

# **6th International Phosphorus Workshop (IPW6)**

**Towards a sustainable control of diffuse P loss: risk,  
monitoring, modelling, and mitigation options**

**Book of  
Abstracts**



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COST action 869 “Mitigation options for nutrient reduction in surface water and groundwaters”

COST is supported by the EU RTD Framework Programme



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## **Phosphorus mobilization at plot and field scale**

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To control P transfer from soil to water it is crucial to know in detail the mechanisms that rule P accumulation in soil, mobilization and transport.

Here it will be reviewed studies dealing with mobilization of P from soil, at plot and field scale.

Mobilization is defined as the initiation of P movement; solubilization and detachment are the two primary processes by which P may be mobilized. Solubilization indicates the transfer of P from a solid phase to a water phase and the driving mechanism is chemical non-equilibrium. Physical detachment brings into suspension soil particles and colloids with attached P due to mechanical forces exerted by moving water. The reactions responsible for solubilization are dissolution/precipitation, sorption/desorption and mineralization/organization that control the amount of P in the soil water phase both in inorganic and organic forms. To predict the risk of P mobility associated with solid soil particles, both the amount of P associated to the different size fractions and the dispersibility of soil particles as a function of soil properties and management practices must be evaluated.

Due to the heterogeneity of the soil both the entity and the direction of the processes regulating P solubilization and detachment, vary substantially from one particle to the others, and both in vertical and horizontal directions determining the overall fate of the mobilized P. Thus researches aimed to develop a basis for understanding the mobilization processes regulating P export from soils to waters need to use a range of scale issues and of methods of investigation. Laboratory experiments have been designed to assess the relationships between soil properties, including P surplus, and potential P mobility. Profile or plot-scale experimental studies provide accurate data on P losses related to specific soil type, agronomic practices and climatic conditions; field scale research provides information on P losses induced by particular land use and allows the assessment of heterogeneity within the systems. Laboratory, profile, plot and field studies cannot provide information on the fate of exported P beyond their individual boundaries but they do provide a means of determining the relative significance of individual processes and identifying the controlling factors. These two informations are essential when considering system behaviour at larger scale.

## Mitigation options implementation: from science to agricultural policy

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It has been known for decades that too high phosphorus (P) concentrations in surface water cause problems due to eutrophication, and also that agriculture can locally be a main contributor to this problem. When a government becomes aware of such a main contribution it will aim to reduce losses of P from agriculture via regulation, fees or subsidies. In an “ideal” situation the government asks researchers to propose mitigation options, and they will either develop these options themselves, or take an option developed by others and test and adapt it for local conditions. If an option is accepted by the government it can become part of regulation. However, deviations from this “ideal” situation are not uncommon.

A first example is that agricultural policy may not accept a mitigation option that seems scientifically sound, because the consequences are considered unacceptable. E.g, a soil with a high P status connected to a water course is a risk for water quality. Lowering the P status by harvesting without P (or manure) application lowers the P status and reduces the risk. However, forbidding to further apply manure to soils with a high P status connected to waterways may create a manure surplus on farm, regional or even national scale. This can be a reason why the option is not implemented within agricultural policy.

A second example is that an option that is applicable for a certain environmental issue is too simply copied for attacking another, without a preparatory scientific evaluation. A relatively small buffer zone along waterways where fertilizers and pesticides cannot be used will reduce a direct input of these agro-chemicals to water. However, assuming that a wider buffer zone of uniform width will be effective for reducing P loss from soils to water in all cases, is a strong simplification that will not be cost-effective in many cases. Nevertheless, buffer zones of uniform width are found in 70% of River Basin Management Plans.

During the presentation examples will be given of the interaction between science and agricultural policy, based on experience in a number of countries.

## **Soil organic phosphorus dynamics - pools, actors and processes**

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Phosphorus (P) is indispensable for all living organisms. Plants and soil organisms take up P as orthophosphate from the soil solution, assimilate it and release it to the soil in different forms. In addition, in agricultural systems a significant proportion of the P taken up by plants can be exported with the harvest or in animal products. Agricultural soils contain between 30 and 70% of the total P in organic forms and in their upper horizon up to 10% of soil total P can be found in the microbial biomass. These organic P forms have different turnover rates and can be differently influenced by management practices. This review will highlight the pools of organic P, the actors controlling biological P transformations in soils and the methods used to analyze them. At the end, examples showing the relevance of these processes in P cycling will be presented for different ecosystems. We will not consider rhizospheric processes in this review as they will be dealt with in another presentation.

The techniques for measuring and characterizing organic P pools will be first addressed. These include chemical extractions, nuclear magnetic resonance spectroscopy, X-ray absorption techniques and the targeted use of phosphatase enzymes. The recent advances made in analyzing P species in intact microorganisms which were extracted from the soil will also be covered. The role of soil micro-organisms in solubilizing mineral P compounds, producing extracellular phosphatase enzymes and scavenging and releasing P under different conditions will be analyzed. The recent developments in the use of phosphorus radioisotopes to assess microbial P turnover and organic P mineralization will also be covered. The potential of using the stable oxygen isotopes associated to P compounds to trace biological processes occurring at different time scales during P cycling in soil/plant systems will be presented. Finally, the importance of these biological reactions, their drivers and their significance for plant nutrition and P management in cropped and in grasslands soils will be sketched.

## **Phosphorus dynamics and impact in water bodies-standing on the shoulders of giants**

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Anthropogenic addition of nutrients to a catchment provides a hazard for the *status quo* of aquatic ecosystem structure and function. The risk of an impact on a water body depends on the rate of mobilisation transporting the nutrients, the connectivity between source areas and pathways, and the susceptibility (or resistance) of a waterbody's biota to increased supplies of nutrients. Generally, our knowledge of phosphorus dynamics in soil, agronomic nutrient needs of crops and the mobilisation of dissolved and particulate phosphorus is sufficient to provide guiding principles that can limit impacts on waterbodies from diffuse phosphorus loads. What we often lack is empirical data linking soil phosphorus state, agronomic management and nutrient movements across soils, catchments and climates at appropriate temporal and spatial scales. This limits the persuasive power to effect precautionary management against a back-drop of powerful traditions and interests, geared to maximise agriculture production, and often distorted by a history of subsidies and a culture of entitlement. As for soil science and landscape hydrology, our basic knowledge of the effect of nutrients in general, and phosphorus in particular, is sufficient to understand the impact of increasing nutrient loads on the ecology of water bodies, and the interplay between physical, chemical and biotic components of food webs. Understanding fundamental principles of waterbody hydrology, chemistry and biology have developed over the last century. In 1969 Arthur Hasler wrote "Our knowledge of what causes eutrophication is sufficiently good that firm and effective precautions can be recommended", and in relation to Lake Monona in the U.S, "buck passing, economy measures, false information..., inconclusive action and lack of cooperation between Government and citizens hampered progress" Since Hasler (1969) expressed his exasperation, our knowledge of ecological processes and nutrient dynamics have continued to progress, and policies across the world have been put in place that should provide the basis for sound ecosystem management. Nevertheless, impacts on freshwaters continue and often increase, with loss of biodiversity and a failure, especially, to protect the sites of highest quality. These failures are primarily of politics, not ecological understanding. Meanwhile, national and international research programmes continue to support policies designed to protect water bodies, but which may ironically promote greater homogenisation of ecosystem structure. Recommended concentrations of phosphorus in rivers may, for example, lead to loss of quality in downstream lakes. The drive to implement standard criteria across regions risks losing sight of the fundamentals, ignoring the dynamics of function and the wealth of site-specific knowledge. We may stand on the shoulders of giants, but our vision can be occluded by a mist of political rhetoric and global modelling.

Hasler, A.D. 1969. Cultural Eutrophication Is Reversible. *BioScience*, 19: 425-431.

## **Using a field-scale index to assess phosphorus loss from an agricultural environment**

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There is a huge knowledge gap between knowing what levels of phosphorus contamination exist in a water body to what are the immediate sources of phosphorus in the landscape contributing to this contamination. Knowledge of the potential source and intensity of phosphorus are critical for successful mitigation. The decision to mitigate the various forms of P that are leaving the agricultural environment is much more complex if the source and form of the material is not known. A field-scale index allows the conservation planner and landuser to identify where in the landscape of the field there is a need for treatment and which index parameters need to be addressed using management practices and techniques. As these potentials are identified and assessed the conservation planner, along with the landuser, can work toward applying conservation practices and management techniques to mitigate whatever phosphorus movement risk has been identified. Re-assessing the phosphorus risk after mitigation has been implemented will reveal how much benefit and where the situation has been alleviated. An index can also develop a relative ranking of sites to allow the conservation planner and landuser to prioritize the mitigation work ahead. A simple phosphorus index was developed in 1993 to make such an assessment. Since then most states in the USA, providences in Canada, and many European countries have adapted some form of phosphorus assessment tool. Indexing is a non-evasive assessment, uses field and producer available information, and can be displayed by geospatial graphics. Applying geographical information system (GIS) spatial overlays can quickly and easily depict where problem fields and source-transport-sink risk lay.

The future use of an assessment index should be short and limited as more sophisticated field-level process models are quickly developed that uses hydrologic, chemical, and physical parameters in order to quantify the relative benefits of detecting and mitigating phosphorus movement. Replacing a qualifying index with a field-scale quantifying process model is the best step toward solving phosphorus management and runoff control situations. A purpose of developing a field-level risk index that qualifies and ranks field to their vulnerability is for directing our conservationist and landusers intensions to a certain location or aspect of a field and its management that could be potentially a source-transport-sink of phosphorus. Knowing where the source is located and something about the amount and potential risk for movement presents an immediate communication between the landuser and conservation planner. Once the problem is identified, a full-scale management plan can be developed to alleviate the risk. Conservation and management proceed in a step-wise fashion. One of the first steps in identifying and locating the risk can be accomplished by a field-scale assessment tool, such as an index.

## **Moving towards manure phosphorus mass balance in watersheds through pyrolysis to biochar**

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There are sometimes more manure nutrients produced than local crops need, with approximately 10% of all counties in the USA producing more phosphorous (P) in manure than is taken up by crops (Maguire et al., 2007). This excess manure P has historically been land applied locally and increased soil test P above agronomic optimum which increases P losses to surface waters. However, as only 10% of all counties in the USA produce more P than is harvested in crops, this also means that 90% of counties do not have sufficient manure P to meet crop needs and must use commercial P fertilizer. Therefore problems with excess manure P are heavily related to distribution, and a cost effective method to redistribute manure P could help alleviate environmental concerns. Pyrolysis of manure into biochar is one possible solution. Pyrolysis is thermal conversion of organic materials, such as manure, in an oxygen-free environment into liquids, gases and solids. There are several forms of pyrolysis, such as fast, slow and vacuum. The fast and vacuum pyrolysis processes emphasize bio-oil production with biochar and gases as byproducts, while slow pyrolysis favors biochar production at the expense of bio-oil and gases. Biochar is substantially lighter than manure because of moisture loss and volatilization of the organic compounds. However, most of the inorganic compounds and P originally in the manure are retained in the biochar residue after the pyrolysis. "Terra preta" soils amended with material similar to biochar in the Amazon hundreds of years ago show improved productivity relative to native soils. This is primarily due to increased water holding capacity, cation exchange capacity and nutrient use efficiency. The fact that Terra preta soils have elevated carbon hundreds of years after biochar application has also raised interest in biochar for carbon sequestration. If pyrolysis can produce bio-oil and the biochar is a value added product that contains all the manure P, then it may be a cost effective solution for regional surpluses of manure P. We produced biochar from broiler litter using fast pyrolysis and then evaluated it as a value added product in two greenhouse trials using two soils. Salt toxicity of biochar was investigated using lettuce seeds germinated at 15 rates of biochar application to soils ranging from 100% soil to 100% biochar by weight. Results showed that litter biochar addition at and above approximately 5% caused salt toxicity. In humid regions the salts would leach throughout the growing season, so the salt in the biochar limits annual applications, but not total application rates over several years. Staying below this 5% by weight upper application rate, peppers were grown with five rates of biochar application. We will pepper harvest and quality and total plant biomass. We will also report soil properties, including Mehlich 1 extractable nutrients, pH, cation exchange capacity, soluble salts, and water holding capacity. We will also discuss the implications for large scale pyrolysis of manure.

Maguire, R.O., D.A., Crouse, and S.C. Hodges. 2007. Diet modification to reduce phosphorus surpluses: A mass balance approach. *J. Environ. Qual.* 36:1235-1240.

## **Phosphorus bioavailability – nothing but a rhizosphere story**

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A major challenge in the coming decades is to achieve the necessary ecological intensification of agroecosystems in order to keep the pace of a growing population while decreasing agricultural inputs such as fertilisers. The Millennium Ecosystem Assessment underlined that the cycles of nutrients, especially nitrogen (N) and phosphorus (P), were among the most affected ecosystem services, leading to a massive and fast-increasing eutrophication of aquatic ecosystems, as a direct consequence of the considerable increase in agricultural inputs alongside of a steady decrease of their efficiency. For P, at the current rate of consumption of P fertilisers, the fast exhaustion of high grade phosphate ores worldwide clearly challenges the sustainability of current P fertiliser use in developed countries in the coming decades. This rather short deadline which may be further extended by using lower quality resources and paying a greater cost clearly requires a major shift in P fertiliser use (Cordell et al. 2009). A better understanding of the processes governing P bioavailability to plants is thus needed. This review will stress the importance of rhizosphere biogeochemistry, which is currently ignored in most models of plant nutrition. Indeed, their central hypothesis is that the driving force of nutrient acquisition is the absorption process which results in a decrease in nutrient concentration at the surface of the root, leading to a diffusion gradient in the rhizosphere. Experimental evidence for nutrient depletion occurring in the rhizosphere is especially documented for poorly mobile, major nutrients such as P (Hinsinger 2001). Recent measurements conducted after sampling the rhizosphere *in situ* in various field-grown plant species have further shown that depletion of P may not be a general rule in low P input conditions. Such findings invalidate classical models of nutrient acquisition. While nutrient uptake models adequately predict P uptake by crops grown under non-limiting conditions, they most often largely underestimate the actual P uptake in low P soils. This suggests that processes that are not accounted for in such models play a key role in determining P bioavailability. Among these, root-induced pH changes as well as changes of ionic (e.g. carboxylates, calcium) concentrations have been shown to be major drivers of changes of inorganic P availability in the rhizosphere (Casarin et al. 2004; Devau et al. 2010; Hinsinger 2001). In addition, the fate of organic P may also be altered by rhizosphere processes involving microbial communities and mycorrhizae. Better understanding the impact of such processes on P bioavailability shall help designing more P efficient plants and agroecosystems.

Casarin, V., C. Plassard, P. Hinsinger, and J.C. Arvieu. 2004. Quantification of ectomycorrhizal fungal effects on the bioavailability and mobilisation of soil P in the rhizosphere of *Pinus pinaster*. *New Phytol.* 163:177–185.

Cordell, D., J.-O. Drangert, and S. White. 2009. The story of phosphorus: Global food security and food for thought. *Global Environ. Change* 19:292–305.

Devau, N., E. Le Cadre, P. Hinsinger, and F. Gérard 2010. A mechanistic model for understanding root-induced chemical changes controlling phosphorus availability. *Ann. Bot.* 105:1183–1197.

Hinsinger, P. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. *Plant Soil* 237:173–195.

## **Management of phosphorus in the low-input agricultural systems of the West Asia and North Africa region**

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The Mediterranean region, where settled agriculture began, and where cereals and pulses evolved, is invariably constrained by drought. The climate is typically Mediterranean, with a relatively wet season (fall-winter) where rainfed cropping is practiced (rainfall range of 200 to 600 mm rainfall) and a dry summer period where cropping is possible only with irrigation. Historically, irrigation was possible where surface water sources (rivers) were available, but irrigation has increased in formerly rainfed areas, with the proliferation of deep wells to tap groundwater. With declining groundwater levels, management of dryland/rainfed agriculture is all the more important. The Mediterranean climate of the North Africa-West Asia region is modified by landmass features, especially elevation. Areas inland tend towards a continental climate. The dominant cropping system is based on cereals, barley in drier area and wheat in more favorable areas, and food and forage legumes, as well as a range of other crops. Livestock, mainly sheep and goats, are integrated with cereal production. Though the cropping system was traditional and unchanged for centuries, and was characterized by low yields, much has changed in recent decades, especially with mechanization, new varieties, and chemical inputs, especially fertilizers. Land use pressure has caused a reduction of fallow, which was practiced as a hedge against drought. Increasingly, monoculture is practiced, with inevitable concerns about its sustainability. Since the 1970s, most countries of the region have experienced a 10-20 fold increase in nitrogen use, with somewhat lower amounts of phosphorus (P). By comparison, the amounts of potassium used are low due to the inherent richness of the region's soils in that element. The awareness of micronutrients in the region's agriculture is recent, and the practice of micronutrient fertilization is rare, except in Turkey. Much research attention has focused on P, not only for its direct impact on crop growth, but also its indirect effects in relation to adaptation to drought as well as its complex chemical reactions in soils. The work conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA) in northern Syria, in conjunction with the national programs in the region, provide a broad insight into the course of P research in the past 3 decades. The work on P response of various crops in the range of rainfall zones in Syria mirrored similar collaborative work elsewhere, especially in Pakistan, Turkey, and Morocco. Much has been accomplished at the applied level to assess crop responses and application methods, and at the basic level to understand the fundamental reactions that underpin P behavior in Mediterranean soils. Despite perceptions of irreversible reactions of P fertilizer in calcareous soils, a significant change has been the gradual build-up in available P, and thus the need for less P on an annual basis. Despite the accumulated knowledge on all aspects of P use in the region's dryland cropping, the major obstacles to effective transfer of this knowledge to farmers are the general absence of soil testing services upon which to base rational fertilizer use, and the weak extension-technology transfer systems. This presentation gives a snapshot of soil and fertilizer P research in the West Asia-North Africa region through the context of an international research center dedicated to the agricultural development of the region.

## **Modeling field-scale phosphorus transfer: model strengths and weaknesses, gaps in knowledge, and the role for scientists**

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Arguably, the ultimate goal of applied research of phosphorus (P) transfer from agricultural fields to surface waters should be to develop and apply mathematical models. There are two primary reasons for this assertion: (1) models formalize our understanding of P transfer and force us to test that understanding and identify knowledge gaps; and (2) models allow us to quantify P transfer for environmental and management conditions when physical monitoring is not possible. An effective way to formalize understanding is through systematic model development from a perceptual model of our qualitative understanding of a system to a conceptual model of the mathematical equations to a procedural model of computer code. Two main approaches to modeling P transfer are empirical export models to calculate annual or seasonal loads or process-based models to simulate physical dynamics. Quantifying P transfer requires both a predictive capability of models and confidence that model algorithms function properly and represent the most current scientific information. Models must be structured in a way that allows for adequate validation with field monitoring data. Without validation, there is little confidence that the model can reasonably quantify P transfer. It is possible that the structure of a model, especially qualitative P transfer risk assessment tools, prevents its validation because its output is generated in a substantially different mathematical way from the how validation data are generated and processed. This may be different from a situation where a model does not validate because it is perceptually or conceptually incorrect or because of data uncertainty or limitations. Thus, it can be a challenge to understand why a model does not validate adequately, and thus to know when a model should be rejected because of poor perceptualization or conceptualization. Many commonly used, process-based P transfer models such as SWAT or ANSWERS often share the same algorithms and equations, many of which are empirically based. Many of these equations may be nearly 30 years old and could certainly be updated to better reflect current science. Furthermore, some models may be applied in situations for which their algorithms are not adequate. For example, a model like EPIC that was developed to estimate the impact of erosion on crop productivity may now be used to estimate P transfer from surface-applied animal manures or the degree of soil P stratification without appropriate changes to model formulation. While it is true that model development and validation is frequently limited by data availability, this may often be due less to our inability to generate adequate data and more to a disconnect between field scientists and model developers, whereby field scientists fail to communicate their perceptual understanding of P transfer and modelers fail to communicate where translation from perceptual to conceptual models is data limited. Ultimately, there may currently be too great an emphasis on, and thus unnecessary, data generation and too little emphasis on model development and application.

## Global phosphorus fluxes and the threat to food security

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Anthropogenic activities have greatly accelerated the cycling and fluxes of phosphorus (P) at global and regional scales in recent decades causing eutrophication of terrestrial and aquatic ecosystems and associated loss of biodiversity and increased human health risk. Widespread use of highly-soluble inorganic P in fertilizers and feeds, specialization and regionalization of farming systems, deforestation and increased urbanisation are key activities that have promoted greater losses of P in dissolved and particulate forms from land to rivers and the oceans. Current estimates suggest that fluvial transport of dissolved (ca. 5 Tg yr<sup>-1</sup>) and particulate P (ca. 20 Tg yr<sup>-1</sup>) to the oceans (i.e. a permanent sink over the human timescale) are at least double those in the pre-industrial era (Filippelli, 2008; Smit et al., 2009). Large (temporary) storage of P also occurs in soils (due to fixation, 45,000 Tg) and in the oceans (due to N limitation, 90,000 Tg) because of inefficiencies in P use. Greater consumption of manufactured fertilizers and urbanisation in the future will further increase P storages and fluxes in line with world population growth, regional economic growth, higher yielding crops and more widespread production of bioenergy crops. Although clearly uncertain, P fluxes from agricultural land at regional scales can also be expected to increase under climate change due to the effect of higher temperatures on P mineralization rates and the effects of greater storm intensities on soil erosion rates and/or hydrological connectivity to watercourses. More severe eutrophication can be expected due to reduced river flows and increased residence time during summer. Phosphorus plays a central role in the functioning of biological systems and the manufacture of inorganic fertilizers has allowed rapid expansion of food production during the 20th century. However, Smit et al. (2009) calculate that current fertilizer consumption (18 Tg yr<sup>-1</sup>) is over 5 times greater than the intake of P by the global population (i.e. <20% efficiency), yet is still lower than the estimated global losses of P to the oceans. This inefficiency and permanent loss of P to the oceans at such accelerated rates poses a real threat to the future food security because the reserves of rock phosphate (RP) used to manufacture P in fertilizers and feeds are becoming rapidly depleted. Recent estimates suggest that exploitable reserves of RP may last for only about 100 years (75-125 years depending on forecasts) with peak consumption occurring within the next few decades, (Cordell et al., 2009; Smit et al., 2009). Reserves are also concentrated in few and politically unstable regions suggesting supply routes may become more fragile raising concerns over pricing and availability. As there is no alternative source of P, protecting our future food security requires a radical re-think in how P is managed from field to global scales incorporating key concepts of valuing existing P stores (e.g. soils), and closing the P cycle by minimizing wastage and recovering nutrients for recycling. More effective utilization of P already in circulation will reduce society's dependence on inorganic fertilizers and the environmental footprint of their manufacture. Some options are discussed.

- Cordell, D., J. Drangert and S. White. 2009. The story of phosphorus: global food security and food for thought. *Global Env. Change* 19: 292-305.
- Filippelli, G.M. 2008. The global phosphorus cycle: past, present and future. *Elements* 4:89-95.
- Smit, A.L., P.S. Bindraban, J.J. Schroder, J.G. Conijn and H.G. van der Meer. 2009. Phosphorus in agriculture: global resources, trends and developments. *Plant Research Int. Rep.* 282.

# **GLOBAL PHOSPHORUS FLOWS**

## **ORAL PRESENTATIONS**



# A modeling approach to estimate P flows and balance at country scale: a case study for France

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As non-renewable resources, global P reserves are quickly depleting (Cordell *et al.*, 2009; Gilbert, 2009). Agriculture is mostly responsible of such depletion. The determinants of the P consumption may apply at different levels (Schlecht and Hiernaux, 2004). In particular, intensive import/export relationship at country scale may influence P flows and balance. Additionally, the segregation of animal and crop production basins at country scale may impair P recycling opportunities. Finally new sources of P (e.g.: sewage sludge), need to be quantified in term of P availability. Modelling approach may be helpful (i) to quantify P flows within a country, (ii) to evaluate the consequences of import and export and (iii) to identify recycling opportunities. Our work was based on conceptual, and then mathematical, modelling of P flows and compartments within France (Figure 1). Preliminary results showed that soil P content was steadily increasing: crop uptake represented some 675 1000t P/yr whereas the sum of crop residues, animal manure and P fertilisers represented 755 1000t P/yr. This suggests that one third of P fertiliser amount could be saved annually.

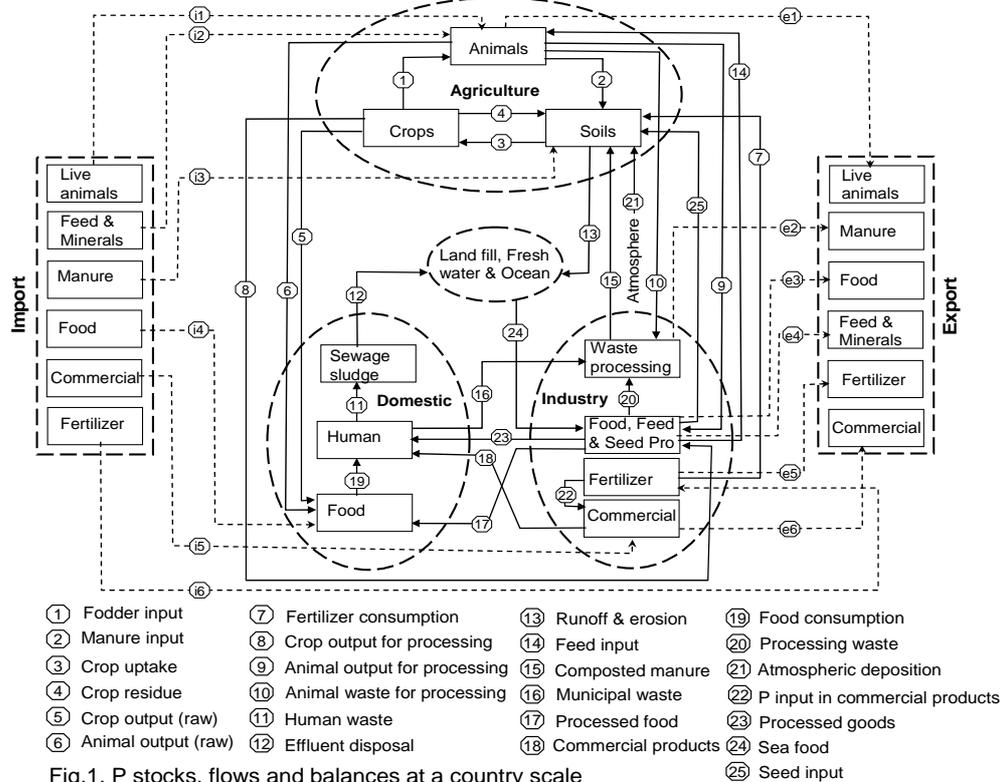


Fig.1. P stocks, flows and balances at a country scale

## **Phosphorus flows in the Netherlands: options for a more sustainable use**

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Phosphorus (P) is one of the major nutrients needed to sustain life. The low concentration of P in most agricultural soils, along with its low solubility, makes P a key limiting factor for plant growth nearly everywhere on the world. In the past, natural ecosystems and low-input agricultural systems adapted to the low P availability by recycling P from organic waste streams (litter, refuse, night soil). Animal manure was used as much as possible and was also collected from grazing outside the farm. External P-inputs became available in the second half of the 19th century through the mining of phosphate deposits. This led to large ecological and agricultural changes including the development of agro-production systems without a (negative) P-feedback (Duncan Brown, 2003). As a consequence these changes reduced the need for P-recycling from organic waste streams, including manure. This led to the current situation that globally food production cannot maintain its current level without fertiliser. However, P-resources are finite.

Taking this into account it is striking that the remaining P-reserves are nowadays not used as they should be, namely as an essential resource to produce food for the estimated nine billion people on earth in 2050. To realize a more sustainable use of P we first analysed the P cycle on the global scale and identified various reasons for the apparent low efficiency of fertilizer (from “mine to fork” only 20% (Cordell, 2010)) and distinguished between i) direct losses (mining losses, erosion), ii) missed opportunities (non-recycling of waste streams, such as slaughter waste and sewage sludge) and iii) accumulation of P in soil (on various scales).

The Netherlands are a prime example of countries with a highly intensive and specialized agriculture. Livestock and arable production became spatially separated leading to regional P-accumulation in soils and to less P recycling (also induced by some societal developments). For its use of P, the Netherlands is totally dependent on sources outside the country, the main flow now being the import of feed (soybean etc.) from South America. Like the rest of Europe, this might be in the future a vulnerable situation when P-resources become exhausted.

To investigate the possibilities for a more sustainable use of the remaining P-resources, an identification and quantification of the major national P-flows was done (in agriculture, industry and society). This provided us with data on various topics such as i) P-accumulation in agricultural soil, ii) losses to the environment, iii) degree of recycling and reuse of P in waste streams etc. It allowed us to identify and quantify the potential for P-recycling at various points in the national P-flow diagram. The outcome of preliminary scenario studies will be discussed

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## **An inventory of UK soil phosphorus and the implications for sustainable food production**

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Due to inefficient use and dwindling reserves, inorganic phosphorus fertilizers will become decreasingly economically-viable. Without action this situation will lead to declining agricultural productivity. UK arable farmland occupies a diminishing, highly favorable ‘agricultural window of latitude’. This window is being squeezed by changing climate, and coupled with rising population, more food will need to be produced from a decreasing area. This likely intensification for agricultural areas such as the UK will need to be carefully balanced with negative ‘externalities’ such as pollution from nutrient runoff. Our research aims to investigate the utilization and sustainable use of the soil phosphorus resources and to minimize P losses that contribute to agronomic inefficiency and degradation of water quality. To date we have undertaken an inventory of the forms of P in a range of UK soils (n=32) including arable, extensive and intensive pasture and semi-natural. This has included conventional properties and P release indices, but most importantly quantitative <sup>31</sup>P NMR spectroscopy of forms of soil P. This has provided evidence of an appreciable ‘bank of residual P’ in UK soils that is currently unavailable to crops. Our limited knowledge of the extent to which we can better understand and utilize residual phosphorus pools to sustain crop production is surprising since (i) phosphorus limitation / co-limitation is the fundamental cap on world food production, and (ii) organically-complexed P can be a substantial soil P form (30-65% typically, but up to >90%). Our future goals are to explore a range of methods to make wider parts of this soil ‘P bank’ better available to crops, but less likely to be lost from the system. The possibilities for this range from ‘bio-technological’ solutions to simple ‘on farm’ management actions using readily-available materials: (i) plant physiology and manipulation – comparing crop types and examples of known efficient P ‘mining’ plants, (ii) manipulations of soil physico-chemical conditions - the effects of wetting and drying on the release of P from organic forms, and (iii) use of soil amendments. We also explore a concept of an ‘ideal soil P state’ of low potential for diffuse pollution losses to waters and highly available P for crop growth. Our results suggest that given an extreme hypothetical case of cessation of inorganic P fertilizer inputs the ‘P bank’ in UK arable and intensive grassland soils could only sustain productivity (current P uptake rates) for <50 years. This also assumes that we could overcome the technological barriers to making this P available. Hence, in a world where terms such as ‘peak P’ are becoming used, our message is for a combination of approaches: to work towards increasing the proportion of residual and added P that remains available for crop uptake, but also importantly to reduce system inefficiencies so that P losses are minimized using sustainable practices, nutrient trapping and recycling methods.



# **PHOSPHORUS DYNAMICS AND CYCLING**

## **ORAL PRESENTATIONS**



## **Identification and quantification of organic phosphorus forms in soils from fertility experiments**

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In order to investigate the influence of different fertilizing regimes and fertilizer types on the soil content of organic phosphorus (P), soils of different characteristics were investigated with nuclear magnetic resonance spectroscopy (P-NMR). Four soils were chosen for the study, of the following types: silty clay loam, loamy sand, sandy loam and clay. On each of these soil types 4 different levels of fertilizer additions were made, corresponding to zero P addition, P addition equivalent to the amount of P removed annually by harvest etc (henceforth called P addition), P addition + 15 kg P/ha, and P addition + 30 kg P/ha. In addition, each of the additions was made in two crop rotations, one with commercially available fertilizer, and one with manure. On the zero P addition soils, were no fertilizer was added, the potential influence of using ley farming on the organic P content of the soil was investigated. Each of the tested set ups were made in replicates. The study was thus aimed both at investigating the impact of various fertilizing regimes on the composition of organic P compounds in the soil, as well as increasing the knowledge on organic P in typical Swedish soils in general.

Results show that without P addition the soils contain a majority of phosphate monoesters (40-80%), which is a rather refractory form of P, not generally available to plants and microorganisms. Other P species in these samples were primarily orthophosphate (20-60%) and pyro/polyphosphate (1-4%), species that generally are more available than the phosphate monoesters. The ratio between monoesters and ortho-P varied significantly depending on the soil type, with the loamy sand having the lowest amount of monoesters, and the silty clay loam the highest. These differences were diminished with increasing fertilizer addition. Already a P addition equivalent to the replacement level changed the relative distribution of the identified P compound groups, making orthophosphate the dominant species in the samples. This trend increased with increasing fertilization, and with fertilization corresponding to P addition + 30kg/ha the orthophosphate constituted more than 70% of the extractable P in all soils, while the proportion of monoesters decreased correspondingly. No differences due to fertilizer type or use of ley farming on the composition of organic P compounds in the soil could be concluded in the study.

In general, the addition of fertilizer changed the organic P composition of the soils markedly. Without fertilizer the majority of the P in the soils existed in the form of relatively refractive and unavailable organic compounds, while addition of fertilizer increased the proportion of available P, which with the highest P addition was over 80% of the total P content. In addition to this, fertilizing the soils increased the total extractable P by 2-3 times, and this seemed to in part depend on the soil type, with the soils with the coarsest particle sizes showing the lowest amount of tot-P, both before and after fertilizing.

## Phosphate and arsenate adsorption on iron mineral surfaces

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Phosphate and arsenate are of major concern in environmental chemistry. Phosphate is essential for plant growth in natural systems and is a nutrient that usually limits algal growth and eutrophication in surface water bodies. Arsenate, on the other hand, is a contaminant that may be present at high concentrations in groundwater. Even though both species are analogous, there may be very important differences between phosphate and arsenate since their biogeochemical behaviour is completely different. In fact, whereas phosphate is a macronutrient constituent of most biological tissues, arsenate is a toxic substance even at very low concentrations.

It is well known that both phosphate and arsenate have relatively strong affinity for mineral surfaces. They are strongly adsorbed at the surface of metal (hydr)oxides, especially iron and aluminium oxides, which are important constituents of soils and sediments and key solids for the control of the transport and bioavailability of many nutrients and contaminants in the environment (Gao and Mucci, 2003; Li et al., 2010).

In the present study, extensive adsorption experiments for phosphate and arsenate on different iron oxide (goethite, ferrihydrite) were conducted. Effects of pH, ionic strength, surface coverage and the presence of competing ions,  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$ , on the phosphate and arsenate adsorption were analyzed. The experimental results for the anion retention were explained by means of the CD-MUSIC model (Hiemstra and van Riemsdijk, 1996; Hiemstra and van Riemsdijk, 2006). This surface complexation model has been developed to macroscopically quantify ion adsorption onto mineral oxides under various conditions and has become one of the most popular models to describe the surface reactivity of iron mineral surfaces. For the modelling calculations, the available spectroscopic and molecular information were used to select adequate surface species for both phosphate and arsenate. The combination of the experimental results and the modelling calculations showed that the dominant surface species in the whole pH and ionic strength range studied are the bidentate species.

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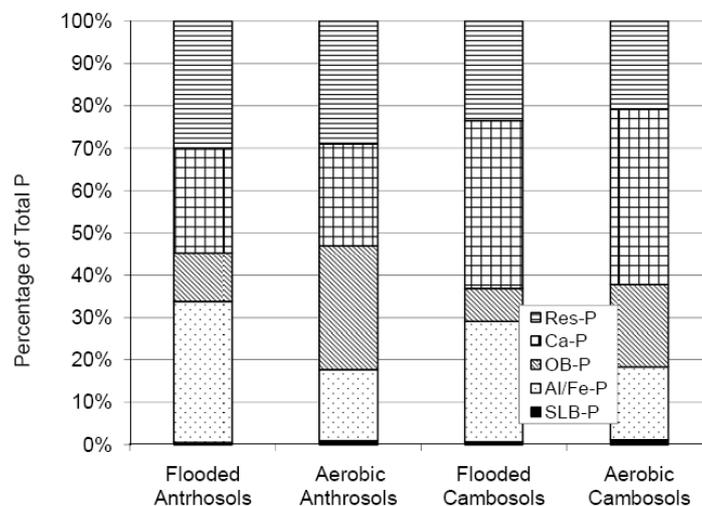
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## Effect of moisture conditions in rice paddies on phosphorus fractionation in agriculture soils of developing regions of China

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Moisture conditions in rice paddies play an important role in phosphorus (P) cycling and may affect P loss to nearby water bodies. This study seeks to identify factors that contribute to P fraction transformations in flooded rice paddies on Cambosols (Endisols) and Anthrosols (Inceptisols) using Zhangjiagang County of the Yangtze Delta Region, China, as a study area. Soil samples with wide ranges of soil pH and organic matter preserved under flooded and aerobic conditions (n = 60) were collected and P fractions and soil properties were measured. Under flooded conditions, soluble and loosely bound P (SLB-P) significantly decreased to half of aerobic levels, aluminum/iron bound P (Al/Fe-P) increased by 66%, and organic bound P (OB-P) decreased by 64%. Moisture conditions do not affect the more unavailable forms such as calcium bound P (Ca-P) and Residual P (Res-P) :



P fraction percentages in rice paddies of Zhangjiagang County, China

Soil organic matter, cation exchange capacity, pH, and active Fe were well correlated with soil P fractions under both moisture conditions across two soil orders despite a disparity in soil properties. Because of the increase in Al/Fe-P, and because Al/Fe-P is available to plants, plant available P is generally sufficient for rice production under submerged conditions. However, the production of wheat during the dry season, as is commonly the practice in the area, requires P fertilization. Further research goals are identified which would aid in specific fertilizer recommendations and management strategies.

## **Evolution of the phosphate saturation degree and its distribution with depth in acid sandy soils in Flanders**

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Intensification of agriculture, with concentration of intensive livestock breeding and intensive horticultural cropping systems in certain areas in Western Europe, has resulted in excessive fertilization both with mineral fertilizers and organic manures especially between the 1970's and 1990's. This has resulted also in excessive P build-up in specific areas, and especially acid sandy soils are prone to P leaching. According to Van der Zee et al. (1990), an acid sandy soil is considered P saturated when the phosphate saturation degree (PSD) is > 25% (or when the P concentration in the shallow groundwater is > 0.1 mg o-P l<sup>-1</sup>).

Between 1995 and 1997 an intensive sampling campaign was launched to make an inventory of the PSD of acid sandy soils in Flanders (DeSmet et al., 1996). This was used as a basis for enforcing strict P fertilization rules on P saturated soils. In 2009, we revisited a number of locations, part of which were P saturated fields with severe P fertilizer restrictions, and part of which were not P saturated at the time of the first survey.

Fields that were not P saturated in general had a higher PSD in 2009, while fields that were P saturated (with severe P restrictions) had equal or slightly lower PSD in 2009.

In the majority of cases, we observed a very clear movement of P from the upper 0-30 cm soil layer to deeper soil layers. While the total PSD of the field may have remained unchanged, the movement of P from the top layers to the deeper layers in a time span of only about one decade is of very serious concern. Indeed, it shows that P movement in these soils is relatively fast, and that these soils are an increasing threat to groundwater quality. Additional measurements from samples taken in the beginning of 2010 will be used to further check this trend.

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## **Dynamics of easily soluble and plant available phosphorus in relation to soil phosphorus status and fertilization rate**

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Phosphorus (P) is an important nutrient for agricultural crops but also main limiting nutrient causing eutrophication in both inland lakes and the Baltic Sea. Agriculture is an important contributor of P to these systems and therefore it is utterly important to reduce P losses from arable land and simultaneously maintain both crop yields and soil P status at optimal levels. Losses of P from arable land are often described as episodic, with high losses constrained to small parts of the watershed (critical source areas) during limited period of time, i.e. few larger storms. Conclusively, abatement focus should be put into soil P status and P amendments (fertilizer and manure) on critical source areas. Agronomic soil test P (STP) are often the only available information about soils P status and therefore used not only for fertilization recommendations but also for environmental risk assessment and modeling of P release and transport from arable land to water recipients. The main method for determination of plant-available P in soils in Sweden is extraction with ammonium lactate/acetic acid at pH 3.75 (P-AL). Lighter extractions of soil P (eg. with water or with 0.01M CaCl<sub>2</sub>) are used to determine soils' potential P release and to mimic P losses. Amendments of P with fertilizer or manure alter the levels of these and other P pools in soil and our understanding of short-time dynamics (days, weeks, months) is important for accurate quantification and modeling of P losses.

In this study, we followed the development and dynamics of P-AL and P-CaCl<sub>2</sub> in five soils included in the long-term fertility experiments within one year after fertilizer/manure application. At these sites, applications of P are based on the principles of replacement. Beside a treatment in which P removed by the crops is replaced, two levels of higher P additions were included in this study. These two levels are intended to achieve slow (treatment C) and rapid (treatment D) increase of the soil P status. Also, two crop rotation systems, one with and one without livestock/manure were included in the study. Soil samples were taken and analyzed for P-AL and P-CaCl<sub>2</sub> following P fertilizer or manure application approximately after 1, 3, 7, 14, 21, 28, 45, 60, 120, 180, 240, 300 and 360 days.

Although two last sampling occasions and consequent analyses remain to be done at two sites, preliminary results show following patterns:

1. P amendment cause rapid increase and subsequent slow decrease in both P-AL and P-CaCl<sub>2</sub>. Increases in the replacement treatment (B) are much lower than in C and D treatments.
2. No significant differences exist between crop rotations, i.e. fertilizer and manure amendments.
3. Responses to P amendments are site-specific, with large differences between different soils. Some of these differences could be explained with soils' P sorption capacity.

## Phosphorus in agricultural soils around the Baltic Sea – Comparisons of laboratory methods as indices for phosphorus leaching to waters

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One main factor for high inputs of nutrients to the Baltic Sea is diffuse leaching from agricultural lands in surrounding countries. Commonly used methods to evaluate the risk of phosphorus (P) leaching are based on chemical soil tests. These tests were originally developed to quantify the amount of plant-available P in soil for crop production and several soil extraction methods are in use: ammonium lactate (P-AL) in Sweden and Lithuania, double lactate (P-DL) in Latvia, Mehlich 3 (P-M3) in Estonia and Olsen-P in Denmark. The method used to quantify the amount of P in the extracts is either colorimetry or inductive coupled plasma spectrometry (ICP). The aim of this study was to compare these methods as risk indices for P leaching together with a P sorption index (PSI) and the amounts of P in relation to aluminium (Al-AL) and iron (Fe-AL) in the acidic AL extract (DPS).

A total of 99 soil samples from five agricultural catchments and two field trials in the Baltic States and Sweden were extracted according to the four methods listed above and the amount of P was quantified with the practices of the respective country. The amount of P extracted by the four methods increased in the order: Olsen-P < P-DL ≤ P-M3 < P-AL, with Olsen-P values being on average only 24% of P-AL values. The amount of P determined by ICP in the P-AL extract was nearly always (in 98% of cases) higher than that determined colorimetrically, with an average difference of 19% of measured amount of P. Differences between the amount of extracted P could be explained by the active agents in the extraction solutions and their efficiency in releasing P from different minerals and organic compounds.

In the Baltic Sea area, either PSI or DPS in the acidic AL extract alone is suggested to be a general good predictor of soil capacity to adsorb P or release dissolved reactive P (DRP) to waters, based on the results from the limited numbers of sites in the present study. PSI was related to different soil characteristics at different sites (Table 1). The results showed good agreement between all methods analysed and DRP in stream water, except for one site with high clay content.

At present, the results obtained by the different methods are often compared without considering the efficiency in extraction solutions. A way to solve this problem may be further intercalibration between the methods or development of a common method for risk assessment of P losses.

**Table 1.** Regression equations for phosphorus sorption index (PSI) in terms of other soil characteristics. The units used in the regression are Al (mmol kg<sup>-1</sup>); Ca (mmol kg<sup>-1</sup>); Fe (mmol kg<sup>-1</sup>); C (%)

Site	Regression equation	adj. r <sup>2</sup>	p
1	$PSI = 0.929 + 0.599Fe-AL + 0.00814Ca-AL + 0.0273Al-AL$	0.92	<0.001
2	$PSI = - 1.28 + 0.731Fe-AL + 0.0938Al-AL$	0.92	0.010
3	$PSI = 0.01 + 0.370Fe-AL$	0.24	0.010
4	$PSI = 1.30 + 0.235C + 0.0433Al-AL$	0.83	<0.001
5	$PSI = 1.97 + 0.0879Al-AL$	0.61	0.002
6	$PSI = 0.562 + 0.000701Ca-AL + 0.00376Al-AL$	0.64	<0.001

## **Development and validation of new fertilizers of high bioavailability and reduced nutrient losses: “Rhizosphere controlled fertilizers (RCF)”**

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The development of highly efficient granulated fertilizers is of great importance to optimize the economical cost of each unit of fertilizer applied and to reduce the environmental contamination caused by nutrient losses. This study proposes a strategy that consists of developing specific fertilizers having nutrient release patterns that are dependent on plant activity in the rhizosphere, thus becoming more sensitive to plant nutritional needs. Therefore, the aim is to protect P from soil fixation and losses maintaining it bioavailable at the moments of plant uptake. This type of fertilizer is named “rhizosphere-controlled fertilizer” (RCF fertilizer). This fertilizer is based on the introduction of an organomineral matrix composed of humic-multimetal-phosphates (García-Mina, 2006). The presence of this matrix modifies the nutrient release pattern of the fertilizer. In this way there are two main nutrient fractions: (i) a water-soluble fraction or “starter” fraction and (ii) a “rhizosphere-controlled” fraction insoluble in water but soluble by the action of the rhizospheric acids released by microorganisms and plants, specially in nutrient demanding conditions. This study shows the chemical and structural characterization of the RCF organomineral matrix, as well as its efficiency in adapting nutrient fertilizer release rates to plant needs, principally with respect to P and N, which was directly correlated with the root release of rhizospheric organic acids (Erro et al., 2007; 2009, 2010). It is demonstrated that this RCF nutrient protection was also reflected in the significant reduction in nutrient losses concerning both ammonia volatilization and N leaching in a pot system study (Erro et al., 2007). Finally, pot experimental studies on the effect of RCF based P-fertilizers on the growth and P assimilation of wheat plants cultivated in alkaline-calcareous and acid soils showed the higher efficiency of RCF-P with respect to that of water-soluble P (simple superphosphate). This RCF-P higher efficiency was well correlated with those P soil fractions related to potential plant available P.

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## Characterization of organo-metal-phosphate complexes. Development of new superphosphates: organic-complexed superphosphate (CSP)

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A number of studies have proposed that the formation of stable and water-soluble organo-metal-phosphate complexes (OMP) is involved in the role of humic substances and soil organic matter as protectors of phosphate (Pi) from soil retrogradation.. Recently a number of studies described the formation and physico-chemical features (molecular size distribution, maximum binding ability (MBA), stability constants and molecular electronic configuration) of OMP involving humic substances (Guardado et al 2005, 2007 and 2008; Riggle and von Wandruszka, 2005).

In this work we present new results showing the ability of different types of humic-based OMP to protect soluble Pi from soil fixation in several soil types (Pi absorption isotherm studies), and the plant ability to take up Pi from humic-based OMP. Likewise, we describe the technical application of these findings in the development of a new family of superphosphates: organic-complexed superphosphate (CSP) (Roullier Group; **FR 1050009**; 2010). The new methodology involved in CSP manufacture involves the formation of organo-calcium-phosphate complexes. These complexes are studied by using <sup>31</sup>P NMR, fluorescence and molecular modeling. Finally, pot studies on the effect of CSP on the growth and P assimilation of wheat plants cultivated in alkaline-calcareous and acid soils shown that CSP is more efficient than ordinary superphosphate (SSP) as P source for plants cultivated under P deficient conditions. This CSP higher efficiency as P source was well correlated with the value of those P soil fractions related to P potentially plant available.

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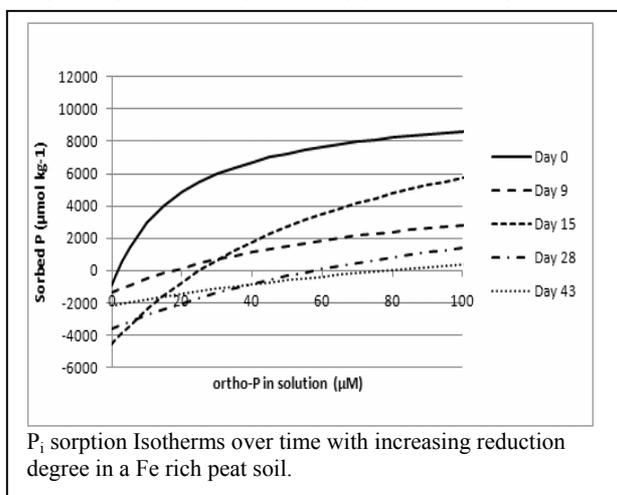
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## Phosphate sorption in anoxic soils - as influenced by the degree of Fe<sup>III</sup> oxide reduction

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There is much focus on wetland restoration as mitigation options for reducing agricultural nutrient losses. While wetland restoration is considered efficient measures towards N, the impact on phosphorus (P) is much debated. Phosphorus retention in Danish lowland soils mainly occur by phosphate (P<sub>i</sub>) sorption to Fe<sup>III</sup> oxides. Under reductive conditions Fe<sup>III</sup> oxides are reduced to Fe<sup>II</sup> which may potentially lead to P<sub>i</sub> release. The question is then, i) to what degree can the Fe<sup>III</sup> oxide pool in a soil be reduced and, ii) what happens to the P<sub>i</sub> sorption properties of the soil when the Fe<sup>III</sup> oxides are reduced? We investigated the P<sub>i</sub> sorption in a cultivated, lowland peat soil, rich in Fe (55g Fe kg<sup>-1</sup>). During a gradual reduction of Fe<sup>III</sup> by wetting the soil and keeping it strictly anoxic (in a N<sub>2</sub> atmosphere at room temperature), 0.1M HCl extractable Fe<sup>II</sup> and P<sub>i</sub> in the soil solution (P<sub>sol</sub>) was measured. At four occasions we measured the P<sub>i</sub> sorption(S) by means of sorption isotherms



fitted by a modified Langmuir equation;  $S = (S_{inc} K_L (P_{sol} - D) - 50D) / (1 + K_L (P_{sol} - D))$ . By introducing the variable  $S_{inc}$  the equation includes the native P<sub>i</sub> in the soil and allows for desorption. The average reduction rate was 16 mmol Fe kg<sup>-1</sup> day<sup>-1</sup> and reached a maximum reduction level of 75% (727 mmol kg<sup>-1</sup>) of the citrate-bicarbonate-dithionite extractable Fe (Fe<sub>CBD</sub>) after 49 days. PH increased from 5.8 to 7.8. The amount of released Fe<sup>II</sup> exceeded the estimated pool of amorphous Fe<sup>III</sup> oxides (237 mmol kg<sup>-1</sup>), determined as oxalate extractable Fe (Fe<sub>ox</sub>) in the oxic soil sample. This shows that in this soil, even crystalline Fe<sup>III</sup> oxides are microbially reduced. The

sorption isotherms showed that with increasing degree of reduction the Langmuir constant ( $K_L$ ) decreased (from 0.05 to 0.005 kg µmol<sup>-1</sup>), the point of zero net P<sub>i</sub> sorption (EPC<sub>0</sub>) increased dramatically (from 1.7 to 66 µM) and the desorption (D) increased (from 80 to 1200 µmol kg<sup>-1</sup>). Even a small change in Fe<sup>III</sup> reduction caused a pronounced increase of EPC<sub>0</sub> indicating that temporary Fe<sup>III</sup> oxide reduction alter the Pi retention properties of lowland soils.

## Advances in phosphorus speciation in environmental samples by Synchrotron-based X-ray absorption Near-Edge Spectroscopy

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In developing countries P from agro-industrial byproducts can be either a significant source of freshwater pollution or a valuable fertilizer for soil amendment. For both cases, it is important to speciate the P in common byproducts. We have investigated dry (COD) and wet (COW) coffee, sisal (SIS), barley malt (BEB) and sugarcane processing (FIC) byproducts, and filter cakes of linseed (LIC) and niger seed (NIC) with sequential P fractionation, solution <sup>31</sup>P nuclear magnetic resonance (NMR) spectroscopy, and X-ray absorption near edge structure (XANES) spectroscopy at the P K- and L<sub>2,3</sub>-edges. Sequential fractionation recovered 59 to about 102% of total P (P<sub>T</sub>), and more than 50% of P<sub>T</sub> was extracted by H<sub>2</sub>O and NaHCO<sub>3</sub> in five out of seven samples. Since sequential fractionations only provided a first hint to potential P mobilization but no direct speciation, we investigated the residue after each extraction step by P K- and L<sub>2,3</sub>-edge XANES. Semiquantitative evaluation of P K-edge spectra of by linear combination (LC) fitting as well as the L<sub>2,3</sub>-edges spectra provided unequivocal evidence for the enrichment of Ca-P along the extraction sequence and its complete removal by the H<sub>2</sub>SO<sub>4</sub>-treatment for the FIC sample. The LC fitting was unsuccessful for the NIC samples, most likely because of the absence of significant proportions of Ca-P as confirmed by both P XANES methods (Kruse et al., submitted). In the bulk samples of agro-industrial byproducts, the results of sequential fractionation, especially the proportions of inorganic and organic P were confirmed by <sup>31</sup>P NMR spectra. Again, only the combined application of P K- and L<sub>2,3</sub>-edge XANES provided unequivocal evidence for the abundance of Ca-P phases in a few samples (Negassa et al. 2010). The results strongly called for the combined use of all these four analytical methods for a comprehensive P speciation in environmental samples but P-XANES at the P K- and the L<sub>2,3</sub>-edges provided the best information on mineral P phases. Furthermore, for environmental protection and P nutrition of field crops the byproducts should be applied to soils instead of dumping.

Kruse, J., W. Negassa, N. Appathurai, L. Zuin, and P. Leinweber. Phosphorus speciation in sequentially extracted agro-industrial byproducts: Evidence from X-ray absorption near edge structure spectroscopy. *J. Env. Qual.* (submitted).

Negassa, W., J. Kruse, D. Michalik, N. Appathurai, L. Zuin, and P. Leinweber. 2010. Phosphorus speciation in agro-industrial byproducts: sequential fractionation, solution <sup>31</sup>P NMR and P K- and L<sub>2,3</sub>-edge XANES spectroscopy. *Environ. Sci. Technol.* 44:2092–2097.

## **A dynamic model describing phosphate uptake of oilseed rape growing in rhizotrons**

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Mathematical modeling is an important tool in rhizosphere research. Considering that rhizosphere traits govern plant resource efficiency, accurate modeling of plant nutrient uptake is an important challenge in the light of upcoming shortages of mineral fertilizers and climate change. In this work we show a simulation case study where phosphate uptake of a young oilseed rape root system is investigated. Simulation results are compared to experimental data.

We describe the root system growth by the approach presented in Leitner et al. (2010). The parameters of the root growth model are estimated from measured root system architecture parameters. Root branching angles and interbranch distances were obtained using image analysis of photographs of root systems grown in rhizotrons. Root length and diameter were measured with the WinRhizo software package. The model is able to predict the influences of gravitropism and chemotropism. Furthermore, root growth is confined to growth inside the rhizotron geometry. In this way it is possible to directly compare the simulated case study to the real experiment.

In order to obtain a realistic model for phosphate uptake the root growth is coupled with a nutrient uptake model that describes plant and soil interaction. The model describes nutrient transport in soil by partial differential equations. Root system uptake is represented by a sink term following Roose et al. (2001). This sink term depends on the root density in specified small soil volumes. However, effects which are dependent on local root geometry like the overlapping of depletion zones are neglected.

The simulations are performed using Matlab. The partial differential equations of the model are solved using Comsol Multiphysics. By mathematical modeling we hope to increase insight into underlying processes and to provide a flexible tool for experimental design.

Leitner, D., S. Klepsch, G. Bodner, and A. Schnepf. 2010. A dynamic root system growth model based on L-Systems - Tropisms and coupling to nutrient uptake from soil. *Plant Soil*, DOI: 10.1007/s11104-010-0284-7

Roose T, A.C. Fowler, and P.R. Darrah. 2001. A mathematical model of plant nutrient uptake. *J Math Biol* 42(4):347–360.

## **Production and nutrient uptake improvement of sweet corn by organic-inorganic fertilizers and AMF inoculation**

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*Zea mays saccharata* (sweet corn) important as food and ruminant feed in Indonesia. However, most of the land that used for crops production is characterized by a low nitrogen and phosphorus availability. As the high cost of superphosphate (SP) is a major limiting factor, a combination of rock phosphate (RP) fertilization and arbuscular mycorrhizae fungi (AMF) inoculation is a promising technique. Farmyard manure (FYM) is manure made from cattle dung and urine mixed with waste of forages or straw, while it combined with RP called FYM 'plus'. Farmyard manure and FYM 'plus' as organic fertilizer very important to improve soil physical fertility. Inorganic fertilizer important to improve chemical soil fertility, and AMF as biofertilizer could increase soil nutrients availability especially of phosphorus. A field experiment was conducted on acid latosolic soil, low phosphorus and nitrogen availability. The objective of the research is to evaluate the effects of phosphorus and nitrogen fertilizer from different sources combined with AMF inoculation and FYM, on sweet corn yield, nutrient uptake, and dry matter production of stover. The experimental design was a completely randomized block design 8 treatments in 3 replicates. The treatments were T1 (FYM + RP + ZA), T2 (FYM + SP + urea), T3 (FYM + RP + ZA + AMF), T4 (FYM + SP + urea + AMF), T5 (FYM plus + RP + ZA), T6 (FYM plus + SP + urea), T7 (FYM plus + RP + ZA + AMF), T8 (FYM plus + SP + urea + AMF). Size of each plot was 3 m x 3 m, fertilized with 200 kg N ha<sup>-1</sup>, 66 kg P ha<sup>-1</sup>, and inoculated with AMF at level 50 g per hole, according to the assigned treatment at the time of planting. All plot received basal fertilization of KCl (125 kg K ha<sup>-1</sup>). Level of FYM at 1 ton ha<sup>-1</sup> and FYM 'plus' at 1 ton ha<sup>-1</sup> + 66 kg P ha<sup>-1</sup>. Fertilizers of organic and inorganic were placed in the planting hole and filled again, before planting of sweet corn seeds, according to the assigned treatment. Sweet corn seed was dibbled into small holes at the rate of two seeds per hole, spaced 100 x 50 cm. Each plot contained 30 plants from 15 holes planting. *Zea mays saccharata* was cut at ground level on 70 days after planting and analyzed for nutritive value of stover. Results showed that corn production at T8 significantly higher compared to another treatments except T7. Fresh stover production did not affected by the treatments. Dry matter production and nutritive value of stover at combination of AMF + FYM plus + NP from difference sources tend to higher compared to combination of FYM + NP without inoculation AMF.

**Keywords:** Nitrogen, phosphorus, farmyard manure, mycorrhizae fungi, *Zea mays saccharata*

## Response of *Zea mays* to the residual effect of phosphorus fertilizers in latosolic soil

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Maize (*Zea mays* L) is an important crop as a source of food and maize stover used as livestock feed in Indonesia. However, most of the land used for crops production has acid latosolic soils in low phosphorus availability, and phosphorus fertilization needed as solution the problem. A field experiment was conducted to evaluate the effects of RP and SP-36 fertilizers and interaction between treatments on the maize grain yield on acid latosolic soil (low available Bray-II extractable P) on two periods of planting. A split plot design with three blocks as replicates was used. The sub-plot consisted of four levels of P fertilizer (0, 66, 132, and 198 kg Pha<sup>-1</sup>) were added at the first planting period only. At the first and second planting period, maize seeds var. Bisma were sown at a spacing of 70 cm x 40 cm. All plots received basal fertilization applications of 100 kg Nha<sup>-1</sup> as urea and 83 kg potassium ha<sup>-1</sup> as KCl . At harvest, grain yield was calculated on 14 % moisture. Result at the first planting period showed that RP and SP-36 fertilizers significantly increased maize grain yield over those of the control that did not receive P fertilizer. SP-36 application resulted in significantly higher maize grain yield than crops treated with RP fertilizer at the same rate. The residual effect of RP and SP-36 fertilization at the second planting period resulted in the maize grain yield significantly higher than those from control plants that did not receive P fertilizer. Maize grain yield was not significantly affected by the difference sources of P fertilizer at the residual effect. However, the result of the first planting period was higher compared to the second planting period. Phosphorus dynamics in the soils are complex, because they involve both chemical and biological processes and the long-term effects of sorption (fixation) and desorption (release) processes (Bationo and Kumar, 2002).

Table 1. Maize grain yield with P fertilizers and the residual effect

Level of P kg ha <sup>-1</sup>	First Planting Period		Second Planting Period	
	RP	SP-36	RP	SP-36
	ton ha <sup>-1</sup>		ton ha <sup>-1</sup>	
0	4.02 d	4.08 d	2.85 d	3.57 cd
66	5.19 c	6.28 c	3.88 bcd	4.82 abc
132	5.88 bc	7.34 a	5.44 ab	5.63 ab
198	6.25 bc	7.59 a	5.74 a	5.91 a

- Means followed by the same letters at the same period are not significantly different at DMRT 5%

Bationo, A., and A.K. Kumar. 2002. Phosphorus use efficiency as related to sources of P fertilizers, rainfall, soil, crop management, and genotypes in the West African semiarid tropics. Proc.of Food Security in Nutrient-Stressed Environments. ICRISAT-Patancheru, India. pp. 145-154. Kluwer Academic Publishers.

## Effect of pH and soil P content on phosphate solubilization mechanisms by different organic acids in soil

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The release of organic anions (e.g. citrate, malate, etc.) and protons (rhizosphere acidification) by plant roots are considered important plant response mechanisms to increase phosphate ( $P_i$ ) availability in the soil solution and are often observed to occur simultaneously. In non-calcareous soils a major proportion of  $P_i$  is strongly sorbed to metal oxi(hydr)oxides of mainly Fe and Al and organic anions are known to compete with  $P_i$  for the same sorption sites (ligand exchange) or solubilize  $P_i$  via ligand-promoted mineral dissolution. However, the efficiency of these solubilization mechanisms is clearly soil-type dependent (sorption sites, P coverage, pH) and conclusive information on the P solubilizing mechanisms of carboxylates in natural soils is scarce. Also, the effect of concurrent rhizosphere acidification on P mobilization by organic anions is not well understood.

To gain a better mechanistic understanding of the solubilizing mechanisms of carboxylates in soil, the  $P_i$  solubilizing efficiency and the concurrent Fe, Al and Ca solubilization by four different organic anions (citrate, malate, oxalate, malonate,  $2.5 \mu\text{mol g}^{-1}$ ) was investigated in 5 different, non-calcareous soils (Cambisol, Podzol top and subsoil, and 2 Andosols) previously amended with  $25 \text{ mg kg}^{-1}$  and  $356 \text{ mg kg}^{-1}$  P, respectively. To minimise pH effects, the carboxylate solution pH was adjusted with KOH (1M) to the natural soil pH. The effect of rhizosphere acidification was simulated by adding carboxylate solutions with a pH of 3.3 and potassium chloride (KCl, 1 mM) was used as background electrolyte and control for all treatments.

Results of this study indicate that in medium to high sorbing, non-calcareous soils, ligand-promoted mineral dissolution of Al- and Fe-oxides is mainly responsible for a carboxylate-driven increase in  $P_i$  solubility, with the importance of ligand exchange increasing with increasing P sorption site coverage. The relative  $P_i$  solubilizing effect of carboxylates compared to KCl was the greatest in soils with medium to high amounts of anionic binding sites, but decreased on average by 50% at a higher P sorption site coverage (high P treatment).

Simulated rhizosphere acidification generally further increased the  $P_i$  solubilization at low P concentrations while little or the reverse effect was observed in the high P treatment. In soils with high amounts of exchangeable Ca, the proton-induced Ca solubilization reduced soluble  $P_i$ , presumably due to ionic-strength-driven changes in the electric surface potential of the soil matrix favoring a higher  $P_i$  retention.

We conclude that the efficiency of carboxylates in solubilizing  $P_i$  in different soils is a function of both, the amount of anionic binding sites and their coverage together with the corresponding  $P_i$  concentration in the soil solution, with the largest effects being observed at medium to high amount of sorption sites and coverage.

## Effect of parent materials and land use on soil phosphorus characteristics in Southern Belgium

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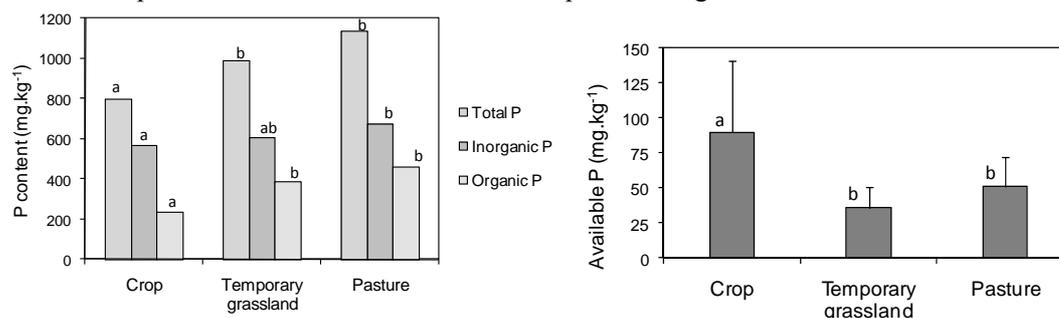
Appropriate management of soil phosphorus fertility should rely upon sound knowledge about phosphorus (P) reserve and bioavailability. The fate of P in the soil-plant-water system depends on both soil characteristics and agronomic practices. The evaluation of soil P compartments can be a tool for the assessment of P susceptibility to migrate to other compartments of ecosystems.

In this study, twelve parent materials were selected according to their spatial representativity. Surface (0-25 cm) and deeper (80-120 cm) horizons have been sampled in ten crop or pasture fields for each parent material. Total ( $\text{HNO}_3 + \text{HClO}_4 + \text{HF}$ ), inorganic ( $\text{H}_2\text{SO}_4$ ), organic (Total minus inorganic) and available ( $\text{CH}_3\text{COO-NH}_4 + \text{EDTA}$ ) P pools were measured in the laboratory.

A large range of P content was observed among results under significant influence of both parent material and land use. Evidence of parent material influence was found for surface as well as deeper horizons for available, total, organic but also inorganic P. Highly significant differences have been shown for these parameters. As a result, a North-South gradient can be observed in Walloon Region.

Land use had also an influence on P content but only for surface horizons. Pasture soils presented higher P content than crop soils but lower available P. Temporary grasslands presented similar properties than pastures, except for inorganic P which showed an intermediate behaviour between pasture and crop.

The ratio of organic to inorganic P depends on land use and no significant differences were observed between parent materials. This ratio is higher in pasture than in crop. Organic P won't be available for plants before mineralization unlike a part of inorganic P.



Generally, the trend of P availability is opposite to total P. This could be explained by the Al and Fe content of the soil, which reflects P sorption capacity. Linear relationships between available or total P and total Al and Fe contents were observed. These characteristics are clearly linked to the soil texture. In light textural soils, such as sandy or silty soils, P is more readily available for plants and for lateral transfers. Other parameters, such as pH, clay content or organic matter which depend from land use, also seem to have an impact on P availability. This study confirmed that the management of phosphorus resources in cultivated soils has to take into account the sub-regional specificities of soil parent materials and land use.

## The Olsen soil P test - trends in time, certainty and sources of variation

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A modified version of the Olsen soil P test has been used by farmers in Denmark since 1987. Initially it was used to roughly judge the soil P status and facilitate recommendations on P fertilization. Today it is also used as an indicator for increased risk of P losses to surface waters, as it is now stated in Danish law-based regulations, that farmers, who wish to extend their number of livestock, have to live up to requirements regarding the soil P test values. This development necessitates high precision and reliability of the test results along with information on how fast Olsen P changes with time in response to different P fertilization. The objective of this study is therefore: (1) to estimate the uncertainty and sources of variation in the results obtained with the Danish modified Olsen soil P test, (2) to suggest how to improve certainty of this soil P test and (3) to evaluate the regional trends in Olsen P from 1987 to 2007. We analyzed three datasets:

***Inter-laboratory comparisons:*** Estimates of uncertainty and sources of variations in modified Olsen P test were obtained from a statistical analysis of results of the mandatory, inter-laboratory comparison of performance of the modified Olsen P, which was carried out on seven authorized soil laboratories between 1997 and 2003. We found that the test result varied systematically between laboratories and between individual test series at the labs. Furthermore accuracy of the labs was highly variable exemplified by a 10 fold larger residual variance at the lab having the highest compared to the lab having the lowest residual variance.

***Repeated analyses of two reference soils at two labs:*** A statistical analysis of results on two reference soils analyzed 205 times between 1999 and 2003 at the lab responsible for practical aspects of the soil laboratory authorization and a similar dataset on the same reference soils analyzed 77 times at our research lab between 2004 and 2008. The date of analysis, temperature and slope of the standard curve was included in this analysis. Test results varied much less between these two labs and with time of analysis than in the above described inter-laboratory comparison. On the other hand this analysis revealed that the test results declined significantly ( $0.8 \text{ mg P kg}^{-1} \text{ y}^{-1}$ ) with time in the oldest dataset, but much less and insignificantly between 2004 and 2008, indicating that Olsen P value of stored reference soils may decline during the early years of storage. Increasing the temperature during extraction with  $1^\circ\text{C}$  resulted in increases of  $0.7 \text{ mg P kg}^{-1}$  in the early test period. In the second and newest dataset the protocol for the analysis only allowed modest temperature variations, which eliminated the effect of temperature. The residual variance of the test value of one of the soils could be minimized by using the test result of the other soil for correction. To overcome the difficulties of obtaining precise and accurate Olsen P values we therefore recommend strict control of extraction time and temperature and inclusion of well stored reference soils in each set of analyses to be used for final correction of the test result.

***Farmers' routine soil analyses:*** Farmers' test results were collected between 1987 and 2007 for seven Danish regions. Regions known to have low animal densities also had lower test levels. From 1992 there was a significant decline in Olsen P in all regions, which corresponds to the positive yet declining yearly net national agricultural P surplus. In regions having low animal densities Olsen P declined faster than in regions having high animal densities.

## Chemical imaging of dissolved phosphorus reveals complex P dynamics in the rhizosphere of *Brassica napus*

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Due to the important and often limiting role of phosphorus (P) for plant growth substantial research has been conducted to understand the rhizosphere processes involved in plant P acquisition. Major mechanisms of P solubilisation such as proton and carboxylate exudation and enzymatic decomposition of organic, P containing substances are well known. However, spatial allocation of P dynamics in the rhizosphere, especially in the vicinity of soil-grown roots, remains experimentally challenging. The aim of this study was to develop a system capable of localised sampling of dissolved P which allows for P distribution monitoring at a sub-mm scale.

Existing diffusive gradients in thin films (DGT) methodologies for sub-mm chemical imaging in aquatic sediments were adapted for their use in the soil and rhizosphere environment. DGT gels were deployed onto *Brassica napus* roots grown in a low-P Eutric Cambisol in rhizotrons for sampling of dissolved P. After drying the gels were analysed for P using Laser-Ablation-Inductively-Coupled-Plasma-Spectrometry (LA-ICP-MS). By these means we were able to map the dissolved P in the *B. napus* rhizosphere.

The resulting images of the P distribution in the rhizosphere were overlaid by photographic images of the roots under investigation. This allowed the allocation of localised changes in P concentration to specific root zones. We observed complex patterns of P distribution in the rhizosphere of the studied roots. As expected, P depletion zones were found alongside the roots. Using mathematical modeling, zones of elevated P concentrations within the depletion zones could be attributed to efflux of P from plant roots. The simulations further showed that DGT measured P efflux from roots was linearly correlated with the P efflux rate. Large increases of the P concentration around the very root tips were also observed. These features could either be caused by mobilisation of P from the soil solid phase or by P exudation or loss at the root tip.

This study is the first visualisation and quantification of dissolved P in rhizosphere soil at the sub-mm scale. Our results contribute to the current understanding of P dynamics in close proximity to plant roots. Apart from further enhancing our understanding of solute dynamics, chemical imaging in the rhizosphere could be applied to select crop cultivars based on their P acquisition efficiency in plant breeding programs. Moreover, chemical imaging can be used for the validation of mathematical models of nutrient uptake and use efficiency. The method presented here is not restricted to P but should in principle be applicable to all solutes that can be sampled by DGT and analysed by LA-ICP-MS.

## Oxygen isotopes in phosphate: Can it work in the soil/plant system?

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First used as a paleotemperature tool (Longinelli and Nuti 1968), oxygen stable isotopes in phosphate ( $\delta^{18}\text{O-P}$ ) are gaining importance in understanding the phosphorus (P) cycling in the environment. The theoretical foundations for its use lie in the following points: in natural systems, P is bound to oxygen (O) which has three stable isotopes; inorganic processes at ambient temperature can not break P-O bonds, but organic processes can, promoting exchange or incorporation of O from ambient water; depending on the process at work, equilibrium or kinetic fractionation accompany these exchanges (Blake et al. 2005), but equilibrium seems to prevail in natural system. Enzymatic activities are suitable examples: inorganic pyrophosphatase, ubiquitous intracellular process, promotes temperature-dependent equilibrium between O associated to P and O in water. On the other hand, extracellular enzymatic catalysis of organic compounds, such as alkaline phosphatase, release inorganic phosphate, which partially inherits the signature of the original compound but also incorporates O with kinetic fractionation. Pioneering studies have focused on processes (Blake et al. 2005) and on the marine P cycle (Colman et al. 2005; Paytan et al. 2002). Only recently researchers have used  $\delta^{18}\text{O-P}$  to track P sources in surface water bodies and soils (Elsbury et al. 2009; McLaughlin et al. 2006) and to understand soil development processes (Mizota et al. 1992). However, they were not fully successful in identifying processes and sources as little information on the effects of processes on the  $\delta^{18}\text{O-P}$  of P pools and of P sources is available. But what can we really expect from using  $\delta^{18}\text{O-P}$  in soils? Which processes will be paramount and to which extent the  $\delta^{18}\text{O-P}$  of a soil P pool will be affected? We have developed a conceptual model where we consider inorganic and organic processes acting in the soil/plant system and fluxes between the different P pools accompanying these processes. Finally we hypothesize on the expected imprints on the  $\delta^{18}\text{O-P}$  of the P pools. Results from preliminary experiments and field observations will support our model.

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## **Anion exchange resin membranes to assess soil P status following organic and mineral fertilizers in eastern Canada**

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Anion exchange membranes (AEMs) have been successfully used as an alternative to chemical extraction in several studies to estimate soil nutrients availability to crops including P (Ziadi et al., 2006; Qian et al., 2007). This technique appeared to provide a better index of plant P availability than chemical extractions and may provide useful tools for monitoring *in situ* soil P availability/mineralization. However, few studies have assessed the utility of AEMs for *in situ* monitoring of P availability especially under organic fertilizer such as compost and paper mill biosolids. We investigated (i) the ability of AEMs as a P index during the growing season of different crops including potato (*Solanum tuberosum* L.), corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr), and (ii) evaluate soil P mineralization during winter after potato and soybean harvest. Instead of soil sampling, AEMs were buried in the field for a period of time depending of the objectives of the study. To measure *in situ* adsorption of P onto membranes ( $PO_{4AEM}$ ), AEMs were buried in the surface horizon (0-15 cm) at different periods during each growing season from early spring until late on fall depending of each crop/experimental site. On average, the AEMs were incubated during 2-week periods during the growing season and up to six months during winter periods. After each contact period, AEMs were collected, washed with distilled water in the field to remove adhering soil particles and placed in individual tubes containing 25 mL 1 M NaCl and analyzed in laboratory for adsorbed  $PO_4$  (Ziadi et al., 1999). Soil  $PO_{4AEMs}$  varied among P application rates, P fertilization (organic or inorganic) and with time in the growing season. Generally, an increase of  $PO_{4AEMs}$  was observed early in summer (mid June) of each year, which we attribute to soil P mineralization. Subsequent decreases in a  $PO_{4AEMs}$  from July until the beginning of September were observed each year, which we attribute to plant P uptake. Phosphorus addition had also a significant effect on  $PO_4$  adsorbed onto AEMs during winter. Relatively large amounts of  $PO_{4AEMs}$  were obtained each spring (after winter period incubation) suggesting the possibility of soil P mineralization during winter. The  $PO_{4AEMs}$  also varied with the profiles where membranes were buried. In general, the highest amounts were obtained in the 0-15 cm layer. Obtained results indicated the ability of the AEMs to detect differences between organic/inorganic P fertilizer treatments and to predict the amount of soil P which is available to different crops produced in eastern Canada. Based on its simplicity, rapidity, and low cost, AEMs have many practical advantages over chemical extractions for assessing soil P availability.

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# **PHOSPHORUS DYNAMICS AND CYCLING**

## **POSTERS**



## Availability of phosphorus and its relationship with some micronutrients in a Vertic Argiudoll in Argentina

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Phosphorus (P) is an essential element for crops. In order to assure a profitable output and return to the soil the P taken out by harvesting, it should be fertilized with this macronutrient in accordance with crop requirements. Nevertheless there exist interactions between P and other nutrients which can affect the availability of the latter if P is used as a fertilizer in high concentrations.

The objective of this study was to evaluate availability of P and its relationship to the availability of iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) in a rotation of wheat followed by soybean in no tillage systems.

In Parana, Entre Rios Province, a soil classified Vertic Argiudoll was sampled in two consecutive assays (2006 and 2007). The grid point sampling consisted of 25 cells 20 by 20 meters each, and all samples were obtained in 12 extractions from 0-5 and 5-20 cm in depth around the center of each area prior to sowing with soybean. The availability of nutrients from 0-20 cm was estimated based on a weighted average of data for other depths. Fertilization was with 250 kg of triple superphosphate in bands application, in the case of wheat (2007). Extractable P was determined by the Bray and Kurtz II method and concentrations of Zn, Fe, Cu and Mn by the EDTA extraction and follow up reading by atomic absorption. The kringing interpolator 3.2 module was used to get distribution maps for each element.

The average concentration of P was 16.6 mg kg<sup>-1</sup> in 2006 and 29.0 mg kg<sup>-1</sup> 2007 (81% higher), with high variation for both samplings. The averages for concentrations of Cu, Zn, Fe and Mn were adequate for both years. Except Zn the other micronutrients were lower in the second year. There was observed a negative correlation between P levels and the concentrations of micronutrients analyzed the second year, connected, among other factors, with the increased P in fertilizer used. In the maps created it can be noted for the second year that the areas with greatest values for P correspond to the lowest levels of the micronutrients studied here (Figure 1). It is concluded that with increasing levels of P in the soil one should consider adding fertilizer with micronutrients.

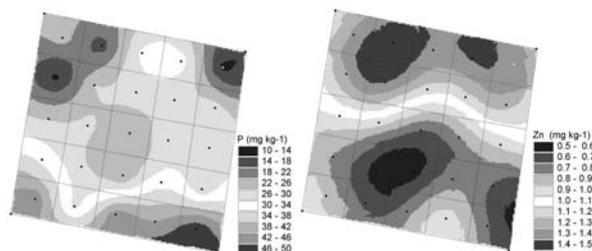


Figure 1. Relationship between availability of P and Zn for the second year.

The present study was carried out within the Technical Cooperation Agreement by and Between The National Institute of Agriculture Technology, Argentina and the College of Agriculture, Iowa State University of Science and Technology, United State of America.

## **Phosphorus under long-term and short-term no-till in a wheat-pea rotation with five P fertilization rates**

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Conservation tillage has become a common practice in the Canadian prairies, to minimize wind and water erosion, conserve moisture and sequester organic carbon. However, little is known about the fate of applied fertilizers with long-term no-till, particularly phosphorus (P), which is relatively immobile and can stratify without mixing from tillage. This study examined the forms and concentrations of soil P under long-term (> 28 years) and short-term (8 years) no-till, using duplicate plots of a wheat-pea rotation. Seed-placed monoammonium phosphate was added at rates of 0, 11.2, 20.4, 33.6 and 44.8 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> added every year to the same plots. Soils were sampled each fall at 0-7.5, 7.7-15 and 15-30 cm depths, beginning in 2008. Preliminary results on soils sampled in 2009 indicate that total P was significantly higher under short-term no-till, while total inorganic P and bicarbonate-extractable (Olsen) P were significantly higher under long-term no-till in the top two depths. There were no significant differences with crop or fertilizer rate, but there was a significant interaction with length in no-till and fertilizer rate for total P and Olsen P, which were highest in long-term no-till receiving higher rates of fertilizer than short-term or long-term no-till receiving lower rates of fertilizer. Total organic P was generally high in these soils, averaging 60% at the surface and 40% at 15-30 cm depth, with no significant differences with length of no-till. Phosphorus-31 NMR showed a range of P forms at all depths, including phytate, DNA, phospholipids, orthophosphate and pyrophosphate. Orthophosphate was highest in the surface of soils receiving higher P fertilization, and was comparable at lower depths regardless of fertilization rate. These results suggest that P fertilizer can accumulate in the surface of soils under no-till, especially sites under long-term no-till receiving high rates of P fertilizers.

## Comparative soil P changes following nutrient management planning

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Lough Neagh is Ireland's largest fresh water lake with a catchment area of 4,450km<sup>2</sup> and is hypertrophic. An estimated 66% of the TP input into the lake is from agricultural sources and most likely from diffuse P transfer from soils (Heaney et al, 2001). Soil nutrient management planning is likely to be one of the most effective mitigation measures to alleviate these transfers but needs to be cognisant of agronomic as well as environmental objectives.

To highlight these measures, in a 2005 demonstration study, farmers were provided with soil nutrient management plans in two small grassland sub-catchments (5km<sup>2</sup>) in Counties Tyrone and Monaghan. This followed field-by-field soil testing and was devised according to advice in the two Irish jurisdictions. The plans advised that only zero P fertiliser should be applied to fields with soil index > 2 (Olsen-P  $\geq$ 16mg/L) or equivalent while fields with index  $\leq$ 2 could continue to receive P fertiliser if warranted.

In the winter of 2009/10, a repeat survey was conducted and similar Olsen-P concentrations and indices were determined in the two catchments. In the Tyrone catchment mean soil concentration for the 160 fields was not found to be significantly different between 2005 and 2010 (t-test  $P = 0.497$ ,  $n = 160$ ); however, the distribution of the soil index classes had changed. In 2005 19% of the fields were index 4 (46-75 mg/L) and in 2010 this had dropped to 12% (Fig.1). Maximum Olsen-P decrease for these high index fields was 20 mg/L. Fields which had initially been  $\leq$ 16mg/L, Olsen-P index 0-1, were fewer and the increase in Olsen-P concentration was most likely due to continued application of P fertiliser as recommended by the NMP. The number of fields within indices 2 and 3 (>16<46 mg/L) had increased as a result of the decreases in the lower and upper ends of the index.

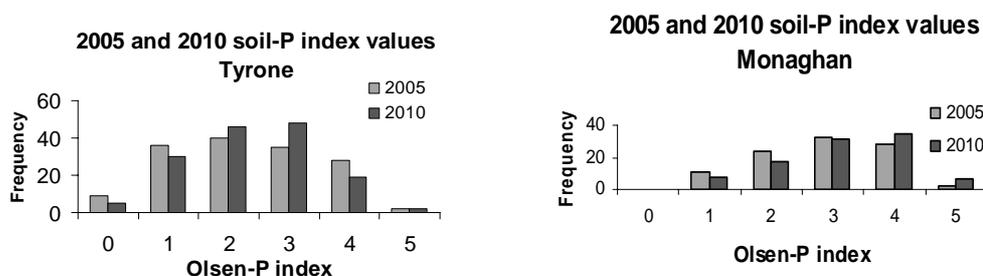


Fig.1. Soil Olsen-P changes in the two catchments from 2005-2010.

In the Monaghan catchment the mean soil P concentration had increased by almost 6mg/L over the five years ( $n = 100$ ), with a decrease in the number of index  $\leq$ 3 fields towards index 4 indicating excessive nutrient management (Fig.1). These data suggest that NMP recommendations may not have been sufficient or followed as rigorously despite farmer advice, agri-environmental schemes and implementation of the National Action Programme. As these Programmes become embedded into national measures to control diffuse P transfers from land to water, a next phase to this work will be to understand the reasons for inconsistent soil response or uptake of NMP in farming landscapes and how these issues can be managed in the future.

## Estimation of critical Olsen P values in reclaimed marsh soils from southwestern Spain

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Chemical indices to assess soil P for environmental or agronomic purposes are based on the estimation of the amount of P that is in equilibrium with the surrounding solution, and can thus be potentially released and taken up by plants or algae. However, the P buffering capacity (PBC) varies widely between soils so different amounts of sorbed P can be in equilibrium with the same solution P concentration. This obviously affects the critical level for a soil P availability index, below which plants cannot take up sufficient P for optimal growth. It is well established that the PBC is a key factor determining the critical value of any soil P test, and should thus be considered for making P fertilizer recommendations. The main objective of this work was to study the effect of different soil properties, in particular PBC, on the critical Olsen P values for fertilizer response in a group of calcareous soils from a reclaimed marsh area in the Guadalquivir River Valley (southwestern Spain). To this end, Olsen P and P in the solution (estimated as that in the 1:10 soil:0.002 M CaCl<sub>2</sub> extract) were determined after each crop in a pot experiment in which four consecutive crops were grown. The “critical” Olsen P level for each soil was then estimated from the relationship between Olsen P and P concentration in solution (linear relationship;  $R^2 > 0.93$  and  $P < 0.01$  in all cases) for the Olsen P value corresponding to 0.02 mg P L<sup>-1</sup>, which is the external P requirement typical for field crops. The P sorption capacity of the soil was characterized by constructing sorption isotherms at 6 days. Data were fitted to the Langmuir equation and sorption maximum capacity,  $X_m$ , surface affinity factor,  $k$ , and P buffer capacity, PBC (slope at 1 mg P L<sup>-1</sup>), were estimated.

The estimated critical Olsen P value ranged from 2.3 to 14.8 mg kg<sup>-1</sup>. This range is much wider than that reported for calcareous clayey soils from southern Spain and limits the usefulness of Olsen P as a P available test for the studied soils. The estimated critical level for Olsen P was related to PBC (exponentially,  $R^2 = 0.63$ ,  $P < 0.01$ ). PBC is related not only to soil's P sorption properties but also to the degree of saturation of the P-sorbing surfaces (as estimated by the saturation index, SI, calculated as the ratio of Olsen P to clay) ( $R^2 = 0.55$ ,  $P < 0.01$ ). This explains the positive linear relationship between the estimated critical Olsen P levels and SI [ $Y = 1/(-0.06 + 0.008 \text{ SI})$ ,  $R^2 = 0.68$ ,  $P < 0.001$ ]. The estimated critical levels for Olsen P decrease with increasing the Na/Ca mole ratio in the soil:water 1:1 extract ( $R^2 = 0.84$ ,  $P < 0.001$ ) because soils with a high Na/Ca ratio in the solution can maintain a higher P concentration in solution with lower amounts of P sorbed than soils with low Na/Ca ratios. Thus, estimates of the critical values for Olsen P above which response to fertilizer application is unlikely depend on those soil properties which affect the relationships between quantity and intensity factors. In particular, the P saturation of the P-sorbing surfaces seems to play a relevant role through its effect on PBC. The simple SI based on the initial Olsen P and the clay content (an estimate of the P-sorbing capacity of soil) can be useful in defining the critical Olsen P values in calcareous soils—in which the widely used test based on oxalate extraction of P-reactive soil components does not perform well.

## **Modelling long-term phosphorus and trace metal accumulation in Swiss agricultural soil**

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Application of manure and inorganic fertilizers is the main pathway for the input of phosphorus (P) and some trace metals (e.g. zinc) into agricultural soils. Accumulation of these elements in soil is undesirable. Above certain levels they negatively affect soil fertility. Their accumulation also implies elevated risks of export with runoff and erosion into surface waters. Furthermore, excessive application of nutrients is a waste of limited resources. A sustainable management of agricultural land and other environmental resources requires that the accumulation of P and trace metals in soils is avoided.

The overall objective of the project is the development of a tool that allows the identification of areas where P surplus inputs and trace metals accumulation are likely to take place, using available information from agricultural statistics and other sources. The specific objective of this work is to model long-term P and trace metal fluxes at field scale for representative sites in Switzerland. To this purpose the EPIC model was calibrated by using data from well documented soil monitoring sites. On these benchmark sites, soils have been sampled every five years and agricultural management has been recorded annually since 1986, allowing the estimation of P and trace metal fluxes. The EPIC model was chosen because of its capability to predict the effects of agricultural practices on soil, water and nutrient fluxes and the resulting impacts on soil loss and water quality as well as on crop yields. Adaptations have to be made so that it can also be used to simulate trace metal fluxes.

The calibrated model will then be used to estimate P and trace metal accumulation in the agricultural soil of the two Swiss cantons Thurgau and Fribourg and to analyze scenarios related to agricultural management options and their impacts on the accumulation of P and trace metals in soil in the long term (see abstract by Gärtner et al.).

## Soil properties and phosphorus isotopic exchangeability in agricultural temperate soils

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Isotopically exchangeable phosphate (P) is the main source of P for most crops but there is no model yet describing soil P exchangeability in relation to soil properties other than the concentration of soil water extractable P ( $C_P$ ). We make in this paper the hypothesis that it is possible, knowing  $C_P$  and selected soil properties determining P sorption, to predict the amount of P located on the solid phase of the soil that remains isotopically exchangeable ( $P_{r1day}$ ) and the soil buffering capacity of isotopically exchangeable P ( $PBC_{iso1day}$ ) both assessed for an exchange time of 1 day. This work was done in three steps. First, isotopic exchange kinetic experiments were carried on 9 soil samples (set A) sampled in 1998 that had been incubated in the presence of increasing concentration of water soluble P. Results from these experiments allowed developing a statistical model to calculate  $P_{r1day}$  and  $PBC_{iso1day}$  as a function of  $C_P$ , soil pH, total organic carbon, clay, oxalate and dithionite extractable Fe. In a second step, we compared  $PBC_{iso1day}$  to the PBC measured from sorption curves and to the PBC measured from Olsen P and water P extractions made in these soils in 1993 and 1998. These estimations of the PBC were strongly correlated with each other suggesting that the model was delivering relevant information on the PBC. In the third step, we compared  $P_{r1day}$  predicted with the model to the values derived from the experiment in an independent set of 52 samples (set B). Predicted and experimental values were different, but the model was able to reproduce the major trends observed in the experimental data. In both soil sets (A and B) highly significant relations were also observed between the  $PBC_{iso1day}$  and the *Olsen-P* to  $C_P$  ratio for soils with  $C_P$  values larger than  $0.1 \text{ mgP L}^{-1}$ . The importance of the soil properties selected in the model on P exchangeability and the limits and applicability of the approach are discussed.

## **The long-term evolution of phosphates from the Cambic Chernozem at Ards Caracal – Romania**

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Within the period after 1989 the production and consumption of fertilizers in Romania have dramatically decreased. Whether in 1989 there were applied, in the lump, 36 kg ha<sup>-1</sup> active ingredient (a.i.) (N+P<sub>2</sub>O<sub>5</sub>+K<sub>2</sub>O), in 2000 there were used 36.5 kg ha<sup>-1</sup> a.i. and in 2007 there were applied 33.9 kg ha<sup>-1</sup> a.i.

The phosphorus and potassium consumption have decreased more than nitrogen. As a result, the yields have decreased as well as the soil phosphorus pool. At ARDS Caracal that belong to the University of Craiova within 1989-2000 period there were applied no phosphorus and potassium fertilizers whatsoever but only nitrogen fertilizers. Within 2000-2008 period there were applied phosphorus as complex fertilizers, 44 kg P<sub>2</sub>O<sub>5</sub> per hectare.

As a result, the soil phosphates content has substantially decreased. In this manner, in 1988 the phosphorus supplying degree of the cambic chernozem from ARDS Caracal was as follows:

- 98 ha very low supplied (less than 8.0 mg P kg<sup>-1</sup>)
- 574 ha low supplied (8.1-18.0 mg P kg<sup>-1</sup>)
- 920 ha middle supplied (18.1-36.0 mg P kg<sup>-1</sup>)
- 632 ha well supplied (36.1-72.0 mg P kg<sup>-1</sup>)
- 260 ha very well supplied (more than 72 mg P kg<sup>-1</sup>)

In 2008 the soil supplying degree by phosphorus has dramatically decreased, the situation being as follows:

- 562 ha very low supplied
- 1,348 ha middle supplied
- 562 ha well supplied
- 12 ha very well supplied.

## Effect of slurry acidification on phosphorous fractionation after soil application

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Animal slurry is commonly applied to soil as a source of organic matter and to supply nutrients to plants, namely nitrogen (N) and phosphorus (P). However, slurry management at farm and field scale led to high ammonia emissions and slurry acidification has been promoted as an efficient solution to decrease such emissions. Nevertheless, little is known about the effect of slurry acidification on P dynamics after soil application. In the present work, a laboratory incubation was performed to assess the effect of pig slurry acidification on P fractionation after soil application. Three treatments were considered: non acidified pig slurry (PS), acidified pig slurry (APS) and a control. Slurry was applied at a rate of 120 mg P kg<sup>-1</sup> dry soil to a sandy soil. Soil samples were collected immediately after setting up the different treatments (T0) and at 182 days (T6). A modified version of the Hedley P fractionation scheme described by Roboredo (2007) was determined in each sample. The fractionation scheme included the extractions with cationic and anionic resin in the membrane form (CAEM-P), NaHCO<sub>3</sub>, NaOH, NaOH plus ultrasound (u.s.) and HCl. Inorganic P was determined in all the extracts by the modified molybdenum blue method. Total P was also determined after a potassium persulphate digestion in the NaHCO<sub>3</sub>, NaOH and NaOHu.s. extracts. Organic P (Po) was evaluated as the difference between total and inorganic P (Pi). Data was analyzed as the increases observed in the PS and APS treatments relative to the control and expressed as percentage. At the beginning of the incubation (T0), the Hedley fractionation revealed that the CAEM fraction represented the majority of the increase resulting from the slurry application. These increases were significantly (P<0.05) higher in the APS treatment, 87.4%, when compared to the PS treatment, 75.8%. Also, when comparing both treatments, it was observed that all the other Pi fractions (NaHCO<sub>3</sub> Pi, NaOH Pi, NaOHu.s. Pi and HCl) presented significantly (P<0.05) lower increases in the APS treatment. There were no significant differences between both treatments with respect to the organic P fractions. At the end of the incubation (T6) differences between treatments followed a similar trend, although the NaOH Po presented small but a significant (P<0.05) increase (0.14% and 0.36% in PS and APS treatments, respectively). When comparing data T0 and T6, PS treatment revealed that the NaOH and NaOHu.s. organic fractions showed significantly (P<0.05) lower increases at T6, when compared to T0 (8.09% and 0.57% for the NaOH Po + NaOHu.s. Po at T0 and T6, respectively). These variations were followed by significant (P<0.05) increases of the NaHCO<sub>3</sub> Po, NaOH Pi, and, particularly, the NaHCO<sub>3</sub> Pi fraction (4.30% and 9.92% at T0 and T6, respectively). The CAEM fraction remained constant with no significant alterations. The APS treatment followed a similar trend between T0 and T6 with the NaHCO<sub>3</sub> Pi presenting the highest increase (from 1.28% to 9.42%). Nevertheless, the CAEM fraction decreased significantly (P<0.05), from 87.4% to 82.6%. The results evidence that slurry acidification enhanced the increases in the most biologically available P fraction, the CAEM. Also, in both treatments, PS and APS, the incubation promoted the mineralization of occluded Po and the consequent increment of more labile and plant available fractions.

Roboredo, M. 2007. A aplicação directa de rochas fosfatadas ao solo. Comportamento químico e agrónómico. Dissertação de Doutoramento, UTAD, 291 p.

## Evaluation of soil test methods for the estimation of plant available phosphorus in soils derived from volcanic material

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Soil testing is the most convenient and widely used procedure for estimating the P status of the soils when providing fertilizer recommendations. Nevertheless, routine tests often fail because the extractant solutions dissolve a fraction of P which is not always proportionally related to plant availability. The complexity of P behaviour involves differences in mineralogical and chemical and characteristics of soils and great diversity exists among and within agricultural regions. Accordingly, the inadequacy of using one single method applicable to all situations has been evident and justifies the effort needed for the selection of the most appropriate procedure for a particular region. Consequently, a study was undertaken to compare soil P tests in soils derived from volcanic materials of Azores Islands, mostly classified in the Andisol Order.

Fifty-one soil samples (0-10 cm) from grazed pastures were selected from different islands in Azores, to represent a wide variety of the major soils from this region. Seven soil P were compared with respect to their effectiveness in extracting P. The extracting procedures used were the following: Bray I (0.03M NH<sub>4</sub>F+0.025M HCl); Bray II (0.03M NH<sub>4</sub>F+0.1M HCl); Olsen (0.5M NaHCO<sub>3</sub>); Egner-Riehm (0.4M NH<sub>4</sub>C<sub>3</sub>H<sub>5</sub>O<sub>3</sub>+0.1M C<sub>2</sub>H<sub>4</sub>O<sub>2</sub>); Truog (0.01M H<sub>2</sub>SO<sub>4</sub>+0.023M (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>); AEM (anion exchange resin membranes) and (CAEM (cation-anion exchange resin membranes). A pot experiment was carried out in a greenhouse with ryegrass (*Lolium perenne*) and orchardgrass (*Dactylis glomerata*). Each soil received two treatments (nil and 150 mg P kg<sup>-1</sup> soil) in four replications. The aerial biomass was harvested twice, at about 20 cm height, dried (65°C), weighed and grounded. Soil P in the extracts was determined by the Murphy and Riley method. The suitability of the different tests was evaluated by correlating the amounts of soil P extracted by each method with relative dry matter yield (P<sub>0</sub>/P<sub>150</sub> x 100) of the biomass. The asymptotic exponential model was used as the expected distribution of the observations. Complementarily, the analytical procedure of Cate-Nelson for partitioning data into two classes was applied and the number of false positive and false negative diagnosis of P deficiency were counted.

The values of r<sup>2</sup> (ranging from 0.654 to 0.477) and S<sub>y,x</sub> (ranging from 13.8 to 19.6) obtained with the regressions revealed different levels of correlation for each soil P test, in the following crescent order: Bray II < Bray I ≈ Truog < Egner-Riehm < CAEM < Olsen < AEM. Considering the false diagnosis of P deficiency (false positives + false negatives), the crescent order was: Olsen (5) < AEM = CAEM (6) < Bray II (8) < Egner-Riehm (9) < Truog (10) < Bray I (12).

For this heterogeneous group of pasture soils, which includes a very wide range of soil pH as well as clay and organic matter contents, a differentiation occurs among soil tests. Olsen (a worldwide used procedure) and methods based on exchange membrane techniques showed equivalent performances in accessing the P status of these soils. The Egner-Riehm method (traditionally used in Portugal for fertilizer recommendations), Truog method (used in some regions with volcanic soils, such as Hawaii) and both alternatives of the Bray procedure revealed to be lower accuracy tests for these particular soils. Those conclusions (i) advice the use of Olsen method as the most reliable test to be used in routine laboratories for these type of soils; (ii) and agree with our previous results regarding the promising use of resin (membrane) techniques to assess the soil P availability.

## Recovery of sorbed fertilizer phosphorus by three water extraction methods

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The replenishment of P in the soil solution is of considerable importance from the standpoint of plant nutrition, for the reason that the quantity of inorganic P in the solution phase at any time is usually insufficient to meet crop requirements over the whole of the growing season.

Through this study we are concerned in the phosphorus recovery from the soil solid phase that have received different levels of P-additions and of acidification applying three different water extraction methods.

A calcareous loamy soil of,  $\text{pH}_{\text{H}_2\text{O}} = 7.9$  was incubated with 0, 80 and 320  $\text{mgP.kg}^{-1}$  soil for one month. Four levels of acidification (pH 7.9, 7.3, 6.0 and 4.5) were adjusted by adding calculated volumes of HCl and incubating the soil samples far further one month, then equilibrated with different rates of phosphorus as 0, 80, 160 and 240  $\mu\text{g P.10 cm}^{-3}$ . The desorbed quantity of phosphorus was determined applying EUF, HWP and multistep desorption methods.

The multistep phosphorus desorption study was applied to the soils with different previous P-additions under two levels of acidity (pH 7.9 and 4.5). For this purpose, phosphorus adsorption was determined with different P-levels: 0, 80, 160 and 240  $\mu\text{gP. 10 cm}^{-3}$  (recently additions) as 1 g soil and 10  $\text{cm}^3$  of aqueous phosphate solution was shaken for 24 hours, and after that phosphorus desorption was measured by extraction with distilled water through 12 steps.

The EUF procedure was applied to the incubated soil samples under two levels of acidification pH (7.9 and 4.5) after adsorption experiments with phosphorus solutions (0, 80, 160 and 240  $\mu\text{gP.10 cm}^3$  (recently additions) as described in multistep water extraction technique. The residual solid phase was transferred quantitatively into the container of the EUF apparatus. The desorption has been conducted under a constant field strength of 400 V  $5 \text{ cm}^{-3}$  and temperature of 20 °C. Ten-minute fractions were collected for 400 minutes (Németh, 1976).

Hot Water Percolation (HWP) was carried out on the soils that have only received previous P-additions (0, 80 and 320  $\text{mgP.kg}^{-1}$  soil) with a wide range of pH (7.9, 7.3, 6 and 4.5) in the HWP instrument.

Some part of the added phosphorus can be recovered by all methods, depending on the dose and time of P addition (previous or recent), on acidity of the soil and on the method used. The desorbable phosphorus amount percentages are approximately 19% of the sum of P-loading at 0  $\text{mgPkg}^{-1}$  level, and rise to about 31 and 64% at 80 and 320  $\text{mgPkg}^{-1}$  levels, respectively. With general conclusion, in acidified cases, the phosphorus recovery are higher than those of non-acidified soils, while with the increasing of P-loading the apposite is true.

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## Phosphorus status in intensively used soils in Krakow

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Many elements can be introduced in the soil as a result of human activity, including mainly: carbon, nitrogen, phosphorus, sodium, calcium and heavy metals. Among them, phosphorus is a particularly sensitive and persistent indicator of the former human settlement and activities. In the soil environment soluble phosphates are rapidly moving in insoluble forms through the chemical adsorption. In acid soils insoluble aluminum and iron phosphates are formed, and in alkaline soils calcium and magnesium phosphates. Soils of urban areas, because of strong human impact, are usually characterized by a large enrichment in phosphorus compounds (Zhang et al. 2001, Gašiorek 2007). Soils of Krakow, a city with more than a thousand years of history - located in the south-eastern Poland, were also exposed to strong anthropopressure. Convent gardens are these places in Krakow, where in the soils, as a result of the impact of the urban environment and horticultural use, occurred accumulation of anthropogenic phosphorus.

On the area of convent gardens in Krakow were performed soil profiles, from which all horizons and anthropogenic layers soil material was taken for further analyses. These soils according to WRB (2006) were classified to Hortic Anthrosol. They were characterized by deep humic horizon, high content of humus and neutral reaction. Phosphorus content extracted in  $0.5 \text{ mol} \cdot \text{dm}^{-3} \text{ NaHCO}_3$  (Olsen method), especially in the humus horizons was higher than  $100 \text{ mg P}_2\text{O}_5 \cdot \text{kg}^{-1}$ . Thus, it was met the criterion of phosphorus content to distinguish in them *hortic* horizon. Research of Zhang et al. (2001) indicate that urban soils with high phosphorus content can contribute to water eutrophication. There was significant correlation between the amount of phosphorus in ground water and the content of phosphorus in the soil determined by Olsen method. In order to verify the possibility of transfer of phosphorus from convent garden soils in Krakow to soil solution an experiment with the use of vacuum soil water samplers was established in spring 2010.

Zhang G-L., Burghardt W., Lu Y., Gong Z-T. 2001. Phosphorus-enriched soils of urban and suburban Nanjing and their effect on groundwater phosphorus. *J. Plant Nutr. Soil Sci.* 164 (3): 295-301.

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## Organic-complexed superphosphate (CSP) and soil biological properties

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The positive effect of the humic substances (HS) on soil phosphate (Pi) bioavailability is well known. In fact, HS are efficient in protecting P from retention on Ca, Al and Fe oxides, in increasing the soil labile P fraction and in improving the utilization efficiency of P fertilizers. As a consequence, a variety of fertilizers consisting of a mixture of superphosphate and humic substances or organic matter has been produced. However, often, the methodology employed in the production of these organo-mineral fertilizers (a mixture during the granulation process) did not involve the real formation of organic-calcium-phosphate complexes, which can more efficiently protect phosphate from soil retrogradation. Recently, a new methodology for the production of an organic-complexed superphosphate (CSP) has been developed (Roullier Group; **FR 1050009**; 2010). This methodology involves the real formation of organic-calcium-phosphate complexes during the manufacture of CSP.

In principle, CSP could be able to protect Pi from insolubilization and retention processes through chemical and/or physical stabilization (Roullier Group; **FR 1050009**; 2010). However, CSP compounds, in particular their organic component, could play a key role in the soil Pi bioavailability also influencing some soil biological processes. Up to date no information are available about that.

For this purpose, we examine the effect of two CSPs, CSP-1 and CSP-2, characterized by a different quality and content of organic C, respect to a mineral superphosphate (SP) on: i) Pi bioavailability in a calcareous soil (measured as Olsen-P); ii) the mineralization of soil organic C (C-CO<sub>2</sub> soil emission); iii) the hydrolysis of fluorescein diacetate; iv) on some specific soil enzymatic activities linked with the principal nutrient cycles.

Our results have shown that: i) CSP-1 and CSP-2 were able to protect Pi from insolubilization in a calcareous soil at different humidity levels. As well known, higher levels of soil humidity, in a calcareous soil, influencing the Ca activity in the soil solution, promote Pi insolubilization as Ca-phosphates. In all the tested humidity conditions, we were able to recovery from CSP-1 and CSP-2 treated soil a Olsen-P fraction significant higher than from SP treated soil. In particular CSP-2 seemed to be the most effective product. In general, Olsen-P measured in CSP-2 treatment was 40 % higher respect to SP treated soil; ii) mineralization of the soil organic C, was significantly higher in the soil treated with CSP-2 and CSP-1 respect to SP treated soil; iii) the dynamic of fluorescein diacetate hydrolysis was in agreement with the mineralization of soil organic C. In fact, in CSP-2 treated soil the hydrolysis level was all the time higher than CSP-1 and SP treated soil; iv) The trend of alkaline phosphatase and urease seemed to confirm the stimulative effect of CSPs, in particular CSP-2.

In conclusion, our results showed that CSP products, added to a calcareous soil at agronomical doses, were able to protect Pi from insolubilization processes and to act as a real biostimulant of soil microbial activities. These effects seem correlated with type and amount of organic C present into the CSP product.

## Soil phosphorus evaluation: correlation between the Olsen and ammonium lactate extraction methods in Portuguese acid soils

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Most methods currently in use to quantify soil phosphorus (P) were developed for agronomic purposes, that is, with the aim of providing an estimate of the phytoavailable soil P. From an environmental standpoint it is well established that freshwater eutrophication is partly attributed to non-point source pollution from agricultural land, and the eutrophication risk is mainly correlated with soil P level. Currently, there are more than twenty methods of soil P extraction, of which about ten are in use in Europe. This makes it difficult to compare soil P levels between countries and even different regions within a country, and also to establish guide-lines in terms of common agronomic and environmental policies. In particular, the Ammonium Lactate (AL) method, which is the official one in Portugal, is seldom used in laboratories of other countries. However, replacing it for one of the commonly used methods is time consuming and costly. Previous work suggested that Olsen's method is suitable for Portuguese acid soils for both agronomic and environmental purposes. The main objective of this work was to compare the AL-P with the Olsen P values and propose an accurate model for predicting Olsen P from AL-P. For this purpose, forty-eight soil samples belonging to twelve different reference soil groups were used. Some soils were incubated with Gafsa phosphate rock (500 mg P kg<sup>-1</sup>) for 120 days at 20° C. Following this incubation period, AL-P and Olsen-P were also measured. Despite their contrasting composition, both reagents extracted phosphate from the same sources (as previously evaluated from a sequential fractionation scheme), albeit in different proportion. Both Olsen P and AL-P were strongly correlated with resin-extractable and dilute electrolyte-desorbable P, which are respectively related to the soil contents in phytoavailable P and P that can be released to runoff or drainage water. Olsen-P and AL-P were strongly correlated ( $R^2 = 0.870$ ), the correlation becoming stronger when three overfertilized soils were excluded (Olsen P = 2.35 + 0.45 AL-P;  $R^2 = 0.908$ ;  $P \leq 0.001$ ,  $n = 45$ ). No correlation was observed for a group of soils recently fertilized with Gafsa phosphate probably because the acidic AL reagent dissolved residual calcium phosphate, thus overestimating the soil content in desorbable P.

## Phosphate desorption in Luvisols and Solonetz from a Mediterranean region

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Transfer of P from soil to water is controlled by the P retention capacity in the solid phase, namely by the equilibrium between adsorbed and precipitated forms. Desorption of P and/or phosphate dissolution govern the amount of P released into drainage water, runoff or freshwater. The Olsen method showed a strong correlation with the capacity of soil to desorb P and, within certain limits, the transfer of P to water. This transfer of P relates to losses that occur either in surface horizons (to runoff or by soil erosion), or in subsurface horizons to drainage water.

This study aimed to evaluate the capacity of surface (Ap) and subsurface (Bw, Bt, Btn and C) horizons to desorb P to water. The study was carried out on samples of a set of eleven pedons from Southern Portugal belonging to three Reference Soil Groups: Cambisols (1), Luvisols (7) and Solonetz (3). After evaluation of P sorption, P was added to soil in amounts from 6 to 160  $\mu\text{g P/g}$  soil to reach a soil solution concentration of 0.5 - 0.6  $\text{mg P L}^{-1}$ , which is adequate for plant nutrition. P was added in the form of a commercial fertilizer (superphosphate, 18%  $\text{P}_2\text{O}_5$ ), using 50 g of soil. After this addition, soil samples were wetted to 70% of their field capacity and incubated for 4 months at 23 °C. After incubation soil samples were finely ground and suspended in a  $\text{CaCl}_2$   $2 \times 10^{-3}$  M solution in the following soil:solution ratios: 1:100, 1:1 000 and 1:10 000. These ratios simulate the amount of P desorbed to drainage water (1:100), to runoff (1:1 000), and to freshwater (1:10 000). Solution was sampled after 14, 30 and 60 days. Solution samples were centrifuged at  $\approx 1.04 \times 10^5 \text{ m s}^{-2}$  for 15 min and P was measured by the Murphey and Riley method (1962).

Soil pH values were 5.3-7.0 in A horizons, 6.3-8.1 in B horizons and 7.1-9.1 in C horizons. Addition of P brought soil samples into the range 7-60  $\text{mg P kg}^{-1}$  (Olsen method). At short term, considering a 60-day plant growing cycle, it was observed that P concentration in solution exceeded 0.1  $\text{mg L}^{-1}$  (considered as the critical level for groundwater quality) in 2 samples (6% of a total of 32); it was higher than 0.05  $\text{mg L}^{-1}$  (the critical level for runoff to prevent water eutrophication) in 47% of the samples; and exceeded 0.02  $\text{mg L}^{-1}$  (the critical level in aquatic systems) in 60% of the samples. Overall, it was concluded that soil capacity to transfer P to water is related with the sorption capacity of the solid phase surfaces, that is, the surfaces of reactive Fe and Al oxides, and with exchange base cations, especially calcium. After fertilization, study soils showed a high capacity to transfer P to runoff and to aquatic systems, which allows us to a proper fertilizer management.

## The long-term P and K depletion trial at Taastrup, Denmark

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Field testing of crop response to P and K application generally requires an experimental site with low available soil P or K status. However, many arable soils are high in available P and K due to generous fertilisation with inorganic fertilisers and animal manures for decades. At the University of Copenhagen the Long-term Nutrient Depletion Trial was established back in 1964 by staff at the Department of Plant Nutrition on 8.5 ha of a sandy clay loam. The site did not receive any P or K containing fertilizers or manures in the period up to 1995 and in this period the field was managed with continuous cereal production. The available P and K levels decreased to relatively low values over these more than 30 years of depletion (Olsen-P of 11 mg kg<sup>-1</sup> and exch. K of 55 mg kg<sup>-1</sup>). In 1996 a new experimental design was applied in the majority of the field, with two more varied crop rotations and seven nutrient application treatments, including both mineral fertilizers and animal manures. The overall objectives of the new experimental design were to study how soil biology, physics and chemistry and crop performance behaved when an arable soil low in P and K, receives moderate amounts of N, P and/or K in mineral fertilizers or animal manures. Specific objectives were to study soil ability to supply crops with N, P and K and crop uptake of N, P and K, physiological response and yield for different crop species and cultivars.

**Table 2. Nutrient treatments, with application rates in kg ha<sup>-1</sup> y<sup>-1</sup> and source.**

Treatment	N	P	K	S	Source
A	0	0	0	0	
B	60	0	60	25	Fertilizer
C	60	10	0	25	Fertilizer
D	60	10	60	25	Fertilizer
E	120	20	120	50	Fertilizer
F	75*	10	75		Animal slurry
G	150	20	150		Animal slurry

\*: 75 kg of total N for the animal slurry treatments corresponds to approximately 60 kg NH<sub>4</sub>-N

Crop biomass production, yield and nutrient uptake results are available for most years and will be summarized in the poster together with some of the data on crop nutrient uptake. The experiment has also accommodated related studies on e.g. the relationship of root hair promoted P uptake of selected barley genotypes to the grain yields in P limiting soil (Gahoonia and Nielsen, 2004) and the ability of different catch crop species to mobilise and take up P and K from soils of low availability, as well as their ability to deliver P and K to the subsequent main crop (Jensen et al., 2005).

Gahoonia, T. S.; Nielsen, N. E. 2004 Barley genotypes with long root hairs sustain high grain yields in low-P field. *Plant and Soil*. 262, 55-62

Jensen LS, Pedersen A, Magid J, Nielsen NE. 2005 Catch crops have little effect on P and K availability of depleted soils. *DARCOF e-news* 2, 1-7.

## Phosphorus fertilization of maize seedlings using side-band injected animal slurry

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The third *Action plan for the aquatic environment* passed by the Danish parliament in 2004, stipulates a 50% reduction of the P-surplus in 2015. Maize is typically fertilized with animal manure in amounts, which fully covers the P requirements. On top of that, mineral P fertilizer is placed close to the seeds at sowing to overcome potential P deficiency in the early growth stages. Maize is typically grown on the same field with high frequency. Therefore maize cropping often cause unintended accumulation of P in the soil. Our aim is to examine the possibilities for replacing mineral starter P fertilization by placement of animal manures as P source for maize seedlings, and this poster will show our preliminary results:

**Field experiment:** In spring 2008, 108 miniplots (1 m row of maize, 10 plants) were sown at Jyndevad experimental station (54° 54'N 9° 08'E) in a coarse sand soil with low P status. Compared with mineral P references, two types of animal slurry labelled with <sup>15</sup>N were side-band injected 5 cm next to the seed row at the time of sowing. Three replicates of each treatment were harvest weekly at six dates from 7<sup>th</sup> May to 12<sup>th</sup> June. Plant dry matter was analysed for N, <sup>15</sup>N, P, K, S, Ca, Mg, B, Na, Mn, Fe, Cu, Zn, Cd and Al.

The concentrations of <sup>15</sup>N and K in plants were increased 2-4 weeks after emergence synchronous to a decrease in the Ca and Mg concentration irrespective of slurry type. Placement of mineral P fertilizer affected the plant P concentration 2-4 weeks after emergence. In contrast, animal slurry P did not affect the plant P concentration, which was comparable with the mineral reference without P. Placement of a reduced rate of mineral P fertilizer within the seed row increased the plant P concentration 1-3 weeks after emergence, but also cause a 2-4 days delayed germination and a tendency to reduced plant density.

The roots of maize were able to take up N and K from the animal slurry, but P uptake seems unaffected. This illustrates that specific, yet undefined, barriers, may restrict P uptake in maize seedlings from the slurry.

**Growth chamber experiments:** The field experiment raised the questions of how to identify and eliminate the barriers limiting P availability in manure applied at sowing. Processing of animal manures may be a way to go. In April 2010 a pot experiment was initiated with the aim to study the interaction between side-banded P-sources and temperature. We side-band injected cattle slurry treated in three different ways (raw slurry, acidified slurry and raw slurry spiked with mineral P) side-banded to the maize seeds. The reference treatments were side-banded N and NP. Maize was grown at 7, 10 and 13°C (increasing +0.1°C/day, ±4°C during 24h for a day/night of 16/8h). Plants are sampled at one of 9 dates during the first 6 weeks of growth, in total 270 pots (5 treatments×3 chambers×9 samplings×2 replicates). We will analyse the dry matter growth and off-take of P and other elements.

## **CRUCIAL<sup>δ</sup>: a long-term field trial to assess waste recycling impacts on environment and production system integrity**

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Recycling of waste from urban to rural areas will become increasingly important in lieu of global urbanization dynamics (Faerge et al. 2001), and the finite amounts of available P resources. However, the societal perception of organic urban waste has become increasingly negative, leading to widespread advocacy of incineration. In the post-industrial era a significant change in composition of urban organic waste products has occurred in many first world countries, due to cleaner technologies as well as outsourcing of heavy industries. At the same time animal wastes have attained increasing contents of medicinal residues and other xenobiotics. Therefore we established the 'CRUCIAL' long-term field trial in 2003, in order to meet the societal demands for assuring that recycling of waste can be done without compromising environmental quality and production system integrity (Magid et al., 2006). This facility is offered to the international research community.

The facility was established based on the rationale that by approaching the known limits for a number of heavy metals below which no profound disturbance should be observed on key soil ecological functions, it should be possible to discern if some of the many unknown components in the composite urban waste as well as agriculturally based fertilizers have measurable impacts. The following treatments were established: human urine, sewage sludge (normal and strongly accelerated level), degassed and subsequently composted organic municipal waste (normal and accelerated level), deep litter, cattle slurry, cattle manure (accelerated level), NPK fertilizer, unfertilized but with clover undersown and an unfertilized control.

The poster will present results obtained from a mid-term baseline soil biological characterization, completed work on microbial diversity using high throughput DNA sequencing, as well as work on multiresistant pseudomonad dynamics after fertilization. Ongoing work on leaching of metals and bacteria will be briefly described, and potentials for future collaboration highlighted.

Faerge, J., Magid, J. & de Vries, F.W.T.P. 2001. Urban nutrient balance for Bangkok. *Ecological Modelling*, **139**, 63-74.

Magid, J., Luxhøj, J., Jensen, L.S., Møller, J. & Bruun, S. 2006. Establishment of a long-term field trial with urban fertilizers – is recycling of nutrients from urban areas to peri-urban organic farms feasible? In: Long-term Field Experiments in Organic Farming (eds J. Raupp et al.), pp. 59-78. Verlag Dr. Köster.

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<sup>δ</sup> Closing the Rural-Urban Nutrient Cycle - Investigation of Urban Fertiliser pre-treatments, Agronomic research on Urban Fertiliser turnover in soil and impact on Crop growth, and Initiation of a Monitoring Programme on Soil Quality changes wrought by using Urban Fertilisers in Long-term Field Trials

## Phosphate sorption by acidic soils

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For acidic soils, it is assumed that the sorption of phosphorus (P) by the hydrous oxides of iron (Fe) and aluminium (Al) binds added P, and that the reverse reaction controls the concentration of P in runoff from pasture swards. Therefore, understanding the contribution of different soil properties to P sorption, and the interactions among their effects, may lead to new ways to control the concentrations of P in runoff. The surface properties of the hydrous oxides of Fe and Al are well known, as is the selectivity of oxalate solutions in extracting them. Our interests include the drivers of P runoff from grass swards and indices of P runoff; consequently we explored the variation in P sorption ( $P_{\text{sorp}}$ ) among 42 acidic surface soils as a function of the combined effects of pH and of oxalate-extractable Fe ( $\text{Fe}_{\text{ox}}$ ), Al ( $\text{Al}_{\text{ox}}$ ) and P ( $\text{P}_{\text{ox}}$ ). The soils studied varied widely in these properties:  $\text{Fe}_{\text{ox}}$  (280–4300 mg/kg),  $\text{Al}_{\text{ox}}$  (180–3780),  $\text{P}_{\text{ox}}$  (50–372) and pH (4.0–5.3). All variables other than pH were  $\log_{10}$  transformed to stabilise variance. Multiple linear regression modelling showed that all four explanatory variables significantly ( $P < 0.01$ ) affected  $\log_{10} P_{\text{sorp}}$  and that collectively they explained ~94% of the variation in  $\log_{10} P_{\text{sorp}}$  among the soils. The coefficients of the explanatory variables decreased in the order:  $\log_{10} \text{Al}_{\text{ox}} > \log_{10} \text{Fe}_{\text{ox}} \gg \log_{10} \text{P}_{\text{ox}} > \text{pH}$ . And as predicted from chemical principles, the signs of the coefficients of  $\log_{10} \text{Al}_{\text{ox}}$  and  $\log_{10} \text{Fe}_{\text{ox}}$  were positive, whereas those for  $\log_{10} \text{P}_{\text{ox}}$  and pH were negative. Though the effects of some of these properties on  $P_{\text{sorp}}$  have been documented, to our knowledge this is the first time that their combined effects have been demonstrated. We are in the process of assembling similar data for other soils to test the model and will present the results at the Workshop. The modelling is suggestive of a greater role for the hydrous oxides of Al than of Fe in the rapid initial sorption of phosphate by acidic soils. It also suggests a mechanism for the effect of P buffering on the relation between agronomic soil tests and the concentration of P in runoff that is the subject of another contribution to the Workshop from our group.

## Modeling phosphate adsorption on a Brazilian Oxisol

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Adsorption controls the mobility of nutrients and contaminants in soil and aquatic environments. The prediction of the solubility and transport of these compounds in soils is not simple due to the large complexity of soil systems, with the presence of a variety of different adsorbing materials and competing ions.

Phosphate is an essential compound in natural systems and a major nutrient for terrestrial plant growth. Phosphate ions are strongly adsorbed onto mineral (hydr)oxides, preferentially onto iron and aluminium oxides. Changes in soil surface charge and phosphorus sorption capacity of soils may affect the availability of phosphate in soils.

In the present study, batch adsorption experiments combined with modeling calculations were carried out in order to analyze soil surface properties and phosphate availability in two horizons of a Brazilian Oxisol. Initially, phosphate adsorption isotherms and adsorption edges were obtained at different pH values, ionic strength and phosphate loadings. Even though the mineralogical composition of both horizons is quite similar, phosphate adsorption on the Bw1 horizon is significantly higher than on the Ap1 horizon. These differences are in good agreement with the different charging behaviour for both soil horizons. The pH effect on the adsorption is analogous to the effect observed for typical iron oxides as goethite or ferrihydrite, that is, a decrease in the amount of adsorbed phosphate is observed as the pH increases.

A novel bicarbonate extraction method (Hiemstra et al., 2010) was carried out in order to measure the reactive oxide surface area and the total amount of reversible phosphate in the soil samples. The results of these extractions have been considered in the modelling of the adsorption data. For this purpose, the Charge Distribution Multisite Complexation (CD-MUSIC) model was used. This model was initially developed to describe surface charging behaviour and adsorption properties of mineral oxides (Hiemstra and Van Riemsdijk, 1996), but few attempts have been made with it to describe the adsorption behaviour of field samples

Hiemstra, T., and W.H. van Riemsdijk, 1996. A surface structural approach to ion adsorption: the charge distribution (CD) model. *J. Colloid Interface Sci.* 179:488–508.

Hiemstra, T., J. Antelo, R. Rahnemaie, and W.H. van Riemsdijk, 2010. Nanoparticles in natural systems I: The effective reactive surface area of the natural oxide fraction in field samples. *Geochim. Cosmochim. Acta* 74:41–58.

## Effects of plant uptake on the $\delta^{18}\text{O}$ signature of phosphate

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In order to use phosphorus more efficiently in an agricultural system, it is essential to have information about the P cycling in the soil/plant system. To trace P cycling we are using a new approach, namely the use of stable isotopes of oxygen bound to phosphorus. The  $\delta^{18}\text{O}$  signature of phosphate ( $\delta^{18}\text{O}_\text{P}$ ) can be altered by biological processes, but under ambient temperature and the absence of biological activity the signature of the phosphate source is preserved.

In order to see if and how plants are altering the  $\delta^{18}\text{O}_\text{P}$  values in a soil/plant system, we carried out a preliminary experiment. We set up two hypotheses. The first is that plants preferentially take up the lighter phosphate and leave the nutrient solution enriched with the heavier isotopologue. Secondly, we assumed that the phosphate in the leaves equilibrates with the leaf water, which is enriched in the heavier isotopologue due to evapotranspiration. We used three different plant species (*Glycine max*, *Trifolium repens*, *Helianthus annuus*), grown in a hydroponic system under constant temperature and relative humidity, and with a sufficient concentration of essential nutrients. After six weeks, the isotope signature of the remaining phosphate in the nutrient solution is similar to the value of the phosphate source, showing no preferential uptake of the lighter phosphate by the plants in a P-sufficient system. The signature of the roots is similar to the phosphate source; however this value is also close to the one calculated for the T-dependent equilibrium between water and phosphate (Longinelli and Nuti, 1973). The second hypothesis was verified. In fact, the signature of phosphate in the leaves is heavier than the source, with the obtained values close to what expected from equilibrium.

To prove our first hypothesis we are performing a second experiment. We assume that plants fractionate more in a P limited system, leaving the nutrient solution more enriched with the heavier phosphate than in the case of a P-sufficient system. The experiment is also designed to test whether the phosphate in the roots is equilibrating with the water contained in the roots or if it keeps the  $\delta^{18}\text{O}_\text{P}$  signature of the phosphate source.

Longinelli, A. and S. Nuti. 1973. Oxygen isotope measurements of phosphate from fish, teeth and bones. *Earth Planet. Sci. Lett.* 20: 337-340.

## Spatial variability of phosphorus and its relationship with some of the chemical properties of soils in Argentina Republic

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Considering that soils are heterogenous and their variability depends, among other factors, on original material, topography, climate and human activity, it very important to know their nutrient concentrations and the specific requirements for the different crops, in order to carry out a rational fertilization program. The aim of this work is to evaluate the spatial variability of available phosphorus (P) and its relationship with some properties of the soils under no tillage system in different areas. Studies were made in soils in Paraná, Entre Rios (Vertic Argiudoll, slope 3%), in San Andres de Giles, Buenos Aires, (Vertic Argiudoll, slope 0,5%), and in General Villegas, Buenos Aires (Typic Hapludoll, slope 0,05%). A plot of a hectare was sampled with a 25 cell grid, collecting compound samples in two depths, before soybean sowing. Chemical determination was made using the standard routine methods of the laboratory of the Institute of Soils. The availability of the nutrient from 0-20 cm depth was estimated on a weighted average of 0-5 and 5-20 cm. Result interpretation was based on the critical value rank cited by INTA. Descriptive statistics and geostatistics techniques were used to analyze data and to generate P distribution and availability maps though interpolation. In Paraná the media obtained for extractable P was 17,21 mg kg<sup>-1</sup> with a coefficient of variation (CV) of 40,85%. In San Andrés de Giles the media obtained for extractable P was 4,24 mg kg<sup>-1</sup> and the CV 33,61%, both considered extremely high. In General Villegas the media for extractable P was 10,86 mg kg<sup>-1</sup> with a CV of 26,14%, considered high. Considering land topography, extractable P variability increased when the slope increase. The concentration media for extractable P were in decreasing order for: Paraná, General Villegas and San Andrés de Giles. In Paraná extractable P was very significantly correlated with pH and significantly correlates with manganese (Mn), In San Andres de Giles very significantly with magnesium (Mg) and significantly with Mn and in General Villegas extractable P very significantly with organic matter (OM) and total nitrogen (Nt).

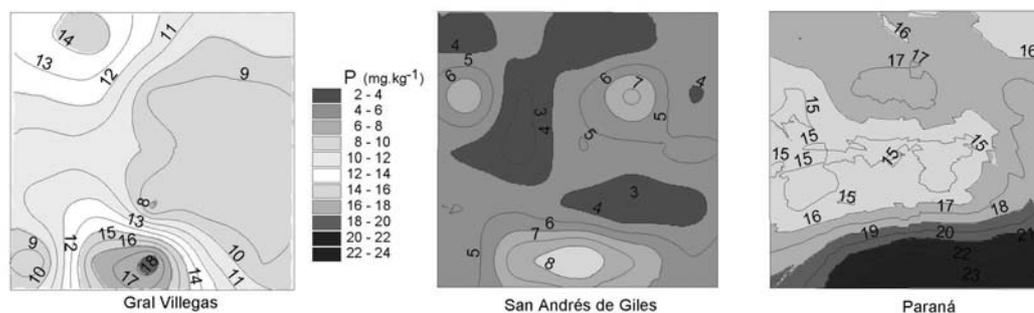


Figure 1. Phosphorus distribution map in the three sites.

The present study was carried out within the Technical Cooperation Agreement by and between The National Institute of Agriculture Technology, Argentina and the College of Agriculture, Iowa State University of Science and Technology, United State of America.

## Using the anion exchange membranes to determine the phosphorus desorption of two distinct soils

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Phosphorus (P) desorption isotherms assess the P stability in soil solution in relation to labile adsorbed P, reflecting the reverse reaction between soil solution P and soil constituents. Despite the practical difficulties in establishing these reactions, P desorption isotherms bear valuable information to predict crops needs and environmental risks when managing soils with various P contents.

The current work uses a new P desorption method that establishes the relationship between equilibrium P concentration and P remaining adsorbed after successive anion exchange membrane (AEM) extractions. Two soils were considered: one soil incubated with 250 mg P kg<sup>-1</sup> (K<sub>2</sub>HPO<sub>4</sub>) under controlled conditions (20° C at 70% field capacity) during 30 days, soil A, and one soil agriculturally enriched in P, soil B. Dry soil samples were allowed to equilibrate in a CaCl<sub>2</sub> 0.01M solution during 21 hours being shaken during four periods of 30 minutes. After, the soil suspensions were centrifuged and the equilibrium P concentrations were determined. It followed an extraction with one AEM in a soil:water suspension during 60 minutes. After, the AEM was removed and P was eluted from the AEM with HCl 0.5M during 60 minutes. The resulting soil:water suspension was restored to give a 0.01M CaCl<sub>2</sub> suspension by adding an adequate amount of CaCl<sub>2</sub>. This procedure was repeated for 18 days. Phosphorus adsorption isotherms, based on the procedure proposed by Fox and Kamprath (1970), were also determined for both soils under study. Data obtained in the adsorption experiment was fitted to the modified Freundlich model [ $p = a \times c^{(b/a)} - d$ ]. The accumulated desorbed P, by the successive AEM extractions and equilibriums, in soil A was 210 mg P kg<sup>-1</sup>, value that did not reach the amount of added P during the incubation (250 mg P kg<sup>-1</sup>). However, when compared to the amount of P initially adsorbed, as predicted by the *d* parameter of the modified Freundlich adsorption model ( $d = 100$  mg P kg<sup>-1</sup>), soil A desorbed higher quantities of P. The equilibrium P concentrations, varied between 2.026 mg P L<sup>-1</sup> in the first equilibrium (removing 29.0 mg P kg<sup>-1</sup>) and 0.038 mg P L<sup>-1</sup> in the last. These observations point at the presence of high amounts of easily extractable P and suggest the low stability of the added P in soil A. Further investigation with respect to soil P enrichment should be carried out in order to bring the laboratory incubation closer to field conditions.

In soil B the accumulated amount of desorbed P, 150 mg P kg<sup>-1</sup>, was lower than the *d* parameter of the modified Freundlich adsorption model ( $d = 577$  mg P kg<sup>-1</sup>) but higher than the extractable P by the one-single extraction Olsen method (104 mg P kg<sup>-1</sup>). In this soil, the equilibrium P concentrations varied between 0.266 and 0.046 mg P L<sup>-1</sup>. These results evidence a higher P stability of soil B and a higher capacity to maintain the equilibrium P concentration in the last equilibriums. The new P desorption method performed in distinct soils has accomplished its aim and has provided reliable data to establish relationships between equilibrium P concentration and adsorbed P.

Fox, R. L. and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Science Society of America Proceedings, 34: 902-906.

## **Influence of different types of nitrogen fertilizers on barley's phosphorus uptake and phosphorus content in barley's tissues**

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A number of pot experiments was conducted to investigate the influence of four types of nitrogen fertilisers: NS 32:5, ammonium nitrate (AN, N 34,5%), NS 26:15 and ammonium sulphate (AS, N 21%) on uptake of phosphorus from soil by spring barley and on phosphorus content in plant tissues. Experiment were conducted on three soil types: sod-podzol well-cultivated soil with high level of P and K (soil I); sod-podzol low-cultivated soil with high level of P and medium level of K (soil II) and sod-podzol low-cultivated soil with low level of P and K (soil III). It was found that application of NS 32:5 increased degree of extraction of phosphorus from soil III and from soil III with additive of ground phosphate rock; application of NS 26:14 increased degree of extraction of phosphorus from soils I and II, application of AS showed similar results. Also, it was found that application of NS 32:5 on soil III increased phosphorus content in plants by 12,3-16,5% in comparison with other tested fertilizers.

*Keywords:* Phosphorus uptake, NS 32:5, degree of extraction of phosphorus, NS 26:14.

## Combining organic and inorganic amendments to improve maize growth and phosphorus availability in phosphorus deficient soils in Kenya

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Phosphorus (P) deficiency is one of the main biophysical constraints for crop production in soils in western Kenya. The use of mineral fertilizers provides a solution to reverse the predominant P deficiency. Because chemical fertilizers are often not within socio-economical reach of smallholder farmers, they use organic materials such as biomass, manures and compost as alternative nutrient sources. Since the P content of plant residues and manures are normally insufficient to meet crop requirements, combination with inorganic P fertilizer is recommended. Apart from providing P, organic fertilizers are expected to have additional positive effects on P availability through changes in soil characteristics otherwise constraining soil P availability. For example, an increase in soil pH will favor P availability to crops in acidic soils. Also, organic anions resulting from decomposing residues can bind some metals such as Fe and Al responsible for P sorption. Understanding the processes behind the beneficial effects of organic resources to enhance P availability and plant growth will contribute to the development of appropriate technologies.

In this research two different types of organic inputs were tested: farmyard manure (FYM) and *Tithonia diversifolia*. Because the quality of organic materials used has been shown to impact the improvement in P availability (Nziguheba et al. 2002), a high and low P input was selected for both organic materials (P contents were 0.48 vs 0.2 % P for *Tithonia* and 0.82 vs 0.21 % P for FYM). In a greenhouse trial of 6 weeks, two soils representative for P deficient soils in the area (Kuinet and Segal) were selected. The P rate of 216 mg P kg<sup>-1</sup> was selected to test positive substitution effects. 0, 25, 50, 75 and 100% of the TSP as then replaced by an organic P input, still maintaining the target P rate of 216 mg P kg<sup>-1</sup>.

Both soils proved to be responsive to P applied, with yields increasing up to 432 mg P kg<sup>-1</sup> applied. The substitution 25 % low P *Tithonia* and 75 % TSP shows a positive substitution effect in both soils. In general, yields are little affected by substitution rate when high P FYM or high P *Tithonia* is used. Application of low P organic inputs at 100 % resulted in yields below the potential of 100 % TSP. These results implying that the quality of organic materials used are important.

## **Early root trait indicators for phosphorus uptake efficiency of soybean varieties in soils with low phosphorus availability**

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Legume crops such as soybean have a major potential to improve the livelihoods of smallholder farmers in Sub-Sahara Africa by increasing the soil fertility status in low-input cropping systems through their nitrogen (N) fixing capacity. By rotating soybean with other crops, farmers can break the spiral of ever-decreasing soil fertility. However, soybean depends largely on the amount of available phosphorus (P) in the soil, since the process of biological N fixation needs substantial amounts of P. Poor P nutrition associated with low P availability in P-fixing soils undermines the positive influence of soybean incorporation in cropping systems. Relatively large amounts of P fertilizers are required to increase production levels, which is neither within reach of resource-poor farmers nor sustainable in the long-term. However, there is potential in exploring the genetic variability between species and plants in their capacity to grow under low P conditions. Plants can adapt to P-limiting environments by developing strategies to enhance their P-uptake capacity, which is generally associated with specific root characteristics, such as root architecture, root length and diameter, root hair morphology, mycorrhizal symbiosis, P uptake kinetics, and rhizosphere processes like rhizosphere acidification, phosphatase activity and exudation of organic acids (described in detail by Gahoonia and Nielsen (2004).

Direct screening of large sets of varieties for P uptake efficiency under field conditions is costly and time-consuming. Therefore we set up an experiment to test whether certain root traits determined in early stages of growth correlate with P efficiency under field conditions. P was adsorbed on aluminum oxides at different P concentrations, whereafter the oxides were mixed with sand. Two-dimensional mini-rhizotrons were filled with the sand-alumina-P medium and used to grow 5 soybean varieties under different levels of phosphorus availability. After 2 weeks, the mini-rhizotrons were scanned to determine basal root angles. Roots were washed out and root length, root diameter and root hair length and density were determined using root analysis software. A field trial with the same varieties and 3 P fertilizer rates was installed on 20 locations in Kenya to test for P efficiency under field conditions across a wide range of soils. The relationship between early root traits determined with this quick screening method and phosphorus efficiency of soybean varieties under field conditions is presented in this work.

Gahoonia, T.S. & Nielsen, E.N. (2004). Root traits as tools for creating phosphorus efficient crop varieties. *Plant and Soil*, 260: 47-57.

## **Comparison of colorimetric analysis, ion chromatography, ICP and DGT for model phosphorus solutions and natural water samples**

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Dissolved organic phosphorus in natural water samples is traditionally measured as the difference between total P – measured with colorimetric method (CM) after digestion or ICP – and inorganic P (Pi) – measured with CM or ion chromatography (IC). Determinations performed in this way are however questionable because of possible hydrolysis during measurement, overestimating the Pi fraction. To obtain a better understanding in the analytical methods for P measurement, the malachite green colorimetric method and ion chromatography were compared to total phosphorus measurement by ICP for two different sets of model P compounds and one set of natural water samples.

The first set consisted of 11 model organic phosphorus components and one polyphosphate. In general, neither CM nor IC measured any phosphate for these model organic phosphorus components (less than 4% of total P). However, acetylphosphate and phosphocreatine did hydrolyze during analysis of both IC and CM and 17 up to 100% of the P was detected. We hypothesize that this is explained because of the labile N-P bond for phosphocreatine and the stable resonance form after hydrolysis for acetylphosphate. Phytate, phosphocreatine, ATP, triphosphate and acetylphosphate were also measured using the diffusive gradient in thin films (DGT) technique. After deployment, the adsorbed P on the mixed binding layer was eluted and measured for total P (ICP) and inorganic P (difference of ICP and CM). The measured total P and Pi are given relative to what would be expected to be measured if a Pi solution was subjected to DGT. Only Pi was detected on the ferrihydrite gel for phosphocreatine and ATP for respectively 60% and 30%. This might be due to hydrolysis of the organic molecule prior to adsorption on the ferrihydrite gel or due to hydrolysis during CM measurement since phosphocreatine proved to be labile during this analysis. Triphosphate and glycerolphosphate hydrolyzed partially prior to adsorption on the ferrihydrite gel so that respectively 20% and 4% Pi was detected. Total phosphorus adsorbed on the ferrihydrite gel accounted for respectively 48% and 54%. Phytate was not able to adsorb on the ferrihydrite gel and was not measured after DGT deployment.

Next, the analysis of an Pi/ferrihydrite solution - a model colloidal P solution - was performed using CM and IC and compared to total P (ICP). Up to 80% of the colloidal bound P can still be measured using the CM because of the acid environment during the analysis. Measurements with IC of colloidal bound P were below detection limit.

In a final experiment, the CM, IC and ICP results were compared for 120 natural water samples obtained from rivers, ditches, drainage tubes and ground water. On average, the CM and IC measured respectively 95% and 77% of the total P (ICP). The difference in these results can be explained by the presence of colloidal P or P associated with Fe or Al, which in turn are part of an organic molecule. For this set of 120 natural water samples, the malachite green CM appears to be a better measure for total P instead of Pi.

## Soil P status under conventional and no-tillage systems in a long-term corn-soybean rotation conducted in eastern Canada

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Agricultural management including tillage system and fertilization may influence soil P status and dynamics. Phosphorus has been found to accumulate in the surface soil layer in long-term and fertilized agricultural systems under no till (NT) management (Selles et al., 1997; Messiga et al., 2010). We investigated the effect of tillage system (NT versus conventional tillage (CT)) and P fertilization on soil P status. The study was conducted on a clay loam soil in a long term experimental site with corn (*Zea mays* L.) -soybean (*Glycine max* L. (Merr.)) rotation established since 1992 in Quebec, Canada. Soils were sampled (0–15 cm and 15–30 cm) during fall 2007, 2008 and 2009 in plots that received 0, 17.5 and 35 kg P ha<sup>-1</sup> and 160 kg N ha<sup>-1</sup> every 2 yr since 1992. Soil was characterized for different parameters including: total C and N, pH, Mehlich 3 extractable nutrients (K, Ca, Mg, Fe, Al, etc.). Soil P status was determined by Mehlich-3 (P<sub>M3</sub>) and water extraction (P<sub>w</sub>). Soil P fractionation and soil biomass P and C were also performed on soil sampled in fall 2008 and fall 2009, respectively. The pH of the plough layer was slightly acidic in both tillage management systems (6.3–6.5) and did not vary from 1992, when the experiment was established. Total C was 2.3% in CT and 2.5% in NT while no difference was observed between the two systems for the total N (0.2%) indicating a limited effect of NT on soil organic matter content. The P<sub>w</sub> concentration was averaged 6.2 mg P kg<sup>-1</sup> in NT and 5.2 mg P kg<sup>-1</sup> in CT. In fall 2007, the P<sub>M3</sub> concentration of the plough layer in NT was 36.9 mg kg<sup>-1</sup> and 27.1 mg kg<sup>-1</sup> in CT showing a trend of lower P<sub>M3</sub> concentration in CT than NT. Soil P<sub>w</sub> and P<sub>M3</sub> varied significantly with tillage, P fertilization and season. In both NT and CT, the P<sub>w</sub> and P<sub>M3</sub> increased with increasing fertilization rate, but the rate of increase was greater in the NT than CT. Total soil P was higher by 20% under NT compared to CT as reported by other studies (Selles et al., 1997). The P/Al saturation index was 0.03 under CT and 0.04 under NT. Soil biomass P increased with P rates only in the 0–15 cm layer under NT. This study indicated that there is an accumulation of soil P (inorganic and organic) under NT system with low potential environmental problems, considering the critical P<sub>w</sub> value of 9.7 mg P kg<sup>-1</sup> and the (P/Al)<sub>M3</sub> saturation rate of 0.05 (Pellerin et al., 2006).

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Pellerin, A., L. E. Parent, C. Tremblay, J. Fortin, G. Tremblay, C. P. Landry and L. Khiari. 2006. Agri-environmental Mehlich III soil phosphorus saturation index for corn in Quebec. *Can. J. Soil Sci.* 86: 897–910.

## Soil P status following annual paper mill biosolids application in eastern Canada

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Industrial by-products such as paper mill biosolids (PB) and different liming materials have been used as fertilizers and amendments in agricultural soils for many decades (Gagnon et al., 2010). However, little is known about the effects of their repeated application on soil nutrient availability, particularly P. A 6-yr field study (2000-2005) was conducted in the province of Quebec, Canada, to investigate the effect of repeated annual applications of different PB and industrial by-products on selected soil chemical properties, especially soil P status. The soil was a Chaloupe loam (Humic Orthic Gleysol) with 149 mg Mehlich-3 P kg<sup>-1</sup>, a P/Al saturation index of 20%, and a pH (water) of 6.2 in the 0-15 cm surface horizon. Different PB rates (0, 30, 60 and 90 Mg wet ha<sup>-1</sup>) and several liming products (lime mud, wood ash, calcitic lime, and Mg by-products) were manually applied each year on the soil surface, about 1 mo after crop seeding. From 2000 to 2002, continuous grain corn (*Zea mays* L.) was planted, and from 2003 to 2005, annual rotation consisted of dry beans (*Phaseolus vulgaris* L.), grain corn, and soybeans [*Glycine max* (L.) Merrill]. Soils were sampled before seeding in May 2003 and at harvest in October 2005. Then, air-dried ground samples (0.20 cm) were sequentially extracted by the Hedley procedure as described by Tiessen and Moir (2007). In addition, soil P availability in the field was estimated by using anion-exchange membranes (PO<sub>4AEMs</sub>, Ziadi et al., 1999). In 2005, PO<sub>4AEMs</sub> and resin-P increased linearly with PB application rate ( $P < 0.01$ ), suggesting that PB increased P availability owing to the mineralization of organic P(Po) associated with the decomposition of PB. The HCl-P fraction was the largest P pool, accounting for about 64% of the total P fraction; the repeated applications of liming products significantly increased this pool and decreased the organic P pools. The NaOH-Po and residual-P were significantly lower in 2005 than in 2003, indicating that PB application without supplemental P fertilizer enhanced the mobility and/or mineralization of NaOH-Po, and the transformation of recalcitrant P to more labile forms with time. Lime mud was found to be the best liming material owing to its high neutralization capacity and positive effect on soil P availability over time.

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# **PHOSPHORUS IN WATER BODIES**

## **ORAL PRESENTATIONS**



## Phosphorus Dynamics in Buffer Strip Soils

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A buffer strip is a generic name for a vegetated piece of land, typically 2-15 m wide, which is managed separately from the rest of the agricultural area. It is usually sited within fields or next to water courses with the purpose of reducing agriculturally derived pollutant transfer to surface waters. The most important pollutant affecting freshwater eutrophication is phosphorus (P).

Most research into P loss from agricultural soils has focused on inorganic P, as organic P was not considered to be readily available to plants and microorganisms. However, in recent years it has been shown that some organic P compounds are, or can readily become, bioavailable, and thus may pose a pollution risk. This is particularly important because organic P can have a greater contribution than inorganic P to total P in leachate from grassland (Preedy et al., 2001). Buffer strips have been shown to be effective at retaining P, but many studies have focused on inorganic P retention or total P retention, with organic P dynamics being inferred by difference. Therefore it is unknown whether there is a net retention or release of organic P from buffer strips.

Presented here are preliminary results of the quantification and characterisation of the P in the runoff from a hydrologically isolated and replicated grassland plot scale experiment, on a drained clay soil. The experiment has been designed in such a way as to allow comparison of the runoff from 40x10 m plots, either with or without 6x10 m buffer strips, and the monitoring of separate surface and subsurface hydrological pathways. Many studies investigating retention of P within buffer strips only account for surface runoff, but losses in subsurface drainage can be significant (Haygarth et al., 1998) and may by-pass buffer strips completely, especially where drainage has been installed.

Previous work has determined the organic P species present in manures and the soil, but we are developing methods to characterise the organic P species in runoff and drainage water from grassland, which is still in its infancy. This will be used to establish whether organic P loss from grassland is in the form of labile phosphomonesters and phosphodiesteres, or the more recalcitrant inositol phosphates, and allow the effect of the buffer strip to be determined. Furthermore the effect of applying cattle slurry will be investigated, as application to lysimeters has been shown to significantly increase organic P concentrations in leachate (Preedy et al., 2001). This will also present an opportunity to characterise both the P inputs to the plots via slurry and the P outputs from the plots in surface and subsurface flows, and hence investigate the mobility of the organic P species relative to each other and inorganic P forms.

Haygarth P.M., Hepworth L., Jarvis S.C. (1998) Forms of phosphorus transfer in hydrological pathways from soil under grazed grassland. *European Journal of Soil Science* 49:65-72.

Preedy N., McTiernan K., Matthews R., Heathwaite L., Haygarth P. (2001) Rapid incidental phosphorus transfers from grassland. *Journal of Environmental Quality* 30:2105-2112.

# Setting critical values for phosphorus loading in ditches and streams with an ecological model

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The Water Framework Directive demands good ecological status of all surface waters. For ditches and (small) lowland streams the good status is described as a clear water state, dominated by a diverse submerged macrophyte community. In many urban and agricultural regions most surface waters do not comply with this condition, due to high nutrient loads and intensive management practices. Subsequent deteriorated ecological states are: single species dominance (e.g. *Elodea*), floating plant dominance (e.g. *Lemna*) or even dominance by filamentous algae. The transitions of vegetation structure are not gradual but occur often suddenly at certain critical nutrient conditions. To study this the ecological model PC-Ditch was developed (Janse, 1998), that was calibrated with datasets of experimental ditches. In a preceding study critical values for nutrients were derived (Van Liere, Janse & Arts, 2007). The ditch research project PLONS (2007-2011) revealed new insights in the effect of nutrient loading and management practices on vegetation structure, but importantly also vice versa. Complex feedbacks occur in contrasting vegetation types, regulated by dissolved oxygen content, temperature, light etc. These conditions, in turn, affect nutrient processes and availability both in the water column and the sediment. As an example: small temperature increase will boost denitrification in ditches rates disproportionately (Veraart, submitted). Also it may be expected that internal phosphorus release will increase with increasing temperature. In this study we present results of simulations with a combination of the PC-ditch model and a dynamic hydrological flow model (Duflow). This coupling enables taking into account the effect of macrophytes on flow properties and subsequent residence times. The objective is to study changes in critical values of phosphorus loading, in the light of management practices and projected temperature rise due to climate change.

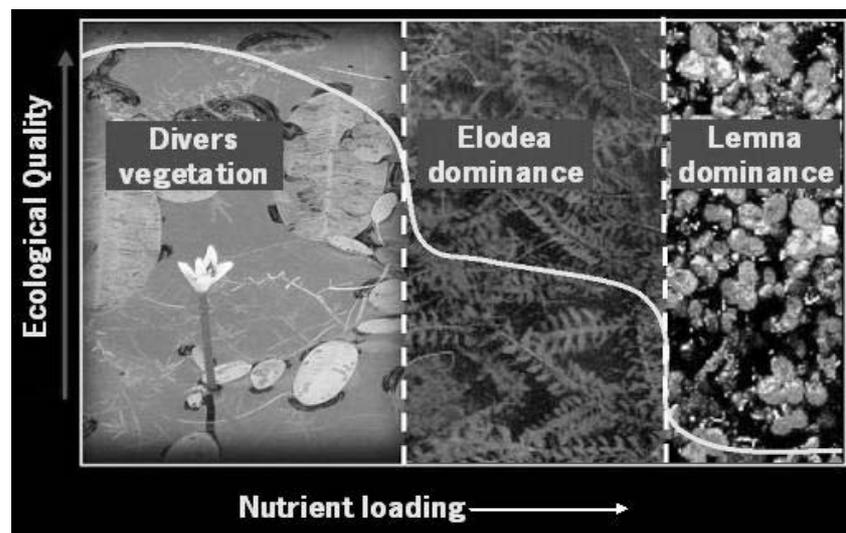


Fig 1. Transitions in vegetation in ditches due to nutrient loading.

## **Should we focus only on P load when aiming to reduce eutrophication in a P-limited aquatic system?**

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Since N and P have been identified to be the principal growth limiting nutrients in most water bodies, eutrophication abatement actions are also focused on reducing the mobilization and transport of these nutrients. However, the concentration of P in a body of water may be affected by many other factors than external P loading. Benthic release of P is a key problem in many strongly eutrophic waters and it also retards the recovery upon load reduction measures. From the viewpoint of benthic biogeochemical processes, the release of P from bottom sediments can be hypothesized to be lowered by an influx on Fe oxides and accelerated by an influx of sulphate. Soil erosion is the main process transporting Fe to sediments. Thus erosion control may not necessarily lead to the desired improvement in the ecological state of a water body as along with the reduced flux of particulate P the flux of Fe oxides is also decreased. The eutrophying effect of sulphate has been known for long. Sulphate is transported via atmospheric deposition but also in agricultural runoff. Extensive data on Finnish lakes showed a correlation between the field percent in the catchment and sulphate concentration in lakes. In this paper, by focusing on benthic processing of P we propose hypotheses on the role of Fe oxide and sulphate fluxes on P cycling and eutrophication in agriculturally loaded lakes and discuss the practical implications.

## **Riparian buffers of small streams have larger phosphorus mobilization potentials than adjacent farmland in Eastern Denmark**

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The mandatory establishment of 10 m riparian buffer zones is a prioritized means of legislators to reduce phosphorus (P) transfer from agricultural land to water in Denmark. Whereas the buffer zones' retention potential for surface transported P is well documented in the international literature, relatively little is known about their overall source or sink function for P transport in landscapes. In Denmark riparian buffers have previously been found to be more P-enriched than adjacent agricultural land indicating amongst others a correspondingly higher P leaching potential.

The objective of our study was to compare the P mobilization potential in soil profiles along short transects spanning from the crest of stream banks across 3 m wide riparian buffers into adjacent arable fields. The selected four sites were situated in the River Odense catchment at 1<sup>st</sup> or 2<sup>nd</sup> order streams and representative for intensively farmed land in the Weichsel moraine landscape of Eastern Denmark. We discuss the spatial distribution of different P forms and the degree of P saturation in different soil profiles in relation to general soil properties, land use, management of riparian buffers and stream typology. Additionally, the P mobilization potential is related to P concentrations in the shallow ground water obtained with piezometers along the transects. Our study questions the effectiveness of riparian buffers in reducing subsurface P losses the low order streams.

## Predicting phosphorus release following wetland restoration

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Restoration of wetlands on reclaimed agricultural lowland has been recognized as one of the most important mitigation options in obeying the quality goals of the European Water Framework Directive. While the nitrogen removal efficiency of restored wetlands is well accepted, the impact of wetland restoration on phosphorus (P) is less obvious. An increasing number of studies have called to the attention that wetland restoration on former agricultural soils may result in phosphorus release. Despite the high priority of wetland restoration there is a serious lack in the documentation of phosphorus dynamics following wetland restoration, and predictive model tools are highly needed. Prediction of phosphorus dynamics in restored wetlands is extremely challenging because of the complex interactions and feedbacks between hydrology, hydrochemistry and sediment geochemistry. We hypothesized, however, that a P risk assessment tool to predict the potential phosphorus releases following wetland restoration could be developed based on easily accessible soil parameters.

A large number of riparian lowlands representing the variation in Danish lowland soil types and geochemistry was sampled and analyzed for a large number of soil parameters including contents and forms of P, Fe, Al. The results demonstrated very large variations in contents of total P (600-16.000 kg/ha in 1 m) in Danish riparian lowland soils, where high contents of TP were correlated with similar high contents of oxalate extractable iron ( $\text{Fe}_{\text{ox}}$ ). Oxalate extractable aluminum ( $\text{Al}_{\text{ox}}$ ) contributed to more than 50% of the P sorption capacity in 1/3 of the soils investigated, but these soils were generally lower in P-sorption capacity compared to the iron dominated soils. The high amounts of Fe-bound phosphorus in a large number of Danish riparian lowland soils, may be critical for the retention of P as wetland restoration most often facilitates reductive Fe(III) dissolution followed by P release.

Batch and convective-flow column experiments were carried out to investigate the iron reduction kinetics and phosphorus release following rewetting. Soil pore water was analyzed for pH, Fe(III), Fe(II),  $\text{PO}_4\text{-P}$  and total dissolved P (TDP) as a function of time following rewetting. Results indicated that the P release kinetics in organic lowland soils could be described by the soil  $\text{Fe}_{\text{BD}}:\text{P}_{\text{BD}}$ -molar ratio (BD – bicarbonate extractable), while organic carbon additionally contributed as a key parameter for mineral lowland soils. Predictive models describing potential P release based on key soil parameters will be presented and discussed.

## **Bank erosion as a phosphorus source in a Danish river basin**

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Bank erosion was studied in the River Odense, Denmark during a three years period (2006/2007, 2007/2008 and 2008/2009). A total of 36 different stream reaches each being 100 m long and representing different stream types and bufferzone types were deployed with a total of 3000 sixty cm long steel erosion pins. Each 100 m reach consisted of five plots each having three columns of erosion pins sitting from stream bed to bank top. The total phosphorus (P) content of the studied banks were analysed from soil samples taken 20 cm and 60 cm above stream bed and in the first meter of the buffer strip. Turbidity was measured at a downstream station in the 475 km<sup>2</sup> catchment and grab samples were taken for analysis of suspended sediment concentration, total phosphorus and particulate phosphorus. Moreover, an in situ sampler for suspended sediment (SubMarie) was deployed at the monitoring station to extract suspended sediment for characterization of the different sediment phosphorus forms being exported from the catchment. Information on the discharge from different point sources of P in the catchment was obtained and the background P loading was calculated in order to establish the amount of P derived from agricultural areas. Bank erosion amounted to an annual gross input of particulate P to surface water between 13.8 and 16.5 tonnes P. The net input of particulate P from bank erosion was calculated as the difference between gross erosion input from plots and the measured deposition within the plots. The net input amounted to 2.9-6.0 tonnes P per year. A relationship was established between gross input of P and net input of P against annual runoff during the three study years the latter relationship showing the best relationship. The net contribution of particulate P from bank erosion amounted to 18-21% of the total P transport at the monitoring station at the outlet of the catchment, and 24-62% of the calculated loss of total P from agricultural land during the three study years.

## Alternatives to Tile Risers for Managing Farmed Depressions

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Closed depressions, also known as prairie pot-holes, are a common landscape feature in the glacial till landscape of the Midwestern United States. When these landscape features are farmed, they are typically drained using a tile riser. A tile riser is a pipe that extends above the soil surface with 2 to 4 cm holes in the side to drain ponded surface water. Recently, watershed scale research has found that greater density of farmed depressions results in greater phosphorus losses to streams (Smith et al., 2008). Many of these depressions are several kilometers away from the streams, and the tile risers provide no filtration of sediments or other contaminants. We developed a blind inlet to remove sediments and contaminants from water via filtration. Two adjacent farmed depressions (3.5 and 4.0 ha) have been located and instrumented in the St. Joseph River Watershed in Northeastern Indiana. The experimental design allowed for drainage to occur through either the tile riser or the blind inlet in each of the monitored depressions. Following storms, hydrology was continuously monitored, and water quality samples were collected for the duration of runoff events. In 2009, one of the depressions (West) had very little residue (~10%) and had a large amount of soil disturbance, while the other depression (East) had considerably greater residue cover (~90%) and no soil disturbance. The West depression was drained using the blind inlet, and the East depression was drained using the standard tile riser. Sediment loading from the West depression was 66% lower than what was predicted using the WEPP model. Soluble and total phosphorus loading from the West depression were decreased by 64 and 52%, respectively, compared to the East depression. An approved USDA-NRCS conservation practice in Indiana has been adapted to include the use of blind inlets to minimize sediment and phosphorus loading to streams. In 2010, a 300 ha monitored watershed is being used to test this practice at the catchment scale. In this watershed, there are 15 tile risers, all of which have been located and are being replaced with blind inlets. Preliminary results from watershed scale testing of this technology will also be presented.

Smith, D.R., S. J. Livingston, B.W. Zuercher, M. Larose, G.C. Heathman, and C. Huang. 2008. Nutrient losses from row crop agriculture in Indiana. *J. Soil Wat. Conserv.* 63:396-409.

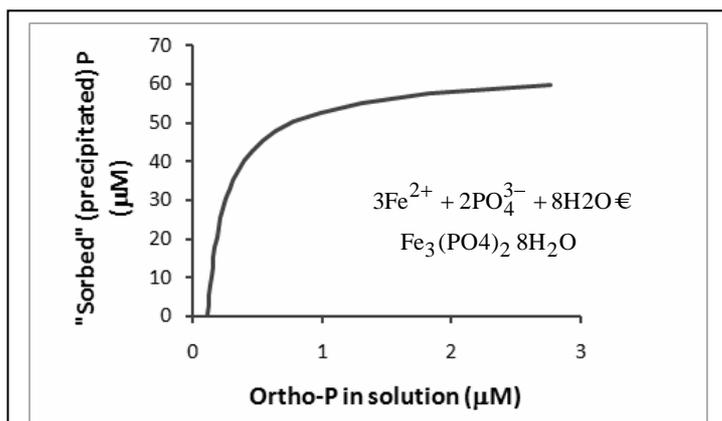
## Do iron(II) phosphates control phosphate solubility in anoxic soils and sediments?

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Investigations of phosphate retention in lowland soils and lake sediments show highly contrasting results ranging from high net P retention to substantial P release as soil/sediment samples become increasingly anoxic. Reductive dissolution of Fe<sup>III</sup> oxides causes release of P. However, in most cases the released P is not transferred to the solution phase, but sorbs to the remaining, non-reduced Fe<sup>III</sup> oxide fraction, Al oxides, and silicate clays, or alternatively phosphate may precipitate e.g. as Fe<sup>II</sup> phosphates (e.g. vivianite, Fe<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub>·8H<sub>2</sub>O).

We are currently evaluating the role of vivianite in these environments. Evidently, for pore water in equilibrium with vivianite, the total ortho-P concentration will be strongly depending on the concentration of Fe<sup>2+</sup>, and pH, and the presence of phosphate complexing metals.



MINTEQ modelled ortho-P "sorption isotherm" for a system at equilibrium with vivianite. pH 7.0, P<sub>CO<sub>2</sub></sub> 0.00036 atm, and total initial solution concentrations of Fe<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Cl<sup>-</sup> of 200, 500, 100 and 1000 µM, respectively.

Assuming equilibrium and that vivianite is the only phase causing P retention then an apparent "sorption isotherm" can be constructed, demonstrating that vivianite can control ortho-P concentrations at a very low level.

A field investigation is being performed where pore water from a waterlogged histosol with a subsurface vivianite-containing horizon is being sampled. Horizon Fe<sup>II</sup> solution concentrations range between 40 and 800 µM, and pH is close to 7. Ortho-P solution concentrations in the vivianite-

containing horizon range between 0.2 and 0.6 µM while concentrations from other anoxic and oxic horizons below and above are several times higher. Similarly, for a lake sediment (lake Ørn Sø, Demark) containing vivianite total ortho-P concentrations vary between 0.2 and 1.2 µM during winter, and with dissolved Fe<sup>2+</sup> concentrations between 200 – 500 µM, and pH around 7.2.

For the vivianite-containing soil horizon and for the lake sediment, equilibrium computations including the concentrations of all main cations and anions show that the saturation index for vivianite is close to zero indicating that ortho-P concentrations are in equilibrium with and controlled by vivianite in these sediment and soil materials, which may strongly limit the solubility of ortho-P.

# **PHOSPHORUS IN WATER BODIES**

## **POSTERS**



## Phosphorus characterization in freshwater lake sediments using $^{31}\text{P}$ NMR spectroscopy

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Sediments of several shallow bays in Lake Champlain, USA, are a significant source of phosphorus (P) to the water column and to cyanobacteria that bloom over extended lengths of time during late summer. A large part of this P has been shown to be strongly tied to iron oxyhydroxide minerals in the sediment; analysis of redox dynamics in sediment porewaters further indicates these iron oxyhydroxides actively change over seasonal and even diel time scales. We have characterized the total, reactive, and organic P content of sediments collected over three summers (2007-2009) in Missisquoi Bay, Lake Champlain, USA, and utilized both NaOH-EDTA and ascorbic acid to extract organic P from these sediments (this is the first known analysis of organic P from Lake Champlain sediments). For NaOH-EDTA analyses, the organic P content ranged from 18-26% of the total P. Orthophosphate monoesters were the dominant compound class, and both phytate and *scyllo*-inositol phosphate were identified in most sediments. Monoester to diester ratios ranged from 4.6 to 13.1, the highest being in the surface sediments in August 2008. Polyphosphate was only detected in a few samples in 2007, but not in 2008. Pyrophosphate decreased across the 2008 season and was not present in the deeper sediments in October. Organic P was strongly correlated ( $R^2 = 0.89$ ,  $p < 0.05$ ) to porewater Fe(II), indicating that its mobility is associated with the reduction of Fe(III) hydroxides. Organic P was also extracted using ascorbic acid in sediments collected in 2009, a method utilized as it specifically targets nanocrystalline iron oxyhydroxides, the mineral phase of primary importance in P mobility for these systems. This extraction yielded a higher concentration of organic P, and had a speciation distribution that was different compared to identical samples extracted using the more commonly used NaOH-EDTA extraction technique. However, these differences were not extreme and did not change interpretations of the overall behaviour of organic vs. inorganic P mobility in iron-rich freshwater sediments.

## **Evaluation of phosphorus sediment remobilization in the Anllóns River (NW Spain) using pH–stat kinetic leaching procedures**

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Anthropogenic inputs of phosphorus (P) into river waters have in some cases increased the P concentrations to excessive levels. Sediments play a key role in the P cycle in river systems, acting as sinks for soluble P but also as P sources, depending of the environmental conditions. In previous works, P was identified as a major pollutant of the Anllóns River. The main P sources were the effluents of a wastewater treatment plant and agricultural activities in the basin. The knowledge of P geochemical dynamics in the Anllóns River is relevant considering that the Anllóns River sediments also contain high geogenic As concentrations (up to 265 mg/kg), which can be released into the water column due to displacement by P, thus increasing health risks. In this work, the remobilization kinetics of P from bed sediments of the Anllóns River is studied employing pH-stat leaching procedures in conjunction with geochemical modeling. Four sediments differing in their location, properties and P concentration (ranging between 434 and 1600 mg/kg) were subjected to pH-stat leaching at pH 4 and pH 10 during 96 hours. The results obtained showed that P release was promoted (between 14 and 26 times) at alkaline pH in comparison to acid pH. At pH<sub>stat</sub> 4 the percentages of P released ranged between 0.3 and 5% of total P, whereas at pH<sub>stat</sub> 10 they reached up to 46% of total P. The greatest relative P mobility was observed in the sediment containing the highest As concentration, although the percentages of As that were simultaneously released were low (~7%). The kinetic study showed that at acid pH the P release profiles were characterized by an initial rapid P release, followed by a continuous decline, a behavior which can be indicative of readsorption and/or precipitation processes. In contrast, at alkaline pH the kinetic profiles were characterized by a rapid P release in the first 24 h, followed by a slow release process, visualized as a plateau in the kinetic profiles. This behavior was adequately described ( $r^2 = 0.951\text{--}0.998$ ) by a “two-pool” model, which considers a “labile” and a “slowly labile” operational P pools in the sediment. It is noteworthy that P and As –examined in a previous work- exhibited similar release behavior and similar kinetic profiles at both pH values, reflecting the similarities in chemical properties of both elements. The low amounts of P released at pH<sub>stat</sub> 4 suggest that P is mainly associated with stable phases of the sediment, such as Fe oxyhydroxides, which are scarcely dissolved at this pH value. On the other hand, P release at alkaline pH was significantly ( $p < 0.01$ ) and positively correlated with the dissolved Fe, Ca, Mn and organic matter. This behavior can be indicative of desorption of strongly adsorbed P by the increased concentration of hydroxyl ions and/or dissolution of organic matter, with the concomitant release of its associated elements. The results obtained let us to conclude that alkalization promotes both the amounts and rate of P mobilization from Anllóns River sediments and that a strong interaction between P and As is expected under these conditions.

## Observations from high resolution nutrient monitoring in rivers

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Phosphorus transfers in rivers can be broadly categorised as long residence time patterns from point sources or episodic patterns from diffuse sources – this is especially noticeable in rural catchments with high soil fertility, low soil permeability and with dispersed point sources such as domestic sewage systems. With multiple transfer patterns from multiple catchment sources, sampling representative water chemistry is problematic; discrete sampling has a high probability of monitoring point source transfers and not diffuse events and storm-water sampling ignores the potential impacts of point sources on streamwater ecology. High resolution methods offer a solution to these issues and have the potential to capture diffuse, point and singular pollution events. In several Irish catchments bankside analysers are measuring sub-hourly TP and TRP concentrations synchronously with water discharge. A further development is the addition of a 0.45µm filtration step that can provide measurements of four P fractions per hour (TP, TRP, TSP and SRP). Results indicate that sediment associated P is the primary fraction transferred in the main river networks during storm events, even from grassland dominated catchments, and that when the storm pathways are disconnected the magnitude of residual P concentrations appears to be concomitant with upstream soil impermeability. Annual sub-hourly P concentration data (e.g. Fig.1) can be organised to show high duration concentration ranges that will have a high ecological impact in rivers and how diffuse events can be described by a power-law relationship indicating a fractal process. These high-resolution concentration-frequency relationships may form the basis for assessing change in river chemistry in catchments with multiple P sources that are controlled under different hydrological conditions.

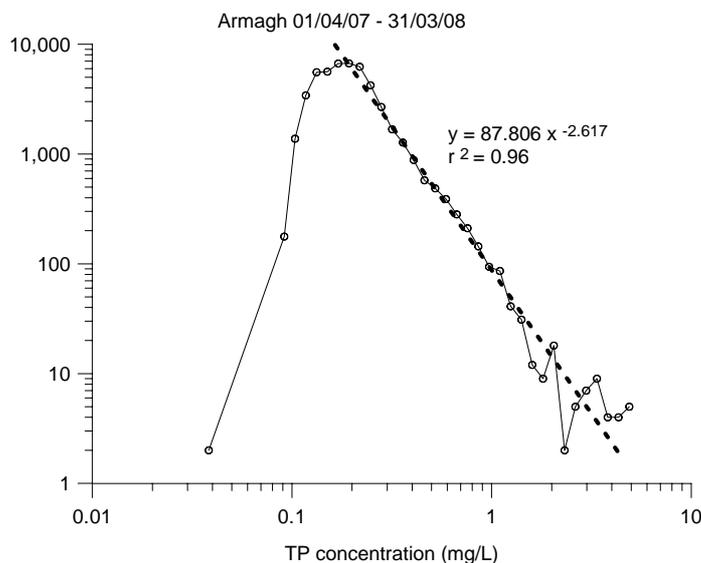


Figure 1. One year discrete magnitude-frequency distribution of TP concentrations from sub-hourly sampling in the Blackwater River, Northern Ireland. The TP range of 0.1-0.2mg/L is due to continuous point source inputs. For concentrations >0.2mg/L the frequency of occurrence of events with size scales as a power-law and is more related to diffuse transfers.

## Seasonal and spatial changes in easily soluble P in buffer zones under different management practices in Finland

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Fertilization and harvesting of agricultural fields cause changes soil P cycle. Along with the human induced changes in soil P status, soil labile P is also subjected to seasonal changes caused by varying e.g. meteorological and soil conditions (Styles and Coxon 2007). Regarding buffer zones (BZs) established between a cultivated field and a watercourse, the P status of BZs is also affected by the management of the field above these sites. The aim of this study was to evaluate the amounts, and seasonal and spatial changes in easily soluble P in differently managed vegetated BZs in Finland.

The vegetated, unfertilized BZs, established in 2002 or 1991 in SW Finland, have been (i) harvested by cutting the grass and subsequently removing the residue or, (ii) the vegetation has not been removed at all. The experimental soil was classified as a Vertic Cambisol (clay content > 50%, pH(H<sub>2</sub>O) > 6.0, org. C < 5.4%). The soil samples were taken with six replicates in 2005 on May, August and October and in 2006 on April to the depth of 10 cm. Dilute CaCl<sub>2</sub> extraction (0.01 M, 1:50 w:v, 1 h) was done for air-dried and sieved (2 mm) soil samples. Molybdate-reactive P (MRP) and total P (TP, acid K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> oxidation) were determined on centrifuged and filtered samples with a molybdenum blue method of Murphy and Riley (1962). The preliminary results indicated that in the uppermost 2.5 cm, differently managed BZs exhibited different, even reverse trends in seasonal variation in soil easily soluble P. In the 14-year-old unmanaged BZ, TP and MRP showed a spring maximum, and summer and autumn minimums, whereas in the 14-year-old mechanically harvested BZ, MRP and TP peaked distinctly in late growing season. Regarding the deeper soil layers, the differences between BZs in seasonal patterns for soil P evened out. However, high variation between replicates indicates the complexities of sampling unploughed and/or unmanaged soils where the organic residues accumulated on the soil surface. Variability within the BZs and mechanisms related to effectiveness of P removal may vary in differently managed BZs, and these differences are reflected to P cycling in the soil. Further studies with more frequent sampling are therefore needed to understand the management-related variation in biogeochemical cycling of P.

Murphy, J. and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* 27:31–36.

Styles, D. and C. Coxon. 2007. Meteorological and management influences on seasonal variation in phosphorus fractions extracted from soils in western Ireland. *Geoderma* 142:152–164.

## **Quantifying phosphorus transport in spring flow in two rivers in northern Sweden – implications for annual load estimates**

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A large quantity of different elements is transported in Swedish rivers as the water discharge reaches its maximum in connection to snow and ice melting in spring. In this study, water chemistry data from daily water sampling during spring flood 2008 and 2009 in the river mouths of Kalix and Ume River in northern Sweden has been evaluated. Both rivers are included in the national monitoring program for large rivers, where the main aim is to deliver data on element loads to the surrounding seas. As much as 30-60% of the total annual load of phosphorus in these rivers are transported during spring flow. This means that there is a risk that the total riverine load of phosphorus to the Bothnian Bay, Bothnian Sea and Baltic Sea may be significantly underestimated if the spring peaks are missed in the regular monitoring program. The water discharge in both Kalix and Ume River is characterized by a distinct peak during the first half of May which will slowly decrease until middle of June when a second, considerably smaller peak will occur, the so-called mountain flood. The daily concentrations of the examined variables pH, total organic carbon (TOC), Tot-P, PO<sub>4</sub>-P, Tot-N, NO<sub>2</sub>+NO<sub>3</sub>-N, Fe, Cu and Zn have similar patterns in both rivers during spring flood. Significant relationships with discharge could be seen in pH, which decreases when discharge increases, while TOC, P-fractions, Fe and Cu increase. The loads calculated from daily samplings have been compared with loads calculated from ordinary monthly water sampling to examine how an increased sampling frequency will affect the quality of the load calculations. The results of the load calculations showed that the total flux of most of the elements calculated from daily samplings was higher compared with calculations from monthly samplings, indicating that the monthly sampling underestimates the loads to the sea. Generally, the proportion of total annual element flux during spring flood is higher in Kalix River than in Ume River for most of the variables. This is specifically pronounced for Tot-P and Fe. During spring flood in the regulated Ume River the loads of Tot-P and Fe are one third of the total annual load, while the loads of Fe and Tot-P in the unregulated Kalix River are almost two thirds of the total annual loads. One reason for the difference may be that the unregulated Kalix River has a more powerful spring flood and a quicker ice breakup that together cause river bank erosion and transport of suspended particles downstream. In the regulated Ume River the river bank erosion is probably not as pronounced as in Kalix River and sedimentation of suspended particles may be more effective. Using monthly sampling in an unregulated river like Kalix River will, hence, in most cases lead to underestimation of the total annual flux of many water quality variables, especially for phosphorus. Flow-weighted water sampling would improve the precision in element flux calculations for unregulated rivers in northern Sweden but may complicate trend estimates. An alternative approach could be to intensify the water samplings by, for example taking weekly or daily samples during spring flood. Since regulated rivers have a more constant discharge over the year and, thus a more or less constant element flux, monthly samples will produce reliable annual load estimates for these types of rivers.



**PHOSPHORUS MOBILIZATION AND MODELLING  
AT THE FIELD AND CATCHMENT SCALES  
(JOINT SESSION IPW6 –COST 869 WG1)**

**ORAL PRESENTATIONS**



## Processes involving phosphorus accumulation and losses in undisturbed soil columns

Teresa Borda<sup>1</sup>, Luisella Celi<sup>1</sup>, Daniel Said-Pullicino<sup>1</sup>, Dario Sacco<sup>2</sup>, Elisabetta Barberis<sup>1</sup>

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Nutrient losses to ground and surface waters following soil fertilisation largely contribute to the deterioration of water quality, and may lead to eutrophication of adjacent water bodies. Inappropriate fertiliser management may result in a supply of P that exceeds crop needs, and in the long term, may also affect soil P buffer capacity. These processes may lead to P losses via runoff, mainly in the particulate form, and leaching. Based on these considerations the effect of agronomic practices on P losses was evaluated in two temperate overfertilised cropping systems (NW Italy) managed since 1996 with (traditional; TRAD) and without (agro-environmental; PSR) mineral P fertilisation. Over 14 years, the absence of P fertilisation in the PSR system led to a reduction in Olsen P levels from 45 to 20 mg/kg, whereas Olsen P levels in the TRAD plots remained almost constant (35 mg/kg).

To evaluate the effect of fertilisation and organic amendment on the risk of P losses from TRAD and PSR maize plots, in 2010 three subplots were established in each system and treated with (i) mineral P, (ii) municipal solid waste compost, and (iii) a no P control. A compost application dose was chosen to deliver the same amount of total P as for the mineral P subplots. Intact undisturbed soil columns (0-15 cm) were installed in each subplot immediately after fertilisation, by means of PVC tubing each having an anion exchangeable resin bag at the bottom to trap the leached soluble phosphate. Soil columns and bulk soil samples were destructively sampled in triplicate at four different times during the growing season to evaluate P losses after fertilisation, before and after irrigation/rain events and at harvest.

P leaching was evaluated by analysing the anion exchangeable resins while P susceptibility to runoff was evaluated by applying a soil dispersion test which simulates surface runoff, in order to quantify the amount of total dispersed solids and the main forms of soluble and colloidal P. In addition, the main processes involved in soil P cycling, including crop P uptake, microbial activity and P deriving from free and stabilized organic matter have been studied.

## Characterizing dissolved and particulate phosphorus in snowmelt runoff from cattle winter bale-grazing sites

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Bale grazing of cattle in fields during the winter has become a common practice in the Canadian Prairies, replacing winter corral feeding. The aim is to have the cattle spread feed and manure uniformly across the field, thereby increasing soil fertility while reducing manure handling, hauling and spreading. However, little is known about the environmental impact of this practice, particularly with respect to nutrients in spring runoff while soils are still frozen. To test this, we established six 350 m<sup>2</sup> microwatersheds. During the first year (winter 2009) of the three-year study, four microwatersheds were bale grazed (300 cow days ha<sup>-1</sup>), and two were ungrazed controls. One-litre runoff samples were collected during a thaw event in March, 2009, and were filtered to through 0.7-µm glass fibre filters. Particulates were analyzed for total P, C and N. Filtrate was analyzed for dissolved C, ammonium, nitrate, total N, total P and molybdate-reactive P (MRP). Additional 5-litre samples were also analyzed by <sup>31</sup>P NMR to characterize dissolved and particulate P forms, along with samples of manure mixed with hay and plant litter from the feeding site. Preliminary results indicate that concentrations dissolved C, particulate organic C, total N, dissolved ammonium, total P, dissolved total P and MRP were significantly higher in runoff from bale-grazed sites relative to ungrazed controls. Dissolved P from bale-grazed sites was almost entirely orthophosphate, while a range of organic (orthophosphate monoesters, including phytate, and orthophosphate diesters, including DNA) and inorganic (orthophosphate, pyrophosphate) P forms were seen in runoff from the control sites. There were no significant differences in particulate P concentration. Particulates from both bale-grazed and control sites contained both inorganic and organic (orthophosphate monoesters, including phytate, and orthophosphate diesters, including DNA) P forms, as did the manure/hay and litter samples. The P forms in particulates from both feeding and control sites were significantly different from P forms in the manure/hay and litter samples. These contained more orthophosphate and less organic P than the particulates. Because this is an on-going project, it is not possible to draw conclusions about the full impact of winter bale grazing on nutrients in runoff. However, the work to date shows that it is possible to quantitatively characterize both dissolved and particulate P forms in relatively small volumes of runoff. This gives a much clearer picture of the forms in which P is transported than do simple measurements of total P and MRP.

## **Modeling Nitrogen and Phosphorus transport in a small agricultural stream in Eastern Sweden**

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In Sweden, environmental monitoring and modeling of nitrogen (N) and phosphorus (P) transport from arable land have been conducted in several scales ranging from soil profiles, experimental plots, single fields, small agricultural catchments to large river basins. At smaller scales (experimental plots, fields), P transport has been modeled with the focus on P chemistry and soil properties as explanatory variables. At larger scales (river basins), the main focus has been on hydrology, with weather parameters and topography as driving forces, while description of N and P cycling on a regional or national scale is simplified by the use of average or generalized export coefficient values that are produced by using process-oriented models driven by input data collected at regional scale. Scarce and inadequate input data is therefore often identified as a main source of uncertainty. This also limits possibilities to test uncertainties coupled to models structure. Consequently, a knowledge gap exists especially at the medium scale (catchments 1-10 km<sup>2</sup>), where an equally accurate description of both hydrology and biogeochemistry is needed for proper understanding of especially P mobilization and delivery processes. Additionally, the spatial variability of P losses at this scale is high. Since evaluation of best management practices will take place at this scale it is utterly important to correctly identify critical source areas within these small catchments. A process-oriented, semi-distributed SWAT (Soil and Water Assessment Tool) model has been set-up for a small agricultural catchment (8 km<sup>2</sup>) in SE Sweden. The results of a soil survey, GIS maps, regional and national statistic data bases, and yearly catchment-wide questionnaires regarding management practices were used to gather input data for the model. The SWAT model was coupled to SWAT-CUP (SWAT Calibration and Uncertainty Programs) where the GLUE (Generalized Likelihood Uncertainty Estimation) procedure was used to perform uncertainty analysis of model parameters regarding their effect on model prediction. Calibration data includes daily water discharge at the catchment outlet as well as fortnightly concentrations of suspended material and loads of nitrate N and total P, both at catchment outlet and at one central sampling point within a watershed representing area draining to a culverted stream (2.9 km<sup>2</sup>). The modeling period was from 1 October 2002 to 30 September 2008. Satisfying agreement was reached for water discharge (Nash-Sutcliffe coefficient 0.6) but model performance regarding suspended material, nitrate-N and especially P is rather poor. However, it remains to see if we will be able to improve model performance regarding these constituents in ongoing model runs.

## **Prediction of runoff P concentration on diverse soils using routine soil P tests**

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Concentrations of phosphorus (P) in runoff from intensively managed dairy pastures are often high, but are highly variable between soils for a given soil test P value. Although measures of soil P such as weak electrolyte extractable P and P saturation provide better predictors of runoff P concentration, they are not routinely measured in Australian soils. The development of reliable prediction of potential runoff P concentration using routine soil tests would benefit risk assessment and water quality modeling efforts alike. Partitioning of P between the solid and solution phases is controlled by P quantity and buffering properties of the soils. In this research, we investigated the effect of two agronomic bicarbonate extractable soil P tests (Olsen P and Colwell P), and P buffering (PBI) on runoff P concentrations using rainfall simulation. Non-routine soil tests such as CaCl<sub>2</sub> extractable P and P sorption saturation were also examined. Six soils were collected that had a wide range of soil PBI (~20–1200). Fifteen runoff trays for each soil were packed with soil that had varying amounts of P added in order to achieve a wide range of soil test P (STP) values. The trays were incubated for 8 months, during which pasture was grown and then artificial rainfall was applied. Runoff was collected and analyzed for dissolved and total P (TDP and TP respectively). Soil samples (0–0.01 m) were collected and analyzed for the soil P parameters previously mentioned. Relationships between soil test P and runoff P were then examined.

Soils with low PBI had much higher concentrations of P in runoff than soils with high PBI, for given Olsen and Colwell P values. For example, soils with low PBI's and STP values three times the agronomic optimum (common levels on Australian dairying soils) resulted in P runoff concentrations in the range of 5-8 mg/L. In contrast, soils with the same STP excesses, but high PBI's had P runoff concentrations of <1 mg/L. The relationship between both Olsen P and Colwell P and runoff P (TP and DRP) was significant (P<0.01) for each soil. However both agronomic soil tests were found to be extremely poor predictors of runoff P concentration across all soils. This limits their use in modeling and risk analysis. A model including the terms Colwell P or Olsen P and PBI was found to explain >80% of the variation in runoff TP and DRP concentrations. Although CaCl<sub>2</sub>-P and P saturation are equally effective predictors of runoff P they are not routinely measured in Australian laboratories, thus limiting their utility. From an environmental management perspective, particular attention should be paid to management of P fertility and runoff P risk on soils with low P buffering.

## Effects of P fertilizing practices on soil P pools – temporal variations within a ten-year field experiment

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The application of organic residues like compost and manure in crop production is a common fertilization practice and important for P recycling in agriculture. The nutrient release from those substances varies widely and depends, among other from the composition of the material, stability of organic substances, soil properties and type of cropping systems. Also organic materials, especially composted products, contain a considerably part of P in the inorganic fraction (Frossard et al. 2002). In a field experiment which was established in autumn 1998 the effects of organic, inorganic and combined organic x inorganic fertilization on soil and plant characteristics were investigated for maritime climate conditions. The organic fertilizers (cattle manure and biowaste compost) were applied at a rate of 30 t ha<sup>-1</sup> in autumn 1998, 2001, 2004, and 2007. The inorganic fertilizers (TSP and TSP/biomass-ash) were applied once a year. In autumn 2008, after ten years of experimental time the P contents in soil reflect the different treatments. In the treatment without any P supply the soil P contents were found to be considerably lower than in the treatments with combined organic and inorganic fertilization (see table 1). However, compared to the values in autumn 2004 (Eichler-Löbermann et al. 2007) the high soluble P contents in soil (Pw and Pdl) changed only slightly. Notable differences were found in dependence of the sampling date. In March, with the beginning vegetation period the Pw and Pdl contents in soil were higher than in September after the crop harvest. Differences between the sampling dates were less pronounced for Pox and the degree of P saturation (DPS). According the analyses of variance and the estimation of the effect size (eta-squared), the impact of the organic fertilizers on soil P fractions were more pronounced than the mineral fertilization. Spatial differences in P resulting from former cropping practices were also visible after ten years.

Table 1: P supply with fertilizers after 10 experimental years and the effects on soil characteristics

organic	inorganic	P supply (kg/ha)	Pw (mg/kg soil)	DPS%
without	without	0	0.93	42.1
	TSP	215	1.25	47.4
	TSP/ash	232	1.17	47.1
cattle manure	without	264	1.23	45.7
	TSP	479	1.48	49.9
	TSP/ash	496	1.40	49.1
biowaste compost	without	296	1.42	49.7
	TSP	511	1.71	52.8
	TSP/ash	528	1.61	50.5
<i>LSD (0.05)</i>			<i>0.15</i>	<i>3.8</i>

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## **Process-based modelling of phosphorus losses from an agricultural dominated catchment in S-E Norway**

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Agricultural practices and the consequent losses contribute to the transport of phosphorus to surface waters. Climate change can potentially increase the environmental pressure of agriculture on freshwater ecosystems. In the Nordic Region, climate change may lead to an increase in the number of freeze /thaw cycles and to an increase in precipitation amount after the growing season from September to April. These changes can cause increase in the amount of runoff and its intensity, with subsequent adverse effects on erosion and nutrient loss.

Mathematical models integrate the available knowledge on environmental responses to main driving forces and therefore they are essential tools for studying water and mass transport from soil profile to catchment scales. By successful adaptation of such models to study areas the combined effect of changes in driving forces (e.g. climate, land use) can be assessed and used for developing efficient mitigation measures to prevent unfavourable environmental impacts.

In this study we used the process-based INCA-P model (Wade et al., 2002) aiming to improve our understanding of runoff generation and P loss processes from various land use and soil management systems of an agricultural dominated catchment in South-East Norway. The Skuterud catchment is a small artificially drained agricultural catchment being part of the Agricultural Environmental Monitoring Program (JOVA) in Norway (Bechmann et al., 2007). The area of the catchment is 4.5 km<sup>2</sup> of which agriculture covers 2.7 km<sup>2</sup>, forest 1.3 km<sup>2</sup> while the rest is occupied by urban areas. The main agricultural crops are wheat, barley and oat.

The INCA-P model was parameterized for four different land use groups (grass, forest, cereals and urban) and for two soil management systems (with and without autumn ploughing). Daily meteorological data and soil water content deficit were used as driving variables. The simulated values were compared with discharge and water quality data measured at the outlet of the catchment. The calibration and validation periods were from 1994 to 1999 and from 2000 to 2007, respectively.

In our study we present the results of model calibration and we discuss the possibilities of predicting the long term hydrological and environmental impacts of climate change for Norwegian conditions. Special attention is paid to the problem of the parameterisation of various mitigation measures in the modelling procedure in order to evaluate their effects on runoff and phosphorus losses.

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## **Inter-comparison of suspended sediment and phosphorus fluxes and concentrations on two agricultural headwater catchments**

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The temporal variability of suspended sediment (SS), particulate phosphorus (PP) and soluble reactive phosphorus (SRP) concentrations and fluxes is high in headwater streams, which highlights variability of availability and transport of phosphorus sources. This paper compares two small agricultural headwater catchments of northwestern France, the Moulinet and the Kervidy-Naizin catchments which present similar physical environments but contrasted landscape infrastructures and landuses. On the Moulinet catchment, agriculture is moderately intensive, with mostly dairy farming. The land use is dominated by pasture grassland (more than 50% of agricultural surface area), mostly in the riparian area, and the landscape is structured by dense hedgerows (7.8 km hedgerows per km<sup>2</sup>). On the Kervidy catchment, agriculture is more intensive, consisting of dairy, cattle, and pig farming. The surface area of maize and cereal fields exceeds that of grassland fields, and the hedgerows are few (2.7 km hedgerows per km<sup>2</sup>) but located along the stream.

Annual and monthly SS fluxes are highly contrasted in both streams. Annual SS, PP and SRP fluxes are 64 10<sup>3</sup> kg km<sup>-2</sup>, 60 kg km<sup>-2</sup>, 10 kg km<sup>-2</sup> respectively, on the Moulinet stream, and 12 10<sup>3</sup> kg km<sup>-2</sup>, 20 kg km<sup>-2</sup>, 10 kg km<sup>-2</sup> respectively on the Kervidy stream. The ratio between SRP and PP is therefore different. We show that high SS and PP fluxes in Moulinet are mainly due to the mobilization of deposited sediment or bank particles. SS and PP fluxes in Kervidy are due to slope erosion caused by intensive farming, but limited in amount because of vegetated banks. In contrast SRP fluxes are similar in the two streams. P concentrations of bank and sediment are lower than P concentrations of crop surface soil, indicating two signatures in the Moulinet catchment. At the opposite, the concentrations of all the potential sources are similar and high in the Kervidy catchment. Moreover P concentrations of the SS in this stream are much higher than the P concentrations of the sources. We think that high SRP background in the Kervidy catchment can have polluted all the areas even those usually considered as natural. If in Moulinet SRP is controlled by surface runoff, it is probably controlled in Kervidy by a high availability from PP and subsurface processes. At the flood scale, phosphorus concentration or specific turbidity are used as fingerprint to precise the mobilization of the source along the flood. SS, PP and SRP origins were different on both catchments studied. Very contrasted fluxes were explained by the riparian area management that is a key domain, being a SS, PP and SRP source in one catchment, a SS sink and a SRP source in the other one. Such inter-comparison would be developed to increase our understanding of the phosphorus transfer in agricultural catchments in a large range of situations.

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## Sediment delivery – Limitations of empirical models in Bavaria

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Sediment input by surface runoff is an important diffuse pathway for phosphorus in aquatic ecosystems. It therefore forms an integral part of nutrient models. A combination of Universal Soil Loss Equation (USLE) and simple catchment properties is commonly used to predict sediment yields at the catchment scale. However, other studies conclude that empirical approaches may not match measured yields (Boomer et al., 2008). The objective of this study is to assess the suitability and limitations of model outcomes in the hilly and mountainous terrain of Bavaria, Germany.

The study area comprised the catchments of 60 gauges with areas between 20 and 8800 km<sup>2</sup> spanning from lowland to alpine terrain. Gross erosion with 100 m raster resolution was calculated using the USLE, commonly available data and standard functionality of ArcGIS 9.2. Two calibrated lumped and one distributed (Veith, 2002) sediment delivery ratio (SDR) approaches were applied to estimate sediment yields (SY) and compare them to “critical yields” calculated for 22 Bavarian gauges according to Behrendt et al. (1999).

As the USLE is limited to sheet and rill erosion, the modeled SY of alpine catchments are below 10 % of critical SY. For non-alpine catchments, both calibrated approaches match observed yields ( $R^2 > 0.8$ ), although outliers strongly influence the linear regression model. The uncalibrated model overestimated SY by about 50% ( $R^2 > 0.7$ ). Four of these predictions resulted between 200 % and 500 % above observations. Although no catchment property could be singled out, short time-series of runoff and suspended solids (<5 years, SEM > 25 %), water diversion and Karst conditions in the Franconian Switzerland might be possible reasons.

Modeled SY were highly correlated (Spearman's  $r_s > 0.8$ ), in contrast to SDR ( $r_s < 0.7$ ). Significant correlations between  $SDR_{mod} / SDR_{crit}$  and  $SDR_{crit}$  ( $r_s < -0.8$ ,  $p < 0.001$ ) suggest a systematic error for all models. The same pattern was observed with an independent USLE-based erosion dataset. Power equations with exponents between -0.7 and -1.2 best described the relationships ( $R^2 > 0.9$ ).

These first results indicate general difficulties of even calibrated empirical SDR approaches to predict sediment yields at catchment outlets. However, the influences of catchment properties, measurement uncertainties and the assumptions behind the “critical” SY have to be further scrutinized.

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## **Mobilization of slurry injected phosphorus during sequential irrigation and drainage cycles compared to continuous irrigation**

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Many studies show significant dynamics of phosphorus in soils connected to initiation of infiltration; large concentrations in phosphorus leaching directly after precipitation. We hypothesize that sequential irrigation and drainage cycles activates a larger volume of the soil pores and therefore can lead to a higher leaching of injected phosphorus compared to a situation of continuous irrigation. In this study, we examine the impact of sequential precipitation and drainage compared to continuous precipitation on phosphorus mobilization from slurry injected intact soil cores (20\*20 cm) of a loam soil. Three experiments were conducted i) continuous irrigation (2 mm h<sup>-1</sup>) at -5 hPa for 4.5 days; ii) cycles of irrigation of 2 mm h<sup>-1</sup> for 5 hours (-5 hPa) followed by drainage for 5 hours at -20 hPa; iii) cycles of irrigation of 10 mm h<sup>-1</sup> for 1 hour (-5hPa) followed by drainage for 5 hours at -20 hPa. The experiments were carried out so equal amounts of water was applied in each experiment.

Tritium and brilliant blue tracers revealed a more pronounced preferential flow behavior at high intensity (10 mm h<sup>-1</sup>) compared to both continuous and transient flow at 2 mm h<sup>-1</sup>.

Higher values of electric conductivity was observed with sequential irrigation at both 2 mm h<sup>-1</sup> and 10 mm h<sup>-1</sup> compared to continuous irrigation, reflecting activation of a larger volume of the soil pores by the drainage/and rewetting cycles. This was followed by leaching peaks of phosphorus at initiation of irrigation, whereas leaching of phosphorus decreased during drainage. During the experiment at 10 mm h<sup>-1</sup> phosphorus leached at higher concentrations compared to the 2 mm h<sup>-1</sup> leaching experiments during the irrigation events, however dropped to the same low values as the 2 mm h<sup>-1</sup> experiments during drainage. Accumulated phosphorus leaching did then result in higher accumulated values in the sequential precipitation at 10 mm h<sup>-1</sup> whereas accumulated phosphorus values did not differ among the sequential and continuous experiments at 2 mm h<sup>-1</sup>.

These results imply as previous studies have shown that irrigation intensity is a major factor influencing leaching of phosphorus. Furthermore, the results suggest that at near-saturated conditions and under low precipitation, accumulated values of phosphorus are leached in similar values whether irrigated under sequential and continuous conditions despite activation of a larger volume of the soil pores by the drainage/ and rewetting cycles.

## **Spatial Validation of a Rainfall-Runoff-Phosphorus (RRP) model**

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In many regions, diffuse Phosphorus (P) losses from agriculture are the main cause for eutrophication of surface waters. Studies in different countries indicate that these losses originate from a small portion of a given catchment only. The localisation of such critical source areas (CSA) is a prerequisite for the evaluation of efficient and cost-effective mitigation options and catchment models are a valuable tool to identify them. However, models are often validated only at the catchment outlet. Furthermore, an increasing number of studies suggest that different runoff types (infiltration excess and saturation excess runoff) need to be distinguished when modelling phosphorus losses. Artificial rainfall experiments that we carried out in 2008 showed for example that SER has the potential to mobilise P more strongly than IER.

Here, we report on a comparison of field measurements with predictions of critical source areas obtained by means of the Rainfall-Runoff-Phosphorus (RRP) model of Lazzarotto (2005). The RRP model is a parsimonious semi-distributed model that was in particular designed to account for fast transport of dissolved P from intensively used grassland soils by surface runoff and preferential flow to tile-drains. The model was calibrated using runoff data from 4 different sub-catchments of Lake Sempach, Switzerland. At the catchment outlet, measured and modelled runoff and P concentrations matched well. The calibrated model was then used to assess the quality of the spatial predictions within a different catchment.

For this purpose, we performed soil moisture and runoff measurements within a sub-catchment of Lake Baldegg, which is located in the vicinity of Lake Sempach on the Swiss Plateau and, like the latter, is characterised by intensive agriculture. Four permanent measurement stations were set up at different locations in the catchment. Each station is equipped with 12 TDR probes, 2 temperature sensors, one runoff sensor and a piezometer. Soil moisture is measured at 10 and 30 cm depth. These stations provide continuous data which show whether the model is able to catch the temporal behaviour at these locations. Further data are obtained from piezometers, runoff sensors and mobile soil moisture measurements, as well as from P analysis of water samples collected at the catchment outlet and further upstream. Based on the topographical distribution of the measurement points, we expect that the setup will allow us to assess the relevance of infiltration excess and saturation excess runoff in P export from the catchment.

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## **Daily fluctuation of phosphorus and nitrogen concentration based on automatic measurements**

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Models of nutrient transport in rivers, like the other models require, the collection of measurement data for calibration and verification. In many cases, there is only a limited number of measurement data or the data are collected too infrequently that they can be used to calibrate the models. At the same time, too large time step suppresses the phenomena that occur in a short time periods. On the basis of 10 minute automatic measurements of concentrations of phosphate, total phosphorus and nitrates in the small lowland Zagożdżonka river in central Poland the daily fluctuations in nutrient concentrations has been determined. The measured concentrations have been related to hydro-meteorological variability as river discharge, air and water temperatures.

## Horse paddock as a hot spot for P leaching in a small Swedish catchment

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Grazed grassland (savannas, grasslands, prairies steppes and shrub lands) covers more than 25% of the total earth land area and is a significant source of phosphorus (P) losses to natural waters (Parkyn and Wilcock, 2004). If the land is grazed for a long period this could lead to highly enhanced P concentrations in recipient water bodies (Nash et al., 2000), due to accumulation of manure and the decreased infiltration capacity of the soils in the trampled pastures. A horse paddock (3 ha) in central Sweden with dominant clay soil was studied in order to evaluate the risk of this being a “hot spot” for P losses to a recipient lake, which serves as the reserve drinking water reservoir for the city of Stockholm.

P concentration in drainage water from the underlying culvert of the entire catchment (30 ha) has been monitored for 10 years (1998-2008), and a soil characterisation was carried out in June 2009. The soil characterisation revealed that extracted P in an acid (pH 3.75) ammonium lactate solution (P-AL) from topsoil samples was in some areas of the paddock more than 500 mg P-AL kg<sup>-1</sup> soil. The average for the five most frequently used yards was 190 mg P-AL kg soil<sup>-1</sup>. The degree of P saturation in the same soil extracts (DPS-AL) was 15%, which was similar (12%) to DPS estimated from oxalate soil extraction (DPS-ox). Flow-weighted averages of total phosphorus (TP) and dissolved reactive P (DRP) in subsurface run-off water were 0.50 and 0.37 mg L<sup>-1</sup>, respectively. Concentration levels in tile drain water from a nearby monitored 4.4 ha agricultural field with a cereal and ley rotation were 0.17 and 0.05 mg L<sup>-1</sup> for TP and DRP, respectively. In other words, the leaching load from the catchment with the horse paddock was approximately three times larger than from the nearby field while, the proportion of DRP (74%) was approximately twice as high. In addition, the seasonal leaching patterns were quite different with elevated P concentrations in summer periods from the horse paddock catchment. As opposed to high P concentrations that only appeared in connection to high water flow pulses during water saturated conditions in the field.

To mitigate P transports from the studied horse paddock and protect the recipient water body, a designed wetland has been constructed in August 2009. This contains a deeper sedimentation basin and two shallower vegetation-filter parts with planted wetland vegetation.

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## **Sensitivity analysis of the modified ICECREAM model to improve parameterization for Swedish conditions**

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A modification of the simulation model ICECREAM to which macropore flow was added (Larsson et al., 2007) has been used in national calculations of P loads from Swedish agricultural soils. A need for a model uncertainty measure to report with calculated loads, and a refined parameter set to represent Swedish conditions, has been identified. The overall objective is therefore to carry out an uncertainty analysis of the modified ICECREAM model, and to optimize the parameterization for future national calculations.

The first step, which is presented here, is to get a general view of model sensitivity and to identify the parameters to include in the optimization. A modification of the Morris method (Morris, 1991) was used, where the measure of sensitivity was made dimensionless to allow sensitivity ranking of parameters with different units. The elementary effect as a measure of sensitivity relates the percentage change in the output variable to the percentage change in the input parameter. Results presented include elementary effects where a percentage change in the input parameter results in a larger percentage change in the output variable.

Analyzed response variables can be divided into eight different groups: Partitioning of water between surface runoff, infiltration and macropore flow; partitioning between transpiration and soil evaporation; flow between soil P pools; erosion; particle transport in macropores; P in surface runoff and leached to drains; mineralization of manure; and plant uptake of P. Preliminary results show that input parameters related to the simulated crop (growth and senescence, the partitioning between yield and residues and above-ground/below-ground biomass), and the generation of macropore flow, have a large elementary effect on the first five response groups. This is true even for soil physical parameters such as porosity and field capacity, and for the incorporation efficiency by soil tillage equipment. High elementary effects for the erosion and particle transport in macropores were shown for specific input parameters related to soil loss, and particle generation, respectively. Transport of dissolved and particle-bound P in surface runoff and dissolved P leached to drains, mineralization of manure, and plant uptake of P were not sensitive to changes in any of the input parameters. The high sensitivity and non-linear response of model output for changes in several groups of input parameters indicates a need for further refinement of the parameterization, while the lack of sensitivity of P transport is important to consider in future model development.

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## Phosphorus release and retention in Irish agricultural drainage ditches: a bed sediment P fractionation and EPC<sub>0</sub> study

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Extensive networks of agricultural drainage ditches in Ireland exist primarily to improve field drainage and agricultural productivity. They also act as hydrologically efficient conduits that facilitate the rapid transport of diffuse phosphorus (P) output (Haygarth *et al.*, 2005). This study investigated the role of ditch bed sediments in terms of potential release and/or retention of P, in relation to seasonal changes in hydrology and storm events. Between April 2008 and March 2009, ditch water and surface bed sediment (1 cm) were sampled on a fortnightly basis at six locations in two rural sub-catchments of the Ulster Blackwater in Counties Monaghan and Armagh (Arnscheidt *et al.*, 2007). The sediment P composition was analysed using a modified Psenner fractionation scheme (Hupfer *et al.*, 1995), and the sediment equilibrium phosphorus concentration (EPC<sub>0</sub>) was determined by batch sorption experiments. In terms of spatial comparison, sediments with the higher total P and sediment EPC<sub>0</sub> appeared to be associated with higher water column P concentrations, although sediment EPC<sub>0</sub> in relation to water column P almost always indicated non-equilibrium condition and potential for P retention. The redox-sensitive P fraction extracted by bicarbonate-dithionite was on average the largest single fraction in sediments at all locations. In terms of temporal comparison, there was not a consistent pattern of sediment total P, P composition and sediment EPC<sub>0</sub> reflecting changes in hydrological conditions over the 12-month period.

However, during a sequence of storm events in August 2008, there was clear evidence of sediment P depletion at some but not all sample sites. In conclusion, the bed sediments did not appear to exert marked control over water column P concentrations; rather, it is much more likely that water column P and changes in hydrological condition have considerable influence on the sediment.

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## The influence of soil and manure variables on phosphorus leaching from Swedish agricultural soils

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The Baltic Sea Action Plan requires participating countries to reduce phosphorus (P) pollution in order to mitigate Baltic eutrophication (HELCOM, 2007). Agriculture is Sweden's primary source of P to the Baltic Proper (Brandt and Ejhed, 2003), with leaching of P through agricultural soils a major concern (Ulén et al., 2007). We conducted two rainfall simulation studies to examine the role of soil and manure sources of P on P leaching. In the first study, intact soil cores (20-cm diam. x 20-cm deep) were collected from three different long-term (>50 yrs) field trials in which varied fertilizer rates produced a range of soil P levels (ammonium lactate P = 0.15-1.83 mg kg<sup>-1</sup>). This study was intended to shed light on the role of P desorption on P leaching from top soils. In the second study, dairy (*Bos taurus* L.) manure was added at a rate of 30 kg P ha<sup>-1</sup> to the soil columns to determine the relative role of soil and manure P on P leaching. We found clear, strong (R<sup>2</sup> = 0.82-0.94) linear relationships between ammonium lactate P (AL-P) in the soil and dissolved reactive P in leachate. However, relationships varied significantly between the three soils with regression slopes differing by an order of magnitude. These findings contrast with previous work in Sweden examining deep soil cores (90 cm) in which no relationships were apparent (Djodjic et al., 2004) suggesting that topsoil P leaching is modified by subsoil properties. When manure was applied to soil columns, antecedent AL-P appeared to affect manure P leaching, with the interaction more pronounced in some soils than others. Phosphorus leaching from intact soil columns increased from 26 to 4647% with the addition of manure. Results seem to be consistent with the hypothesis that greater P sorption saturation in soils with elevated AL-P results in lesser sorption of applied manure P and therefore greater risk for leaching losses. Findings from this research will be used to inform P management recommendations in Sweden.

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## **Assessment of phosphorus fertilizing practices in altered wetland soils using uncertainty analysis**

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Intensive P fertilization has been widely applied in altered wetland soils even when soil-test P indicates sufficiency (Olsen-P > 10 mg kg<sup>-1</sup>). Reexamination of this practice using 48 lysimeters (1.5 m<sup>3</sup>), three soil types, two fertilizers (Superphosphate and P-rich biochar), two application rates, and typical crop rotation, have shown no yield response to the fertilizers. Hence, we recommended reduction in the use of P fertilizers in these soils. The finding of the lysimeter study was further assessed using sequential Gaussian simulation approach. First, we sampled 90 soil locals with unique georeferencing to generate a robust cumulative conditional distribution function. The locations of the sampled soils were determined according to their parent material (deep peat, shallow peat, marl) and the practiced crop rotation. The soils were analyzed for their Olsen-P content, bulk density, pH, electrical conductance, and the concentrations of nitrate, chloride and sulfate in the saturated paste extracts. Next, we conducted a variogram analysis after transforming the data with normal score routine. The 'best' spatial structure of the Olsen-P distribution with estimated local accuracy was conducted with ordinary kriging. We used the simulation model to produce 100 alternative realizations as a measure of the joint spatial uncertainty of the P concentrations in the study area (~ 1500 ha). Finally, we post processed the simulation results after back transforming the data to compute the probability of exceeding the threshold value of 10 mg Olsen-P kg<sup>-1</sup>. This simulation approach provides a robust quantitative mean for planning the reduction of P fertilization across farm lands.

## **Identification of processes controlling phosphorus leaching from a long-term field experiment using the ICECREAM model**

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Best management of animal manure and cultivation of catch crops are considered to be two important strategies to mitigate phosphorus (P) leaching losses from agricultural fields. However, no significant effect of either animal manure or catch crops on P leaching was observed in a long-term field experiment at Mellby in south-west Sweden. At this site, pig slurry has been applied at different rates, in combination with use of catch crops, since 1983. Measured P leaching results were evaluated for a 15-year-period (1989-2003) using the simulation model ICECREAM. The main objective was to explain the experimental data and to identify the critical processes controlling P leaching from this type of soil.

The experimental site consists of a layer of sandy soil overlying a glaci-fluvial clay at 90 cm depth, with an iron-rich subsoil (30-90 cm). Measured mean annual total P (TP) leaching was  $0.17 \text{ kg ha}^{-1}$  and mean annual concentration was  $0.06 \text{ mg L}^{-1}$ , of which 45% comprised dissolved reactive P (DRP). The ICECREAM model managed to accurately simulate the 15-year total drainage volume and drainage dynamics, as well as P leaching dynamics. Both simulations and measurements indicated a rapid flow of water through this soil, which constitutes a risk of fast transport of P to drainage pipes. However, the model overestimated TP and DRP concentrations in drainage water by a factor of approximately 10 and 18, respectively.

According to measurements, the long-term application of pig slurry has built up a high P content in the topsoil (P-AL:  $38 \text{ mg P } 100 \text{ g soil}^{-1}$ ) with a degree of P saturation (DPS) higher than 20%. The high soil P and DPS values indicate a high potential for P leaching. However, this was not reflected in the leaching measurements, probably because soluble P leached from the topsoil is adsorbed by Fe-oxides and/or Al-oxides in the far less P-saturated subsoil (DPS < 20%). The sorption processes in the subsoil seemed to substantially reduce P leaching and counteract the effects of slurry application and cultivation of catch crops. The ICECREAM model did not account for the sorption capacity of Fe- and Al-oxides, which could explain the overestimation of DRP, and thus of TP concentrations, in the simulations. The sorption capacity of the subsoil is obviously substantial, providing good protection against leaching of dissolved P. According to the simulations, more than 70% of the manure P applied was retained in the soil, which could consequently be a potential source of future P losses. For example, with changes in hydrological conditions leading to wetter soil and more frequent reducing conditions, the risk of high P leaching losses would increase.

Although the Mellby soil has several properties (high soil P content, high DPS in the topsoil, high hydraulic conductivity) that could promote P leaching, the high sorption capacity in the subsoil seemed to negate the influence of these properties. To further improve the ICECREAM model, it is obviously necessary to account for the influence of Fe- and Al-oxides on P solubility.

## Long term lysimeter experiments about the influence of irrigation on phosphorus leaching

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It is well known that phosphorus (P) losses from soils, in combination with other nutrients, may cause severe eutrophication problems in adjacent water resources. Besides the surface-bound lateral transport of P via the erosion pathway, the vertical movement through the soil profile has been increasingly recognized as an important process. Long-term study of mineral fertilization and nutrient leaching started in 1991 at the present UFZ-Helmholtz lysimeter station at Falkenberg, Saxony-Anhalt. The objective of this lysimeter trial is to investigate the influence of irrigation on the P balance and especially the P leaching losses. The 24 lysimeters were manually filled from autumn 1981 to spring 1982; soil textures were sand (n = 6), sandy loam (n = 6), loam (n = 6), and silt (n = 6). The lysimeter depth is 125 cm, with an A-horizon from 0 to 30 cm, a subsoil from 30 to 100 cm and a drainage zone from 100 to 125 cm consisting of sand, gravel and stone gravel. Leachate was continuously collected at lysimeter bottom. The total volume of leachate was monthly determined, and an aliquot was taken for analysis of total P ( $P_t$ ). Mineral fertilizer P was applied in three amounts – optimal fertilization (100%); reduced fertilization (50% of the optimal variant) and over supplied fertilization (150% of the optimal variant). The lysimeters have been used as grassland (each soil texture 3 lysimeters) and arable land (also each soil texture 3 lysimeters). Arable land use consists of a grain and feed-grain crop rotation clover/grass – winter wheat – winter barley – oats. After harvesting the winter barley, a mixture of corn and sunflowers was planted as an interim crop. Clover/grass was seeded between the oats. The soil P content ( $P_t$  and plant available  $P_{DL}$ ) of each lysimeter was measured once per year. Furthermore, the P uptake by the biomass was also analyzed. A comparison between the intensive irrigation period from 1991 to 2003 and the non-irrigation period from 2004 to 2009 will be carried out. First results showed that the reduction of the leaching amount in the non-irrigation period was connected with reduced P leaching losses, lower yields and reduced P uptake by plants. Based on a statistical analysis recommendations will be given regarding a sustainable management of agricultural used areas to reduce P leaching losses and to evaluate climate change impacts on water and P balance in soils.

## **Multiobjective optimization for the allocation of cost-effective BMPs at the watershed scale**

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The mitigation of non-point Phosphorus (P) losses to surface waters is currently a major issue for the implementation of Environmental Directives in Europe. These losses are often driven by location specific factors in catchments, such as climate, topography, soils and management practices. The identification of the agricultural areas that pollute most, is also very crucial for the implementation of cost-effective Best Management Practices (BMPs). The difficulty in the selection and placement of BMPs increases with catchment size and the number of BMPs available for implementation. Additionally, cost is always a restricting factor that limits the number of possible combinations as well as targets to reduce P losses may sometimes negatively impact on other environmental objectives such as the reductions of nitrates concentrations in surface waters. Thus, success of conservation programs for water protection highly depends on planning tools that can assist the watershed management process. Herein a novel optimization methodology is presented for deriving catchment-scale phosphorus control plans that incorporate multiple, and conflicting, objectives. For the development of this method the watershed non-point pollution tool SWAT (Arnold et al., 1998) that is highly capable in representing BMPs was combined with a MATLAB Genetic Algorithm - spatial search procedure. A database that provides the different BMP implementation costs was developed with site-specific information from the medium-sized (940 km<sup>2</sup>) Arachthos catchment in Northwestern Greece (Panagopoulos et al., 2007). The tool applies different kinds of nutrient, crop, soil and livestock management practices on corn, alfalfa and pastureland and tries to find solutions that are both economically and environmentally effective. Optimization was done by setting each time two conflicting objectives and using the third as constraint. Phosphorus loads were first optimized against total cost of implementation with an upper acceptable value of nitrates concentration being the constraint. Subsequently P loads were optimized against loads of N-NO<sub>3</sub> by putting constraint on the total cost. The results of both multi-objective optimizations resulted in potential reductions of more than 25% for P from the catchment with affordable cost of non-structural BMPs implementation. Of high interest is that the tool achieved to satisfy the objectives by considering a significant part of the agricultural land under no BMP implementation and suggested solutions that would be impossible to be planned otherwise.

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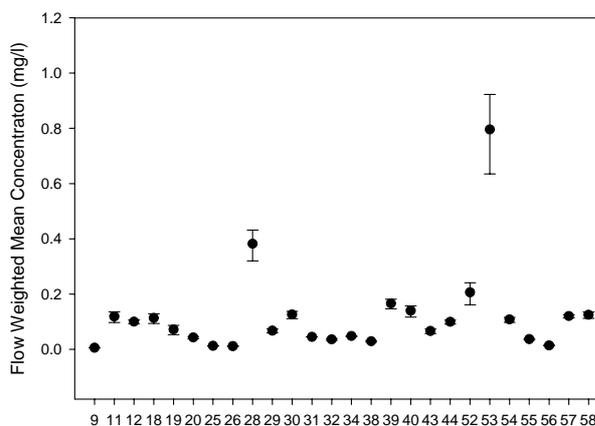
## Spatial patterns of phosphorus in the Ribble and Wyre catchments, a source to sea approach

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The Ribble and Wyre flow westward to the Irish Sea and their basins drain upland areas of outstanding natural beauty (part of the Yorkshire Dales and the trough of Bowland). The Ribble includes part of the urban/industrial heartlands of Lancashire while the Wyre is much more rural in nature. Across the Ribble and Wyre basins, 26 sites were monitored.

Water quality measurements included major ions, nutrients, trace elements, pH, alkalinity and conductivity. Water samples were filtered in the field through either 0.45  $\mu\text{m}$  cellulose nitrate filters for metals and glass fibre (GFC) filters for anions, nutrients and dissolved organic carbon (DOC). For the wide array of water quality determinands, electrometric, colorimetric, ion chromatography and inductively coupled optical-emission and mass spectrometry was used. These measurements were collected over the period Winter 2007 to Summer 2010, with a 2 weekly sampling interval. Phosphorus (SRP,  $\text{PO}_4^-$ , TP, and TPP) measurements were assessed in relation to land use, climate, anthropogenic inputs and associative relationships. The dominant sources of phosphorus are sewage treatment point sources, however background diffuse sources dominate. Boron measurements were also made which is a marker for septic tanks. Flow weighted mean concentrations of phosphorus ranged from 0.01 to 1.03  $\text{mg l}^{-1}$ . These relationships are discussed in relation to the hydrology (15 min resolution) collected for all 26 sites. Estimates of nutrient fluxes from all catchments to an assesment of the total estuarine flux are also presented.



**Figure 1** Flow weighted mean concentrations of  $\text{PO}_4$  in relation to the 26 catchments. Values are 8 year means (2003-2010).

## **A new methodology to estimate Phosphorus *LE*Aching from Soils to the *En*vironment (PLEASE)**

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In 1990 a methodology was developed to estimate the phosphorus (P) losses to groundwater in the Netherlands (Phosphate Saturation Degree; PSD). This approach has been subsequently adopted in many other countries as an indicator for P loss. The phosphate saturation degree is based on the phosphate accumulation above the highest groundwater level in relation to the phosphate sorption capacity of the same layer. The PSD is an indicator for the *potential* P loss to groundwater and does not give any information about the *actual* P loss from agricultural land to surface waters. Phosphorus transport from soils through the upper groundwater is an important pathway which contributes highly to the P loads to surface waters in flat areas with shallow groundwater or in areas with tile drains. To locate those agricultural areas, which are the prime contributors of diffuse P losses to surface waters, information on the actual distribution of phosphorus throughout the soil profile and the distribution of lateral water fluxes is needed. In order to predict the actual P loss to surface waters a simple approach has been developed to estimate the annual P loss from a field to the adjacent surface water in terms of total-P and ortho-P (Schoumans et al., in prep.). In this presentation this simple methodology to quantify *actual* P loss, called PLEASE, will be discussed. The P concentration profile in the soil solution is determined by combining information of soil-P test with information of the soil chemical sorption capacity (which is e.g. in acid sandy soils related to the Al<sub>ox</sub> and Fe<sub>ox</sub> content). The concentrations in the upper groundwater may also be influenced by groundwater at greater depth and therefore also the upward seepage is taken into account. In our approach, the relative contribution of different soil layers to surface water loading is derived from the precipitation surplus and information about the upper and lower groundwater level during the year. The approach has been tested and published by Van der Salm et al. (this issue) and Dupas and van der Salm, 2010.

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Schoumans, O.F., C. van der Salm, and P. Groenendijk (in prep.). PLEASE: A simple procedure to determine P losses by leaching.

Van der Salm, C., G. Heckrath, B. Kronvang, M. Pleijter, G. Rubæk, and O.F. Schoumans (this issue). Predicting phosphorus losses with the model PLEASE on a local and regional scale in Denmark and the Netherlands.

## **Critical source areas - empirical evidence and consequences for implementation**

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The concept of Critical Source Areas (CSAs) has received considerable attention over the last years in the context of mitigating diffuse pollution. It is an attractive concept because it is conceptually plausible and offers a way of minimizing conflicts between agricultural production and water protection. In order to convince practitioners to implement this concept, its effectiveness needs to be demonstrated. This entails two aspects: firstly, it needs to be shown that CSAs cover only a limited fraction of catchments. Secondly, CSAs have to be localized reliably in space. In this presentation, we review the empirical basis underpinning the CSA concept for P- and pesticide losses as well as erosion (and hence total P transport). We use ROC (Receiver operation characteristics) analysis to assess the quality of spatial predictions of CSAs by common tools like variants of the P index and the USLE.

Mass flow analysis for P, herbicides and soil material (erosion) suggest that CSAs covering 15 - 30% of the catchment area often contribute 60 to 70% of the load to surface waters. This is supported by hydrological studies investigating the spatial extend of saturated areas generating fast flow processes. However, the number of independent empirical studies is fairly limited. Hence, the models for delineating CSAs are still highly uncertain. This seems to hold especially for the prediction of soluble P losses in contrast to particulate losses. Due to a much broader empirical database on erosion and the availability of high resolution digital elevation models (DEMs), predictive tools for erosion - and hence total P - are more advanced. This will be illustrated by contrasting a recent comparison of modeled and observed erosion in test catchments in Switzerland with the tools and data available for soluble P.

These different levels of empirical support and predictive power of tools for particulate and soluble P have consequences for the implementation process. We will report on the status of CSA implementation in Switzerland, which is currently discussed by the federal authorities.

## **Monitoring and modelling Phosphorus dynamics during runoff events over a transition from semi-arid grassland to shrubland**

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During the last 150 years land degradation across the semi-arid grasslands of the south-western USA has been associated with an increase in runoff and erosion. Concurrent with this increase in runoff and erosion is a loss of phosphorus (P), which is a plant-essential nutrient. This paper investigates the runoff-driven redistribution and loss of dissolved and particulate-bound P that occurs during natural runoff events over a trajectory of degradation, from grassland to degraded shrubland, in central New Mexico. In the first part of our experiment, runoff-driven nutrient dynamics were monitored at four stages over a transition from grassland to shrubland, for naturally occurring rainfall events over 10 x 30 m bounded runoff plots. Results show that particulate-bound forms of P are responsible for the majority of P lost from the plots, due to erosion occurring during runoff events, whereas the dissolved component of P loss is negligible. Results indicate that for high-magnitude rainfall events, the output of P from the plots may greatly exceed the amount input to the plots, particularly over shrub-dominated plots where erosion rates are higher. Thus, the progressive degradation of semi-arid grassland ecosystems across the south-western USA and other semi-arid ecosystems worldwide has the potential to affect P cycling significantly through an increase in nutrient loss in runoff.

In order to model the observed P dynamics during runoff events (in particular particulate-bound nutrients), the Model for Assessing Hillslope to Landscape Erosion Runoff, And Nutrients (MAHLERAN) was then evaluated against runoff, erosion and P data from the four plots detailed above. A new module was developed to include a representation of particulate-bound nutrient dynamics. Understanding dynamics of both dissolved and particulate-bound nutrient dynamics during runoff events is imperative, because of their differing roles in terms of nutrient bioavailability and potential implications for plant dynamics.

Results of the model evaluation show that the runoff and erosion components of MAHLERAN perform reasonably well, as does the new particulate-bound nutrient sub-model, though not consistently. Performance of the particulate-bound nutrient model was better for the end-member (grass and shrub) plots, because of better parameterization data available for end-member vegetation types. Since the particulate-bound nutrient sub-model is by necessity strongly dependent on the simulated erosion rate, the performance of the particulate-bound nutrient model is dependent on the performance of the erosion component of MAHLERAN. The performance of the dissolved nutrient component of MAHLERAN was poor in this application, which indicates that the process representation for this semi-arid environment and the parameterization of the dissolved nutrient component were inadequate. However, given the low fluxes of dissolved P from this system, which appears to be dominated by P associated with particulates, such results do not detract from the ability of the model to simulate P dynamics of this semi-arid system.

## Phosphorus mobilisation and risk assessments in a small agricultural catchment with heavy clay soil

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A refined version of a conditional phosphorus risk index (PRI) for P losses to waters was tested in a small (7.3 km<sup>2</sup>) agricultural catchment in south-eastern Sweden. The catchment has a hummocky landscape of heavy glacial till overlying moraine and an overall balanced soil P level. Background estimation of stream water total phosphorus (TP) concentrations in the period 1988-2007 revealed a stable concentration, with mean 0.26 mg L<sup>-1</sup>. Average TP concentrations in flow-proportional water samples were nearly twice as high (0.44 mg L<sup>-1</sup>) as those estimated from flow-weighted manual samples (0.23 mg L<sup>-1</sup>) at the catchment endpoint in 2008-2009 and more than three times higher than TP values based on flow-weighted manual samples in an underlying culvert in the upper part of the catchment (0.15 mg L<sup>-1</sup>). High concentrations of TP (up to 0.63 mg L<sup>-1</sup>), mainly in particulate-bound form (PP), were recorded along the open reach of the stream in the rising limb of high flow pulses. A clear anticlockwise hysteresis effect was demonstrated for NO<sub>3</sub>-N concentration in every autumn event. In contrast, the peak of suspended material (analysed as turbidity) appeared 4-7 hours before the NO<sub>3</sub>-N peak and hysteresis was clockwise.

Water-extractable soil P (P<sub>w</sub>) and P sorption index (PSI) in the topsoil were used for risk assessment of P source together with the degree of P saturation (DPS) in the three layers of the soil profile down to tile drain depth (90 cm). An empirical relationship was established (Pearson correlation coefficient 0.861, p<0.001) between PSI, measured in a weak calcium chloride solution, and iron (Fe-AL) aluminium (Al-AL) and phosphorus (P-AL) in soil extract with acid ammonium lactate. Differing relationships were found for a field that had not received any manure in the last 15 years and a field that had received chicken litter very recently. In addition, a general relationship (Pearson correlation coefficient 0.839, p<0.001) was found between the ratio of phosphorus extracted from fresh soil in water (P<sub>w</sub>) to PSI and DPS. One exception was a single field, representing 7% of agricultural land in the catchment, that had been treated with glyphosate shortly before soil sampling. Saturated hydraulic conductivity (SHC) in clay in contact with the moraine base (at 1 m depth) was on average 0.06 m day<sup>-1</sup>. In clay not in contact with moraine, SHC was significantly lower (mean 0.007 m day<sup>-1</sup>). A reduction in the present tile drain spacing (from 14-16 m to 11 m) is theoretically required to maintain satisfactory water discharge and groundwater level. Up to 10% of the arable land was estimated to be a potential source area for P, based on different indices. Parts of a few fields close to farm buildings (1% of total arable land) were identified as essential P source areas, with high DPS values and low PSI values throughout the soil profile. A further 3% of arable land was identified as potential important transport areas, based on visible surface water rills or frequent water-ponded conditions. Fields comprising 10% of the total arable land in the catchment should be re-drained in the near future to improve water infiltration and avoid unnecessary channelised water flow. Precision fertilisation and manure application to some fields, soil structure improvement and restoration of the technical function of the tile drain system and open stream are recommended measures to counteract P losses.

## **Predicting phosphorus losses with the model PLEASE on a local and regional scale in Denmark and the Netherlands**

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The application of large amount of phosphorus in agriculture has led to the accumulation of phosphorus in soils in many intensively used agricultural areas, causing excessive losses of P to surface waters. In many countries the present policy is to reduce P application rates towards a situation where P input equals P exported with the crop. Due to the high P content in the soil such plans are mostly not sufficient to reach surface water quality standards and additional measures to reduce P loading to surface water are necessary. For a cost effective implementation of these measures an instrument to identify critical fields/areas for phosphorus leaching is indispensable.

In the Netherlands phosphorus losses to surface water are simulated with a comprehensive process oriented simulation model (STONE, Wolf et al., 2005). STONE distinguishes, for the Netherlands as a whole, 6405 spatially explicit calculation units (plots) with an average area of about 500 ha. The identification of critical fields requires a much higher spatial resolution. STONE is less suitable for this purpose, because of the large number of input parameters required for this model (Schoumans et al., 2009). For this reason, a simple model (PLEASE, Schoumans et al., in prep.) has been developed based on a simplification of the process description in STONE. With this model P leaching to surface waters can be calculated using field characteristics like depth of the groundwater table, precipitation surplus, P status and phosphorus adsorption capacity of the soil.

To evaluate the performance of the model, it was applied to 29 sites (fields) and a number of (mini)catchments in the Netherlands and Denmark. For 8 sites in the Netherlands the model could be validated on measured P leaching fluxes, for the other sites validation was limited to a comparison of measured and simulated concentrations in lysimeter cups, drainwater or piezometers. The validation showed that for most sites the model was able to rank sites from low to high concentrations and from low to high leaching fluxes. Deviations between measurements and simulations may be due to simplification of the model and the use of generic sorption characteristics. Large deviations were found for eutrophic peats soils and soils with shrinkage cracks. Eutrophic peats soils often release large amount of phosphorus from the subsoil. Shrinkage cracks may lead to transport of P through macropores to drains and surfacewater. In order to apply PLEASE to such soils these aspects need to be considered.

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## **Uncertainty analysis of the FyrisNP model for source apportionment of phosphorous and nitrogen in catchments**

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In catchment management, models are usually used to interpolate between measurements of environmental variables, apportionment of pollution sources and scenario simulations. It is now generally accepted that such models have to undergo some uncertainty analysis to demonstrate the reliability of the model. These analyses are commonly performed for a single catchment. As each catchment is unique in its composition of landuse, nutrient load and climate there is, however, a need to perform uncertainty analysis for several catchments of varying types. In this study uncertainty analysis has been performed for several Swedish catchments with the semi distributed nitrogen and phosphorous source apportionment model FyrisNP. The FyrisNP model is a relatively simple model that works with weekly or monthly time steps and uses a tree structure of interconnected sub-catchments. It uses time series on runoff, water temperature and nutrient concentration as input data. Information on landuse percentages and lake and stream area is also required. The diffuse nutrient load from land is calculated from type specific concentrations for each land use type and, in the case of agriculture, for each sub-catchment, accounting for differences in crops, soil type and for phosphorus also slope and P-content in the soil. Data on atmospheric deposition as well as major and minor point sources, e.g. sewage treatment plants and rural households, is also needed. The main model outputs are retention, source apportionment and gross and net transportation of nutrients. Calculated nutrient concentrations are compared with measured concentrations to calibrate and evaluate the model. The two calibration parameters are both used in the equation for retention calculation. The first results show that the type specific concentration in runoff from arable land is the most sensitive model parameter. Model results are usually sensitive to the calibration parameters. Equifinality occurs for type specific concentrations for most landuse types, except for arable land. Arable land has much higher type specific concentrations than the other land use types. The model calculates the source apportionment of nitrogen and phosphorous in separate runs. Nitrogen simulations have fewer parameters with equifinality than phosphorous and so exhibit less model uncertainty. This is explained by the higher type specific concentrations for nitrogen leakage than phosphorous leakage. The land use percentage is sometimes important for the sensitivity of the corresponding type specific concentration while the amount of calibration data apparently has no effect on number of parameters with equifinality or the absolute values of the model efficiency. Other factors with possible influence on the model uncertainty will be further studied, as well as the effect of the parameters on the source apportionment.

## **Phosphorus concentration in overland flow from grassland field plots**

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Grassland is a large proportion of farmland in many countries. In Ireland more than 80% of the 4.2 million ha of farmland is grassland. The main objective of this study was to measure the phosphorus (P) concentration in overland flow from grassland (cut and grazed) on six field plots with a range of soil test P (STP) levels and identify influencing factors. Morgan's STP between plots ranged from 3.5 to 17.9 mg L<sup>-1</sup> soil. Data collected from six grassland field plots over two years (Jan. 2002 to Mar. 2004) are presented. The overland flow was sampled in proportion to flow and concentrations of dissolved reactive P (DRP) in overland flow varied from the detection limit to 3 mg L<sup>-1</sup>. Annual mean DRP concentrations were positively correlated with log STP. There was more than a ten-fold difference in mean annual DRP concentrations between the plots with the lowest and highest STP (0.047 vs. 0.585 mg L<sup>-1</sup> P in 2002 and 0.029 vs. 0.723 mg L<sup>-1</sup> P in 2003). The calculated annual dissolved DRP loads in overland flow from the plots ranged from 0.2 to 1.7 kg ha<sup>-1</sup> yr<sup>-1</sup>. There was a significant correlation between the three P fractions measured (86 % of total P (TP) was total dissolved P (TDP), 77% of TP was DRP and 90% of TDP was DRP). There was a wash out effect of the P fractions in overland flow in autumn (combining high flows and high P concentrations) after the summer dry period. The grazing animal can significantly increase the P concentration in overland flow, but the large variations between plots were related predominantly to soil factors rather than the presence or absence of grazing animals. The conclusion from the study are:

- 1) there was a marked autumn P wash out effect when P concentrations and overland flow were both high, giving high loss;
  - 2) there was a wide variation in P concentrations in overland flow with a positive correlation between log STP and mean annual DRP concentrations for the six plots for 2002 and 2003;
  - 3) there was a significant correlation between the three water P fractions measured;
  - 4) the effect of the grazing animal on DRP concentrations was small relative to the effect of STP.
- The results show that grassland farming can contribute to high P concentrations and loads in overland flow that may impact on soil and water conservation.



**PHOSPHORUS MOBILIZATION AND MODELLING  
AT THE FIELD AND CATCHMENT SCALES  
(JOINT SESSION IPW6 –COST 869 WG1)**

**POSTERS**



## Phosphorus fertilisation in Romania

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This paper presents a comparison between two different phosphate systems fertilisation which are now recommended in Romania in crop production system:

-the first method use the economically optimal rates of P (EOR) which are thought to result the maximization of net income from P fertilizer use, extracted from crop yield regression on P rates from all available sources;

-the second method use the optimal rates of P for stabilization of phosphate level in the soil and crop yields (ORSSY), extracted from mobile phosphorus ( $P_{AL}$ ) regression on P fertiliser rates applied in long duration field experiments.

Table

The variation of specific yield increases (SYI kg/kg of  $P_2O_5$ ) due to P fertilisation in EOR and ORSSY rates, for wheat and maize, depending on expected yields and  $P_{AL}$  content in soil

Crop and expected yields (kg/ha)	SYI kg/kg of $P_2O_5$			
	EOR of P		ORSSY of P	
	$P_{AL}$ content in soil (ppm P)			
	25	50	25	50
<b>Wheat</b>				
3500	7.6	9.8	4.4	2.0
4500	8.7	7.9	5.8	2.9
5500	8.9	8.8	6.4	4.0
<b>Maize</b>				
4500	10.3	16.4	5.0	2.5
5500	11.1	10.6	5.8	3.3
6500	11.6	12.1	6.2	4.1

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## **Adaptation of the Phosphorus Index to irrigated areas in the middle Ebro Basin. Las Filadas watershed case study (Huesca, Spain)**

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In semi-arid irrigation areas, one of the most important surface water quality problems is nutrient pollution from agriculture through irrigation return flows, which can lead to their eutrophication. The element that most frequently limits the growth of aquatic vegetation is phosphorus (P) that may cause eutrophication above certain thresholds. Several management models for phosphorus diffuse pollution by agriculture are available currently, some of which resort to the use of indices. An index of phosphorus risk loss (PI) is a (usually) numerical value that weighs in a qualitative way the risk of water pollution by P associated to the farming practices and the soil and meteorological conditions of a zone. For that purpose, a PI must account for and integrate the processes involved in P availability and P transport. In this work, a new PI (called IPreg) has been developed for the irrigated area within “Las Filadas” gully watershed (Huesca, Spain), with a total 4920 ha and included in the water users associations of Orillena, Lanaja and Lalueza of the *Riegos del Alto Aragón* Irrigation Scheme. The original PI developed by Lemunyon and Gilbert (1993) has been adapted to irrigated farming systems of the middle valley of the Ebro (IPreg) introducing two new transport factors related to the irrigation management: (1) the Seasonal Irrigation Performance Index (SIPI) (Faci et al., 2000) and (2) the efficiency of the mean irrigation dose that represent average water losses below the root zone when an average irrigation dose was applied. Altogether, the IPreg includes 9 factors: three of which account for the P availability in the soil and six for the P transport processes. Results indicate that four percent (216 ha) of the study area showed High to Very High risk of phosphorus loss and 44 % (2315 ha) Medium risk. There was no significant difference between the IPreg mean values in the three water users associations in the study area. Corn and alfalfa showed the highest IPreg values for all parcels in the study area, as a result of the high water irrigation volumes served and the excessive phosphorus fertilization. Also, parcels on which organic fertilizers (especially pig slurry) were used showed a higher IPreg than the others and phosphorus-rich soils presented an IPreg superior to the rest. Finally, the IPreg can be used as a tool to 1) identify irrigated agriculture areas that may present a greater risk of P loss and thus guide more detailed research work towards them, 2) to promote farmers sensibility about implementing conservation measures and 3) to assist policy makers in the definition of priority actions within the environmental programs for sustainable agriculture.

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## **Spatial distribution of soil phosphorus and implications for catchment-scale predictions of losses in South Spain**

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Accurate definition of critical sources areas for P loss in catchments involve not only the knowledge of the soil P status but also the connectivity of soil with transport pathways. Nowadays, all these data can be monitored realized by using kriging method in combination with GIS contour.

Two small catchments in South Spain were studied in order to study soil P level and release potential by means of single extractions (Olsen P and water extractable P at a soil:water ratio of 1:10). These observations were intensively done in each catchment by sampling on a regular square grid (grid spacing 100 m). Dominant soil type in one of the catchments were Typic Haploxerert (Vertisol catchment, 60 ha surface), and in the other were Calcic Haploxeralfs (25 ha surface) according to the Soil Taxonomy. Fertilizer (usual 30 kg P ha<sup>-1</sup> applied each two years) and crop management was similar in both catchment and absolutely homogeneous within each catchment. Topographic Index (TI) were calculated on the basis of slope and upslope contribution area estimated from the digital elevation model (DEM) of each catchment. High TI values indicates areas of low slope and/or large upslope contributing areas (hillslope concavity, guillies), meanwhile low TI values area associated with steep sloping areas and/or small upslope contributing areas (e.g. topographic ridges, plateau). Thus, a high P loss potential through runoff and erosion can be expected at low TI values.

Most of the catchment points sampled presented Olsen P levels above critical values for fertilizer response of crops (8-10 mg Olsen P kg<sup>-1</sup>), ranging from 10 to 70 mg kg<sup>-1</sup> in the Vertisol catchment and from 5 to 80 mg kg<sup>-1</sup> in the Alfisol Catchment. Water extractable P was significantly correlated with Olsen P ( $r = 0.90$  and  $0.92$ ,  $P < 0.001$ , in Alfisol and Vertisol catchment, respectively). Correlations performed using the values estimated on a 10 x 10 m grid revealed that Olsen P increased with increasing elevation ( $r = 0.71$ ,  $P < 0.05$ ) and decreased with increasing slope and TI ( $r = -0.19$ , and  $r = -0.12$ , respectively,  $P < 0.05$ ) in the Vertisol catchment. On the contrary, in the Alfisols catchment, Olsen P decreased with increasing elevation ( $r = -0.48$ ,  $P < 0.05$ ) and increasing slope ( $r = -0.3$ ,  $P < 0.05$ ), meanwhile increased with increasing TI ( $r = 0.05$ ,  $P < 0.05$ ). In the Vertisols catchment, higher Olsen P were associated to low TI values, meanwhile the opposite was observed in the Alfisols catchment.

Spatial distribution of Olsen P values in the Vertisol catchment can be ascribed to the soil type dominant in the upper part of the catchment, where Haploxeralfs-Palexeralfs are dominant. Different P dynamics between soils in the upper part of this catchment and Vertisols dominant in the rest of the catchment (Haploxeralfs-Palexeralfs have a lower P buffer capacity) explain the increased Olsen P at increased height in the catchment. In the Alfisol catchment, the observed relationships between soil P indexes and position must be the consequence of P enrichment of soils in the bottom of the catchment due to erosion. It can be concluded that the definition and management of critical source areas (hot areas for P loss) in catchment should consider not only geographical and hydrological information and the estimation of P level, but also soil properties affecting P dynamics in order to reduce the density of observations required to define the critical source areas.

## Phosphorus loss and forms in overland flow from two representative catchments from southern Spain

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Available information about P losses in agricultural soils from southern Europe, in particular in Mediterranean areas from Spain, is scant. We studied P losses in two representative agricultural catchments under a rainfed bi-annual crop rotation located in Palma del Río (Province of Córdoba, Spain) (37°41'N, 5°18'W) between 2001 and 2002. One catchment had an extension of 60 ha and soils were mainly classified as Vertisols, with 44–50 % clay in the upper horizon and pH ranging from 7.4 to 7.9. Soils in the other catchment, with an extension of 25 ha, were mainly Alfisols, with 6–33 % clay in the upper horizon and pH between 7.4 and 8.0. Dissolved total P, and total P were determined in runoff samples (composite sample for each runoff event). Phosphorus forms in soil (18 sampling points in the Vertisol catchment and 10 in the Alfisol one) and sediments in runoff samples were studied by means of the sequential fractionation method of Ruiz et al. (1997) involving extraction with: NaOH, citrate-bicarbonate (CB), citrate (C), citrate-ascorbate (CA), citrate-bicarbonate-dithionite (CBD), acetate, and HCl. Iron extraction involved sequential extraction with of CA and CBD, which dissolve the poorly crystalline and crystalline Fe oxides, respectively.

Most (>99 %) P lost via overland flow from both catchments was particulate P. For similar runoff (~50 mm), sediment and P lost under sunflower were much higher in the Vertisol (9.7 kg P ha<sup>-1</sup>) than in the Alfisol catchment (1.35 kg P ha<sup>-1</sup>). The same amount of runoff in March in two consecutive years promoted a loss P of 1.35 kg ha<sup>-1</sup> under sunflower (low soil coverage), and 0.35 kg ha<sup>-1</sup> under wheat in the Alfisol catchment. The sum of P fractions did not differ significantly between soil and eroded sediment (4 events) in the Vertisol catchment (means 587 and 537 mg P kg<sup>-1</sup>, respectively). However, the sediments from the Alfisol catchment (5 events) were significantly enriched in P (566 mg P kg<sup>-1</sup>) when compared with the original soil (232 mg P kg<sup>-1</sup>). The increased P content in the sediments eroded from the Alfisol was mainly related to an increased content in Fe oxides relative to the with soils: CA extractable Fe increased from 0.9 to 4 g kg<sup>-1</sup>, and CBD from 6.3 to 17.1 g kg<sup>-1</sup>. This explains why the Fe-related P fractions (NaOH-, CA-, and CBD-extractable) were those showing the greatest increase. The ratio of the more labile P forms (NaOH-P + CB-P) to the sum of P fractions in the eroded sediments was 0.59 in the Alfisol but only 0.21 in the Vertisol catchment. Thus, although total P loss per ha was smaller in the Alfisol than in the Vertisol catchment, the P release potential of sediments eroded from the first catchment was significantly higher, particularly under reducing conditions because Fe-related P is concentrated in the sediments. Furthermore, the sediment was more enriched in poorly crystalline Fe oxides (which are readily soluble under anoxic conditions), than in crystalline Fe oxides (more resistant to reductive dissolution). In summary, the environmental impact per unit of P lost was potentially higher in Alfisols than in Vertisols which are representative of the study area.

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## **Regional assessment of Phosphorus and trace metal accumulation in Swiss agricultural top soils due to manure application**

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Delimitating areas with high risks of phosphorus (P) and trace metal accumulation is an important task for the limitation of their export from intensively used agricultural land into surface waters. Avoiding excessive P application on agricultural land also is an important step towards a sustainable management of the very limited resources of this important nutrient. In Swiss agroecosystems, major inputs of P and trace metals into soils result from the application of manure. Thus, the spatial pattern of these inputs is driven by farm management decisions. Here, we describe a regional approach to account for farmers' fertilizer application strategies in a model designed to identify areas with high risks of P and trace metal accumulation in topsoils. The approach, which is based on newly available georeferenced farm census data, is used to estimate the P and trace metal fluxes associated with manure application in two Swiss cantons (Thurgau, 991 km<sup>2</sup> and Fribourg, 1671 km<sup>2</sup>) over the last three decades. The available data base includes data on land management (crops, areas) and livestock (animal type and quantity) for each farm in the target region. In addition, the coordinates of each farm are available. For spatial referencing, we used Swiss areal statistics, which is available on a hectare raster. In a first step, each hectare cell that corresponds to agricultural land is attributed to a farm, and the distinction between arable and grassland is made on the basis of distance and topography (slope). In a second step, the amount of manure applied to each hectare cell is estimated, taking into account the P need of the crop, the livestock composition of the farm and boundary conditions such as legal restrictions in manure application due to groundwater protection. Using data on P and trace element concentrations of the manure, the model then predicts georeferenced element fluxes into soils. Together with soil and climate data, this information will be used as input into the EPIC model to simulate the temporal evolution of soil P and trace metal concentrations. The EPIC model is being adapted and calibrated for this purpose in a parallel project (see abstract of R. Della Peruta et al.), using data collected over the last three decades on reference sites of the Swiss Soil Monitoring Network. Using the calibrated EPIC model, we will analyze dynamic scenarios of P and trace metal pools in soils linked to changing economic and environmental boundary conditions.

EPIC model: <http://www.brc.tamus.edu/simulation-models/epic-and-apex.aspx>

## Phosphorus transfer across boundaries: From basin soils to river bed sediments

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Phosphorus transfer from soils to water bodies has attracted increasing interest, as P is a driver for biological activity in waters and needs to be managed to avoid eutrophication. Several studies have highlighted the importance of soil erosion and physical transfer of P with soil particles from land to water. Moreover, in some rivers the particulate fraction can dominate the total P flux. In this work, the variation of particulate P concentrations and forms in the Anllóns River basin (NW Spain) was studied, comparing their status in the soils of the basin with that of the suspended sediments and the deposited bed sediments. Eighty nine complex soil surface samples (<2 cm) were taken from forest, cultivation and pasture land, in two sub-basins in the upper part of the river (Upper Anllóns and Grande River). Thirty three samples from river bank and road talus were also taken, as they can contribute to suspended material in the river channel. Twenty samples of suspended sediments were taken at each of the sub-basins closure. Bed sediments (<5 cm) were sampled at 14 sites along the main course of the Anllóns River, downstream from the confluence of the Grande River and the Upper Anllóns. Liofilized samples < 63  $\mu\text{m}$  were analyzed for C, N, total P and available P (Pa).

The soils with the highest total P concentration were those from pasture or cultivation land, related to amendment and fertilizer inputs. Total P increased from soils (mean value 653  $\text{mg kg}^{-1}$ ) to bed sediments (mean value 1598  $\text{mg kg}^{-1}$ ) and suspended sediments (mean value 1961  $\text{mg kg}^{-1}$ ). For Pa the differences were even stronger, ranging from 98  $\text{mg kg}^{-1}$  for the soils, to 849  $\text{mg kg}^{-1}$  for bed sediments, and 1314  $\text{mg kg}^{-1}$  for suspended sediments. The high surface area and organic matter contents of the fine suspended particulates may be responsible for the P enrichment due to sorption reactions with soluble reactive P during transport and on entering the water column. The percentage contribution of Pa to total P is relatively low in the soils (15 %) but increases in the bed sediments (53%), and even more in the suspended materials (67%).

The C:N:P molar ratios varied from 243:16:1 in the soils to 125:11:1 in the suspended sediments collected in the Upper Anllóns sub-basin, and from 398:26:1 in the soils to 254:19:1 in the suspended sediments of the Grande River, which clearly contrast with the lower 44:3:1 C:N:P ratios observed from the bed sediments. Even though biofilms develop over the bed sediments of the Anllóns River, their ratio is well below the Redfield ratio (106:16:1) or average rate for phytoplankton, and only the suspended material of the Upper Anllóns was close to this ratio. When C, N and total P concentrations were plotted in a ternary diagram, the biggest separation was observed between all the forest soils, on the one side, and the bed sediments, on the other side, due to their marked differences in organic matter contents. In the central part of the plot, the non-forest soils and suspended sediments from the Upper Anllóns are grouped together and separated from those of the Grande River, pointing to an influence of the lithology (schist and gabbro, respectively) on total P concentrations. Nevertheless, when Pa was plotted instead of total P, all the soil types lie close together at the organic rich base of the ternary diagram, and far from both the suspended and bed sediments, which are enriched in Pa. A discriminant analysis showed that, together with C and N concentrations, it was the available P and not the total P, which allows to clearly differentiate between the soils and the suspended sediments, with bed sediments lying between these two groups.

## Clay-bound phosphorus retention in wetlands – a catchment comparison

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Ten constructed wetlands, situated in agricultural areas in the south of Sweden, are investigated for phosphorus (P) retention and factors affecting the efficiency. These wetlands are situated in areas dominated by clay or heavy clay soils. National monitoring and estimations have shown that agricultural areas dominated by such clay soils have among the highest phosphorus losses. It has also been shown that a large proportion of P is transported in particulate form; hence, it is expected that sedimentation is the predominant P retention process in the selected wetlands. Sedimentation of clay may, however, be difficult to achieve in wetlands, and the aim of the study is to quantify the function of wetlands as sinks for the P lost from the catchments.

Sedimentation and accumulation of particles are measured once a year using sedimentation plates (40×40 cm) placed on the bottom of the wetlands. Additional sedimentation traps (estimating gross sedimentation) have been placed in three of the wetlands, and those are emptied two times per year. This paper presents results for P and soil retention after the first year (in kg P ha<sup>-1</sup> year<sup>-1</sup>), estimated by extrapolating the amount of sediment accumulated on the plates, and the content of total phosphorus (TP), to the whole wetland area. Furthermore, one wetland was selected for a detailed investigation of the effect of a vegetation filter, which in a previous study has been shown to have a positive effect on particle retention. Here, estimates of net and gross sedimentation are measured before, within and after the vegetation filter.

To identify some factors of significant importance for wetland P load and retention efficiency, the statistical relationship with different wetland and catchment characteristics is analyzed. The factors included are the ratio wetland area to catchment area, average hydraulic load, and various catchment characteristics, e.g. soil type, topography, fertilization history, and soil P fractions.

Since there is some uncertainty regarding sedimentation of fine clay particles (< 0.2 µm), the size fractions of the accumulated sediment is determined to see whether or not the finest clay particles from the catchments settle in the wetlands. Previous studies have shown a correlation between particle size and bioavailability, where finer clay particles contain larger proportion of easily available P. Trapping the finest clay particles is therefore of particular ecological importance and needs to be further investigated.

## **A model to predict soil P depletion to achieve agronomic and environmental objectives**

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Management of the soil P reserve is one of the key measures to reduce the risk of diffuse P transfer from agricultural soils with the aim of mitigating the eutrophication of freshwaters. In Ireland soluble P levels in grassland, above the agronomic optimum of Index 3 (Morgan P 5.1mg L<sup>-1</sup> to 8.0mg L<sup>-1</sup>), have been identified as one of the dominant pressure factors for P-loss in runoff (Tunney, 2000). The Nitrates Directive National Action Programme therefore requires soils that are above index 3 to have zero mineral P amendment following offtake where a soil P test exists and to assume index 3 for replacement P where there are no soil test data. In terms of meeting Water Framework Directive targets for water quality, the time taken to deplete the soil P reserve to index 3 is therefore important to guide the expectations of farmers and policy makers. In this study an exponential decline of the available soil P following zero P amendment was noted from plot study data (three P-fertiliser treatments on four soil-P indices over eight common soil associations) (Schulte and Herlihy, 2007). The decline parameter, *c*, was subsequently modelled using step-wise regression of a range of soil parameters. The P balance (inputs minus offtake) and total P concentration of the soil created the most parsimonious model ( $R^2 = 0.63$ ). This model was applied to a number of soil P and P balance scenarios assuming zero mineral P amendment to predict the rate decline of index 4 fields to the boundary condition of index 3. For very high starting points (high Morgan and total P concentrations) the average time to the boundary was 7 to 15 years depending on the P balance. Uncertainty analysis indicated this range to be 3 to >20 years. Expressed as a landscape mosaic with some fields having index 4 soils and with different initial conditions and P balances, this could mean between 25% and 90% of those soils remaining in index 4 by 2015 and 3% to 45% by 2021.

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## **Pedotransfer Functions to Estimate Mineral Phosphorous Fractions and Dynamics in Swedish Agricultural Soils**

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In Sweden estimation of phosphorous (P) losses from agricultural land has been calculated with the modified ICECREAM model (Larsson et al., 2007) both for scientific purposes and for national environmental assessments (HELCOM) (Brandt et al., 2008). However a need to adjust the model description of the mineral P dynamics to better describe conditions for Swedish soils has been identified (Djodjic et al., 2008). Earlier studies have shown a close dependency between the measured P-contents and the desorption and release of P from Swedish soils, but also that P-sorption capacity and P-saturation should be taken into account (Börling et al., 2004). The aim of this project is to develop estimation routines, so called pedotransfer functions, to describe P solubility and the partitioning between P-pools in relation to these and also other basic soil characteristics. The new pedotransfer functions will be used to develop an improved version of the model.

60 soil samples, representing a wide range of soils differing in soil texture and chemical characteristics as well as history of P fertilisation, are used to secure a statistical basis for the pedotransfer functions. Different soluble P fractions in the soils are determined by extraction with HCl, ammonium lactate (AL), Olsen-P, CaCl<sub>2</sub> and H<sub>2</sub>O, respectively. Other soil characteristics determined are ammonium oxalate- and pyrophosphate soluble Al and Fe, Ca-AL, sorption characteristics, P saturation, pH, organic C and soil texture. The pedotransfer function development will be based on the dependency between the sorption characteristics and the P concentration and other measured soil characteristics.

By adapting the description of mineral P dynamics in ICECREAM to Swedish conditions and analytical methods more data for parameterisation and testing will become available. With a better description of P dynamics in the model, the hypothesis is that ICECREAM will be a more reliable tool for national calculations as well as for evaluating the effects on P-losses for different agricultural management scenarios mainly focusing on fertilisation practices.

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## **Modeling the Effect of Buffer Strips on Surface Losses of Particulate Phosphorus**

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A modified version of the ICECREAM model (Tattari et al. 2001, Larsson et al. 2007) is frequently used to estimate the influence of different agricultural management practices on phosphorus losses from Swedish agricultural fields. Since buffer strips (BS) are one of the most important practices to reduce surface losses of particulate phosphorus (PP) from agricultural land it is important to be able to represent the effects of BS in an accurate way in the simulations. In this study the model option to divide the field into different segments with different crops and management was tested to simulate the effects of grass buffer strips on PP losses with erosion. Simulations were carried out to assess the influence of different climate input, crops, soil types, and field geometrical parameters (slope, field length, and BS length) on PP losses and their reduction by a BS when run for a period of 20 years.

The parameter affecting PP losses most strongly was the slope gradient. An exponential increase of the average annual loss up to  $13 \text{ kg ha}^{-1} \text{ a}^{-1}$  was observed when the slope steepness was shifted from 1 % ( $0.5 \text{ kg ha}^{-1} \text{ a}^{-1}$ ) towards 10 %. Of the investigated non field geometrical parameters, soil type had the strongest effect on PP losses. Ten different soil types, ranging from sand to clay, according to the FAO classification system, were tested. The results were differing by the factor 10 with the highest losses of up to  $1.8 \text{ kg ha}^{-1} \text{ a}^{-1}$  (slope steepness 2 %) for soils rich in silt and clay.

Irrespective of climate, soil type, crop, and amount of PP loss, the reducing effect of a 10m BS was rather constant and ranged from 60 % to 70 % in scenarios with 40 m field length and a slope gradient of 2%. However, the field geometrical parameters influenced the relative reducing effect of the BS. With increasing BS length the reduction efficiency increased as well, although with a diminishing effect per each extra length unit added (20 % (1 m BS); 62 % (10 m BS); 81 % (30 m BS)). An exponential increase of the PP loss reduction effect could be observed when the slope steepness was elevated. Expanding the field length led to a decrease of the BS efficiency. This decrease was as well diminishing the further the field was expanded.

The still ongoing evaluation of the results indicates that the model is able to reflect the behavior of a BZ in terms of reducing PP surface losses in a reasonable way and in accordance with observations reported in literature. Hence, the modeling approach is promising and will be further tested in the national assessment of P-losses from Swedish agricultural land performed with the ICECREAM model. However, further studies on how to account for the effects of BS when scaling up the simulated results from field level to catchment and regional level have to be done.

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## **Impact of farming practices on phosphorus transport in an irrigated watershed in the middle Ebro Basin (Spain)**

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Phosphorus (P) losses caused by intensive agriculture have negative effects on water quality of surface aquatic systems. To better understand the impact of farming practices on P transport in irrigated agricultural systems, temporal patterns of P concentrations (total P (TP), total dissolved P (TDP) and particulate P (PP)) were analyzed over two hydrologic years (October 2007-September 2009) in the El Reguero Basin (Huesca, Spain). Water and P mass balances were also calculated in order to identify the main source and transport factors of the transfer of P. Farming practices (mainly irrigation and fertilization) carried out in spring and summer seasons increased TP concentrations reaching a maximum of  $1.01 \text{ mg P L}^{-1}$ . Results of P mass balance revealed that the main source was fertilization responsible for more than 98 % of total P inputs in the watershed. In the case of crop P requirements, results indicated that 60 % of applied P (fertilizer) exceeds crops needs and leads to an excess of  $53.7 \text{ kg P ha}^{-1} \text{ year}^{-1}$ . This excess contributes to the P build-up on the soil surface, making it susceptible to further transfer to streams and subsequent deterioration of water quality. According to the soil survey performed in the study area, soils showed a P enrichment ratio of 31% (P-Olsen from 29.30 ppm at the beginning of the agricultural season to 38.45 ppm at the end). Therefore, P fertilization should be calculated according crop needs and the available phosphorus in the soil. 94 % of TP concentrations were recorded in the dissolved form indicating that the dominant pathway for P transfer was subsurface flow, mainly by leaching process of excess irrigation water. All the water samples analyzed during the study period presented TP concentrations superior to the threshold of eutrophication ( $0.02 \text{ mg L}^{-1}$ ) indicated by Sharpley et al. (2001). The El Reguero stream drainage water was classified as hypertrophic during the 1<sup>st</sup> study year (mean annual TP =  $0.179 \text{ mg L}^{-1}$ ,  $> 0.100 \text{ mg L}^{-1}$ ) and eutrophic during the 2<sup>nd</sup> study year (mean annual TP =  $0.061 \text{ mg L}^{-1}$ ,  $> 0.035 \text{ mg L}^{-1}$  and  $< 0.100 \text{ mg L}^{-1}$ ) (Olmos Gracia, 2000). The exported masses of P were 240 kg in 2008 and 229 kg in 2009 and the TP losses of 0.204 and 0.194  $\text{kg P ha}^{-1}$  for 2008 and 2009, respectively. The amount of TP load in El Reguero stream is very small with regard to total phosphorus input (0.2%). Based on P mass balance, mitigation of P in El Reguero stream watershed should focus on reducing the amount of the applied phosphate fertilizers through accurate nutrient budgeting and fractionating over the vegetative crop cycle. Farmers should also take into account P content in crop residues which is approximately 40- 60% of harvested P, most of which is plowed under (principally corn residues).

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## **The influence of nitrogen chemical sources from foliar fertilizers on P mobility in sunflower plant**

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In order to quantify the influence of nitrogen chemical sources from complex foliar fertilizers (CFF) on P absorption through the plant teguments and his translocation in sunflower vegetative organs (leaves, stems and tops), as well the influence on the fresh and dry weight of these organs view, the labeled phosphorus (<sup>32</sup> P) was used, and diluted CFF solution have been applied only on a part of the leaves while the P determination have been done only in the plant organs untouched by CFF solution. The data obtained, in a green house experiments, have revealed that P absorption through plant teguments was significantly higher in the presence of NH<sub>4</sub>NO<sub>3</sub> and urea as N source, the specific radioactivity level being 529 Cpm/mg P in leaves, opposite to those on which <sup>32</sup>P from complex foliar fertilizer solution has been applied.

The fertilizing composition for foliar application having a pronounced environmentally protective effect, are recommended, especially for crop growing in the areas with restrictions to usual soil fertilisation.

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## **Modelling of hydrology and phosphorus losses in catchments – the importance of spatial and temporal scale**

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Phosphorus losses from land to water courses are often characterized by high spatial variability due to the heterogeneity of the landscape. The losses may also vary considerably over time and short-duration events, e.g. episodes of high erosion, may in some catchments account for much of the total load to watercourses. Choosing a relevant spatial and temporal scale for modelling phosphorus mobilization and transport on land and in watercourses is thus critical to enable a good representation of the key processes in the landscape. We investigate the effect of scale issues when modelling phosphorus losses and transport in a small (7 km<sup>2</sup>) agricultural catchment in the South-east of Sweden using the HYPE water quality model. For this purpose, the HYPE model was reformulated to be able to run on a sub-hourly time steps and catchment was divided into several smaller sub-catchments. Data from an automatic stream flow gauging station at the catchment outlet was complemented with short duration measurements of water stage at important sites in the catchment using mobile observation technologies. In addition, grab samples and high frequency automatic sampling on phosphorus concentrations and <sup>18</sup>O was carried out in a dense monitoring network in support of the modelling exercise. <sup>18</sup>O in precipitation, snow and water was sampled, analysed and used as supporting evidence when attempting to quantify the importance of different flow pathways. Key findings from the study on which hydrological and chemical processes that are most sensitive to scale issues are reported.

## **Meeting EU Water Framework Directive groundwater quality objectives: the challenge posed by phosphorus in western Irish karst aquifers**

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Groundwater can be a significant pathway for phosphorus transfer to surface waters in some circumstances; transfer of ecologically significant quantities of phosphorus has been established in the western Irish limestone lowlands, where thin, or absent, soils and subsoils overlie conduit dominated karst aquifers, providing little opportunity for phosphorus attenuation (Kilroy & Coxon, 2005). In addition, in this karst region, groundwater often provides the majority of surface water flow, and therefore the contribution of phosphorus to surface water bodies can be important.

The E.U. Water Framework Directive (2000/60/EC) required an evaluation of the status of all water bodies, prior to establishing management plans to achieve good status by 2015. The environmental quality standard (EQS) for molybdate reactive phosphorus set for rivers in the Republic of Ireland is 35 µg/l P (as an annual mean). Rivers failing to meet this standard are deemed to be at less than good status. In the Irish Western River Basin District, this includes a large proportion of river channel, much of which lies within the karst lowlands, and this has implications for groundwater body status. The classification of Ireland's groundwater bodies was undertaken in 2008 by the EPA using data from the national groundwater monitoring programme. One of the Water Framework Directive status assessments includes a determination of whether the contribution from groundwater is sufficient to threaten the Water Framework Directive objectives for associated surface water bodies. In the case of phosphorus, the test requires consideration of both groundwater phosphorus concentrations and groundwater flow contributions to surface water. The criteria for poor groundwater status are met if an associated surface water body does not meet its objectives, groundwater threshold values are exceeded and groundwater contributes more than 50% of the pollutant load required to cause the environmental quality standard of 35 µg/l P to be exceeded. The results of this assessment were that 101 groundwater bodies (13.3% of area) in the Republic of Ireland were at poor status due to the contribution of phosphorus from groundwater bodies to associated surface water bodies (Daly, 2009). The vast majority of these groundwater bodies are in karst aquifers.

This situation presents a challenge for those working to attain the required Water Framework Directive objectives of good status by 2015. Further research is required on phosphorus sources and transfer pathways within poor status groundwater bodies, and on the implications for river basin management plans.

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## Oxygen isotopes in phosphate as a tracer for sources and pathways of catchment P in stream water

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This study aims at investigating the feasibility of using oxygen isotope measurements on dissolved inorganic phosphate (DIP) to quantify the contribution of different sources of P to the DIP transport from small catchments in South Sweden. Recent studies by Elsbury et al. (2009) have proven that  $\delta^{18}\text{O}_\text{p}$  values can be an efficient tool to study sources and transport pathways for dissolved phosphate.

We present the results from analyses of samples collected from rural sewage septic tanks, drainage wells from agricultural fields on clay soils, stream-bank erosion spots, and the stream water from one catchment with mixed land-use. Sample handling and isotope measurements were done similar to the procedures described by McLaughlin et al. (2004), but adapted to the specific chemistry of the different water types. Samples were shaken with activated carbon powder prior to filtering in order to remove organic matter (modified after Gruau et al. 2005).

The preliminary results show that the septic tank effluents could be clearly distinguished from the drainage water by the  $\delta^{18}\text{O}_\text{p}$  values of DIP. Depending on the site, the  $\delta^{18}\text{O}_\text{p}$  varied from +7 to +10 ‰ in the field drainage waters, whereas the sewage samples showed significantly higher  $\delta^{18}\text{O}_\text{p}$  values of +12 to +14 ‰, all values reported relative to VSMOW. Phosphate in fresh water with low DIP concentrations is expected to be in equilibrium with ambient water ( $\delta^{18}\text{O}_\text{w} = -16$  to  $-12$ ‰), whereas wastewater contains high concentrations of DIP, is not in equilibrium, and thus reflects the isotope signature of the source.

Focusing on one catchment with mixed landuse, the possible seasonal and flow dependent variations in the isotope ratios of DIP in drainage and stream water is investigated along with sampling of TP and DIP concentrations and water flow measurements. Additionally, the isotopic composition of readily available phosphate in the agricultural soils of the catchment is analyzed. Furthermore, changes in the isotopic composition of stream water DIP caused by sewage discharge are investigated in five small catchments that are not impacted by agriculture. The results from those measurements will be used when modeling the dynamics of phosphorus losses from the studied catchment areas.

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## **P loss risk assessment by a modified P index method in the Fonte Espiño river basin (Galicia, NW Spain)**

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The need to adopt strategies to minimize loss of nutrients from agricultural land has increased greatly as a result of diffuse contamination. The measures taken must be based on the results of studies of the changes in each nutrient in soil and water, and of studies of the transport mechanisms and the effects of different agricultural practices. More detailed studies must therefore be carried out in smaller areas, and should include analyses of soil and water. The river basin considered in the present study is located close to the Fervenza reservoir (Galicia, NW Spain) and includes Fonte Espiño and Rego de Abellas, both tributaries of the river Xallas.

The influence of agricultural practices on the risk of P loss in the river basin and whether such practices generate a risk of eutrophication in the water bodies as a result of modification of the P index were investigated.

The source factor was determined by quantification of the extractable P, of the degree of P saturation and of molybdate reactive P (MRP) desorption. Taking into account the particular characteristics of the river basin, components related to connectivity, distance, degree of run-off and degree of erosion were considered in calculating the transport factor.

The importance of transport factors (usually very low) was evident in the river basin, as low P index values were observed in soils with high and even very high values in the source factor. In general in the river basin, the risk of movement of P to the water is low, especially in areas where forest soils and natural grasslands are common. Confirmation of the low P index values was provided by the low concentrations of P (total and MRP) in the rivers.

## Soil phosphorus management in agricultural catchments in Ireland

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In 2006 the EU Nitrates Directive National Action Programme (NAP) regulations (SI 101, 2009) were implemented on Irish farms. An evaluation of the NAP is being conducted in six agricultural catchments to monitor the consequences of compliance with the regulations in the wider landscape. These catchments were selected to encompass the range of Nitrogen (N) and Phosphorus (P) transfer risks in Ireland. This paper discusses the baseline soil P levels measured in this study in conjunction with P input-output balances and the environmental and farm management implications in relation to the NAP measures for four of these agricultural catchments.

Agricultural catchments ranging in size from 7.5km<sup>2</sup> to 12.1km<sup>2</sup> were selected to represent a range of soil types, geology, climate, land use type and intensity in Ireland. Two catchments are more than 30% cropped with wheat and barley (Tillage A and B) and two are grassland (Grassland A and B) sustaining more than 1.6 livestock units ha<sup>-1</sup> (LU ha<sup>-1</sup>). Average long-term annual rainfall ranges from 900 to 1200 mm. Under the NAP the application rates of P fertilizers and organic manures to agricultural land are governed by soil test P levels (Morgan-P) and indirectly by organic N limits ( $\leq 170$  kg organic N ha<sup>-1</sup>; where derogation granted  $\leq 250$  kg organic N ha<sup>-1</sup>). The nutrient application rules in place are aimed to limit excess availability of P in the soil in order to minimise the diffuse risks of P loss to water. Soils at soil P index 4 ( $>8.0$  mg L<sup>-1</sup> grassland soils;  $>10.0$  mg L<sup>-1</sup> arable soils) are considered to be excessive in terms of agronomic production (i.e. no yield response to P additions) and are at greater risk of transferring this excess via runoff to water bodies (Tunney, 2000). To evaluate these rules a census of soil P was taken across each catchment, with samples collected at a 2 ha resolution according to the standard agronomic soil sampling protocol in Ireland. Nitrogen and P inputs and off-take levels were recorded on farms within these catchments and are being used to develop P balances for these farming systems. These baseline data will act as a reference point from which all trajectories of change in soil P levels can be modelled and monitored over the term of the programme.

On a catchment basis, preliminary results show that mean and median soil P concentrations were lower in the Grassland B catchment compared to Grassland A. The two tillage catchments had similar mean and median soil P concentrations despite their differences in predominance of spring vs. winter cereals and soil type. In all catchments the mean soil P concentrations were within or below recommended optimum ranges of 5.1-8 mg L<sup>-1</sup> for grassland soils and 6-10 mg L<sup>-1</sup> for tillage soils (P index 3). Assessments of high hydrological transport risk coinciding with discrete areas of P-index 4 from legacy farming will inform further nutrient management advice.

SI 101, 2009. Statutory Instrument – EC (Good Agricultural Practice for the Protection of Waters) Regulations 2009, 51p, Stationary Office, Dublin.

Tunney, H., 2000. Phosphorus needs of grassland soils and loss to water. In: Steenvoorden, J., Claessen, F., Willems, J. (Eds.), International Conference on Agricultural Effects on Ground and Surface Waters. Int Assoc Hydrological Sciences, Wageningen, Netherlands, pp. 63-69.

## **Identification of Phosphorus transport and delivery critical source areas at the headwater catchment scale using a fuzzy-rule-based model**

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Implementation of the Water Framework Directive will require the management of phosphorous (P) fluxes to waterbodies. Effective management of diffuse P fluxes requires the identification of *critical source areas (CSA)*. We present results from a UK-based modeling study where we identify headwater catchment-scale hotspots of P sources, P delivery coefficients and P fluxes using a fuzzy-rule-based model trained on field observations made at a scale which minimizes the effects of point sources and instream phosphorus processing: the headwater catchment scale. The PEDAL (Phosphorus Export and Delivery from Agricultural Land) model uses a fuzzy-rule system to classify the catchments where observations were made, based on their propensity to deliver P, using variables available from national databases. The observed variability within catchment classifications, which are described by similar variable magnitudes, determines the resulting uncertainty range around estimates made for catchments where no observations are available. Fuzzy delivery coefficients are linked with uncertain estimates of P mobilization potential to produce fuzzy estimates of P flux. Spatial mapping of the results provides an initial scale-dependent screening for CSAs, whilst quantifying the uncertainty associated with estimates informing risk-based management strategies and providing focus for higher spatial resolution investigations.

# **MONITORING PHOSPHORUS LOSS**

## **ORAL PRESENTATIONS**



## **Phosphorus runoff risk from different fertilizer strategies using rainfall simulation and Bayesian modeling**

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The general increase in soil phosphorus (P) fertility concentrations to optimum or above optimum concentrations under intensively managed pastures in Australia has contributed to greater adoption of a strategy of split P maintenance applications, (i.e. multiple small applications within a year), which in total are equivalent to the annual maintenance P requirements. Although lower rates of P fertiliser generally result in disproportionately lower surface runoff P concentration, there has been very limited research comparing total P losses generated from several smaller applications of P to the same total P rate applied in a single application. This information is essential as lower runoff concentrations associated with multiple smaller applications may be countered by the greater likelihood of runoff occurring soon after one of these applications. In this study we applied a novel approach which combined runoff P concentration data from rainfall simulation trays and long term runoff data from two contrasting catchments using Bayesian statistics to compare the long term risk of P loss in runoff from single and split P fertiliser application strategies.

The single application of 40 kg P/ha resulted in disproportionately high runoff P concentrations should runoff occur at short times since fertilizer application. However, when runoff concentration and temporal understanding of runoff were combined in the Bayesian model, we found that the 3 applications of 13.3 kg P/ha resulted in a greater risk of P runoff compared to a single application of 40 kg P/ha as splitting P fertilizer applications increased the likelihood of a coincidence of fertilizer applications and runoff occurring. We found that the overall risk of P runoff is also increased in catchments where the rainfall/runoff pattern is less predictable, compared to catchments where rainfall/runoff is winter dominant. This suggests that land managers should apply P fertilizer less frequently and only during periods of the year when surface P runoff risk is low.

## **Risk assessment of biowaste application in agriculture: runoff phosphorus loss with simulated rainfall**

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The application of biowastes to agricultural soils provides P in excess of crop needs when applied to meet the N needs of most agronomic crops. These over applications can result in the build-up of P in soils to values well above those needed for optimum crop yields and also may increase risk of P losses with surface runoff.

Non point-source pollution of fresh waters by agricultural P can accelerate eutrophication and limit water use for drinking, recreation, and industry. Manure, sewage sludges, compost and mineral fertilizer P sources vary in their contributions to soil P pools.

The objective of this research is to evaluate the relationship between phosphorous distribution in different biowastes and their runoff losses. Biowaste P speciation has been analyzed using modified Williams's method.

This study assessed P loss immediately after biowaste applications at soils following a Simulated Rainfall Protocol. The experiment was conducted using three biowastes: pig slurry, organic fraction of municipal solid waste and sludge from sewage treatment plant and two soils of different characteristics. Each experiment was replicated three times. In all experiments biowastes were added to each soil at a rate of 100 kg total P ha<sup>-1</sup>. Soils and amendments were mixed together and then poured into plastic boxes (19 cm x 28cm x 5 cm in size), leveled and presaturated 72 h before being placed under a rainfall simulator to ensure that runoff would occur during the rainfall event.

The runoff boxes were placed under the rainfall simulator on plastic racks adjusted to 5% slope. Simulated rainfall (120 mm h<sup>-1</sup>) was applied to boxes, usually within 2 days of application, to collect runoff during 30 min.

Runoff samples were analyzed for concentrations of sediment, unfiltered (RPunf) and dissolved reactive P (RP <0.45 µm), bioavailable P (BPP), and total P filtered (TP <0.45µm) and unfiltered (TPunf). After the last rainfall event, soils from each box were sampled to assess soil P accumulation with depth.

Vadas et al (2004) developed a simple model to predict dissolved inorganic P release from manures. We tested the Vadas Model using data from our experiments.

## Monitoring phosphorus loads from headwater grassland catchments in the South West of England

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Despite advances in researchers' capabilities in predicting phosphorus (P) losses, the strength of these models relies on the robustness of the measured hydrological and water quality data. The data collected in the field are commonly used to both parameterise models and evaluate the results; thus, the choice of monitoring strategy is of critical importance if behavioural models are to be identified correctly. Storm events play a key role in transporting particulate and dissolved P but the significance of these fluxes in terms of downstream water quality may be missed by either daily or weekly sampling. This NERC-funded study presents data from three contrasting headwater, farm-scale grassland catchments in the South West of England, which have been sampled at sub-hourly resolutions during 20 storm events during the 2009/2010 hydrological season. The choice of study catchments was determined through GIS analysis of land use and soils in the regions and examination of existing data sets. The data builds on previously collected datasets from Den Brook (a heavy clay, intensively stocked catchment of 48 ha), Drewston (a sandy, improved grassland catchment of 28 ha) and Slapton Woods (the 24 ha brown earth, mixed management Cairncross subcatchment,). Maximum recorded concentrations of P were 53546  $\mu\text{g/l}$  at Den Brook, 464  $\mu\text{g/l}$  at Drewston and 181  $\mu\text{g/l}$  at Slapton. These concentrations demonstrate that grasslands are significant sources of P as the Organisation for Economic Cooperation and Development suggest that eutrophication problems can be triggered by TP concentrations of 35 to 100  $\mu\text{g/l}$ .

There are significant differences in hydrological responses to rainfall between the catchments; however, all sites demonstrate increased levels of P and sediment during the rising limb of the hydrograph. Velocity measurements used to provide an indication of the uncertainty in stage discharge calculations show that uncertainty is greatest at higher rates of discharge; therefore, calculations of loads should reflect this. The loads should also reflect the uncertainty associated with sampling frequency; using a 60 min sampling frequency (instead of 30 mins) would have led to significant over and under-estimations of both soluble and particulate P loads of up to 17%. In all catchments the uncertainty introduced to total P load determination by stage/discharge calculations is greater than that associated with sampling frequency (based on artificial depopulation of datasets). One storm in each catchment was sampled with six replicate samples and two further storms with three, the degree to which the samples vary, and the influence this has on the loads calculated is discussed. This work, which explicitly quantifies uncertainty surrounding P loading of surface waters, has clear implications for the treatment of measured variables during modelling exercises and the interpretation of observed datasets in support of best land management strategies.

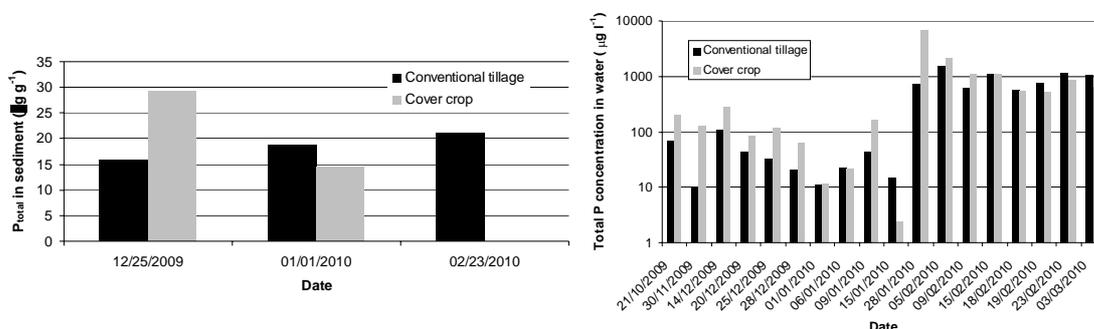
## Influence of soil management on phosphorus losses in olive orchards at the hillslope scale

Ana Moreno Lamarca<sup>1</sup>, Tom Vanwalleghem<sup>2</sup>, Vidal Barrón<sup>3</sup>, José Torrent<sup>3</sup>, Armando Martínez Raya<sup>4</sup>, Jose Ramón Francia Martínez<sup>4</sup>, Belén Carceles<sup>4</sup>, José Alfonso Gómez<sup>2</sup>

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The overall objective of this study was the monitoring and comparison of phosphorus losses in olive orchards with different soil management at the hillslope scale, and the identification of the mechanisms through which phosphorus is lost. Several soil erosion plots were installed in three olive orchards: La Conchuela (plot size: 12 × 24 m), Benacazón (plot size: 8 × 60 m) and Lanjarón (plot size: 8 × 24 m), where the soil was classified as Typic Haploxerert, Petrocalcic Palexeralf and Typic Xerorthent respectively. The average slope of these plots ranges from 11 to 30 %. In all cases the different management systems that were compared are conventional tillage and cover cropping in the inter tree line. At each site, total runoff and sediment losses were measured and sampled. Total phosphorus was determined in the collected sediment and soil samples, while dissolved phosphorus was analyzed in runoff samples. Particle size distribution was determined in the sediment and soil samples using laser-diffraction analysis.



**Figure 1: Total P concentration in sediment (left) and runoff water (right) in Lanjarón for different events during fall and winter of the 2009–2010 season.**

This communication presents the preliminary results of the first hydrological year of the project (2009–2010), a year of high precipitation. Figure 1 presents some of the results to date for the Lanjarón experimental site.

## **Crop growth and phosphorus loss in a clay loam soil amended with Enviropig low-P manure**

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Genetically enhanced pigs, Enviropigs<sup>TM</sup>, that use efficiently phytate P in cereals and excrete manures with up to 75% reduction of P contained, provide an excellent option for reduction of P loading to water resources from agricultural farm lands. Understanding both the agronomic and environmental impacts of Enviropig low-P manure (ELPM) is essential to validate this innovative technology and to develop BMPs for best use of the manure. Studies were conducted to determine crop (rye grass) growth and soil P leaching loss in a Brookston clay loam soil amended with Enviropig manure, in comparison with the conventional pig manure (CPM). With the same amount of P added, rye grass growth and development and consequently the dry matter performed identically in the soil added with ELPM, relative to CPM. Soil P leaching was conducted using an undisturbed large soil core (30 cm d by 70 cm h) technique. Treatments included manures from four combinations of two pig genotypes (conventional pig - CPig and transgenic pig - TPig) with two diet formulas (conventional diet - CD and low P diet - LPD), and a control. All manures were added at a rate equivalent to 100 kg P ha<sup>-1</sup>.

Manure application increased concentrations of all forms of P in soil leachate, regardless of pig genotype and diet formula. Compared with the soil amended with manure from CPig that was fed with CD, contents of leachate total P decreased by 29% in the soil amended with manure from TPig that was fed with LPD, but increased by 3% in the soil amended with manure from TPig that was fed with CD, an indication of excessive P supply. Content reduction of leachate total P was predominately accounted by dissolved reactive P (72% reduction), with a small portion by particular P (6% reduction). Adoption of the Enviropig technology can be an environmental friendly approach, but has to be in combination with low P diet.



# **MONITORING SOIL P LOSSES**

## **POSTERS**



## Effects of soil drying and rewetting on forms and quantities of phosphorus in leachate

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The drying and rewetting of soils has long been known to result in the increased mobilisation of nutrients which potentially can transfer from the soil via leachate and contaminate surface waters. There are still many gaps in our knowledge of the processes, soil properties and sources involved in the regulation of the quantities of nutrients released in this way. In the laboratory we tested the hypothesis that the rate of rewetting of a dried soil affects the solubilisation and ultimately the concentrations of phosphorus (P) and other nutrients present in leachate (Blackwell et al. 2009). Firstly we prepared a grassland pelostagnogley soil by passing it through a 2 mm sieve and removing all visible live floral and faunal material. Half the soil was dried at 35 °C and half was maintained at approximately 40% water holding capacity. Both dried and moist soils were loosely packed into funnels plugged with glass wool and 25 ml of deionised water was added gradually over periods of 0, 2, 4, 24 and 48 hours. The leachate was collected and analysed for dissolved and particulate reactive and total P. Soil microbial biomass was measured in the initial dried and moist soils, and subsequently in all soils following completion of rewetting. While drying caused a significant reduction in microbial biomass, there was no significant difference between the microbial biomass in soils rewetted at different rates. In all cases P concentrations were significantly higher in the leachate from the dried soil treatments than from the moist soil treatments. Dissolved P concentrations were highest in the leachate from the 2 hour treatment, while for particulate P, concentrations were highest in the 0 hour treatment. However, these differences could not be attributed to differences in release or response of the microbial biomass. The results probably reflect variables including the energy of the rewetting water available for mobilisation and transfer of particulates, optimisation of conditions for solubilisation of P and minimisation of opportunities for recycling of released P within the soil. In subsequent experiments we investigated the effect of rate of rewetting on intact soil cores to see if the effects were still apparent in structured soils. We also investigated whether the 2 hour peak concentration was in fact a true peak by replicating the first experiment but at a higher temporal resolution; rewetting was carried out over periods of 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4 hours. In both these experiments the relationships of P in leachate with nitrogen species were investigated. The results of these experiments are also presented. These experiments suggest that changes in patterns of rainfall as a result of climate change could significantly affect the quantities of P leached from soils.

Blackwell, M.S.A., P.C. Brookes, N. de la Fuente-Martinez, P.J. Murray, K. Snars, J.K. Williams and P.M. Haygarth. 2009. Effects of soil drying and rate of rewetting on phosphorus in leachate. *Biol. Fert. Soils*. 45:635-643.

## **A concurrent time and depth assessment of soil and leachate phosphorus in poultry manure-amended soil columns**

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Time and depth studies of phosphorus (P) transport and transformation in soils have previously focused on soil measurements taken initially or following a leaching experiment. In order to better-predict P loss potential from soils we must understand the time and depth scale over which changes in P solubility influence leaching characteristics. Three poultry-manured soil columns were fitted with soil sampling ports at 0-5, 5-10, and 10-15 cm depths as well as a spigot for leachate collection. Soil total P (TP) and metals (Ca, Mg, Al, Fe, Mn), water and bicarbonate extractable P (WEP/BEP), degree of P saturation (DPS), pH, and total C and N were measured biweekly. P species in NaOH-EDTA extracts of soils were assessed using solution <sup>31</sup>P nuclear magnetic resonance spectroscopy. Leachate pH, total P (TP<sub>L</sub>), total dissolved P (TDP), and dissolved molybdate reactive P (DMRP) were measured weekly. Leachate dissolved unreactive P (DUP = TDP – DMRP) and total particulate P (TPP = TP<sub>L</sub> – TDP) were calculated. Degree of phosphate saturation (DPS) in manured and control soils was high (>60%) and did not change appreciably with time. Increasing soil WEP and BEP concentrations were correlated with TDP concentrations during the ten weeks, particularly in the 10-15 cm depth ( $R^2=0.427, 0.532$ ). Particulate-P leaching was enhanced following manure application and was likely mediated by organic matter. Microbial activity in the 0-5 cm depth, as indicated by the presence of pyrophosphate and orthophosphate diesters, likely contributed to the solubilization of organic P (OP) and resultant orthophosphate release to soil and leachate over ten weeks. *Myo*-inositol hexakisphosphate (IHP) remained the dominant form of soil OP and showed little variation with time or depth. The results of this study suggest that: (1) soil extractable-P concentrations have short-term (<10 leaching events) influence on leachate-P characteristics; (2) biological cycling of P may influence soil and leachate-P characteristics; (3) the concurrent sampling strategy described here is useful for assessing the behavior of P in soils.

## Contribution of P supply to P losses from fields

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Phosphorus losses by runoff or subsurface drainage in fields mainly come from two sources:

- mobilization of P accumulated in the soil
- inorganic or organic fertilizer supply followed shortly after by rainfall causing runoff or subsurface drainage. Such losses called incidental losses (Whithers et al 2003) sometimes accounts for the largest losses of P.

The share of P losses due to incidental transfers following P supply was determined in a long term field experiment carried out in western France on a silty soil, during 10 years (1998-2007). Flows from runoff and pipe drainage coming from 5 plots (4200 to 10800 m<sup>2</sup>) were continuously collected and weekly sampled in order to measure the concentration of total and dissolved P (total P in water filtered to 0,70 µm). One of the five plots (L1) was not drained. The plots L1, L2, L3 were cropped with maize and wheat and L4, L5 were cropped with wheat, pea and rape. For L1, L2, L3 each crop received each year a P supply from cattle manure and sometimes an additional supply of triple super phosphate. L4, L5 received only phosphorus from triple super phosphate fertilizer.

Incidental P losses due to phosphorus supplies were detected by the abrupt changes in slope of the relationships between cumulated flows during the 10 years and the cumulated loads of dissolved P. The contribution of the soil to dissolved P losses was calculated from the relationship established by omitting the periods when incidental P losses occurred.

Over the 10 years of this experiment the incidental losses due yearly applications of manure or fertilizers contributed for 36 to 53 % of the total losses of dissolved P depending on the plot. For all the plots the losses attributable to phosphorus applications (fertilizer transfer ratio) represented less than 1% of the amount of phosphorus supplied to the crops.

Table 1: Total P inputs, flows, dissolved P losses and share due to the P supplies for 5 plots during the 10 years of an experiment carried out in western France

Plot	L1	L2	L3	L4	L5
P inputs (kg P ha <sup>-1</sup> )	464	464	464	274	274
Runoff + Drainage (mm)	2225	2965	2661	2491	2727
Dissolved P losses (g P ha <sup>-1</sup> )	7957	5279	6508	4699	4554
Weighed DP concentration (µg P L <sup>-1</sup> )	358	178	245	189	167
Share due to P supply (%)	53	45	42	36	48
Fertilizer transfer ratio (%)	0.91	0.51	0.58	0.62	0.81

Whithers J. A., B. Ulen, C. Stamm, M. Beckmann. 2003. Incidental phosphorus losses- are they significant and can they be predicted? J. Plant Nutr. Soil Sci. 166:459-468.

## Magnitude and duration of the ‘incidental’ fertilizer effect is influenced by soil P buffering properties

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The application of phosphorus (P) fertilizers to grazed pasture systems can increase the export of P in surface runoff via systematic and incidental fertilizer effects. In Australian grazing systems, the dominant incidental effect arises from fertilizer application and can comprise a large proportion of annual P exports. The magnitude and duration of fertilizer incidental effects has been reported to vary widely, yet the soil characteristics which influence this are poorly defined. In this paper we investigate the effect of soil P buffering properties on the duration and magnitude of incidental fertilizer effects using a weak electrolyte solution as a surrogate measure of runoff P.

There was a significant ( $r^2=0.95$ ,  $P<0.01$ ) exponential decay relationship between soil P buffering and incidental fertilizer half life (Fig 1a). For soils with low P buffering capacity, fertilizer half life was up to ~3.5 days, whereas for highly P buffered soils the half life was <0.5 day. Soil P buffering was also found to have a significant effect on the magnitude of the incidental fertilizer effect (Fig 1b). For soils with low P buffering, soluble soil P at  $T_0$  was >4 times higher than that of high P buffering soils. In fact, the soluble P on a poorly buffered soil at  $T_{56}$  was similar to that at  $T_0$  on a highly buffered soil. Soil P buffering properties need to be considered when prescribing management actions to reduce incidental fertilizer effects. Soils with low P buffering require much more careful timing of P fertilizer application to minimize adverse environmental risks.

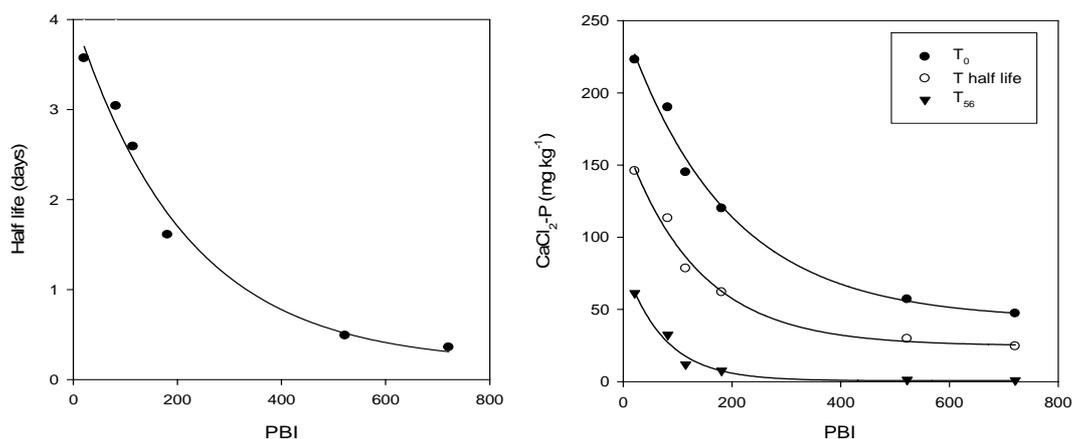


Figure 1. The effect of phosphorus buffering (PBI) on a) fertilizer half-life, and b) soluble soil P concentrations at various times after fertilizer application.

## Variability of phosphorus load from agricultural land in Czech Republic Part I: baseflow condition

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Should we reduce primarily point or non-point sources of phosphorus pollution? Crucial question of many managers is always answered in context of existing data and their interpretation. As well in Czech Republic in 2010', where apparent decrease of TP concentration during last 20 years is recorded in rivers. In spite of improvement, many water bodies stay in risk not to meet good ecological status in 2015 (WFD) because of eutrophication. Gathering knowledge of amounts, impacts and desirable threshold of P load from point and non-point sources revealed agricultural land as a most uncertain P source. Moreover its relative amount is suspected to prevail in future.

Aim of the project is to describe unbiased P load from Czech agricultural land and evaluate its share on present stage of eutrophication. Load is described in terms of P quantity and bioavailability along with its flow, temporal, and spatial variability.

Firstly, flow conditions divide the task into two disparate *modi operandi*. Through incompatible impact, we value them separately (neither potential nor realized uptake is proportional to P emitted during erosion events, thus we exclude stormflow from this part).

Secondly, spatial variability in P load during baseflow conditions is characterized according to 11 dominant soil groups in macro-scale (158 one-shot summer samples over whole country in 2006). TP and SRP concentration in major soil groups (Cambisols, Chernozems, dystric Planosols and orthic Luvisols) were lower than mean of 0.069 and 0.038 mg.l<sup>-1</sup>, respectively. Eutric Fluvisols, albic and albo-gleick Luvisols frequently far exceeded global median of SRP concentrations of 0.024 mg.l<sup>-1</sup>. Although they cover < 10 % of Czech arable land they could be important source of bioavailable P. In addition, micro-scale variability is described by one example of eutric Cambisols, most extent soil group in Czech Republic. In ten profiles within one watershed, which diverge only in land-parcels structure and of course in crop, summer concentration of TP and SRP were 0.038 ± 0.012 and 0.021 ± 0.010 mg.l<sup>-1</sup>, respectively.

Thirdly, temporal variability in P load during baseflow conditions is characterized by seasonality of instantaneous load (monthly sampling of cca 30 profiles) and interannual variability of specific yield (15 headwaters during 2007-2009). Annual specific yields of TP are estimated at range at 1-20 kg.km<sup>-2</sup> of agricultural land. While highest P loads (0.2 mg.s<sup>-1</sup>) are regularly realized after snowmelt or within long lasting rain periods, highest concentrations are reached during summer months, conversely. But only summer maxima at about 1/3 of profiles exceeded 0.035 mg.l<sup>-1</sup> SRP.

We conclude, with respect to threshold for eutrophic water, 0.035 mg.l<sup>-1</sup> BAP, that summer load from agricultural land during baseflow (it unable continuous algal succession) do not afford large capacity for downstream wastewater dilution, but alone cannot hold up persistent blooms. Now first statewide monitoring of exclusively agricultural headwaters is done in Czech Republic. P load during baseflow conditions is comprehensively summarized. Finally, it will help to find appropriate measures in water bodies across the country. Assessment of P from erosion will follow with emphasis on conditions surrounding soil particles during in-stream transport (*i.e.* different delivery of size fractions and their saturation/equilibrium concentration with regard to surrounding water incl. discharged wastewaters) and conditionally delayed P release from riverine or lake sediment.

## **Autumn tillage increases phosphorus leaching from fine textured soils**

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In Denmark 1400 kg phosphorus (P) per ha has accumulated in the plough layer of agricultural soils during the last century, which have raised the potential for P export to the aquatic environment and leaching of P through soil to tile drains is considered an important contributor to the diffuse P losses. Autumn tillage (ploughing + harrowing) is a widely used management practice in Danish agriculture. Restrictions in autumn tillage have lately been suggested as a mitigation option to reduce subsurface leaching of phosphorus from critical source areas. However, only few studies have investigated the impact of autumn tillage on phosphorus mobilization and leaching.

The objective of this study was to investigate the impact of autumn tillage (ploughing and harrowing) on phosphorus mobilization and how it interacts with soil type. A field tillage experiment was conducted along a natural textural gradient. Large intact soil cores (20×20cm) were sampled at three positions along the textural gradient (loamy sand, sandy loam, loam) in the stubble (1<sup>st</sup> September) prior to tillage and in the ploughed and harrowed soil (7<sup>th</sup> October) 14 days after tillage. Prior to the leaching experiment the soil columns were saturated and drained to -100 hPa to ensure identical initial soil water potential. The leaching experiments were performed at unsaturated conditions (-5 hPa at lower boundary) and applying a constant low irrigation rate (2 mm/h) for four days. Tritium (<sup>3</sup>H<sub>2</sub>O) tracer experiments were performed at steady out-flow in both stubble and ploughed soil columns to evaluate the impact of soil management on flow pathways. Column effluents were analyzed for <sup>3</sup>H<sub>2</sub>O, electrical conductivity (EC), turbidity, pH, total dissolved P (TDP) and total P (TP).

The <sup>3</sup>H<sub>2</sub>O-tracer breakthrough curves (BTC's) reflected the differences between soil textures with matrix dominated flow in the loamy sand and preferential flow in the loam soils. Autumn tillage had no effect on the <sup>3</sup>H<sub>2</sub>O-BTC in the coarser soils, but slightly decreased preferential flow in the loam. The electric conductivity (EC) of the effluents was lower in all soil textures in the ploughed situation compared to stubble. Colloid leaching increased with increasing clay content, and tillage significantly increased colloid mobilization resulting in a doubling in accumulated colloid leaching. Increased colloid mobilization may be attributed to the tillage breaking up aggregates and exposing new surfaces, but the lower EC in the ploughed soils might also add to the increased colloid mobilization. Tillage significantly increased TP mobilization by ~0.3 kg/ha in the loam soil compared to the stubble, while less mobilization was observed in the coarser soils. The increase in TP leaching following tillage was mainly attributed to an increase in the fraction of particulate P, but also the leaching of TDP increased following tillage.

## The effect of slurry application technique on Phosphorus loss in overland flow

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Agriculture makes a significant contribution to phosphorus (P) levels in Northern Ireland's waterways, and as such, action is required to reduce P losses from agricultural soils. With livestock manures a significant source of P, there is increasing interest in spreading techniques that minimise P losses following slurry application. To address this, an experiment was conducted to examine the impact of a range of slurry spreading techniques on P loss in overland flow.

Six treatments were investigated in a split-plot design experiment: control (no slurry), splashplate, injection-horizontal to the slope, injection-vertical to the slope, trailing shoe-horizontal to the slope and trailing shoe-vertical to the slope. Treatment plots (0.5 m<sup>2</sup>) were set out in four blocks (6 treatments within each block). Treatments were simulated by hand application of slurry. Slurry was applied to silage stubble immediately post harvest. Slurry was applied at a rate of 40 m<sup>3</sup> ha<sup>-1</sup>. Volumetric soil moisture content was equal to field capacity at application. Overland flow was generated at days 2, 9 and 30 post slurry application using two portable rainfall simulators (Amsterdam design) which simulated rainfall at a rate of 40 mm hr<sup>-1</sup>. Runoff was generated for a period of 30 minutes, collected and analysed for dissolved reactive P (DRP), particulate P (PP) and total P (TP). Data was analysed using SPSS.

	Treatment						SIG	SED
	Control	Splashplate	Injection Horizontal	Injection Vertical	Trailing Shoe Horizontal	Trailing Shoe Vertical		
DRP (mg/l)	0.54 <sup>a</sup>	1.75 <sup>d</sup>	1.10 <sup>bc</sup>	0.91 <sup>b</sup>	1.06 <sup>bc</sup>	1.30 <sup>c</sup>	***	0.361
PP (mg/l)	0.98 <sup>a</sup>	4.44 <sup>c</sup>	4.14 <sup>bc</sup>	2.87 <sup>b</sup>	3.42 <sup>bc</sup>	4.61 <sup>c</sup>	***	0.675
TP (mg/l)	1.60 <sup>a</sup>	6.76 <sup>c</sup>	5.53 <sup>bc</sup>	3.90 <sup>b</sup>	4.78 <sup>bc</sup>	6.19 <sup>c</sup>	***	0.858

Table 1: Flow weighted mean P concentrations measured in runoff at Day 2 post slurry application

Slurry application technique had no significant treatment effect on P runoff at either day 9 and 30 post application due to dry soil and weather conditions. The flow weighted mean P concentrations exported in overland flow at day 2 post slurry application are presented in Table 1. The splashplate spreading treatment exhibited significantly higher levels of DRP in runoff when compared with the injection and trailing shoe treatments ( $p < 0.001$ ). Total P concentrations were again highest from the splashplate treatment however this is only significantly different for the injection vertical and control treatments ( $p < 0.001$ ). There was no significant difference between application direction employed in the injection or trailing shoe treatments.

In conclusion trailing shoe and shallow injection apparatus both reduced DRP loss following slurry spreading at day 2 post application to silage stubble. It is hypothesised that this is due to a higher rainfall-slurry contact area available in the splashplate treatment. Longer term reductions in P loss were masked by weather conditions at the time of rainfall simulation.

## Calculation of Phosphorus Losses from Swedish Agricultural Land in 1995 and 2005

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Nitrogen and phosphorus leaching losses from arable land in Sweden have been estimated within a broader program aimed at calculating the total nutrient load originating from Sweden that reaches surrounding seas. The results were used for following up on the Swedish environmental policy objective “Zero eutrofication”. Nutrient losses from all arable land in Sweden have been estimated for two years; 1995 and 2005. The estimates were performed using the NLeCCS calculation system. (Johnsson et al. 2008).

NLeCCS is a system that is used for calculation of root zone leaching of both phosphorus and nitrogen and surface losses of phosphorus from arable land (Persson et al. 2007). The NLeCCS system consists of several computer programs and simulation models that are linked in a chain. When calculating the change in leaching between different years, the climate has a very strong influence on the results. In order to normalize the effect of climate, NLeCCS uses 20 to 30 years of climate data. An array of agricultural statistics, i.e. crops, harvests, fertilization schemes, and application dates of agricultural practices, are collected in a database. From these agricultural statistics a 10,000 year long crop sequence and management database is generated that complies with specific rules about crop rotations. This data is then divided into parts that match the available climate data period in length. These management files are used as input for the leaching simulations. Phosphorus simulations are performed with the ICECREAMDB, a modification of the Finnish ICECREAM model to which macropore flow has been added (Larsson et al. 2007). The daily results from this model are then aggregated to calendar years. Leaching coefficients are in turn calculated from the aggregated results. The result is a matrix of leaching coefficients for the following categories; region in Sweden, soil texture class, crop, slope and soil phosphorus content.

The estimated mean leaching loss rates for agricultural land in Sweden indicated a decrease from 0.54 to 0.52 kg P/ha, between the years 1995 and 2005. The calculated difference was abscribed to changes in crop distribution, decreased amounts of applied fertiliser and the introduction of buffer strips in the period from 1995 to 2005. The mean leaching rate from the 22 different regions varied from 0.10 to 1.3 kg/ha with the highest rate in Western Sweden. The lowest losses were in regions with little runoff and a large amount of light soils. In almost all regions there was a slight decrease in the leaching rate from 1995 to 2005. The changed crop distribution was the largest reason for reductions in all regions.

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**MITIGATION OPTIONS**

**ORAL PRESENTATIONS**



## A web-based P index as a mitigation planning tool

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We have developed a P index for Denmark by adapting the traditional P Index concept and combining this with an interactive mitigation planning facility. Instead of one single index value per field we calculate sub-indices for individual P loss processes. The risk of P loss is assessed according to the P transfer continuum. For each P loss process we describe and parameterize the factors: source, mobilisation, and transport. At present the Danish P Index includes parameterized descriptions for soil erosion, surface runoff, and leaching by both matrix and macropore flow. Phosphorus index maps have been constructed for the entire agricultural area at the field block level in Denmark. The potential of P loss from field blocks by individual transport pathways is distinguished into low, medium or high risk classes. Fourteen different options for mitigating P loss have been assessed regarding their effect on P loss and the associated cost. The Danish P Index and the associated mitigation options were incorporated into a web-based tool with three components: (1) a GIS component where P risk maps and background information can be viewed; (2) a mitigation planning facility that permits interactive data input by the user and calculates the effect and costs of mitigation scenarios for an area chosen by the user; (3) a download component where GIS information and mitigation scenarios can be downloaded by the user for further processing in local applications.

The tool gathers all currently, for the whole agricultural area, available information regarding P loss and thus facilitates access to relevant data. The purpose of the tool is both educational and to assist local environmental planners and agricultural advisers in prioritizing P mitigation in small and medium-sized catchments with a known problem in a recipient. Despite the conceptual simplicity of the representation of P loss processes, a major challenge lies in quantifying the uncertainties associated with the risk assessment.

## **Defining Phosphorus Concentrations to Prevent Eutrophication of Canadian Agricultural Streams**

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Inputs of nutrients (phosphorus, P, and nitrogen, N) to fresh waters can cause excessive aquatic plant growth, depletion of oxygen, and deleterious changes in abundance and diversity of aquatic invertebrates and fish. Efforts to safeguard or improve the quality of water resources in agriculturally-dominated ecosystems have traditionally focused on managing on-farm activities to reduce materials loss; however, another management measure for improving environmental quality is adoption of environmental performance standards (or “outcome-based standards”). As part of a “National Agri-Environmental Standards Initiative”, the Government of Canada committed to the development of non-regulatory environmental performance standards that establish P concentrations to protect ecological condition of agricultural streams. Comparison of nutrients released to the Canadian environment showed that agriculture was the largest source of P to surface waters (compared to sewage, industry and aquaculture). Analysis of data from > 200 long-term water quality stations across Canada and detailed ecological study at approximately 70 sites further showed that land-use activities from agriculture increased nutrient concentrations in streams, resulting in increased sestonic and benthic algal abundance, loss of sensitive benthic macroinvertebrate taxa, and an increase in benthic diatom taxa indicative of eutrophication. Application of five different approaches for defining environmental performance standards using only chemistry data resulted in values for total P spanning a relatively narrow range of concentrations within a given ecoregion of Canada. Cross-calibration of these chemically-derived standards with information on biological condition resulted in recommendations for total P standards that would maintain high water quality and protect aquatic life from adverse effects of eutrophication. Recommended standards for total P (summer average) ranged from 0.01-0.03 mg/L for the east coast Atlantic Maritime region, to 0.02 mg/L for the Montane Cordillera of western Canada, to ~0.03 mg/L for the Mixedwood Plains of southern Ontario and Quebec, and finally to 0.10 mg/L for the interior Prairies. These recommended standards should result in good ecological condition with respect to benthic algal abundance, benthic diatom composition and benthic macroinvertebrate composition. Research is continuing to determine whether these total P standards are protective of downstream receiving waters and to evaluate interactions of P with other stressors (e.g., N, suspended sediments, pesticides), specifically their combined effects on aquatic food webs.

## **Reducing/omitting phosphorus fertiliser inputs to reduce Australian dairy pasture soil phosphorous concentrations**

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Excessive soil phosphorus (P) is an international problem. Many soils of the United States and Europe contain P concentrations above crop requirement, due to application of P-rich manures. The majority of Australian dairy pasture soils contain high (>25 mg/kg Olsen P) soil P concentrations (National Land and Water Resources Audit 2001), primarily due to fertiliser use. Considering the strong link between soil test P (STP) and P in surface runoff (Sharpley and Rekolainen 1997), strategies are required to reduce soil P. One such strategy is to eliminate further P additions. However, the rate of soil P decline of intensive pasture systems when P fertiliser inputs are reduced or omitted is poorly defined, yet this information is essential to allow land managers to make informed decisions.

We investigated the effect of soil extractable P concentration, soil P buffering properties and P fertiliser input on the rate of extractable P decline across 6 pasture soils. Agronomic (Olsen) and environmental (CaCl<sub>2</sub>) measures of soil P were monitored. At each site, four Olsen P categories were established to represent typical paddock concentrations ('low' ≤ 15 mg/kg, 'medium' 16–30 mg/kg, 'high' 31–40 mg/kg, and 'very high' ≥ 41 mg/kg). In a fully factorial design, four P fertiliser rates were applied every six months since establishment in May 2005. The P fertiliser treatments were 0, 0.5, 1 and 2 times estimated soil P maintenance requirements, according to site P buffering properties, with maximum rates ranging between 20 and 50 kg P/ha/yr.

Preliminary results suggest that soils with high STP concentrations have a greater initial rate of decline. Very low P buffered soils also had faster rates of P decline than other soils, especially at high and very high initial STP concentrations. Further modeling will aim to define the soil characteristics which influence the rate of decline, as this information will allow extrapolation of the current findings to other soil types.

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## **Evaluation of agri-environmental schemes: Cost effectiveness of buffer zones to reduce phosphorus losses**

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The EU financed Rural Development Program provides support for the establishment of buffer zones in Sweden. These buffer zones are the only measure that is extensively used in Sweden to reduce phosphorus losses from agricultural land. In the first program period (2000-2006) over 11 million Euros was paid out to farmers for establishment of buffer zones. A final evaluation of the program performed in 2008 (SLU 2009) estimated that the support resulted in an average cost of over 300 Euros for a reduction of 1 kg P at the edge of the field. The support program was extended for the period from 2007-2013.

Participation in the buffer zone program rose during the first period from 1000 farms (1750 ha) in 2001 to 4850 farms (9080 ha) in 2006. However, this rate has fallen in the first two years of the second period with less than 4000 farms applying for support in 2007 and fewer than 2700 farms in 2008. This paper compares and evaluates the cost effectiveness of the support for buffer zones in the first period and the first three years of the second period. It also compares the uptake in the program from these two periods, in particular the effect of a lower subsidy rate and changing prices for agricultural products between the two periods as possible explanations for the observed decline in participation. In addition to other eligibility rules, the program provides support for buffer zones with a width between 6-20 meters. This paper also evaluates the distribution of buffer zone widths between the two periods as a proxy for the productivity of agricultural land included in the program. The current period mid-term evaluation is in progress and results will be available in July 2010.

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## **Evaluation of Constructed Wetlands as Mitigation Options for Phosphorus and Sediment within UK Agriculture**

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Pollution from diffuse agricultural sources is currently of concern for water quality, with recent UK figures suggesting that agriculture is responsible for 70% of sediment, 60% of nitrate, and 25% of phosphorus inputs into rivers and lakes. The Mitigation Options for Phosphorus and Sediment (MOPS) projects explore practical methods to reduce diffuse pollution from UK agriculture. Previous research undertaken within MOPS has demonstrated that the use of in-field mitigation options such as reduced tillage and tramline management can be effective at reducing surface runoff, sediment and nutrient loss. However, pollutants can still be lost from hillslopes unchecked via subsurface flow pathways, which may transfer high nutrient loads downstream. Current research within MOPS is therefore investigating constructed wetlands as edge-of-field diffuse pollution mitigation approaches, which can tackle both surface and subsurface pathways where they discharge into ditches and streams. The use of constructed wetlands to trap sediment and nutrients is new to the UK, but is well established elsewhere, particularly in Scandinavia. The MOPS project builds on this research, and includes a number of novel factors including assessment of multiple pollutants and pathways and pollution swapping, and the consideration of the economic and social aspects of mitigation options, allowing their potential to be assessed in a holistic manner. To date, MOPS has created seven new constructed wetlands, located at the edge of agricultural fields on three farms with different soil types. The wetlands have been built to three different designs and sizes suited to UK landscapes, and are fed by different flow paths (surface runoff, drains and ditches). Wetland sediment and nutrient load reductions and wetland effectiveness are determined through continuous monitoring of discharge and turbidity and sediment and nutrient storm sampling at wetland inlets and outlets. Sediment and nutrient accumulation will also be assessed by annual topographic surveys and sediment sampling, and tracer experiments will be carried out in the course of the project in order to understand water and sediment residence times. In addition, the project aims to assess the cost of the features at farm scale and explore barriers to wider uptake through farmer surveys and in-depth interviews. Early outputs suggest that: turbidity measurements may be a good indicator of sediment and total nitrogen and phosphorus concentrations, allowing continuous monitoring of sediment and nutrient transfer through wetland systems at high resolution; wetlands built to take drain outfalls may be effective but may not be a practical management option in all circumstances; and constructed wetlands which receive surface runoff inputs can also reduce flood peaks. In this paper we explain the constructed wetland designs being trialled, discuss issues relating to their implementation, and present the results of the first year of monitoring.

## The Aquarius approach on mitigation of phosphorus losses

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The Interreg IVB-project Aquarius focus on farmers as water managers under changed climate conditions within the river Smedjeån sub catchment surrounding an area of ca 277 km<sup>2</sup> in southwest Sweden. The project which has a holistic approach on catchment level aims at delivering knowledge and tools to reach and sustain Good ecological status according to the WFD status in typical agricultural water bodies over time.

The strategy is to combine general farm subsidies, measures to limit erosive P- and N-losses from arable land and point sources, wetland constructions and improved sewage systems. An important factor in the project is to reach understanding and acceptance by land owners and the public of the values connected to the river both concerning nature interests and farmland production.

As a result of high animal density and manure production in the western area there has been an accumulation of phosphorus in the top soils and an increase of light soluble phosphorus over time. As a mean value of the pilot farms application of manure and mineral phosphorus exceed the recommendations by 11 kg P per ha and year. There is an obvious risk that surplus phosphorus application contributes to the present leakage from soils unless different measures not are taken to decrease the input.

The effects of agriculture on water quality as well as measures to mitigate has been developed and demonstrated in cooperation with a stratified sample of pilot farms in an agricultural dominated sub catchment of the River Smedjeån. The pilot farms represent the different types of agricultural production existing in the area of southwest of Sweden, e.g milk-, pig-, grain- and specialized potatoes production.

At least 86 wetlands covering an area of 27 ha have been created within the river Smedjeån sub catchment during the last 10 years. To have a significant effect on the quantity of nutrients transported to the sea, this area need to be increased substantially. It has been realized that use of wetlands for multiple ecosystem services should be developed to motivate the large-scale wetland construction that is needed for substantially decreasing nutrient transports. Ecosystem services obtained in addition to nutrient removal and increased biodiversity are e.g. water storage for irrigation, increased recreational value of the landscape, flood risk reduction and production of bioenergy. Questions that need to be answered and obstacles that need to be overcome to develop the use of multiple ecosystem services provided by created wetlands are being identified within Aquarius.

In order to identify and localize points of erosion (e.g particulate P) and areas of accumulation of sediment it has been necessary within the project to compile and analyse available data about the hydro morphology of river Smedjeån including catchment description, historical changes influencing the sediment system, description of the hydrology, sediment and geomorphologic system.

## **In-situ treatment of agricultural drainage water using industrial by-products phosphorus sorbing materials**

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Agricultural drainage ditches are commonplace in the low-lying coastal plain landscapes of the United States. On Maryland's eastern shore there are approximately 1321 km of publicly managed drainage ditches that drain 74060 hectares of land. Agriculture is one of the major land uses within this region and is dominated by intensive poultry production. Nutrient imbalances that have existed for decades have resulted in soils saturated with phosphorous (P). As a result, drainage ditches represent a direct pathway for high nutrient loads to be transported from fields to surface waters. In one study Kleinman et al. (2007) found that nutrient loads can range from 1.4 to 26.2 kg-P ha<sup>-1</sup> year<sup>-1</sup> from drainage ditches. Furthermore, they found that greater than 90% of the nutrients transported by drainage ditches enter the ditches through subsurface pathways. However, most practices used to reduce P loading from agricultural fields target overland flow and therefore would have little impact in these landscapes. These ditches also represent a possible intervention point in the system at which P derived from runoff and subsurface flow generated across large acreages of agricultural soils can be prevented from entering the Chesapeake Bay at a single point. The objective of this study was to construct a filter structure using industrial waste by-products to directly remove P from runoff and subsurface drainage waters entering ditches on Maryland's eastern shore. Design of filter structure, P removal effectiveness of by-product in filter structure, and overall impact on water quality will be discussed. Field prototypes of the proposed system have shown a high likelihood of success, removing approximately 60 – 90% of the P from treated water. In addition to removing P from ditch water these treatment systems have the potential to remove nitrogen, sediment, and other contaminants.

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## **The Agricultural Catchments Programme; an environmental and socio-economic evaluation of the Nitrates Directive National Action Programme in Ireland**

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The Irish National Action Programme (NAP) under the EU Nitrates Directive (SI 101, 2009) is a policy that constrains the use of phosphorus (P) and nitrogen (N) in slurry and fertilizer and is also the major Programme of Measures to mitigate diffuse pollution from agriculture under the EU Water Framework Directive (WFD). These measures include limits on soil P status; livestock intensity to limit organic N inputs to soils; closed periods for slurry/fertiliser spreading and ploughing to limit the exposure of nutrients to runoff and leaching during winter. The NAP and associated derogation agreed between the EU Commission and Ireland (OJEU, 2007) is being evaluated in the Agricultural Catchments Programme in six soil and physiographic settings representative of grassland and arable agricultural enterprises in Ireland. A ‘nutrient transfer continuum’ from source, through pathways, to delivery and impact in a water body receptor (Haygarth et al., 2005) describes the different phases of diffuse pollution and is also used in this Programme as a framework for evaluation. Compliance with NAP standards may be non-synchronous at different levels of the continuum so evaluation is required at a number of levels in a catchment-scale experimental design. First it is important to demonstrate source compliance with standards for nutrient use and soil nutrient status within the NAP. Second it is important to evaluate the effect that the policy has on water quality in terms of WFD chemical standards set for water body receptors. Consideration here, though, has to be given to legacies of previous nutrient management and the lag time between this and the influence of current policies. Third, although the mobilisation and pathways of nutrient transfers do not have chemical standards, it is important to demonstrate this link between source and delivery to validate conceptual models of P and N transfers in each catchment. Fourth, it is also important to quantify the attitudes of farmer stakeholders towards the measures contained in the NAP and the economic impacts of investment in infrastructure and the introduction of explicit times for nutrient use and ploughing. Some early data are presented showing a census approach to monitoring source and delivery of P and N, demonstration of mobilisation/pathway considerations in surface and sub-surface environments, and socio-economic considerations in the years following NAP implementation.

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## **Reducing Phosphorus Runoff from Biosolids with Water Treatment Residuals**

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Approximately 40% of the biosolids (sewage sludge) produced in the U.S. are incinerated or placed in landfills because of potential water quality problems associated with non-point source phosphorus runoff. The objective of this study was to determine the impact of chemical amendments on soluble P and P runoff from biosolids applied to small plots. Rainfall simulations were conducted in 2006 on small plots fertilized with biosolids that had been treated with alum or ferric chloride. The effect of adding an alum-based water treatment residual (WTR) at a rate of 20% (wt/wt) was also evaluated. The following year, rainfall simulations were conducted using WTR/biosolid blends of 0.15:1 and 0.3:1 that were allowed to incubate for three weeks prior to application. Soluble P runoff loads observed with the 20% WTR treatment were not significantly different from other chemical treatments and resulted in a 48% reduction in soluble P runoff. Soluble P runoff loads in year 2 for the 15% and 30% WTR treatments resulted in significantly lower soluble P compared to untreated biosolids and led to soluble P runoff load reductions of 78% and 85%, respectively. The greater load reductions found in year 2 indicate that longer storage times may allow for greater P adsorption, most likely caused by P diffusion into micropores. Treating biosolids with WTRs will allow for greater land application of biosolids and WTRs and reduce or eliminate the economic costs associated with landfilling and incineration of these two resources.

## **Ranking high P load risk fields in a lowland plain for mitigation measures**

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Dutch manure policy has substantially reduced agricultural nutrient surpluses but is still insufficient to reach the quality standards set by the EU-WFD in all water bodies by 2015 (Van der Bolt et al., 2008). In the eastern and southern sandy regions this is mainly caused by high soil P content due to excessive use of animal manure in the past. Additional measures are needed to further reduce P loads to surface waters. For the sake of cost-effectiveness such measures need to be targeted to critical fields. Three different methods to rank P-load risk are compared.

In the Netherlands P leaching is simulated at national scale with the mechanistic simulation model STONE (Wolf et al., 2005) that distinguishes 6405 spatial units (plots) with unique combinations of input data (soil, hydrology, crop, fertilizers), and with an average area of about 500 ha. Identification of critical fields requires a much higher spatial resolution. STONE is less suitable for this purpose, because of the large number of required input parameters. Besides, the 1D approach of surface runoff in STONE is a conceptual simplification of this poorly understood process under flat conditions. Hence we developed two alternative approaches along separate lines.

The PLEASE model (Schoumans et al., in prep.) combines the same mechanistic process description for inorganic P as STONE and soil P test information to calculate the P concentration profile in the soil, and uses a simplified description of the lateral flow from soil to surface waters to calculate P-loads. PLEASE requires input on the local characteristics precipitation surplus, seepage flux, depth of groundwater table, soil P test value (Pw) and phosphate adsorption capacity.

The third approach was developed for the P policy framework of the Province of Limburg (Noij et al., 2009). It ranks hydrological transport routes according to their expected contribution to P-load for every separate field. We distinguish surface runoff (SR), pipe drain discharge (PD), and lateral groundwater flow to small field ditches (FD) and larger ditches (LD). Shallow routes are more important for P. SR risk per field is ranked based on soil elevation data and connectivity. The importance of soil P was classified based on a comparison with STONE results for specific plots. The effectiveness of measures was judged by the ranking of the transport routes they tackle. The ranking of critical fields with the methods will be compared for the same region.

Noij, I.G.A.M, C. Van der Salm (eds.) et al., 2009. Beleidskader fosfaat voor Noord- en Midden-Limburg. Wetenschappelijke onderbouwing. Alterra-rapport 1894, Wageningen.

Schoumans, O.F., P. Groenendijk and C. van der Salm (in prep.). PLEASE: A simple procedure to determine P losses by leaching.

Van der Bolt, F.J.E. et al., 2008. Ex-ante evaluatie landbouw en KRW. Effect van voorgenomen en potentieel aanvullende maatregelen op de oppervlaktewaterkwaliteit voor nutriënten. Alterra-rapport 1687, Wageningen.

Van der Salm, C., G. Heckrath, B. Kronvang, M. Pleijter, G. Rubaek and O.F. Schoumans, 2010. Predicting phosphorus losses with the model PLEASE on a local and regional scale in Denmark and the Netherlands. IPW6 Workshop Proceedings.

Wolf, J. et al. (2005), The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands. Environmental Modeling and Software 18, 597-617.

## **Effectiveness of unfertilized buffer strips in the Netherlands: field study results**

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Unfertilized grass buffer strips (BS) have been suggested by the EU as an alternative measure to reduce N and P loads to surface waters in agricultural areas in the Netherlands. The hydrogeological setting in the Dutch delta is however quite different from the majority of locations for which experimental evidence on the effectiveness of BS (BSE) exists. In the Netherlands predominant deep groundwater flow routes may cause lower BSE. Therefore, in 2005 a comprehensive study started with five field experiments in different Dutch hydrogeological units.

Before the start of the growing season of 2006 a reference strip (RS) and a 5 m wide BS were installed next to the ditch at each experimental location. In 2007 two additional replicates were installed at two out of five locations. Nutrient balance of the treatment strips was established with crop and soil analysis, and soil moisture or groundwater samples were taken for analysis at two locations. For each treatment a separate reservoir was built in the ditch to collect and measure discharge from the field. Water in the reservoir was automatically maintained at ditch level by pumping out excess water. Discharge proportional samples were taken from the reservoirs and analyzed for N and P to calculate loads.

After three leaching seasons no significant differences in nutrient concentration of the reservoirs or in calculated nutrient loads were found between RS and BS on four locations. At the fifth location only discharge P-concentration and P-load were significantly (10-20%) lower for the BS. This eastern location lies outside the delta, has a gentle slope (2%), a shallow phreatic aquifer on top of an impermeable clay layer and is therefore more comparable to circumstances abroad with relatively more shallow flow. At the workshop we will present updated information including the last fourth winter season.

## Adapting agricultural practice to minimize P leaching

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In Denmark 1400 kg P per ha have accumulated in agricultural soils during the last century, which have raised the potential for P export to the aquatic environment and leaching of P through soil to tile drains is considered an important contributor to the diffuse P losses. Factors controlling P loss from agricultural land may conceptually be distinguished into transport factors and source factors. Source factors are functions of soil, crop and management and describe an area's potential to contribute to P export from the area. Phosphorus is leached as both dissolved and colloidal P. However, the relative importance of these P forms and how their losses are affected by tillage, soil P status, liming and manure application method on different soil types is poorly understood. The objective of this series of studies was therefore to investigate the P leaching potential from the plow layer and how leaching depended on agricultural practice and soil type.

Intact soil cores (20 by 20 cm) were sampled from the plow layer of soils with different texture, P status or liming status. The experimental setup was designed to study solute and colloid P leaching at unsaturated conditions, with possibilities to gain detailed insight into the governing processes and key factors controlling P mobilization and leaching.

Leaching of total P increased with increasing P status, demonstrated by a strong relationship between Olsen P in soil and cumulated amount of TP leached in all soils textures under reference conditions (i.e. soils which had not received experimental treatments like slurry application or tillage prior to sampling). The proportion of dissolved P increased significantly with increasing soil P status and desorption of P from plow layer soil with sufficient to high P status, seemed to support a relatively constant and high concentration of dissolved P in the effluent (1-8 mg l<sup>-1</sup>).

Studies on management practices (slurry application method, tillage and liming) were carried out to establish the mitigation potential offered by these practices. Timing and method of slurry application is generally considered as critical management practices. Our results demonstrated that surface application of slurry at field capacity increased TP leaching especially in fine textured soils, while slurry injection significantly reduced TP leaching in structured soils with low P status. Furthermore the P leaching reduction offered by injection was greater for particulate and organic P forms than MRP indicating an additional physical protection of these forms. Autumn plowing along a textural gradient increased TP leaching from fine textured soils, mainly due to mobilization of soil colloids and increased leaching of particulate P. Investigations on soil lime gradients demonstrated that increasing the liming status of the soil had some potential for reducing P leaching.

We conclude that while management practices such as slurry application method, tillage and liming offers some potential for mitigating the P leaching losses, soil P status seemed to be the main factor controlling P leaching losses from the plow layer.

Glæsner, N., Kjaergaard, C., Rubæk, GH., Magid, J. 2010. Leaching processes in soils of different texture after injection or surface application of dairy slurry (two papers in prep).

Kjaergaard, C., Rubæk, GH. and Heckrath, G. 2010. Autumn tillage increases phosphorus leaching from fine textured soils (Poster presentation at this workshop).

## Operationalising methods for minimising soil compaction and reducing soil erosion and diffuse pollution risk from wheelings in winter cereals

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Recent UK government-funded research has shown that compacted, unvegetated tramlines wheelings can represent an important source and transport pathway, which can account for 80% of surface runoff, sediment and phosphorus losses to edge-of-field from cereals on moderate slopes. For example, recent research found 5.5-15.8% of rainfall lost as runoff, and losses of 0.8-2.9 kg TP/ha and 0.3-4.8 T/ha sediment from tramline wheelings. A new project is now underway investigating the most cost-effective and practical ways of operationalising methods for managing tramline wheelings in autumn-sown cereal systems to reduce the risk of soil compaction from the autumn spray operation and the associated risk of surface runoff and diffuse pollution loss of sediment, phosphorus and nitrogen to edge-of-field. The project is focusing on the over-winter period when soils are close to field capacity and the physical protection of the soil surface granted by the growing crop is limited. The experiment, at three years on four sites with contrasting soils on moderate slopes, is investigating the relative importance of soil compaction, rather than the lack of vegetation cover, in accounting for the much greater losses of surface runoff, sediment and P loss identified down tramline wheelings compared to the uncompacted, cropped area.

This paper outlines methodologies and preliminary results, which include

- hillslope-scale event-based evaluations of the effectiveness of novel mitigation methods on surface runoff and diffuse pollution losses to edge of field,
- cost-effectiveness assessments of the economic and practical viability of mitigation methods,
- modelling the impact on water quality of implementing the most promising techniques at farm and catchment scale.

Initial data on soil physics (e.g. near-surface compaction, bulk density), and surface losses of runoff, phosphorus and sediment, are presented showing the impact of low ground pressure tyres compared to conventional systems, and evaluating the effect of drilling tramline wheelings (and using GPS systems to support autumn crop spraying). Subsequent monitoring is also exploring the cost-effectiveness of techniques to lift the soil compaction caused in the autumn using novel, recently-patented tools developed by machinery manufacturers for attachment to the sprayer unit.

Results from such applied, field scale cost-effectiveness studies provide evidence to support the identification and targeting of practical pollution control measures in the landscape; improve our process understanding of the response of soil systems to land management practices; help inform farm-scale evaluations of diffuse pollution risk; develop practical recommendations to the farming industry; and yield data to parameterise and refine diffuse pollution models at a range of scales.

Silgram, M., Jackson, R.J, Bailey, A.P., Quinton, J.N, 2010. Field-scale runoff, suspended sediment, and nutrient losses from disrupted and untreated tramlines. *Earth Surface Processes and Landforms* (DOI:10.1002/esp.1894).



# **MITIGATION OPTIONS**

## **POSTERS**



## **The importance of subsoil properties for P leaching and selection of effective mitigation strategies**

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Eutrophication is a major problem in the Baltic Sea, to a large extent due to large phosphorus (P) loads from agriculture. The Baltic Sea Action Plan obligates the participating countries to reduce their load of P to the sea. Focus on the research project presented here is to investigate the differences in P leaching from agricultural soils with emphasis on understanding the role of the subsoil as a source or sink for P losses. Undisturbed soil columns (0.295 m inner diameter and 1.18 m in length) were taken out from four Swedish agricultural soils (two clayey and two sandy soils) with and without the topsoil. The lysimeters were thereafter installed in an outdoor station where they will be subjected to natural precipitation for approximately three years when P leaching will be measured. Previous work in Sweden, made on lysimeters of the same size as those used in this project, did not show any clear correlation between P content in the topsoil and P leaching, and pointed out the importance of subsoil properties for P leaching (Djordjic et al., 2004). A calcium based amendment placed on the upper boundary of the subsoil will be tested as a mitigation strategy to reduce P losses from soils prone to P leaching. The soils have been characterized based on their chemical and physical properties. Plant available P extracted with ammonium lactate/acetic acid solution at pH 3.75 (P-AL) and P extracted with water show somewhat contradictory results for the clay soils, especially in the bottom two layers. At 50-70 and 70-100 cm depths in the clay soil Lanna, P-AL were 15.4 and 21.5 mg 100 g<sup>-1</sup>, respectively. At the same depths in the clay soil Bornsjön, P-AL were 0.2 and 1.8 mg 100 g<sup>-1</sup>, respectively. However, P extracted with water at the same depths in the Lanna soil were 0.09 and 0.13 mg 100 g<sup>-1</sup>, respectively, and 0.27 and 0.16 mg 100 g<sup>-1</sup> in Bornsjön. If P extracted with water is to be seen as an indication of the amount of P prone to leaching, these results indicate that P-AL values do not provide good measures of leachable P. Results from this project will shed light on the relationship between subsoil conditions and leachate properties, as well as opportunities to mitigate P leaching with new amendments, which in the end can yield management recommendations in Swedish agriculture.

Djordjic, F., K. Börling, and L. Bergström. 2004. Phosphorus leaching in relation to soil type and soil phosphorus content. *Journal of Environmental Quality* 33:678-684.

## **Integrated mitigation strategy for phosphorus losses to the lake Vansjø, Norway**

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The western part of lake Vansjø in southeastern Norway has a very poor water quality due to algal growth. The water quality of lake Vansjø is of great concern because it is drinking water reservoir of 60.000 inhabitants and is an important recreation area for people living in the region.

During the last 10 years an extra effort has been made to improve water quality by implementing various measures in all sectors contributing to the pollution of the lake. Agriculture is one of the main contributors of nutrients to the lake and within this sector a comprehensive implementation of measures has been attained.

The objective of this paper is to evaluate the effect of the comprehensive integrated effort that has been put into reducing diffuse pollution (especially phosphorus losses) from agricultural areas around the lake western Vansjø.

The measures consisted of reduced tillage, reduced P fertilizer application, vegetated buffer zones and constructed wetlands. The strategy to implement measures consists of information campaigns, farmer meetings with discussions, field trips, environmental planning on individual farms including farms visits and least but not last contracts and economic incentives. Implementation of measures was registered and reported for each farm at the field scale.

Monitoring of the water quality in 9 small streams consisted of manual water sampling carried out weekly and during events starting 18. October 2004 and to d.d. Seven of the small streams represented runoff from agricultural and forested areas, one stream had only forested area within its catchment and one stream represented runoff from the housing areas in the city Moss.

Results show that from 2004 to 2009 the use of P fertilizer has been reduced by approx. 75%. The area of no-till in autumn has increased and for some of the stream catchments cover 100 % of the area. Vegetated buffer zones are established along most small streams and 11 constructed wetlands were built during the period 2004-2009.

The P concentrations of the seven agricultural streams show annual variation according to the weather conditions, but there is a decreasing trend in concentration though the statistical significance has not yet been proven.

The poster will present the statistical significance of trends in P concentration in relation to the measures implemented in the small agricultural stream catchments around the lake western Vansjø.

# **The double dividend from efficient nutrient management of phosphorous inputs on intensively farmed agricultural land**

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Within the constraints of the EU Nitrates and Water Framework Directives, controlling and managing nutrient transfers to water from excessive fertiliser use on agricultural land is a significant environmental policy challenge. This paper assesses whether there is room for land managers to reduce phosphorus inputs by exploring the extent of its' over application using data envelopment analysis methodology.

Data envelopment analysis (DEA) is a deterministic approach to efficiency measurement. It measures the relative efficiency of a decision making unit (DMU) by comparing relative inputs to outputs. DEA establishes the most efficient DMU's (farms) and compares all others to the most efficient. The method uses linear programming to place a non-parametric frontier over the data. This frontier consists of the most efficient DMUs and all other DMUs are measured by their relative distance to this frontier as a measure of their level of efficiency (Coelli et al., 1998).

The main data source employed in this analysis is the Teagasc National Farm Survey (NFS) 2008. The NFS is collected annually as part of the Farm Accountancy Data Network requirements of the European Union. A farm accounts book is recorded on a random representative sample of farms throughout the Republic of Ireland (Connolly et al., 2009). This paper concentrates on specialist dairy and tillage farms. These agricultural systems are the most intensive and may pose the greatest risk in terms of managing nutrient transfer from agricultural land to water courses. The analysis was undertaken and stratified by soil type.

Results demonstrate considerable inefficiency in the utilisation of phosphorus fertilisers across these systems. Average over application compared to efficient benchmark farms ranged from 3.0 to 3.3 kg P ha<sup>-1</sup>. Average excess application of P through imported feedstuffs of between 0.95 to 1.58 kilogrammes / livestock unit was indicated on dairy farms. Potential cost savings on chemical fertilisers across all systems on average ranged from €36 ha<sup>-1</sup> to €50 ha<sup>-1</sup> of which approximately €1 ha<sup>-1</sup> was attributable to phosphorous. While potential cost savings on imported feeds of €68 to €113 per livestock units were indicated on dairy farms. Such reductions have the potential to deliver a double dividend by reducing the risk of nutrient leaching and diffuse pollution from agricultural land while improving economic margins at farm level.

Coelli, T.J., Prasada Rao, D.S., O'Donnell C.J. and Battese G.E., 1998. An introduction to efficiency and productivity analysis, 2<sup>nd</sup> edition, Springer.

Connolly, L., Kinsella, A., Quinlan, G. and Moran, B., 2009. National Farm Survey 2008.

## Proactive mitigation of nutrients at small catchment

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European countries are currently working towards the achievement of common goals for the quality of their freshwaters, as set out in the Water Framework Directive (WFD, 2000/60/EC). In 2006, the UK's Environment Agency stated that, 'diffuse pollution (especially from agricultural nutrients) will make it very difficult for the UK to achieve the Water Framework Directive's objectives'. Consequently much research effort is being made to devise effective methods to control diffuse pollution from agriculture. A four-year project, funded by the Environment Agency, UK, evaluated new and improved mitigation measures to target diffuse pollution and flooding from agriculture. The mitigation features included infiltration ponds, sediment traps, algal pods, straw barriers, and wetlands. They were constructed and instrumented at farms in Northumberland and Essex in the UK using an approach which disconnects fast polluting pathways and reduces flood peaks by creating transient storage and allowing sedimentation by slowing, storing, and filtering runoff. The results from both sites demonstrated that this approach reduced nutrient concentrations and flood risk associated with runoff from farmed land and thus demonstrated the potential for whole catchments to be managed through soft engineering interventions (Jonczyk *et al*, 2008). The cost-effectiveness of the mitigation features were evaluated, and concluded that there is a cost effective basis for nutrient pollution management, especially through sediment trapping (Jonczyk *et al*, 2010). This project has demonstrated the science, engineering, and end user engagement that can potentially yield whole catchment solutions to sediment loss, pollution control and the reduction of flood risk in rural areas. A whole catchment solution is currently underway in a 5.9 km<sup>2</sup> catchment in North East England, where soft engineered runoff management features were constructed to reduce flooding. With funding from the Northumbria Regional Flood Defense Committee, the Environment Agency North East Local Levy team and Newcastle University have created a partnership to address the flood problem using soft engineered runoff management features (Wilkinson *et al* 2010). The multi-purpose benefits of these features, originally designed to reduce flooding, have not yet been fully realised, especially with respect to phosphorus and nitrate concentrations. Nutrient data upstream and downstream of these features are currently being collected and will be used to maximize the full potential of the features to capture nutrients and offer greater protection to the downstream SSSI.

Jonczyk, J.C., P.F. Quinn, D.L. Rimmer, S. Burke, M.E. Wilkinson. 2010. The effectiveness of soft engineering interventions in controlling flooding and diffuse pollution from agricultural land. p. 75-82. In K. Crighton and R. Audsley (ed.) *Climate, Water, and Soil: Science, Policy and Practice*. Proc. Biennial Conf. Edinburgh, UK. 31 March-1 April 2010. SAC and SEPA, Scotland, UK.

Jonczyk, J.C., P.F. Quinn, D.L. Rimmer, S. Burke, M.E. Wilkinson. 2009. Farm Integrated Runoff Management (FIRM) Plans as a tool to reduce diffuse pollution and lower flood risk. In: *Sustainable Hydrology for 21<sup>st</sup> Century*. Proc. 10<sup>th</sup> National Hydrology Symposium. Exeter, UK. 15-18 Sept 2008. British Hydrological Society, UK.

Wilkinson, M.E., P.F. Quinn and P. Welton. 2010. Runoff management during the September 2008 floods in the Belford catchment, Northumberland. *Journal of Flood Risk Management (in review)*.

## Mitigation options of soil phosphorus losses by using organic-mineral fertilizers on slope soils from Romania

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Due to large scale extraction of lignite coal that is used to 5 powerplants of 100-1200 MW that has a high humic substance content in Romania there were produced, since 1994, by Dorneanu A. A new type of fertilizer on lignite base. It contains both humic substances with ameliorative effect to the soil and plant nutrition as well as nitrogen and phosphorus compounds of organic – mineral substance that delay and prolonge hydrolysis, amonification and nitrification processes of nitrogen compounds as well as of transformation of soil phosphates in superior calcium phosphates that are not accesible for plant roots.

In order to estimate the phosphorus losses originating from fertilizers on slope soils there was set up an experiment on an albic luvisoil located at Preajba – Gorj with the following variants: control (not fertilized), N<sub>100</sub>, N<sub>100</sub>P<sub>80</sub>, N<sub>150</sub>P<sub>120</sub>, N<sub>100</sub>P<sub>80</sub> from organic – mineral fertilizer, N<sub>150</sub>P<sub>120</sub> from organic – mineral fertilizer. The organic – mineral fertilizer was SH 120 with 13.8% humic acids, 10% amonia nitrogen and 20% P<sub>2</sub>O<sub>5</sub>.

Within variants were N<sub>100</sub>P<sub>80</sub> and N<sub>150</sub>P<sub>120</sub> dose was used from chemical fertilizers (ammonium nitrate and superphosphate) the phosphorus losses determined in soil and water trickling catchements have been of 2.71 kg P ha<sup>-1</sup> and 3.94 kg P ha<sup>-1</sup>. In variants were the same doses were applied as organic mineral fertilizers with lignite base (SH 120) the phosphorus losses have been lower, to 1.63 and, respectively, 2.36 kg P ha<sup>-1</sup>.



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