negatively impacting watermelon yield and quality.

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Leaching of Dissolved Phosphorus from Danish Soils

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Phosphorus in Danish Agriculture and the environmental effects

Surplus application of phosphorus (P) in Danish Agriculture during the last 50 years has led to accumulation of P in soils (Grant, 1998). About 200 kg P per hectare has accumulated during the period from 1989 to 2001 and today Danish soils contain about 2000 kg P per hectare on average. This has resulted in increased P losses from agriculture to water.

Phosphorus is the critical nutrient for the environmental state of Danish lakes, and today only on third of the lakes fulfil the environmental goals. Phosphorus also plays an important role, along with nitrogen for the environmental state of most inlets, particularly for the enclosed inlets.

The transport processes of P loss via soil erosion and bank erosion are extensively studied. Also, the process of macroporous flow through soils to tile drain is well known (Kronvang et al., 2002). There is much more uncertainty about P losses via leaching through soils to groundwater and surface water. This paper presents preliminary studies on the leaching of dissolved P in Danish soils based on data from the National Monitoring Programme for Agricultural Catchments.

Monitoring the leaching of dissolved phosphorus from Danish soils

The National Monitoring Programme, established in 1990 contains an agricultural component including measurements of phosphorus concentrations in the soil water at 31 sites throughout the country (Grant et al., 2003). Measurements of root zone water (about 1 m below soil surface) were done on a weekly basis during the years 1990-2003 whereas measurements of the upper groundwater (1.5 – 3.0 m below soil surface) were on a bi-monthly basis for the years 1990-1993, thereafter less frequently.

Results

The concentrations of dissolved P in the root zone water were low (annual flow weighted concentration mainly < 0.020 mg P/l) at most sites (80%). At the remaining sites (20%) the concentrations of dissolved P were high, the annual flow weighted concentrations amounting to 0.2-0.5 mg P/l. At one of these sites the concentrations were continuously high, at the other sites the concentrations were high for 2-3 years, then levelling off. For the upper groundwater the concentrations of dissolved P were high at 40% of the sites (0.03-0.09 mg P/l) and mainly below 0.020 mg P/l at the remaining sites.

It was found that the high concentrations of dissolved P in soil water were associated either with high soil-P status or with a crop rotation including grass with cattle grazing.

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Environmental Risk Assessment and Planning Tools Used to Develop and Implement Phosphorus - Based Nutrient Management Plans

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Nutrient Management Planning

The USA livestock sector has undergone dramatic changes in recent decades. Substantial productivity increases in animal agriculture have fuelled consolidation and geographic concentration. Correspondingly, the industry has seen marked declines in the number of livestock operations and an increase in the number of animals produced in confinement. In 1999, the US Department of Agriculture (USDA) and the US Environmental Protection Agency (EPA) released a joint "Unified National Strategy for Animal Feeding Operations (AFO)," which presented a plan for addressing the potential water quality and public health impacts associated with AFOs (US EPA, 1999). Importantly, this strategy articulated a national performance expectation that all AFOs should develop and implement technically sound, economically feasible, and site specific comprehensive nutrient management plans (CNMPs) to minimize potential adverse impacts on water quality and public health, and to accomplish this within a 10-year implementation period.

A CNMP is a conservation system that is unique to animal feeding operations. It includes conservation practices and management activities which, when implemented as part of a conservation system, will help to ensure that production and natural resource protection goals are achieved. The cornerstone of any CNMP is sound nutrient management planning. In an effort to move toward balanced phosphorus-based nutrient management planning, agriculture is transitioning from N-based plans, to plans supplying P-based needs of crops, to ultimately balanced P imports/exports for the farming operation. The Natural Resources Conservation Service (NRCS) Nutrient Management (590) conservation practice standard (USDA NRCS, 2003) and the Nutrient Management Policy (USDA NRCS, 1999) detail criteria for rate, form, timing, and method of nutrient applications for agricultural operations.

Environmental Risk Assessment and Planning Tools

In order to successfully develop nutrient management practices, the NRCS, in conjunction with other federal partners and state land grant universities, have developed a number of risk assessment and planning tools:

Animal Waste Management (AWM) – A planning/design tool to estimate the production of manure, bedding, process water and determine the size of storage/treatment facilities needed to adequately balance farm nutrients. Calculations are based on the USDA-NRCS Agricultural Waste Management Field Handbook (AWFMH).

Revised Universal Soil Loss Equation (RUSLE 2) – A soil erosion prediction tool, used to measure sheet and rill erosion from the landscape. RUSLE 2 is utilized to calculate P particulate transport potential in the PI.

Phosphorus Index (PI) – A field based risk assessment tool that uses readily available data to evaluate two broad categories of factors that contribute to the potential for P loss from agricultural land: 1) P loss potential due to site and transport characteristics, and 2) P loss potential due to management and source characteristics.

Leaching Index (LI) – A field-based risk assessment of the potential for soluble compounds like nitrates to leach below the root zone and pose a hazard to ground water supplies, drinking water, and surface water quality.

Manure Management Planner (MMP) – A Windows-based computer program developed with Purdue University that is used to create manure and nutrient management plans for crop and animal feeding operations by entering information about the operation's fields, crops, storage, animals, and application equipment. MMP helps the user allocate manure and fertilizer (where, when and how much) on a monthly basis for the length of the plan.

Spatial Nutrient Management Planner (SNMP) – A GIS based front-end tool for displaying and storing nutrient management related spatial data.

Nitrogen Leaching and Environmental Assessment Package (NLEAP) – Nitrogen (N) fate process model developed jointly between NRCS and ARS to evaluate N leaching and N losses to the atmosphere.

Phosphorus Process Model – The missing link yet to be developed in collaboration with international P research and modelling experts participating in this workshop. Are you one of these experts?

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Developing and Testing a Phosphorus Ranking Scheme for Ireland

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Introduction

Inputs of phosphorus (P) to agricultural systems exceeded outputs for a number of years in Ireland. This led to accumulation of soil P, which has resulted in P enrichment of runoff and impaired surface water quality. To address this problem it is important to identify critical source areas within catchments that are most vulnerable to P loss. The use of the relatively simple P Index approach has been widely used in the US and elsewhere as a field tool. Lemunyon and Gilbert (1993) published the original P Site Index. The primary objective of this index was that it should discriminate fields relative to their potential to lose P, whilst being easy to use and based on readily obtainable information. Based on this original index, Magette (1998) developed a P ranking scheme (PRS) specifically for Ireland. This project aims to develop and test a P index for Ireland based on the Magette Phosphorus Ranking Scheme.

Developing a modified PRS

Following an assessment of the original Magette PRS a modified PRS was developed that attempts to represent the major processes involved in the movement of phosphorus from fields to surface water. To this end, the ranking factors used in the PRS are divided into P "source factors" and P "transport factors". Both the P source and P transport factors are further divided to represent the main processes involved in P loss to water. The P source factors are as follows:

- *Soil P Factors:* These factors represent the risk arising from processes of P loss resulting from elevated Soil P levels.
- *P application Factors:* The P application factors represent the risk of P loss arising due to the excessive and inappropriate application of phosphorus.
- *Farmyard P Factors:* The risk posed by a farmyard in terms of phosphorus loss to water is assessed and scored.

The P transport factors are as follows:
- *Distance to surface water:* Each field is given a score depending on the distance of the field from surface water.
- *Connectivity:* The connectivity of a field to surface water is considered. The presence of either surface or subsurface drains would result in a higher risk of phosphorus loss from a field

Each factor is given a score depending on the risk associated with that factor. Each score is then multiplied by a "weighting" for that factor. The resultant scores for source factors and transport factors are tabulated separately. The resultant P "source factors" score is then multiplied by resultant P "transport factors" to give an overall PRS score. The overall PRS score is not a quantitative prediction of P loss from a field, but rather a rational assessment of the risk of P loss from a field to surface water.

Testing a modified PRS

Testing of the modified PRS was carried out at two scales:
- *Field Scale:* Three fields were scored using the PRS and the resultant PRS score was then compared to water quality data downstream of each field.
- *Subcatchment scale*: Field scale data for eighteen small subcatchment areas was compiled and scored for the modified PRS. The resultant PRS scores were then compared to water quality data for the most downstream point of each subcatchment.

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Assessment of Cost-Effective Phosphorus Mitigation Options Relevant to UK Agriculture

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The aim of this project was to determine the most useful measures to mitigate phosphorus (P) transfers from agriculture to water in the UK. Measures were assessed in terms of their cost-effectiveness, acceptability to the industry, practicality and time-scale of effectiveness. Agricultural practice data were integrated with costs and applicability to produce a matrix of mitigation options. The 'Phosphorus loss estimation for agricultural systems with mitigation measures' (PLEASE) expert system was designed especially to help compare potential P losses under different model farm scenarios and used input data for each farm model system scenario. The PLEASE approach was used to estimate risk of (1) solubilisation (that may lead to leaching) (2) physical detachment of particles (that may lead to erosion) and (3) incidental losses. For each measure we estimated, using a combination of data extracted from the scientific literature and expert opinion, (1) initial P loss; (2) reduction in P loss due to measure and; (3) cost of the measure. These three components were then integrated to provide an estimate of the relative cost effectiveness of each measure in £ per kg P reduced. The final output was a simple 'cost-curve' assessment of P mitigation strategies.

Mitigation measures were divided according to inputs, mobilisation and transport. For input control we identified 15 measures that aim to reduce P surpluses and therefore are primarily targeted at reducing build-up of P in the soil and the potential for P loss in the longer term. For example there is scope to reduce fertilizer inputs where soils are high in P, depending on the farming system. We estimated, for example, that if fertiliser inputs to all arable soils that were > P index 4 (= Olsen P range 46-70 mg kg^{-1}) were stopped, this would mean a total reduction of inputs to all arable land of about 33 k tonnes for all arable soils in England and Wales, and we calculated from PLEASE that the resulting total losses of P may be reduced by approximately160 tonnes of P (equivalent to approximately 0.07 kg ha^{-1} reduction in loss if normalized across all arable land). All of this could be achieved at zero cost. Mobilisation control is divided into those measures that inhibit either solubilisation or detachment. There are 19 mobilisation control measures and one example is minimum tillage that might be applied to 'combinable' crops that could reduce P loss by nearly 2000 tonnes (or about ~1 kg per hectare). To achieve this, we estimate it could cost £45,000 per tonne, requiring a high farm capital investment. Transport control includes those measures (6 of them identified) that aim to reduce either the channelisation of run-off, or entrap the particulate and soluble P load before it enters the watercourse. One example is grass buffers that could be potentially applied to arable and grassland areas. Here, we estimated that there is potential to reduce P loss by 1100 tonnes at a cost of £3790 per tonne. These options therefore largely control rather than prevent P loss.

This project has helped to (1) illustrate areas where we lack knowledge and highlight priority areas for future research on P mitigation and (2) provide a preliminary identification of the key P mitigation measures. Input and mobilisation options are designed to control P loss at the point of origin; this is more in keeping with the underlying principle behind the Water Framework Directive. As such, they can be more widely adopted and with a greater degree of success than transport options, whose effectiveness is severely limited by local site conditions. Clearly transport options are most dependent on the hydrological linkages between the field and the watercourse, which are unpredictable and vary considerably both spatially and temporally. Transport options therefore require careful targeting to be effective, are more sensitive to local site conditions and might frequently fail during extreme events. One can therefore consider that the degree of uncertainty over effectiveness, and hence inapplicability for national adoption, increases along the source-mobilisation-transport continuum.

Characterization of Labile P Forms in Fresh Dairy Manure under Mild Assay Conditions

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Characterizing labile phosphorus (P) forms in animal manure is a challenge due to their susceptibility to hydrolysis. Harsh assay conditions commonly applied for characterizing P, such as sequential fractionation and ^{31}P NMR analysis, can underestimate labile P in animal manure. In this study, we characterized dairy manure P under relatively mild assay conditions. Fresh dairy manure was separated into soluble part(s) and residual components. The hydrolyzable organic P in these fractions was then characterized by enzymatic hydrolysis at pH 5.0 and categorized as simple monoester P, polynucleotide P, phytate-like P, and nonhydrolysable P.

Autoclaving released residual P in a level similar to that observed with spontaneous hydrolysis over 54 h. Ultra-sonication, intended to release inorganic (P_i) and organic P (P_o) trapped in the manure matrix, released a little residual P. About 75% of total manure P was characterized by the approach used. The remaining 25% could be regarded as recalcitrant P. In water extracts, 77% was P_i, 11% hydrolyzable P_o and 12% enzymatically nonhydrolyzable P_o. In the residual resuspension, 25% was spontaneous labile P, 32% was simple monoester P, 7% was polynucleotide P, 9% was phytate-like P, and 26% as nonhydrolysable P. This study indicates mild enzymatic hydrolysis is useful for quantifying labile (or hydrolyzable) forms of P_o in dairy manure.

Phosphorus and the Water Framework Directive in the Shannon Pilot River Basin

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Water Framework Directive and Pilot River Basin Testing

The European Water Framework Directive (WFD) (2000/60/EC) is the first piece of European water legislation that encompasses all waters: groundwater, rivers, lakes, estuarine and coastal waters. The WFD requires ''good water status'' for all European waters by 2015, to be achieved through a system of participatory river basin management planning and supported by several assessments and extensive monitoring (Mostert, 2003). The main unit of management of the WFD is the River Basin District (RBD). The EU Common Implementation Strategy (CIS) of the WFD provides for the preparation of guidance documents by European working groups on several technical issues and for the integrated testing of these guidance documents in fifteen Pilot River Basins (PRBs). Testing of the CIS guidance documents in the Shannon, Ireland's PRB, is being facilitated through a three year postdoctoral research fellowship with Trinity College Dublin, funded by the Environmental Protection Agency. The overall aim of the PRBs at European level is to ensure that the guidance documents produced by the CIS Working Groups are applicable to and workable within all RBDs across Europe.

Phosphorus and Implementation of the Water Framework Directive

The directive institutionalises ecosystem-based objectives and planning processes at the level of the river basin as a basis for water resource management (Kallis and Butler, 2001). These objectives include achieving both good ecological and chemical status for surface waters and good chemical status for groundwater. This requires detailed understanding of the main drivers and pressures in each river basin. Phosphorus (P) is a key nutrient in freshwater systems and will impact on ecological and chemical status of water bodies. Therefore a detailed understanding of the anthropogenic drivers and sources which result in P loss to waters is required to meet the directive's objectives. Table 1 outlines the key articles of the WFD which are relevant to reducing P loss to waters. These areas are being examined in the Shannon PRB through testing of the CIS guidance documents.

Table 1. Articles in the Water Framework Directive relevant to reducing phosphorus loss

WFD Article	Topic	Relevance to reducing P Loss
Article 5	Characterisation of river basin district	Identification of pressures resulting in P loss and impact on water body status
Article 6	Register of protected areas	Designation of nutrient sensitive areas
Article 8	Monitoring of water bodies	Phosphorus is one of physico-chemical elements used to support ecological classification
Article 10	Combined approach for point & diffuse sources	Emission controls for P and establishment of best environmental practices to reduce P loss
Article 11	Programme of measures	Implementation of pollution control measures
Article 13	River Basin Management Plan	Mapping of status and summary of measures taken to meet WFD objectives

The Shannon Pilot River Basin

The Shannon PRB is Ireland's largest river basin, draining a land area of some 18,000 km^2. It includes part of 18 local authorities in the Republic of Ireland and has a small transnational component of some 6 km^2 in County Fermanagh, Northern Ireland. Current testing has focused on Article 5 of the WFD which requires by December 2004 *inter alia*, a characterisation of all RBDs and a review of the impact of human activity on the status of surface waters and on groundwater. The Shannon PRB is trialling a source–pathway–receptor risk-based methodology to identify surface and groundwater bodies at risk of failing to meet WFD objectives due to P and other pollutant types. Large areas of karst limestone in the river basin will be especially prone to P loss through groundwater – surface interactions and effective measures for reducing P loss will be particularly challenging.

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Phosphorus Desorption Dynamics in Soil and the Link to a Dynamic Concept of Bioavailability

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In areas with intensive livestock farming, soils are often enriched with phosphorus (P) as a result of decades of P application via animal manure, exceeding P removal in harvested crops. In these soils, P mainly accumulates in the inorganic form (Koopmans et al., 2003). In acidic sandy soils, amorphous Al- and Fe-(hydr)oxides are the main reactive solid phases. The overall reaction of inorganic P with these metal-(hydr)oxides can be divided into a fast reversible adsorption reaction at surface sites (<1 d) and a slow, less reversible reaction: (reactive) diffusion through the solid phase or through micropores of Al- and Fe-(hydr)oxides, possibly followed by precipitation and/or adsorption inside the aggregates (van Riemsdijk et al., 1984; Madrid and De Arambarri, 1985). The total pool of sorbed P can be interpreted to be the sum of reversibly adsorbed P and quasi-irreversibly bound P and can be estimated by the acid ammonium oxalate extraction method (P_{ox}). The reversibility of the overall reaction of P with the solid phase of the soil is of both agricultural and environmental interest. Because of the often limited availability of P for plant uptake in soils with a low P input, a better understanding of the P desorption kinetics from soil may help maintaining an optimal soil fertility for crop production. On the other hand, in areas with intensive livestock farming, where soils have been enriched with P, P accumulation can lead to an increase of P leaching contributing to surface water eutrophication. Upon the removal of P from soil solution by plant uptake, a fast initial desorption reaction for P adsorbed to surface sites of Al- and Fe-(hydr)oxides is expected. The decrease of P adsorbed to surface sites may be replenished by desorption of P bound inside these metal-(hydr)oxides followed by diffusion of P to the outer layers of the aggregates. Because intra-aggregate diffusion is slow, this P becomes available again only in the long term. Intra-aggregate diffusion may be the rate-limiting step in the mass transfer of P between sorption sites inside porous sorbents and bulk solution. Hence, this mechanism may be important in controlling the availability of P in soil.

Quantitative information about the reversibility of the overall reaction of P in P-enriched soils in the long term is scarce. To estimate the total amount of P available for plant uptake and leaching, a desorption isotherm, describing the long-term equilibrium relationship between P in soil solution and the total pool of sorbed P, can be used. In a long-term pot experiment, where grass was cropped on a P rich acidic sandy soil to lower the soil P content, Koopmans et al. (2004a) determined a desorption isotherm, which was described by the Langmuir equation. The total pool of sorbed P (P_{ox}) appeared to be close to equilibrium with P desorption in 1:10 (w/v) 0.01 M $CaCl_2$ extracts used to simulate conditions in the soil solution. The $CaCl_2$ extracts were vigorously shaken for 2 h. This may have caused abrasion of soil aggregates leading to (much) shorter diffusion distances and an increase of the mass transfer rate of P, resulting in a faster establishment of equilibrium. This mechanism may have been responsible for the apparent equilibrium of P desorption in the $CaCl_2$ extracts. In the field, kinetic factors may lead to a lower availability of P than would be estimated from the equilibrium desorption isotherm. Using soils from the pot experiment, Koopmans et al. (2004b) determined P desorption kinetics in batch experiments. A diffusion model was used to describe P desorption kinetics from a spherical aggregate. The Langmuir equation obtained from the pot experiment was used to calculate the buffering behavior of P sorbed to the solid phase and the (local) solution in the micropores. The diffusion model was calibrated with the data from the batch experiments. The calibrated model was then used to simulate the distribution of P inside the soil aggregates during plant growth in the pot experiment. A dimensionless ratio, the so-called dynamic bioavailability index (DBI), of the maximal diffusive flux from the soil aggregates to the soil solution, which was calculated with the model, and the measured rate of plant uptake of P at a certain stage in the pot experiment in the same units, was used to determine the importance of P desorption kinetics in controlling the availability of P for plant uptake.

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Determination of Organic Carbon (TOC), Nitrogen (N_t) and Phosphorus (P_t) in Stable Soil Aggregates Fractionated by Ultrasound Dispersion Method

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Introduction and Method

Phosphorus (P) and nitrogen (N) are essential elements for plant growth. Carbon inputs can also increase the biological productivity of agricultural production. P is often the limiting element and its control is important to reduce the accelerated eutrophication of aquatic eco systems. P and N are sensitive for runoff and transport of aggregates and particles, because they are predominantly concentrated on the topsoil (Sharpley, 1985). To get further information of P, TOC and N distribution in soil aggregates a method to separate the stable soil aggregate fractions without any chemical treatment was developed. This method is based on the dispersion method of Edwards and Bremmer (1967). Anderson et al (1981) separated organo-mineral complexes in various size fractions from the surface horizons of two Cherno-zemic soils without chemical pre-treatment by ultrasonic dispersion in water, followed by sieving and centrifugation. In the current work the ultrasonic dispersion method is used to determine and separate stable soil aggregates under defined energy and time conditions, followed by wet sieving and chemical analysis to measure the amount of P, C and N. Ultrasonic dispersion experiments have been performed with probe-type dispersion equipment (Mayer et. al., 2003). In the present work a vibration amplitude of 5μm (0.98 J ml^{-1}). with sonification time of 60 s is used. The Ultrasonic Soil Aggregate Stability (USAS) is calculated (Mentler et al., 2004). Dispersion experiments are performed with 10 g soil in 200 ml pure degassed water suspended by a magnetic stirring device. The standard Soil Aggregate Stability (SAS) which is measured according to the DIN-norm 19683-16 was compared with the USAS method. After the wet sieving treatment the stable soil aggregate fractions are analysed by Austrian standard methods to determine the TOC (ÖNORM L-1080), N_t (ÖNORM L-1082), and P_t (ÖNORM L.1085) content.

Results

Both methods, USAS and SAS describe the Aggregate Stability, the equations are similar and the results are comparable. The correlation of the two methods is significant and has a coefficient of 0,715 (Pearson $p > 0.01$, 2-tailed). This correlation is calculated by measurements of 20 very different soils situated in several European countries. These soils have a wide variety in aggregate stability and soil properties.

With the ultrasonic dispersion method (USAS) it is possible to determine P_t, TOC and N_t distribution in stable soil fractions. In the beginning of the dispersion process there is a very different distribution of TOC, N, and P in relation to the totally dispersed material. The highest phosphorus concentration can be found in the >63 μm fraction. Total organic Carbon (TOC) is equally dispersed all over the aggregate fractions. Most TOC can be found in the micro aggregate fractions. Nitrogen has the same ranking as the TOC distribution. With the ultrasonic dispersion method it is possible to separate aggregate fractions and describe their different chemical properties.

Summary and Outlook

The Ultrasonic dispersion makes it possible to carry out chemical analysis of stable aggregate fractions. This provides full information about the structure and chemical composition of different aggregate sizes. The disruption curve of the soil aggregates classifies soils in their aggregate stability and reaction on dispersion. With this data it is possible to estimate risk factors for element transport through soil erosion in different landscapes.

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Surface Runoff Losses of Phosphorus from Selected Benchmark Soils in Virginia that Have Been Impacted by Animal Manure

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Introduction

Public concerns in the United States over the effects of animal wastes on water quality have increased markedly in recent years. This is especially true for the land application of animal manure, especially poultry litter, in Virginia and other Mid-Atlantic States where the poultry industry is located primarily within the Chesapeake Bay Watershed. Over-fertilization of forages and row crops with poultry litter has generated public concern regarding potential impacts of excessive nutrients on water quality. The two nutrients of primary concern are N and P, which can lead to water quality problems if they are washed off the land to surface waters or leached into groundwater supplies.

Materials and Methods

The field and laboratory procedures we have followed to evaluate soil test P (STP) and runoff P relationships were based on the protocols established for the National Phosphorus Runoff Project (http://www.soil.ncsu.edu/sera17/publications/National_P/National_P_Project.htm; Sharpley et al., 1999). Portable rainfall simulators were used to evaluate the relationships between dissolved reactive P (DRP) concentrations in surface runoff and soil test P (STP) levels in two benchmark soils of the Shenandoah Valley of Virginia. Soils investigated included the Frederick (clayey, kaolinitic, mesic Typic Paleudults) and Christian (clayey, kaolinitic, mesic Typic Hapludults) series. For a given soil series, fields having similar cropping systems and variable soil test P levels were included and all sites were selected to have a slope of 5-10%. In our studies we worked with cropland and we employed 1.5 x 2 m runoff plots that were established in fields having STP ranges resulting from fertilizer and manure applied by the land owner in the course of managing his or her land. Mehlich I extractable P in the surface 0-5 cm depth ranged from 22-821 ppm. For all plots, three successive (time interval between simulated rain events: 24 hours) simulated rainfall events were conducted at an intensity of 65-70 mm/h. Each simulation was conducted for a total runoff time of 30 minutes. Runoff samples were analyzed for total P, and dissolved/soluble inorganic P (APHA, 1992; Pierzynski, 2000). Soil samples were analyzed for Mehlich 1 (Mehlich, 1953), Mehlich III (Mehlich, 1984), Bray-Kurtz P1 (Bray and Kurtz, 1945), and distilled water (Pote et al., 1996) extractable P, and ammonium oxalate extractable P, Al and Fe.

Results

As expected, there was a good correlation between DRP and Mehlich I extractable P for sites having a soil pH <6.5. However, for some sites with high pH and very high Mehlich I extractable soil Ca and P, the relationship between DRP in runoff and Mehlich I extractable P was very poor. At these locations, DRP concentrations were much lower than expected given the very high level of Mehlich I extractable P. These very high extractable soil P and Ca levels were observed in soils with a long term history of receiving poultry litter. In addition to being high in P, poultry litter is also high in Ca due to the addition of calcium carbonate to poultry diets. Thus, the long term application of poultry litter may have altered the P chemistry in these naturally acidic soils. Laboratory studies and mineralogical characterization of the soil clay fraction are being conducted to determine if Ca phosphates are controlling P solubility in these high P and high pH soils.

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Hydro-Geological Influences on P Losses from Rural Catchments

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Introduction

Source and diffuse pollution remain serious issues affecting water systems and water quality. Effective measures on remediation/conservation require accurate qualitative and quantitative knowledge of nutrient sources, transport mechanisms, transformations and dynamics of different N and P forms, as well as the factors influencing them (Haygarth et al., 2000). In this study, SRP (soluble reactive phosphorus) and total-P concentrations and loads are presented for two rural basins differing mainly in their geological substrate.

Study Sites

The Wiltz watershed is situated on Devonian schists in the Ardennes region (Belgium-Luxembourg), whereas the Attert watershed, located southwest of the Wiltz basin, comprises two main geological formations: 25% Palaeozoic, inf. Devon (shales), and 75% Mesozoic, Trias & inf. Lias (limestone, sandstone). The main characteristics of the catchments are summarised in Table 1. In order to obtain a good follow-up of seasonality and storm-related phosphorus variations, intensive sampling protocols were established throughout the period 2000 - 2001 for the Wiltz river, and 2001 - 2002 for the Attert river.

Table 1. Catchment characteristics, runoff, TP and SRP export coefficients for the two basins studied

River	Geological classific.	Soil texture	Catchment area (km^2)	Land-use	popul. density	Year	Runoff (mm a^{-1})	Export (kg ha^{-1} a^{-1}) TP	SRP
Wiltz	Palaeozoic (schists)	90% stony silt	424	40% forest 27% arable 29% past.	40	2000 2001	471 594	0.8 1.2	0.3 0.3
Attert	Mesozoic (sediments)	24% sand 23% clay 53% silt	254	32% forest 25% arable 35% past.	51	2001 2002	596 494	1.6 1.5	0.5 0.5

Results and Discussion

TP and SRP export coefficients and runoff for both catchments during the study period are shown in table 1. Although inter-annual variations of P exports can be substantial (due to variation in runoff), dissolved and particulate P exports are significantly greater in the sedimentary Attert basin. In addition, the annual distribution and dynamics of concentrations and loads are different in both rivers. Despite the lower population density of the schistous catchment, summer SRP concentrations are higher in this river as a result of its reduced summer runoff (0.2 mm d^{-1} against 0.4 mm d^{-1} in the sedimentary basin), resulting in a smaller dilution capacity of point sources. In contrast, SRP concentrations decrease during storm events in the schistous basin, while they clearly increase in phase with discharge in the sedimentary basin. Phosphorus leaching from sandy soils is probably responsible for these acute and numerous SRP peaks in the Attert catchment. Concerning particulate-P, erosion and especially transport processes presumable limit the export rate of P in the schistous basin (with a larger contribution of subsurface flow), whereas erodable soils and bank erosion are key factors for TP exports in the sedimentary basin. Erosion control is an important issue in reducing phosphorus losses from the two rural catchments studied, since the majority of the diffuse phosphorus loads are markedly associated with particulates in runoff. However, the bio-availability of P exported from catchments also has major implications for the cost-effectiveness of phosphorus control alternatives. In fact, the reduction of the soluble bioavailable P-form in the studied basins must clearly take into account their different physiographies (e.g. Grobler and Silberbauer, 1985). Soluble P pathways and dynamics, as well as P retention in soils, vary significantly between both catchments, although their agricultural practices and land-uses remain very similar.

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Phosphorus Forms in Overland Water Flow from a Galician Agro Forestry Catchment

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Increasing awareness of the role of diffuse phosphorus (P) sources motivate land managers in different Atlantic regions of Europe to undertake conservation programs which place more emphasis on water quality than on soil saving. Fertilizer applications and animal wastes are the main sources of diffuse P. This is also the case in Galicia and in the Atlantic regions of Spain. A monitoring program for estimating P load was set up in the Valiñas catchment, a mixed, agricultural and forestry catchment of 36.3 km^2 surface. The sampling strategy was a stratified point sampling involving more frequent sampling when flow was high. A data set collected during four years (1999-2002) showed that mean concentrations were as follow: mean total P 106.7 μg/L (ranging from detection limit to 1111 μg/L), mean particulate P 64.2 μg/L (ranging from detection limit to 1063 μg/L) and mean dissolved P 42.5 μg/L (ranging from detection limit to 259 μg/L). The extent and form of P exported were highly depended on seasonal factors, such as rainfall frequency and intensity, and agricultural practices. Most of the total P load is associated with storm flow. Particulate P comprises the major form of exported phosphorus. The ratio of dissolved P:total P strongly varied, depending on storm flow but also on timing of animal waste applications. Discharge measurements carried out using natural profiles allowed estimation of total, sediment and dissolved P losses from the Valiñas catchment during the study period.

Scale and Uncertainty in Modelling Phosphorus Transfer from Agricultural Catchments to Watercourses

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Controlling eutrophication is focused on reducing phosphorus (P) transfers from agricultural land to freshwaters. Livestock production systems on grassland soils are a high source of P and often import a surplus of P via animal feeds and fertilisers. Contemporary examples of water quality problems that exist downstream of livestock production are the Chesapeake Bay, North Eastern USA, the Gippsland Lakes, Victoria, Australia, the Tamar Lakes, Devon, UK and the Lakes Baldegg and Sempach in Central Switzerland. Understanding of the processes controlling the export of P from agricultural grasslands has been significantly improved in recent years. However problems remain in making predictions of P losses for different management, soil and hydrological circumstances.

This project will attempt to construct a model to predict P export from agricultural land in areas with grassland based livestock production to water courses on a catchment scale. It will test and extend a scale dependent modelling strategy using the fuzzy disaggregation approach developed at the Lancaster University and the Institute of Grassland and Environmental Research (IGER) using datasets from 12 subcatchments of the Lakes Baldegg and Sempach in Central Switzerland. The modelling strategy is intended to reflect the effects of spatial heterogeneity and uncertainty of inputs, soil, land cover and drainage and the connectivity of flow pathways. The aim of such strategy is to distinguish the parts of the landscape unit that will respond in functionally different ways in terms of both flow and transport processes.

Integrating Source Coefficients into Risk Assessments for Phosphorus Loss to Water

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Introduction

Organic P sources vary widely in their P solubility and consequently, when applied to the soil, will have different relative risks for P loss to surface waters (Maguire et al. 2001; Codling et al. 2001). In the U.S., some P Site Indices have included P Source Coefficients (PSCs) to account for differences in P solubility between organic P sources. Preliminary research to develop PSCs has been conducted in the Mid-Atlantic (Leytem et al., 2004; Brandt and Elliott, 2003; Kleinman et al., 2002), however, final PSC values have not yet been widely adopted. Our objectives were to (i) compare the effects of animal manures and biosolids (sewage sludge) that varied in P solubility on P release from eight soils varying in properties important to P sorption and desorption; and (ii) develop a simple protocol that could be used by soil testing laboratories to determine field specific PSC values for the wide range of organic P sources now land applied in this region.

Materials and Methods

Six biosolids, two poultry litters, a dairy manure, a liquid swine manure, and inorganic P were incorporated into eight representative agricultural soils from DE, MD, PA, and VA at a rate of 135 kg ha-1 total P and incubated in 250-mL cups at 80% field capacity. Subsamples were analyzed for water soluble P (WSP) at 48 h and 30 d, pH, organic matter (OM), and Mehlich 3 (M3-) P, Ca, Fe, and Al at 30 d. Mehlich 3 P saturation ratio (M3-PSR molar ratio of M3P/[M3Fe + M3Al]) was also calculated. Effects of soil or P source could not be assessed individually due to significant soil by P source interactions. Therefore, soil/P Source pair means were compared to determine statistical differences between treatments for each soil, and between soils for each treatment.

Results and Conclusions

Biosolids and metal-salt treated manures generally contain higher concentrations of Al and Fe and consequently have lower WSP than untreated manures. When organic P sources are incorporated, it is believed that properties of these materials will control the solubility of added P. The influence of soil properties on P solubility in amended soils should not be overlooked. Incorporation of P sources into soils with low initial M3-PSR values caused no significant increases in WSP with respect to unamended soils and other P sources. However, when P sources were incorporated into soils with high M3-PSR values, untreated manures and inorganic P sources lead to increases in WSP that were significantly larger than when biosolids and treated manures were applied. This indicates that when soils become increasingly saturated with respect to P, properties of the P source become more influential in the control of P solubility than soil properties. In all cases, soil properties influenced WSP after incorporation of organic P sources. Our results showed that application of organic P sources increased M3-P in all soils after 30 d when compared to unamended soils. In general, application of untreated manures and inorganic P lead to larger increases in WSP and M3P than biosolids or treated manures for all soils, regardless of initial soil P saturation. Regression analysis shows that measurement of organic P source WSP and initial soil M3-PSR could predict soluble P when organic P sources are incorporated into soils (R^2=0.66). Analytical testing labs could use a 48 h incubation protocol to assess P solubility of organic P sources when incorporated with a variety of regional soils.

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Phosphate, a Key Factor for Nature Restoration on Former Arable Land?

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Recent nature policy in The Netherlands has as goal to transfer more than 150.000 ha of arable land into nature. The main problem is achieving nature adapted to nutrient poor conditions. Due to fertilisation the arable land mostly contains a large amount of nutrients. In The Netherlands, removing the topsoil is a common practice for reducing the amount of nutrients, but it has many disadvantages. There are also other options, but the effectiveness of these options is not known.

The objectives of our study were (I) to identify the problem for nature development of a high soil content of phosphate, (ii) to describe the present knowledge and (iii) to identify knowledge gaps. The effectiveness of the used management practices and practical aspects were also objectives of our research. Both national and international researchers and nature conservationists were consulted about this subject. The results of the inquiry and further literature research are the basis of the final report.

Our conclusion is that a high availability of phosphate is generally considered to be a problem for nutrient poor vegetation types. However, in most cases it is unknown what the optimum level of P availability is for different 'target' vegetation types. Different methods of soil P testing used in practice make it very hard to compare results of different studies. The available P content of a soil may increase due to rewetting with sulphate or bicarbonate rich water. However, it is unknown at which ground water level this becomes a problem.

The common management practices to reduce the P availability are 1) removing the topsoil; 2) soil mixing by deep tillage; 3) extraction of nutrients by cropping; 4) mowing with removing of the biomass; 5) grazing; 6) a combination of practices. All practices have the potential to reduce the P availability. However, the effectiveness of the individual practices is uncertain, and most practices can have negative side effects like removing of the soil seed bank and increasing of P leaching.

Treating Ditch Sediments to Reduce Downstream Phosphorus Delivery

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Background

Tile fed ditches are commonly used for drainage in the mid-western United States. Most of these ditches are man-made, and managed by local government agencies to ensure their functionality. Each ditch can drain as many as 5,000 ha or more, with the primary source of water being a mix of surface runoff and sub-surface flow from field tile. While many best management practices (BMP's) have been studied to reduce P loads to surface waters, these practices do not eliminate P reaching these water bodies. When P enters a managed ecosystem, such as the tile-fed drainage ditches, there is one more opportunity to reduce downstream delivery of P to receiving water bodies, by a physical or chemical treatment of the sediments that will geochemically bind P to the sediments. The goal of this project was to determine if physical or chemical treatments could change the physiochemical properties of sediments to sequester P, thus reducing the potential for downstream delivery.

Methods

Three tile fed ditches were studied in northeast Indiana. Paired small and large sites draining from 300 to 1,500 ha were selected on each ditch (Table 1). One additional site was selected on ditch A that drained approximately 4,300 ha. One sediment collection occurred in June 2003 and another in July 2003, which was before and after a series of severe storms that caused flooding throughout much of the region. Phosphorus sorption experiments were performed on sediments to determine equilibrium P concentration (EPC_o) and P buffering capacity. Water samples were also collected from the ditch sites and were used to calculate a partition phase index, calculated from the P concentration in water and labile P concentrations in sediments. Sediments were treated with aluminium sulphate (alum) and calcium carbonate in an attempt to enhance the removal of P from the water column by the sediments. Following chemical treatment, EPC_o, P buffering capacity, partition phase index and labile P concentrations were measured on sediments.

Effects of Chemical Treatment and Sediment Disturbance

Chemical treatment of sediment samples taken before sediment disturbance reduced sediment EPC_o in all samples, except the large site in watershed B, which already had an EPC_o of 0 (Table 1). These data indicate that chemical treatments with alum may be used to increase the sorption of P by sediments in these ditches. Sediment disturbance resulting from flooding had a mixed effect on sediment EPC_o. At four sites, EPC_o decreased following disturbance, while an increase was noted at the other three sites (Table 1). Buffering capacity of sediments before the flood were relatively unchanged by chemical treatment of sediments, however, there was a 5 to 10 fold increase in the buffering capacity resulting from the sediment disturbance that occurred from the flood event. The lack of change resulting from chemical treatment may have been due to the fairly high levels of labile P in the sediments prior to the disturbance, and a short reaction time (<24 hrs) between chemical treatment and analysis, thus only allowing enough time for chemical reactions to occur at the particle surface. The partition phase index was reduced by chemical treatment and sediment disturbance by as much as 89% and 93% respectively, another indication that chemical and physical treatments could be used to sequester P in sediments, thus potentially reducing P mass delivered downstream. Chemical and physical treatment of sediments are one more tool that could potentially be used to reduce P transport to sensitive water bodies, and should be studied further to evaluate if the treatments will work at the watershed scale.

Table 1. Effects of chemical treatment and sediment disturbance on equilibrium phosphorus concentrations (EPC_o) at sites on three tile fed drainage ditches in northwest Indiana.

Watershed	Site	Area	Pre-disturbance normal	Pre-disturbance with alum	Post-disturbance normal	Post-disturbance with alum
A	Small	299	0.078	0.017	0.033	0.035
A	Large	1936	0.055	0.008	0.020	0.016
A	X-Large	4307	0.067	0	0.107	0.027
B	Small	311	0.050	0	0.080	0.034
B	Large	1418	0	0	0.023	0.071
C	Small	373	0.051	0.004	0.035	0.052
C	Large	1381	0.110	0	0.068	0.043

Particle P-loss in Soil Erosion - P Distribution in Stable Soil Aggregates after Ultrasonic Dispersion

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Introduction and Method

Phosphorus (P) is a driving force for net primary production in aquatic systems. Fertilization, soil erosion and P transport in runoff increase P in aquatic systems. The European Union develops guidelines for protecting the water resources (Stalzer, 1998). P is particularly receptive to be removed by soil erosion, because this element is predominantly concentrated on the topsoil (Sharpley, 1985). The average ratio between sediment–bound and runoff-bound losses of N and P is in the ratio of 10:1 (Sharpley, 1985). The ultrasonic dispersion method (USAS) provides chemical information about stable soil aggregates and dispersed materials.

Ultrasonic dispersion experiments were performed with probe-type dispersion equipment (Mayer et al.). Based on pilot experiments (Mentler et al, 2004) new experimental conditions with lower energy levels were worked out. Ultrasonic dispersion soil tests are performed using 200 ml of pure degassed water and 10 g of soil with five replications for statistical analysis. The insertion dept of the titanium is constant at 10 mm. The temperature of the solution remains constant at 20 ± 2 C using a cooling device. In addition to the ultrasonic vibration, the suspension is stirred with a magnetic stirring device. To investigate the process of ultrasonic dispersion at different vibration amplitudes, two series of experiments were performed. In the first experimental series the vibration amplitude is set to 5 μm (0.98 J ml^{-1}) and in the second series the vibration amplitude is 10 μm (1.95 J ml^{-1}). Ultrasonic dispersion of aggregates (1000-63 mm) and also the stable aggregates are studied using different vibration amplitudes and different sonification times (30 s, 60 s, 120 s). After wet sieving the material is collected for further chemical analysis. P_t (Austrian standard, ÖNORM L-1085-87) and P_{cal} (Austrian standard ÖNORM L-1087-88) were analysed.

Results

Differentiation in aggregate stability and the amount of phosphorus concentration in soil the aggregates within this small catchment scale of Mistelbach, Lower Austria can be determined. Coarse aggregate fractions have much more P content than other fractions. The weight percent of these aggregate fractions is very low, therefore it is possible to compare the P values with the P concentration in the whole topsoil. This information is important to describe the transport of particles, dispersed material and their bound P. Total phosphorus and plant available phosphorus increases form eroded zones to deposition zones in all aggregate fractions. In this small catchment of Mistelbach (Lower Austria) plant available phosphorus is strongly correlated ($R^2 = 0.96$) to the total phosphorus content in the topsoil.

Summary and Outlook

With ultrasonic dispersion method (USAS) it is possible to get information about stable aggregates and their P concentration in quality and quantity. Enhancement of ultrasonic experiments disrupting particular aggregate fractions to the particle size provides more information about localisation of bound P in the aggregates and dispersed material. Tillage systems can change aggregate stability. In loamy soils conventional management praxis can increase the coarse aggregates and the phosphorus content in the soil, because of the higher P content in this fraction. With the ultrasonic dispersion method (USAS) and P analysis it is possible to estimate risk factors for soil erosion and information where the P is bound.

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Approaching Background Levels in Water-Borne Phosphorus Emissions from Arable Land. What can be Achieved and How Soon?

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Abstract

Background loads and levels of phosphorus (P) from arable land are used in source-apportionment and in models. However, there is a serious lack of data from which these levels can be estimated. Geological conditions vary among soils, especially between arable and forest land in Sweden. Under base-flow conditions, higher P concentrations have been recorded in drainage systems under arable land than in areas dominated by forest. Similarly, annually based phosphorus to silicon ratios are higher in water from arable land. The cultivation background (levels due to cultivation) based on Swedish data was 35-75%. Water of different origin was characterised and compared during base-flow conditions. Recent historic background was based on diatom dating. Calculation of the anthropogenic contribution was based on enhanced phosphorus concentrations of suspended solids from arable land. The long-tem cultivation background was estimated from transport of phosphorus and silicon from arable land. Short-term cultivation background was estimated from a comparison of unfertilised, unploughed grassland with six nearby plots used for cereal production. The cultivation background thus divided into several components indicate the following distribution: recent historic background 35-40% of total load is background, anthropogenic contribution 50%, long-term cultivation background up to 60%, and short-term cultivation background, roughly 75%.

Discussion

Forest land is sometimes used for estimating agricultural background levels but conditions are different (Table 1) and the results may be fundamentally irrelevant. Unfertilized, unploughed land is used to estimate background levels for nitrogen leaching. However, no fast reduction was recorded of P losses from a set-aside area (unploughed and unfertilised grassland) on a tile-drained clay soil and total P loss was not significantly reduced. Taken over a decade, the average, flow-weighed, total P concentration was indicated to be lower (Table 2) than similar concentrations from cereal production. However, losses of phosphorous as phosphate seemed higher from the set-aside area during certain periods; probably those periods characterised by macropore flow.

Eventhough background cultivation levels for arable soils might be quite high, these cannot be achieved in a short time perspective. The "background" concept should be divided into several components since physical influences from tillage and drainage systems enhance aeration and weathering but also reduce soil compaction and lateral flows. For drained clays, soil structure and uniform water infiltration are probably significant factors for reaching the background cultivation level. There is very little known about how closely the cultivation P background level might be approached and how fast it might be reached in practice.

Table 1. Number (No), catchment type, average catchment area and proportion of arable land, period recorded, long-term average of total phosphorus (TOTP) under base-flow conditions and annual ratio of total phosphorus to silicon (TOTP/Si) based on weight

No	Catchment type	Total area (km^2)	Arable land (%)	Period	Base-flow TOTP (mg l^{-1})	TOTP/Si (%)
15	Drained fields	0.14	100	1972-2001	0.034	2.3*
43	Agricultural catchments	12	45	1995-2001	0.057	-
20	Agricultural streams	960	35	1995-2001	0.050	2.3
15	Forest streams	9800	<28	1995-2001	0.009	0.7
1	Forest catchment	0.3	0	1990-1996	0.005	0.4*

* based on one site

<table 2 on next page>

Table 2. Methods for estimating cultivation background concentrations and contributions and to what type of background they have been related, total phosphorus (TOTP) concentration and annual ratio of phosphorus in suspended solids (P/SS) based on weight

Method	Relation of the estimate	TOTP (mg l^{-1})	P/SS (%)
Diatom study	Recent historic background	0.05-0.06	-
Enhanced P in suspended solids	Anthropogenic contribution	-	0.1
Comparing unfertilised, unploughed, grassed land to land under cereal production (10 years)	Short-term cultivation background	0.054/0.073	-
Comparison of grassed and fertilised land to land under cereal production (8 not comparable years)	-	0.089/0.081	-
Silicon leaching from arable land*	Cultivation background	0.06	0.2

* based on one site

Manure-P fractionation – How Does it Predict P Availability for Plants and Long-Term Effects on Soil P?

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Introduction

Characterization of manure-phosphorus (P) solubility by chemical fractionation is suggested to indicate leaching risks during and after application of manures (e.g., Sharpley and Moyer, 2000). Sparsely soluble manure-P is assumed to be less susceptible to leaching losses than manure with more soluble P.

In the Finnish Agri-Environment Programme, the spreading of manure is regulated according to soil P status and availability index for manure-P. There, 40% of P in fur animal (fox and mink) manure (FAM) and 75% of cow manure-P (CM-P) is considered plant-available. The low availability indices result in heavy P applications and P accumulation in soils. However, the fate of surplus P applied as sparsely soluble manure-P is largely unexplored.

We characterized the P solubility of FAM, composted FAM (cFAM), and CM in laboratory. In a pot experiment, we studied the growth response of ryegrass fertilized with FAM, cFAM or with superphosphate (SP). Furthermore, we compared P solubility in soils with long history of FAM applications vs. soils fertilized with more soluble P sources (CM and SP).

Material and methods

Manure P fractions: Solubility of fresh FAM-P, cFAM-P, and CM-P was characterized by a modified Hedley fractionation: extractions (w/v, 1:50) with water (P_w), 0.5 M $NaHCO_3$ (P_{bic}) 0.1 M NaOH and 1 M HCl (centrifuging 1100 g between extractions). Inorganic P (<0.2 µm) and total dissolved P (digestion in an autoclave) in the extracts were determined colorimetrically, and dissolved organic P (P_o) was taken as their difference. Total manure-P was analyzed using aqua regia-HF (AR-HF) digestion.

Pot experiment: Ryegrass (*Lolium multiflorum*) was grown on a sandy loam (Olsen-P 18.6 mg kg^{-1}). Air-dried and sieved (6 mm) FAM, cFAM, CM, or SP was added at three P levels (25, 50 and 100 mg P kg^{-1} soil), with, e.g., 150 mg N kg^{-1} soil. Ryegrass was cut four times and N, K, and Mg (120, 120, and 15 mg kg^{-1} soil, respectively) was applied after each harvest.

Field survey: Soil samples were retrieved from 70 fields that made 35 pair. Within the field pairs, the other field had received long-term surplus applications of FAM-P, and the other one had been fertilized with more soluble P sources, CM and SP. Soil P was extracted using the modified Hedley scheme.

Results and discussion

Manure P fractions: Most of the FAM-P was recovered in acid-soluble fraction. Out of the total P (42–52 mg P g^{-1} dry matter) in FAM and cFAM, the easily soluble P fractions (P_w and P_{bic}) comprised only about 30% and 20%, respectively. For CM (5 mg P g^{-1} dry matter), up to 90% of the total P was P_w and P_{bic}. In all cases, 80–90% of the manure-P was inorganic.

Pot experiment: SP increased ryegrass yield more than FAM or cFAM and judged by the ryegrass yields, P availability in soil amended with FAM and cFAM was about 70–90% and 50-60%, respectively, of that in SP treatment. For CM, P availability exceeded that of the SP treatments (100–120%). However, P uptake from FAM and cFAM was at the same level as in SP and lower than in CM treatments. The contradiction between yield and P uptake was probably caused by low availability of FAM-P and cFAM-P at the early stage of growth, increasing the overall P uptake efficiency but depressing yield potential (see Jarrell and Beverly, 1981).
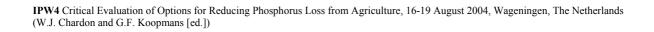
Field survey: The fields that had received long-term FAM-P surpluses contained significantly more total P and extractable P in 0–20, 20–40, and 40–60 cm soil layers than the fields amended with CM and SP. Most of the P accumulation in the FAM-amended soils was in acid-soluble form, but also the concentrations of P_w and P_{bic} were significantly elevated. In the top soils (0–20 cm), the FAM-P surplus accumulation to P_w and P_{bic} pools was most notable in organic soils (30% of accumulated P), followed by coarse-textured mineral soils (11% of accum. P), and least in fine-textured mineral soils (6% of accum. P). The contents of oxalate-extractable Al and Fe did not explain these differences.

In conclusion, even though manure-P fractionation can be used as an indication of leaching risks and short-term effects related to P nutrition of plants, adjusting FAM spreading according to risk status and immediate bioavailability increases the concentrations of mobile and soluble P in soils with time.

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Author index

Numbers in bold denote first-author papers

Notes

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