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SPS 2014
Sustainable Phosphorus Summit

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SPS 2014
Sustainable Phosphorus Summit

Session 1 – Phosphorus in our world

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Keynote presentations

K101

Redefining the phosphate challenge through reciprocity

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Geopolitical trends, security issues, and sustainability concerns have brought phosphate to the fore as a major challenge for Europe. The EU is almost entirely dependent on phosphate rock imports from the rest of the world. There is an increased awareness that this import reliance makes Europe vulnerable to disruptions in the supply of this important commodity. The supply side is heavily concentrated: about two-thirds of production is in China, the US, and Morocco; and Middle Eastern and North African countries account for about 80% of global exports. Geopolitical turmoil can heavily impact the supply of phosphate rock to the EU, as witnessed with the Arab Spring and the Syrian conflict. At the same time, the phosphate challenge is closely tied to global food security. Food shortages and high food prices can be triggers for social instability and therefore create security challenges for the EU. EU Member States are working on strategies to deal with developments in the global phosphate rock market, including the development of an internal market for recycled phosphate. Nonetheless, the EU will remain largely import dependent. In order to create stable phosphate trading relationships with phosphate rock producing countries, it is crucial to redefine this interdependence in terms of opportunities instead of risks. Transforming phosphate trading relations from a zero-sum game into a positive-sum relationship benefits both sides and promotes global food security, environmental sustainability and social stability.

K102

Our Phosphorus World – Picture in intensive agriculture of emerging countries in Asia

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Efficient use and best management of phosphorus (P) in intensive agriculture to ensure both food security and environmental sustainability have become a global concern. Asia, especially emerging countries, has successfully increased food productivity by increasing P input both in crop and animal production. The consumption of P fertilizer has increased greatly and its environmental impacts have become a widespread problem. In this study, China is selected as a typical case to address rethinking the trilemma of food security, environment sustainability and resource use efficiency by closing P management gaps in the holistic pathway of fertilizer application, crop production, animal production, food processing and human consumption. In the past 50 years, cereal grain yields have increased by 3.8 times , but the chemical fertilizers consumption increased by more than 50 times. Now China consumes about one-third of global P fertilizers with low use efficiency (PUEf, phosphorus use efficiency in the food chain, was ~7%) and high environmental cost (P losses from crop and animal production were ~20 kg P per ha agricultural areas). Since 1990s, intensive animal productions have increased by 40 to 80%, depending on different animal categories. Because of de-coupling of animal and crop production, the P in the animal manures is no longer recycled to land yet, which causes severe pollution for surface water. In the future, the improvement of the productivity and sustainability of agricultural systems must follow new trajectories. Here we developed a new strategy of nutrient management, e.g. Integrated Soil-crop System Management technology in the crop production systems, to realize the aim of producing more with less in China. Using NUFER model (NUtrient flows in the Food chain, Environment and Resource), we simulated the future scenarios that equally important strategy for curbing P is to manage P from the whole food production and consumption chain by combinations double high (high productivity and high nutrient use efficiency) technology in crop production with changing diet, precision livestock feeding, waste and manure nutrient recovery and recycling, etc. These combination options can increase PUEf by 13-15% and decreased P losses by a factor of 2-3 simultaneously, compared with conventional practice. China's experience in double high agriculture will provide valuable information for the sustainable development of other nations, particularly in emerging countries.

K103

Present and future phosphorus use in Europe: food system scenario analyses

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Food security in Europe is heavily dependent on the import of phosphorus (P) via fertilizers, feed and food, because Europe has no minable primary P sources. Here, we explore the effects of a possible global scarcity of fertilizer P on food production in the 27 countries of the European Union (EU-27). A dynamic food system model was developed, and linked to the existing MITERRA-Europe model, to calculate crop P uptake as a function of P application and soil P status. Phosphorus flows from, into, and within the food production – consumption system are described in a dynamic way, which makes it possible to analyse the effects of changes in drivers and nutrient management strategies on P dynamics in the food chain over time. Scenario analyses show that a full reduction of the import of mineral P fertilizer has a large effect on food production, especially in the long term (2050-2300). We estimate that mean crop P uptake would decrease by 42 to 78 % in 2300, and as a consequence the overall food system P turnover would also significantly decrease. This decrease is tempered by the buffering capacity of the soil P stock. This stock has accumulated in the last century, especially in countries with intensive crop and animal production systems. Total food production and the amounts of P in food in EU-27 decrease even further in a scenario where the imports of both P fertilizer and animal feed are withheld. The effects can be mitigated by the implementation of best management practices in nutrient management including maximization of P use efficiency in agriculture and minimization of P losses throughout the food system.

K104

Managing the global phosphorus cycle for long-run sustainability and food security

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P is an earthbound, non-substitutable and finite element indispensible to feed an ever-increasing human population. The prospect of constrained access to mineable P resources has already triggered geopolitical disputes leading to market volatility and food crises in developing nations. In the long-run constraint P-supplies will result in environmental ripple effects ranging from expansion of agricultural land to increased emissions of greenhouse gases. Scenario results will illustrate the many interdependencies of policies aiming to regulate the P-market on an Earth System level as well as regional challenges of food security on the African continent. Quantitative foresight will assess a range of transformational technology and policy options containing the risks associated with managing the P-supplies and potential impacts on developing economies. Particular focus will be given to the concept of P-poverty and ways how a new global political economy of P-management for more equitable solutions could evolve. The talk will conclude with a systematic outline of the main research questions associated with the environmental, social and fairness challenges of managing the P-cycle in the 21st century.

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Oral presentations

O101

The vulnerability of global food systems to phosphorus scarcity: an economic scenario analysis

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Recent estimates of identified phosphorus reserves of phosphate ore suggest that more than enough is available to meet future increases in demand during the next century. At the same time, the future availability of these stocks may constrained by various factors, among which include the quality and location of phosphate ore, availability of extraction and processing technologies, and geopolitical stability. The massive price increase of phosphate ores between 2006 and 2008 is an example of how such constraints can influence fertilizer prices and indirectly food prices and availability. This study gathers the most recent data on available phosphorus stocks categorized by availability at different extraction costs. These distinct stock types are then matched with distinct technologies for extracting this ore and estimates of regional technological availability and input costs. This data is then used to distinguish explicit phosphate extracting and processing technologies in a global economic input-output model – the Rectangular Choice of Technology model (RCOT) – including bilateral trade costs for moving both unprocessed and processed ore between regions. A scenario is then simulated in which extraction and transport of unprocessed ore from Northern Africa becomes unavailable for geopolitical reasons, resulting in higher regional phosphate prices, food prices, and land use for the same amount of global demand. The results highlight the vulnerability of the global food system to constraints on the availability of phosphate ore in key places within international phosphorus supply chains.

O102

Phosphorus vulnerability: A new framework for assessing the vulnerability of national and regional food systems

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Phosphorus underpins the viability of food systems. Global phosphorus scarcity therefore has serious potential implications for future food security, yet recent research has focused predominantly on supply forecasts and quantitative flow analyses. Each country's food system is vulnerable to phosphorus scarcity in different biophysical and socio-economic ways. The phosphorus vulnerability assessment (PVA) offers a new integrated context-specific framework for assessing the vulnerability of national food systems to global phosphorus scarcity. A PVA can inform priority adaptive strategies to increase the resilience of a food system. Drawing on vulnerability literature, the PVA identifies 26 phosphorus-related biophysical, technical, geopolitical, socio-economic and institutional factors that can lead to food system vulnerability. Phosphorus vulnerability is a measure of exposure to external hazards (eg market price volatility of fertilizers), local sensitivity (eg soil fertility) and adaptive capacity (eg financial assets). Adaptive capacity refers to the internal capability of the system to cope or respond, ie the preconditions that enable adaptation. PVA offers a theoretical and methodological means of: a) integrating diverse dimensions of phosphorus scarcity hence providing analysis of relationships and causal links between factors; b) enabling analysis of currently under-studied yet important socio-economic dimensions of phosphorus scarcity; c) explicitly facilitating context-specific analysis of how a given food system is vulnerable to phosphorus scarcity. The framework will ultimately provide guidance for food and agriculture policy-makers, phosphate producers and phosphorus end-users to take action to reduce their vulnerability to this new global challenge.

O103

Phosphorus extraction and food security in the long run

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I develop three scenarios for phosphorus extraction and recycling: (1) A simple benchmark scenario describing P extraction in a Hotelling model where –on an efficient price path– resource extraction must decline and, hence, long-run food security can never be obtained. (2) A scenario that includes recycling. The result here is that food security can be maintained but fertilizer use will steadily decline and long-run food security approaches its minimum level. (3) The third scenario is the most relevant and is the novelty of this paper. Since even today's level of food-security is insufficient, a declining path of P-extraction and recycling cannot be acceptable. Therefore, in the third scenario, I introduce a sustainability constraint for food security, that is food production (and therefore fertilizer input) should never decline. It is shown that sustainable food security is feasible if the initial stock of P resources is not too limited. Sustainable food consumption has its price, however. The recycling efforts are larger than without a sustainability constraint, and they will always increase. The model results show the feasibility of sustainable food security even if fertilizer resources are depletable. If sustainable food consumption is a policy goal, ultimately aiming at non-declining levels of food security, an unregulated market will not achieve this. The analysis of the third scenario suggests that sustaining food security requires governmental intervention, for example a tax on P-extraction and subsidies for recycling.

O104

Current distribution of phosphorus in agricultural soils at global scale

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The global distribution of phosphorus (P) in agricultural soils is heterogeneous and this heterogeneity results from variability in both virgin soil properties and past agricultural practices. A current picture of this distribution is required to identify the deficit (surplus) areas with negative effect on productivity (respectively environment). However, such a picture is missing due to limitations in soil P measurement techniques and in modeling approaches. Here, we built a simple soil P dynamic model and combined it with global spatially explicit (0.5°lat x 0.5°lon) datasets to reconstruct the temporal evolution of P in agricultural soils from the cultivation starting up to the current time period. Global datasets provided information about land-use, agricultural soil P input/output and current soil P in unmanaged soil. This latter information was used to approach the initial conditions of agricultural soils, i.e. at the time of conversion from non-agricultural to agricultural land. The design of the soil P dynamic model was chosen to be consistent with Hedley fractionation method, on which some available global datasets are based. Maps of current soil P distribution were simulated and evaluated against a database compiling Hedley measurements on cropland and pasture sites from the literature. Our modeling approach allowed to assess the drivers of the current P soil distribution, and through sensitivity tests, to identify the main sources of uncertainty. It is the foundation for assessing how the agricultural soil P would evolve under different future scenarios of P resource management in context of increasing scarcity.

O105

Pathways to sustainable P and N future through participatory backcasting: case Finnish food system

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Increasing pressure on global food system is widening the sustainability gap of two main inputs, phosphorus (P) and nitrogen (N). Their planetary boundaries have already been transgressed, whilst spatially disparate use, unequal distribution and future scarcity are not reflected on the market or governing institutions. Here, we focus on Finland, which has an extensive coastline of the sensitive Baltic Sea and hundreds of fresh water lakes that are under threat if P and N runoff do not get under control. Future food security cannot be realized sustainably without paradigmatic change in the entire system and hence, in this paper we demonstrate radically different food scenarios than extrapolating on business-as-usual. In order to avoid being confined by prevailing norms, rules and assumptions, we chose to use backcasting approach, in which the point of department was based on cross-compliance of sustainability and societal criteria: delivering essential calorie intake for all, but not exceeding planetary boundaries. Also, we incorporated equity of resources as implicit targets. Backcasting process had functional-dynamic approach to theory-practice interaction, i.e. the key stakeholders were involved in different stages of the process. Participatory backcasting provided a richer picture and valuable insights from practitioners' perspective on hindering and enabling elements, but foremost it was seen essential for systemic change. We came up with two contrasting scenarios that are grounded on three different guiding dimensions: governance level: global vs. local, management paradigm: efficiency vs. recycling, and steering mechanism: policy-led vs. market-led.

Session 1 – Phosphorus in our world

Posters

P101

Comparison of national phosphorus flow analyses and development of a blueprint

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In order to provide a basis for national phosphorus management, numerous material flow analyses (MFA) of phosphorus on a national level have been published in recent years. Among others, the phosphorus flows in the European countries Austria, Finland, France, Germany, the Netherlands, Switzerland, Sweden and the United Kingdom have been quantified. Against the background of current European efforts for sustainable phosphorus management (e.g. European Phosphorus Platform), the results of these MFAs, however, have not been compared with regard to their different patterns of phosphorus flows, stocks and losses. Therefore, a comparison of the European MFAs is being conducted in order to identify diverging geographies of phosphorus flows at the country scale. The MFAs are brought into a common visualisation format displaying flows and stocks in relative instead of absolute figures to facilitate comparisons. Furthermore, the sustainability of individual flows within the countries is analysed by using efficiency and recovery indicators. Unfortunately, the MFAs lack a common procedural approach and therefore differ with regard to the processes and flows identified for the analysis. For this reason, a blueprint for national MFAs of phosphorus will be derived from the comparison in order to provide a standardized procedure that allows for better comparability and transferability of future MFAs.

P102

Mapping phosphorus around the globe – social and environmental issues

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The increased use of phosphorus (P) around the globe during the last decades has led to several environmental problems (eutrophication of lakes and groundwater, ocean dead zones, etc.) as well as several social issues (occupied territories, food scarcity, etc.). This study shows the geographic position of the P reserves (focusing as well on the sociopolitical situation of these countries) and the way P is utilized around the globe. The current global consumption of phosphorus is not sustainable. As previous studies have shown, global phosphorus deposits are limited and will be depleted within 100 years if the current phosphorus mining and processing methodology continues. Social awareness is needed to combat P scarcity. To effectively confront this crisis, there must be cooperation between commercial industry (including agriculture) and the global community to assure food safety and regulation throughout the world. Life cycle assessment (LCA) studies and material flow analysis will be used to compare environmental impact of the reuse/recycling of P from wastewaters and the mining of P.

P103

Leibniz ScienceCampus Rostock Phosphorus Research – an interdisciplinary network for a more sustainable P management

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Agriculture and the entire economy are challenged in the future by the limited phosphorus (P) availability. Despite depletion of P resources, undesired amounts of P are still 'wasted' causing environmental problems, especially in aquatic systems. Because of the central importance of P in a variety of production and environmental systems, an interdisciplinary research approach is necessary. Therefore, five Leibniz Institutes and the University of Rostock have created a research network to intensify collaboration and research around this essential element and its sustainable management. Cooperation partners are the Leibniz-Institute for Baltic Sea Research Warnemünde (IOW), Leibniz Institute for Catalysis (LIKAT Rostock), Leibniz-Institute for Farm Animal Biology (FBN Dummerstorf), Leibniz Institute for Plasma Science and Technology (INP Greifswald), Leibniz Institute of Plant Genetics and Crop Plant Research (IPK branch North/Groß Lüsewitz), and the University of Rostock (with 4 faculties). About 40 research groups with more than 70 scientists with relevant expertise are active in the ScienceCampus. Research foci are 'P-cycles and fluxes in the environment', 'sufficiency and efficiency of P use, P-recovery', 'P as an element in and out of catalytic processes'. Additionally, the development of advanced analytical methods in P-research has been defined as cross-sectional task for serving and stimulating the above research clusters. More than 20 thematically assigned projects covered by various disciplines are ongoing and new projects are emerging continuously.

P104

The North American Partnership For Phosphorus Sustainability: Translating P research into real world solutions

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The P Sustainability Research Coordination Network (P-RCN) was funded by the US NSF to spark an interdisciplinary synthesis of data, perspectives, and understanding about phosphorus to identify challenges and solutions for P sustainability. At the recent 2nd annual meeting, the P-RCN discussed a proposal to establish a North American Partnership for Phosphorus Sustainability (NAPPS). The goal of NAPPS is to work actively with stakeholders (e.g. national and local policy makers, planners and officials, representatives of agriculture, industry) to foster and implement sustainable P solutions in public and private sectors. NAPPS will identify and endeavour to alleviate key bottlenecks for decision-making, policy, and implementation of P efficiency and recycling technologies and strategies. NAPPS activities and stakeholder recruitment will be organized around four main sectors: P Recycling; P Efficiency in Food Production; BioEnergy; and Water Quality. Representative activities will include: communicating opportunities presented by emerging research in P sustainability; building networks between different interest groups and sectors related to phosphorus management; fostering implementation of new technologies by improving the efficiency of business value chains; evaluating new P efficiency and recycling technologies, including feasibility, availability of suppliers, cost/benefit analysis, and life cycle analyses; assessing and facilitating regulatory development pertaining to phosphorus management, including waste, environmental, discharge, and agriculture to improve P sustainability; representing North American phosphorus management stakeholders and innovators in international meetings and initiatives; preparing relevant funding proposals for demonstration projects and integration and dissemination of new technologies and concepts; and defining a common vision for a sustainable P cycle in North America.

P105 + Global P governance Round Table Introduction

Global Phosphorus Governance: Why So Misunderstood and the Mammoth Policy Gap?

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How could an essential dietary element, that limits the productivity of ecosystems, and that exists as fossil rock reserves in mainly one country could remain a low global governance priority? That the UNEP GPNM deals only with nitrogen, that the EU has a Nitrogen Directive but nothing for phosphorus and that the entire UN has no capacity to monitor the extraction of phosphate rock all say that a serious gap exists. That phosphorus prices rose 800% in 2008 is common knowledge. Why did the ensuing three UN Food Security Summits not mention phosphorus or fertilizer as areas of concern? - especially when we know that the soils of most African countries are poor in phosphorus and that smallholder farmers cannot afford today's chemical fertilizers. In the North a common attitude is that food should be cheap since chemical fertilizer is perceived to be limitless. When we subsidize agriculture in the EU with 1 billion Euros per week, should this be a surprise? The extraction of nitrogen from the atmosphere (Haber-Bosch process) has been instrumental in the first green revolution and why we have food for 6 billion people today (1 billion remain malnourished). Phosphorus extraction from fossil deposits has quietly kept pace. But who is managing this finite resource? Are the geopolitics of dependency on 4-5 countries being addressed? That phosphorus is not being used efficiently and not managed to optimize reuse says that much remains to be done. As Duncan Brown coined it, the present way we use phosphorus is more like driving a car at top speed down the highway with no fuel indicator on the dashboard, and we will do nothing until we first run out of gas.

P106 + P Platforms Round Table Introduction

What are all these different initiatives on phosphorus sustainability and where are they going?

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Over the past 15 years, and particularly since 2008, a range of initiatives have been launched addressing phosphorus sustainability. Some target certain objectives (P-recycling, P in agriculture and the environment), others address P sustainability or nutrient management systematically. Some are national, others global. Some are led by motivated scientists, some are led by industry, others are more institutional. 11 of these initiatives were analysed a year ago by Ulrich & Schnug ("The modern phosphorus sustainability movement: a profiling experiment", Sustainability 2013). This analysis will be updated, taking into account developments over the last year and new initiatives and an inventory of the principal initiatives today will be presented, including a mapping of links between these initiatives and of key stakeholders and movers involved. Many of these initiatives have claimed to identify key "knowledge gaps" or "action priorities" through "stakeholder consultation". To what extent are these different conclusions representative or inclusive ? What is the governance of the different initiatives ? Is there a need for a more scientific methodology to address these questions ? What lessons can be drawn from the failure or success of some of the initiatives to date ? What (realistic) proposals can be made for effective initiatives at different levels to take phosphorus sustainability forward and to effectively engage the different stakeholders concerned and decision makers ?

P107 + P Platforms Round Table Introduction

Establishing Stakeholder Platforms for Sustainable Phosphorus Management: A Comparative Analysis of Japan and Europe

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While there is a large potential in recycling phosphorus from different sources, only a small portion of secondary phosphorus resources has been utilized so far. As the supply chain of phosphorus ranges from exploration, mining, and transportation to use and recycling, it is of critical importance to establish a system for collecting, sharing, and utilizing a large amount of data and coordinating the behavior of the relevant stakeholders involved in the different stages in resource flows. The creation and management of stakeholder platforms would be a key for co-creating knowledge, co-designing targets, and co-implementing processes. In Japan the Phosphorus Recycling Promotion Council has been established recently with experts from academia, industry, and the government to design and implement national strategies for socially robust phosphorus recycling systems. In Europe, the Nutrient Platform has been initiated in the Netherlands, with private companies, knowledge institutes, government authorities and NGO's agreeing to share and utilize relevant knowledge. In this paper a comparative analysis is conducted to examine the mechanisms of establishing stakeholder platforms in different contexts. A particular attention is given to analyzing how to design and implement serious engagement and fruitful collaboration among stakeholders, what types of joint initiatives and networking contribute to identifying desirable goals and targets and developing complementary skills and capacities, and what factors promote or obstruct their successful implementation. Implications are discussed for establishing a system for sustainable phosphorus management through global cooperation.

P108

The Phosphorus Sustainability Research Coordination Network: Coordinating research to create a sustainable P system

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Phosphorus sustainability entails an urgent double-sided global challenge that includes increasingly high and unpredictable fertilizer prices while excess P from farms and in urban waste streams degrades downstream water quality. Research in these domains is wide-ranging, multi-disciplinary, and expanding but remains largely disconnected. The goal of the 5-year NSF-funded P Sustainability Research Coordination Network (P-RCN) is to spark an interdisciplinary synthesis of data, perspectives, and understanding about phosphorus to identify and accelerate solutions for P sustainability. The P-RCN has ~52 core members from 10 countries pursuing projects within four working groups: Recycling; Efficiency/Conservation in Production; Demand; and Fate, Transport, and Impact. At the RCN's 2nd annual meeting, held January 2014, each group defined a set of research questions and deliverables to address the questions. Progress in advancing these ideas will be summarized in the poster. In May 2015, the RCN will hold a Synthesis Workshop in Washington DC involving core RCN participants as well as policy makers, government officials, representatives of agriculture and the fertilizer industry, and urban planners, enabling discussions between the researchers and key stakeholders. These discussions will launch the RCN agenda for the final two years of the project: how to integrate P efficiency strategies in food production with P recycling approaches to create a food system with P sustainability.

P109

From MFA to monitoring: quasi-dynamic phosphorus budget of Austria with focus on data quality

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Phosphorus (P) budgets are an established approach for the assessment of flows and stocks of P at different scales in many parts of the world. They typically describe one year, ignoring changes in time and dynamics in the system. Furthermore, they seldom address data uncertainty thoroughly. However, both these aspects are of decisive importance if their results shall form a scientific basis for sustainable P management design. Such aspects were investigated in the Austrian P budget, through a multiple year study from 1990 to 2011, based on Material Flow Analysis. The results show that in a relatively short period of time the P-budget was altered substantially and that the changes affect several sectors. Some notable examples are the enhanced removal rate of P from wastewater, the increased share of imported food, the increasing loss of P in cement kilns and landfills, as well as the rising role of bio-energy. Most of the changing flows and stocks follow clear trends, while others fluctuate. Since they are crucial with respect to sustainable P management, the extent of their change in time and their behaviour have important implications for flows and stocks accounting and modelling, as well as for the monitoring of the performance of future measures aimed at the improvement of P management. The uncertainty of the input data was quantitatively characterized through a novel approach, based on a matrix of 5 indicators. Besides showing clear differences of data quality in time, among sectors and between the layers of materials and P content, the results also allow identifying specific causes of uncertainty, with important implications in view of future monitoring of target flows.

P110

P is for Plunder - Phosphate from Western Sahara

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The export of phosphate rock by Morocco from Bou Craa mine in Western Sahara is contrary to international law. Morocco's illegal occupation of Western Sahara means it does not hold legal title to Western Saharan resources, therefore, the Moroccan state company, cannot contract to pass title to companies in other countries. The income that Morocco gains from the trade contributes to finance the occupation, legitimize the Moroccan claims and to continue the sufferings of the Saharawi people both in the territory and in refugee camps in south-west Algeria. The Saharawi people was recognised by the International Court of Justice as the Sovereign over that territory in 1975. They do not consent to or benefit from this trade. Western Sahara Resource Watch has been monitoring the plunder of the rich Saharawi phosphate deposit and has published a report covering the calendar years of 2012-2013 showing all the shipments made of phosphate out of the territory at the rate of about 2 million tonnes each year. WSRW recommends companies involved in the trade to halt all purchases until a solution to the conflict has been found. Likewise investors are requested to divest from any company importing this material until the status of Western Sahara is decided.

Session 2 – Phosphorus in our resources and environment

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Session 2 – Phosphorus in our resources and environment

Keynote presentations

K201

Opportunities with phosphorus and threats from cadmium in fertilizers

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Phosphorus (P) fertilizers are an integral component of all agricultural systems, and in regions where soils have low P status or strong P retention, the efficiency of P fertilizer use may still be low. Hence there are opportunities to improve P fertilization strategies. Various technologies are available to improve P use efficiency in agricultural systems, among which changes to fertilizer formulations offer some scope to improve use efficiency. Major changes to P fertilizer formulations have not occurred for the last 40 years and many query if we have reached the plateau with fertilizer technology. However, new products are needed, and indeed many are entering the market - it is important that these are evaluated both mechanistically in the laboratory and agronomically in the field to ensure real gains in efficiency are proven. Seeking more efficient formulations where use efficiency is already high should be questioned. The other side of the coin is the threat posed by some impurities in P fertilizers - cadmium (Cd) is an impurity in all phosphate rocks and the hazards to agricultural systems due to this impurity were highlighted more than 50 years ago. Since then, a vast body of scientific literature has documented the behavior of Cd in soils, its uptake by plants, its translocation to harvested foods and its effects on microorganisms, plants and humans. Risks to human health *via* food–chain contamination are usually posed at soil Cd concentrations that are much lower than those which affect soil microbial or invertebrate function. Furthermore, Cd is unusual compared to other potentially toxic metals in that it also poses a low risk to plants in terms of phytotoxicity, yet can accumulate in plant tissue to levels that pose a potential risk to humans or animals eating those plants. Effective management of Cd in agricultural systems is not simply just controlling inputs to soil or soil Cd concentrations, but should include a package of measures to assist farmers to minimize soil-plant accumulation through appropriate selection of species, cultivar, fertilizer type, irrigation regime, and soil amendment.

K202

Environmental Considerations of Phosphorus Use

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The loss of phosphorus (P) from land and into surface water can result in significant impairment via eutrophication. Although we aim to be efficient users of P, even the most P efficient system can still lose environmentally significant quantities of P from land. This paper will outline the complex array and interaction of factors that influence P losses and the strategies we can use to mitigate them. Special attention will be placed on the significance of P forms applied and lost and surface and sub-surface transport pathways in different production systems.

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Session 2 – Phosphorus in our resources and environment

Oral presentations

O201

Been there, done that - A short history of phosphate adequacy research and discourse

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Despite evidence against imminent global phosphate rock (PR) depletion, phosphorus (P) scarcity scenarios and the subsequent consequences for global food security continue to be a matter of controversy. We provide a historicizing account to evaluate the degree and relevance of past human experiences with P scarcity. Using a large body of literature, we trace the origin of the P scarcity concept and the first accounts of concerns; we report on three cases of scarcity discourse in the U.S. and revisit the concept of future resources. In addition, we present past evaluations of PR reserves and lifetime estimates for the world, the U.S., Morocco, and the Western Sahara, including their uncertainties, as well as past supply modeling and PR knowledge depository attempts. Our results show that current concerns have a long legacy and knowledge base to draw from and that promulgating the notion of depletion is inconsistent with past findings. We find that past depletion concerns were refuted by means of new resource appraisals, indicating that the supply was substantially larger than previously thought. Moreover, recommendations for national P conservation policies and other practices seem to have found little implementation. We demonstrate the merit of historic literacy for social learning and the weakness of the current P sustainability debate because it does not include this past knowledge. We conclude with implications for current research and practice efforts.

O202

Using High Temperature Gas-cooled Reactors for low grade phosphate rock processing

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The Nuclear Power Development Section and the Nuclear Fuel Cycle and Materials Section of the IAEA recently proposed a Coordinated Research Project (CRP) to elaborate the applicability and potential of using High Temperature Gas-cooled Reactors (HTGRs) to power energy intensive mineral development processes ("Using HTGRs for energy neutral mineral development processes – a proposed IAEA-CRP" – URAM2014). Phosphate Rock (PR) processing is one of the highest priority processes that may fulfil the energy neutral goal. HTGRs could deliver process heat and/or electricity economically to the energy intensive thermal phosphate rock processing for production of high purity phosphoric acid and 'green' fertilizers. At the same time high value impurities (e.g. uranium, thorium, rare earth elements, etc.) that are unwanted in the final fertilizer product, can be recovered. In fact, the uranium/thorium needed to power the HTGR being utilized could be separated on site while a higher quality end product is produced ("Using high temperature gas-cooled reactors for greenhouse gas reduction and energy neutral production of phosphate fertilizers"-Annals of Nuclear Energy). Yet another important aspect is that thermal PR processing permits the processing of low grade (or depleted) PR deposits that cannot be utilized with the presently preferred chemical processing techniques. HTGRs can be used to (i) calcinate PR for direct application, (ii) upgrade low grade PR so that it can be treated with presently used chemical processing techniques or (iii) process low grade PR directly by powering energy intensive thermal PR processing techniques. This may make an important contribution for future global food security as the availability of phosphorus resources at reasonable prices will be prolonged significantly.

O203

Nutrient footprints in agricultural systems at catchment scale within the UK and China

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Diffuse water pollution from agriculture (DWPA) represents a significant challenge in both the UK and China. The UK has developed policies and practices which seek to mitigate DWPA, yet the risks and adverse impacts of DWPA remain widespread. In contrast, China's past priorities have largely focussed on food security, with an emphasis on increasing food production through high fertiliser application rates with little attention being paid to enhanced nutrient export from land to water and to air. This has contributed to severe environmental problems which are only now beginning to be recognised and addressed. This paper will compare and contrast the nutrient balances (phosphorus and nitrogen) in contrasting agricultural production systems at catchment scale within China and the UK. Our aim is to use these balances to underpin the sharing of knowledge and innovation to mitigate DWPA in both nations. In the UK, the case studies focus on the three Demonstration Test Catchment locations, covering a range of livestock and arable production systems across England. In China, our case studies span kiwi orchard, fruit and vegetable solar greenhouse systems, rice-wheat and wheat-maize production systems. We hypothesise that substantial differences in nutrient stocks and flows exist between individual production systems both across and within the two countries. These differences will be expressed along the source-mobilisation-delivery-impact continuum that underpins our budgets for both phosphorus and nitrogen. Based on our nutrient budgets, recommendations are formulated to mitigate DWPA from farm to policy levels.

O204

Designer riparian buffers – using plant phylogeny to close the arable agricultural phosphorus (P) cycle

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Phosphorus (P) loss from agricultural fields is the primary source of diffuse P pollution of water courses, causing detrimental environmental consequences such as eutrophication. Establishment of vegetated riparian buffers is one tool in a suite of mitigation options aimed at reducing the contribution of P loss from agricultural land to surface water P loads. It is currently unclear how the vegetation in buffers affects the dynamics of dissolved forms of P and there are likely to be differences in the ability of plant species to accumulate P in biomass. To investigate this we performed a phylogenetic study of the ability of plant species common to riparian buffers to take up P supplied at a range of concentrations. We screened tens of species of plants and were able to establish phylogenetic clades of species that had particular P uptake abilities. We then went on to investigate the leaching of P from columns packed with soils of differing organic matter contents and sown with extreme examples of grass species taken from the phylogentic study. These studies showed that the plants ability to accumulate P in tissue reduced the amount of P leached. Plants increased carbon mobility in the soil and this impacted rhizosphere traits which had impacts on the availability of organic P. Current studies are looking at the utility of green manure taken from riparian buffers to act as a P source to agricultural plants, with the aim of closing the arable P cycle. Designed buffers, taking into account the physiological characteristics of plants, could be used to reduce the amount of P leaching to watercourses and provide an alternative fertilizer source for arable cropping systems.

O205

Animal manures applied to soil: Phosphorus bioavailability, losses to water and erosion

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Phosphorus (P) is a non renewable resource which highlights the significance of developing and using alternative sources of P for a sustainable agriculture. Animal manure is an option but its application to soils to meet crop nitrogen needs requires careful management practices to minimize freshwater eutrophication. The aim of this work was to evaluate the partitioning of applied P between plant uptake, losses to water, and erosion losses when using different animal manures and a mineral P fertilizer. A field trial was conducted at an erosion experimental station. The treatments were: Control (0 kg P/ha); cattle manure; solid fraction of pig and duck slurry and superphosphate, each applied at a rate of 50 kg P/ha after *Lolium* sp was sown. Soil samples from each trial were collected over the 9-month study and the water extractable soil P determined. It was found that desorption of P from all additions rapidly increased soon after P application (2 weeks). After that water extractable soil P remained fairly constant. While duck slurry desorbed the largest concentration of P, all sources have the potential to desorb P that could accelerate eutrophication. Plant uptake of P was greater with cattle manure added and released the least amount of P to water compared with the other sources of P. The partitioning of applied P between plant uptake and losses to runoff and sediments ranged between 5-12 % with the higher values in Duck treatment. Animal manures significantly increased soil Olsen-P, plant production and P uptake relative to mineral fertilizer. Animal manures can be considered as a source of available P nevertheless to avoid eutrophication risks increase plant P use efficiency is also important.

O206

Phosphorus buffering capacity in grassland soils with respect to availability and management of phosphorus in fields

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Irish farmers face a multitude of challenges in agriculture today, including environmental constraints on phosphorus (P) use as set out in the Programme of Measures under the Nitrates Directive, rising fertiliser prices and the drive for sustainable intensification to meet rising global food demands. The supply of P in available form for either plant uptake or diffuse losses to water is often a function of the buffering capacity of the soil, yet agronomic advice and policy makers rely exclusively on soil test P (STP) as the indicator of agronomic optimum and source of diffuse losses. We report on P sorption and buffering in grassland soils collected from six river catchments accross Ireland, with constrasting parent materials. Soils from calcareous catchments presented significantly lower buffering characteristics than soils derived from noncalcareous parent material and these differences were reflected in the relationship between STP and labile inorganic P. Soils with high sorption and buffer capacities exhibited larger amount of extractable labile inorganic P compared with poorly buffered calcareous soils. At high STP calcareous soils indicated precipitation of P and lowering of P availability. These results have implications for fertiliser P management on soils of varying P buffering capacities, and for environmental policy which assumes a universal soil type. Extractable Aluminium accounted for 75% of the variation in P buffering capacity across all soils, illustrating the potential to include this as an indirect measure of buffering with STP for fertiliser P advice.

Session 2 – Phosphorus in our resources and environment

Posters

P201

Temporal and spatial studies of organic phosphorus cycling in sediments of a eutrophic bay in Lake Champlain (USA)

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Lake sediments represent a potentially significant internal source of phosphorus (P) in eutrophic freshwater systems during periods of high temperature, biological activity, and oxygen depletion. This work describes the contribution of organic P (Po) to the internal cycling of sediment P during multiple algal bloom stages in Lake Champlain, VT USA (2007-2008) using solution 31-P NMR spectroscopy and enzymatic hydrolysis (EH) to assess P forms and latent bioavailability. Sediments collected during bloom onset and peak bloom stages contained the largest proportion of enzyme-labile-P, whereas pre- and post-bloom sediments where primarily composed of non-labile-P. 31P NMR tracked decreasing monoester: diester ratios with respect to depth, particularly during peak bloom conditions, as well as evidence for the deposition of myo-IHP and subsequent epimerization to alternate stereoisomeric forms. Large enzyme-labile and Po species proportions corresponded to increases in sediment phosphate flux and the presence of reduced iron and manganese species in porewater. On-going studies of the Missisquoi Bay system (2012-2014) will assess the spatio-temporal variability of enzyme-labile P in sediments, as well as employ a delta18O-PO4 methodology for tracking internal and external contributions to surface water phosphates. Sediment Po appears to be a significant and potentially bioavailable nutrient source in aquatic systems, which should be considered to understand the environmental impacts of P on water quality.

P202

Chemical nature of the residual phosphorus in Andisols

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Sequential fractionation has been widely used to study nature and dynamics of soil phosphorus (P), mainly using the 'Hedley' method. One of the main perceived limitations of this method is the assumption that unextractable fraction (residual fraction) is recalcitrant and composed of organic forms. The objective of this study was to quantify, to isolate and to characterize the residual fraction from three series of Andisols developed under grazed pasture. Our conceptual approach included the isolation of residual fraction after sequential Hedley fractionation from fertilized and unfertilized soils. We analyzed the chemical parameters and the contribution of organic P in the residual fraction. Moreover chemical composition of P was characterized by solution 31P nuclear magnetic resonance spectroscopy (31P NMR). Our results showed that a significant proportion of the total P (45-63%) was present in the residual fraction, with most of it being extractable in NaOH–EDTA (61.2 – 114.0 %).. Analysis of these extracts by solution31P NMR spectroscopy revealed that the residual fraction contained mainly inorganic forms of P (43.8 – 69.9%), with smaller amounts of inositol hexakisphosphate in four stereoisomeric forms (myo, neo, scyllo and d-chiro). Based on this first detailed analysis of residual P, we conclude that a large proportion of the total P in Andisols is found in the residual fraction, mainly as inorganic orthophosphates and as monoester ortophosphates.

P203

Distribution and estimated release of sediment phosphorus in a mixed land use catchment from Southern Brazil

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Phosphorus (P) and suspended sediment (SS) mobility from runoff and their subsequent delivery to freshwater reservoirs is of most concern in catchment scale soil and water quality management. The aims of this study were to characterize SS phosphorus forms; total P (TP), inorganic P (IP), total organic P (TOP) and bioavailable P (BAP) and monitor the spatial variation of the SS P content among the different management systems. The study area Guapore catchment is located between latitudes 29.2 S and 28.2 S and longitude 52.4 W and 51.8 W in Southern Brazil with basin area of 2000 km2. A total of 11 monitoring points with different land uses including city effluent, conventional tillage (CT) and no-tillage (NT) systems were selected. The SS were collected by using time-integrated suspended sediment samplers from March 2011 to October, 2013. The results indicated that mean soil TP for cultivated land was 442.5 mg kg-1. The SS exhibits high mean TP 2825.6 mg kg-1 in the CT in December months in both years. In contrast, the TOP was maximum 584.86 mg kg-1 in SS from non-treated city effluent. Generally, across the different land uses, the TP content of SS showed 4-7 fold increase when compared to respective soil TP. The highest IP was in NT system and average across the monitoring points IP showed as much as 95 to 99% of the TP. The BAP content of SS ranges from 18.7 to 84 mg kg-1. The study explains seasonal P export form different management systems and emphasize that moderation of the P fluxes from sediments requires considerable reductions of the phosphorus load from land based sources.

P204

A multicriteria decision model for selecting a portfolio of sustainable

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Phosphorus is an essential, non-renewable resource of crucial importance for the agricultural sector, food security, and within environmental protection. Over the past decades, an increasing attention has been given on developing different strategies for sustainable phosphorus management. However, these single strategies have often turned out to be not sufficient to achieve sustainable phosphorus use. Here we apply a multicriteria decision model for the composition and selection of a set of management strategies to meet phosphorus-related needs, reduce the phosphorus losses and associated negative environmental externalities in different regions. For this analysis we apply the Promethee method to select management strategies that fit to the phosphorus management objectives of different regions, taking into account the economic, environmental and social region-specific conditions to achieve sustainable phosphorus management and multiple socio-economic benefits. The results indicate that the selection of strategies varies substantially across the regions with similar environment and socio-economic conditions. We also find that in some regions without a similarity in environmental and socio-economic conditions, similar sets of strategies for sustainable phosphorus management are selected. The results help to select the most appropriate set of strategies for sustainable phosphorus use in a given region.

P205

Phosphorus transport from agricultural soils to coastal wetlands

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Being the interface between land and the ocean, coastal wetlands are important areas for biogeochemical modification of phosphorus (P). The intense biogeochemical exchanges in wetlands may affect the partition of P and further influence the flux of P cycling. In this study, we aimed to determine mechanisms for the transformation and transport of P across the land-sea margin in terms of quantifying and qualifying the variation in P species. We used Gaomei wetland at Taichung, Taiwan as the study site given that it receives massive discharge from agricultural and industrial activities. Because of the short distance between anthropogenic activities and the Gaomei wetland, to what extent the wetland buffers and retains P runoff is particularly of interest to environmental scientists. The preliminary results indicate that P content decreased from the upstream to the outlet of the agricultural ditch. Such decrease may resulted from the loss Fe-associated P due to the partitioning of colloid particles that have relatively higher P sorption capacity. However, P concentration tended to increase in the wetland as a function of sampling distance from the ditch outlet. The accumulation of P in the wetland could be ascribed to the formation of Ca-associated P. Our results indicate that transformation and transport of P is highly related to its species. Molecular-scale mechanisms developed here show the promise to better understand retention, migration, and dissolution of P in complex wetlands, and thus improve P management in order to increase potential sinks for P retention.

P206

Testing simple criteria for an effective location of measures to control diffuse phosphorus pollution of surface waters

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The next period of the Austrian agri-environmental programme (ÖPUL) is going to include a precautionary measure for the protection of surface waters against erosive phosphorus (P) inputs. At the time of this survey, the proposed design of this measure consisted of two parts: source control by adjusting crop rotations and transport control by establishing riparian buffer strips. Since the effectiveness of these control options depends highly on their location of implementation, the proposed design also included two simple criteria to limit their implementation to certain areas within a river basin: fields with high soil erosion and fields in the vicinity of surface waters. The suitability of these criteria for an effective location of the considered measures has been tested with the raster-based P emission and transport model PhosFate. This model is capable of identifying critical P source areas and preferential transport pathways. Providing a management scenario furthermore enables the model's optimization algorithm to rank and select the raster cells of an investigation area which are most suitable for the planned measures. The results indicate that such simple criteria are a good start for an effective location of measures for source and transport control of erosive P inputs into surface waters; fields selected by them are overall in good agreement with fields selected by the optimization algorithm of PhosFate. Further research, however, should clarify whether there are other simple criteria which lead to an even more effective location of such measures or if an optimal management strategy can only be achieved by separately modelling each single river basin.

P207

Phosphorus mobilisation from sugarcane soils of Mauritius under simulated rainfall

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Continuous application of fertiliser P to sugarcane fields over the last 60 years has caused a general build-up of P in soils of Mauritius. While this long-term residual pool of soil P is desirable from an agronomic perspective, there is growing concern in Mauritius about its possible effect on surface water quality due to accelerated eutrophication. As a better understanding of P transport processes undoubtedly provides useful information for the development of site-specific P management strategies, rainfall simulation studies (100 mm hr^{-1} for 30 minutes) on runoff plots (2.1m x 0.75m) were conducted at 20 field sites to study the mobilisation of soil P from sugarcane fields of Mauritius. The edge of plot total P losses in runoffs ranged from 0.19 to 1345.9 g ha^{-1} with a mean of 163.9 g ha^{-1}. The results also showed that the linear relationship (y= 7.29x -3.71, r^2 = 0.49) between runoff total P concentrations and runoff volume was improved when total P concentration was instead correlated to suspended load in runoff waters (y= 1976.7x -25.7, r^2 = 0.92), indicating that a greater proportion of the P transported in runoff occurred as particulate P rather than dissolved P. Actually, about 89% of total P loss in runoff waters was mobilised in particulate forms, pointing to the importance of erosion as a mechanism for mobilising soil P. The research findings suggest that management practices which reduce runoff volume (e.g. conservation tillage, trash cover) will to a certain extent reduce total P transport from fields. Moreover, reducing suspended sediments in runoff waters will also attenuate P losses and can be achieved by having grassed waterways, riparian buffers or buffer strips in the fields.

P208

Reducing phosphorus and nitrogen leaching in Western Australian catchments using waste materials, lessons learnt

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Reducing the loads of total nitrogen (TN) and total phosphorous (TP) into the Swan Canning river system in Western Australia is imperative for the catchments survival. One of the key targets to achieve a maximum acceptable nutrient load targe, would require a 49% and 46% reduction in TN and TP respectively. One initiative to be investigated in the field was the SCWQIP was the use of soil amendments for soils with low phosphorous retention index (PRI). Modelling of phosphorus reductions as a result of using soil amendments to raise PRI of all rural soils with from a PRI <10 to a PRI of 10 throughout the Ellen Brook catchment, suggest it would achieve a 20% reduction in TP loads. Given that a significant portion of the Ellen Brook catchment fits in this category, it is imperative that products be tested in local conditions. This projects main aim was to provide information on high PRI soil amendments to land managers to spread on their soils to improve nutrient and moisture retention on site. The trial has been monitored for two years and further monitored for another two to three years. It has been conducted on 50ha of actively farmed, low PRI sandy soils in a catchment. In the trial several by-products from industry including älkaloam", ironman gypsum "and an lime amended biosolids from a waste water treatment plant blended with clay were investigated as soil amendments to provide a side-by-side comparison of the effects on pasture growth as well as to analyse the leachates from each treatment to determine the most effective in reducing nutrient loss.

P209

Utilization of soil legacy P, a potential strategy for sustaining crop production and reducing P loss to water resource

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Research advances indicate that legacy P in soils is mainly in absorbed forms that can desorb and be available to crop uptake and/or losses in water discharge. A study was conducted to evaluate the agronomic and water quality consequences of continuous P draw-down in a clay loam soil under corn-soybean rotation from 2008 to 2012. Soil P losses were determined continuously year-round using automated flow monitoring and sampling systems. Corn grain yields with P draw-down were largely identical to those with continuous P addition. However, soybean yields with P draw down were 6-8% lower than those with continuous P addition, indicating that soybeans with small and shallow rooting systems may need a booster of fertilizer P to compromise the temporal shortage of soil available P, especially in the early spring when it is low in soil temperature. Soil Olsen P remained unchanged for the draw-down treatment over the 4-year period, while for the continuous P addition treatment it increased, with 5 kg P ha-1 addition of fertilizer P required to increase each mg P kg-1. Soil P losses in all forms, including dissolved reactive P and particulate P, in both surface runoff and tile drainage decreased with cropping for the P draw-down, while they increased for the continuous P addition. Utilization of legacy P with draw-down can sustain crop production and meanwhile reduce P loss to water resource, although supplemental P application may be required under certain circumstances.

P210

Comparative study of the dissolution by sulfuric acid of two phosphates taken from deposit of Djebel Onk

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The extensive literature research we have done on phosphate rock of Djebel Onk shows that these phosphates have not been enough experience on their solubilization, bioavailability or other tests. Since reserves of this deposit are considerable (about 2 billion tons), it's prémordial that these phosphates must attract the attention of many researchers in different areas of the valuation of phosphates. Based on this finding, we conducted tests of the phosphate solubilization by mineral acids. Sulfuric attack of phosphates is one of those experiences. The purpose of study is to compare the conversion rates of the P_20_5 of two phosphate rock obtained by sulfuric acid attack. These phosphates, which have different chemical compositions, are from the same deposit (Djebel Onk, Algeria). This study show that the acid concentration above 70 wt % has a considerable influence on the decomposition of phospahte ; after 5 minutes of reaction, the conversion rate reached about 63% and after 20 minutes, it's about 82%. After 40 minutes of reaction, the conversion rate remains almost stable and this for both phosphates. The maximum conversion rate that we found are respectively 96.19% for the first phosphate (65.38% BPL) and 94.46% for the second phosphate (53.75% BPL). These experimental results are obtained under the following conditions of the reaction of phosphate with H_2SO_4: H_2SO_4 concentration = 96 wt %; Reaction time = 50 minutes; Agitation speed = 200 rpm; Phosphate particle size between 40 and 80 microns.

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Keynote presentations

K301

Phosphorus in manures and other organic products: what limits proper recycling of this resource in agriculture ?

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Phosphorus (P) in animal manures represents approximately 17 Tg P $year^{-1}$, which is slightly more than the amount of P contained in mineral fertilizers used worldwide (14 Tg P $year^{-1}$). Manures are generally spread on agricultural soils, so that it can be considered that P (and other elements) contained in these materials are recycled. However, there are several factors limiting an optimal recycling of this P resource. The aim of this communication is to discuss these barriers. Manures are effective sources of P to compensate P exports over a crop rotation, provided background soil test P is adequate. When soil P availability is critical, the short-term P availability of any organic material applied as a fertilizer becomes an issue. Questions remain about the short-term bioavailability of P supplied by organic products, depending on the overall composition of the biosolid (C/N/P ratio especially) and on P chemical forms. Because of this uncertainty, the amount of P supplied by organic products is often underestimated by farmers, and the need for additional mineral P fertilizers is overestimated. The N to P ratio of many organic products is lower than the N to P ratio characterizing crop requirements, so that a N based fertilization strategy results in an over-application of P and a low efficiency of manure P utilization. Last but not least, an optimal recycling of P and other nutrients contained in manures is increasingly constrained by the current trend towards specialization and geographical segregation of arable and livestock farms. The technical and organizational innovations that could overcome these barriers will be presented.

K302

Deficiency and management options for phosphorus in maize production in East and Southern Africa

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Soil phosphorus deficiency is recognized as a major factor limiting maize production in smallholder farming systems in East and Southern Africa. This paper reviews the severity and occurrence of P deficiency in the maize-based farming system in the region, and analyses P use efficiencies in maize and grain legume crop production in smallholder farming systems in the region. P deficiency is particularly acute in the highly weathered and acidic tropical soils in East Africa, which have a high P-fixing capacity. The amount of P adsorbed by the soils is associated with high exchangeable aluminum and total iron contents, as well as low pH. In much of sub-tropical soils in Southern Africa, the predominant soils are sandy with low P fixing potential, and P deficiency is mainly due to low inherent fertility and low soil organic matter contents. The deficiency of P in the soils in southern Africa is often obscured by nitrogen deficiency. Improving the crop productivity requires efficient use of limited P resources available to farmers through selection of the right P sources and apply them at right rate, time and place. Experimental results show that mineral P fertilizers offer the best option to reduce P deficiency but their use is restricted by poor accessibility and unaffordability to farmers. Additional P sources adapted to the conditions of smallholder farmers include direct use of reactive P rocks, partial acidification of low reactive P rock and the application of various organic matter sources. A major challenge for improving management of P in East Africa is the development of cost-effective and reliable analytical methods adapted to P-fixing soils.

K303

Breeding for enhanced phosphorus efficiency in rice

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Selection of modern varieties has typically been performed in standardized, high fertility systems with a primary focus on yield. This could have contributed to the loss of plant genes associated with efficient nutrient acquisition strategies and with adaptations to soil-related stresses. Given the necessity to use scarce and increasingly costly fertilizer inputs more efficiently, while also raising productivity on poorer soils, it will be crucial to reintroduce traits and genes associated with efficient P acquisition and utilization into elite crop cultivars. JIRCAS together with collaborators within the global rice research community has screened diverse sets of rice gene bank accessions with the aim to identify now donor varieties for P efficiency traits and genes. After mapping of P efficiency loci, candidate genes have been identified and characterized and tolerance mechanisms were investigated physiologically. At various stages findings have been confirmed by field experiments to assure practical relevance of research endeavors. One successful project recently identified the Pup1 gene enhancing P uptake from low-P soils. Molecular markers diagnostic of the superior Pup1 allele have been identified and shared with breeding partners throughout Asia and Africa, enabling them to conduct their own marker assisted selection program with locally preferred varieties. Similar efforts are ongoing for novel P uptake and P utilization genes. How such improved varieties may affect phosphate flows in agricultural systems will be discussed.

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Sustainable Phosphorus Summit

Session 3 – Phosphorus in our fields

Oral presentations

O301

African crop yield reductions due to increasingly unbalanced nitrogen and phosphorus consumption

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The impact of soil nutrient depletion on crop production has been known for decades, but assessments of the impact of increasingly unbalanced nitrogen (N) and phosphorus (P) consumption rates on crop production are lacking. Here, we use information from FAO maize crop trials and crop modeling across Africa to examine maize yield deficits resulting from unbalanced N:P applications under low, medium, and high input scenarios, for past (1975), current, and future N:P mass ratios of respectively, 1:0.29, 1:0.15, and 1:0.05. At low N inputs (10 kg ha^{-1}), current yield deficits amount to 10% but will increase up to 27% under the assumed future N:P ratio, while at medium N inputs (50 kg N ha^{-1}), future yield losses could amount to over 40%. Crop modeling indicated relative median future yield reductions at low N inputs of 40%, and 50% at medium and high inputs, albeit with large spatial variability. Optimal N:P ratios, i.e. those where the lowest amount of applied P produces the highest yield (given N input) where calculated to be as low as 1:0.5. Finally, we estimated the additional P required given current N inputs, and given N inputs that would allow Africa to close yield gaps (ca. 70%). At current N inputs, P consumption would have to increase 2.3-fold to be optimal, and to increase 11.7-fold to close yield gaps. The P demand to overcome these yield deficits would provide a significant additional pressure on current global extraction of P resources.

O302

Phosphorus fertilization: comparing legislation in Europe

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Although there is no general European Phosphorus (P) Directive or Regulations, several European Member States address the agricultural phosphorus losses by phosphorus application restrictions in their legislation. An inventory of this phosphorus legislation among European countries was performed in 2014, as un update of the inventory of 2007 (COST action 869). Some countries or regions do not have direct P application restrictions in addition to the fertilizer N and manure N restrictions in the Nitrate Vulnerable Zones, while other countries have detailed maximum P application rates. Comparing regulations is complicated since various systems exist, e.g. maximum application rates and balance systems on farm or field scale. Furthermore, the type of restricted P fertilizer varies: e.g. all types of P forms applied, only manure or only chemical fertilizer. Several countries and regions have crop type dependent maximum phosphorus application rates. For grassland, maize, cereals, potatoes and sugar beets the maximum application rates are compared among Member States. In some Member States the soil P content is taken into account based on specific soil P tests, i.e. P application standards are lower for soils with high P status resulting in reduced P accumulation in these soils. In addition, buffer zone widths along surface waters are compared among Member States. It is concluded that phosphorus legislation in European countries and regions varies widely, and that better agri-environmental sound approaches are needed to reduce agricultural P losses effectively. Both the current member state approaches as well as agri-environmental approaches will be presented and discussed.

O303

Efficient use of soil legacy P by maize through modifying rhizosphere processes across different ecological zones

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The majority of soil phosphorus (P) is poorly available and the soluble P applied can be rapidly converted into sparingly soluble form. This has caused great P imbalances, and about 60 kg P_2O_5 ha^{-1} $year^{-1}$ was accumulated in soil during last decade. Along the environmental gradient from calcareous to acidic soils, P is present in different legacy P pools with variation of phosphorus speciation and bioavailability, but the dynamic characteristics of maize rhizosphere processes and adaptive mechanisms to cope with low P availability in different ecological zones are not fully understood. Here, a comparative study was conducted to examine maize rhizosphere processes and underlying mechanism of adaptation to P deficiency in different ecological zones across calcareous, neutral and acid soil in China. Maize experiments with NK and NPK treatments were adopted from three long-term fertilizer experiments across China (Qiyang: red soil; Shenyang: brown soil; Yangling: loessial soil). Root morphological traits (root biomass, total root length, specific root length, and proportion of maize root length in different diameter) and physiological traits (P concentration, phosphatase and carboxylate exudation in the rhizosphere) were measured. Variations in maize growth and P uptake were observed across the different ecological zones; there were similar phosphatase activity and carboxylates exudation rates in the rhizosphere, but the root morphological traits showed remarkable differences. Maize showed strong root morphological adaptation to P deficiency compared to root exudation, suggesting the importance of manipulating root morphology and intensifying rhizosphere effects to enhance P acquisition from soil legacy P.

O304

Making optimal use of P reserves in soils and secondary waste streams in The Netherlands

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Given the current challenges concerning limited world P-reserves and environmental issues it is increasingly important to optimise use of P reserves already present in agricultural soils and re-use of P present in residual and 'waste'-streams. Soil P reserves have accumulated over previous decades in The Netherlands. However, until recently, these reserves were only poorly taken into account in P fertilization recommendations. In a new innovative methodology recommendations have been adapted to include an accurate prediction of the potential of soils to supply P. We will discuss the whole process of developing and implementing this methodology which entails: studying the dynamic soil P processes – interpretation of the results in terms of intensity, buffer capacity, and quantity – translation to a combination of soil tests minimally needed to predict the P supply potential – testing in pot trials and field experiments – developing accurate and generally lower fertilizer recommendations for grass and maize – implementation in practice. This approach also provides an interesting perspective for the rest of Europe. Improved knowledge of soil P reserves may help to improve the proper use of different recycled P sources. A high population density and intensive agriculture result in many P-rich streams like waste water and sludges from sewages and agro-food industry, bio-ashes, animal manure. Numerous initiatives are ongoing in The Netherlands to recycle this P. We will present a decision support tool to determine what P fertilizer (mineral, organic, or secondary P) can be used most effectively and sustainably based on improved understanding of the P supply potential.

O305

Where does the phosphorus in organic products come from?

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Organic farming guidelines ban the use of artificial fertilisers such as manufactured mineral phosphorus (P) fertilisers and emphasize the need for recycling nutrient resources. In consequence, organic production may be considered as a prototype of sustainable agriculture that maximises P recycling and saves fossil P resources. This assumption has been tested through the detailed analysis of P inflows for 63 organic farms distributed into three French agricultural districts differentiated by their specialisation (mixed vs specialised in crop productions or in animal productions). Results showed that P recycling was higher in the mixed district due to exchanges of organic materials between grain growers and livestock farms. However, overall, 73% of the P entering organic farms came from conventional farming through import of conventional manure or straw. Combining these results with a model accounting for the origin of soil P accumulated before conversion to organic farming, it was shown that approximately 71% of the P contained in organic products derived indirectly from artificial P fertilisers. These results raised the question of the indirect reliance of organic farming on mineral P fertilisers. They are discussed in terms of P management in organic production and of global fossil P resource use.

O306

Trends of phosphorus use efficiency in the food chain of China

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Phosphorus (P) inputs by fertilizer and feed additives have greatly contributed to the increased food production in China during the last decades, but have also contributed to increased P losses to water systems. The aim of this study was to quantify the historical changes of P use efficiency and losses in the food chain in China between 1980 and 2005, and to explore possible trends for the period 2005 – 2030, using the NUFER (NUtrient flows in Food chains, Environment and Resources use) model. The results show that the P use efficiency in the food chain decreased from 19% to 7% and P losses to waters increased from 1 kg P/ha to 21 kg P/ha in the period 1980 to 2005. Scenario analyses suggest that P fertilizer consumption and losses will increase by 25% and 71% respectively in the period 2005 to 2030 in the business as usual scenario. Implementation of a package of integrated nutrient management measures (including balance P fertilization and improved manure management), changes in human diets, and increased imports of animal food and/or feed, are effective management options for increasing P use efficiency in the food chain. Our analyses indicate that the P use efficiency in the food chain may increase again to 13-15% and P losses may decrease by a factor of 3 to 5 compared with business as usual. We conclude that combination of diet change and integrated nutrient management) has the highest values of P use efficiency in the food chain, and improved manure management is the most effective simple strategy for decreasing P losses.

O307

Facilitation of P acquisition by intercropping cereal and grain legumes in field conditions

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Intercropping systems consist in growing two or more species simultaneously in the same field for at least part of their growth cycle. In situations of limiting nutrient availability, acquisition of resources in intercrops (IC) is generally improved compared to sole crops (SC), as a result of positive interactions between the intercropped plant species, i.e. either niche complementarity or facilitation. Evidence has recently accumulated that intercropped cereals and grain legumes promote the use of soil P resources, though few reports derived from field trials. We investigated whether (i) intercropping of durum wheat with pea or faba bean does improve soil P acquisition; (ii) facilitative interactions can be detected, and (iii) soil P availability does influence such effects. We conducted two 1-year experiments in a long term P fertilizer field trial with a gradient of Olsen-P soil content from <5 to 30 mg kg^{-1}. Aboveground parameters such as growth, productivity, nutritional status (N and P), fixed N ratios and grain quality were regularly monitored on IC and SC. Relative total biomass was always higher in IC vs. SC as illustrated by LER>1, except in the lower P soil content, where faba bean was outcompeted by wheat in the later stages. P export was increased in IC vs. SC at the legume flowering stage, while it decreased afterwards to similar amounts mainly due to faba bean suppression. Our data suggest positive plant-plant interactions (niche complementarity/facilitation) at earlier growth stages of wheat-legume intercrops that transiently resulted in a more efficient use of soil P resources but then receded until harvest.

O308

Understanding the genetic control of rhizosheath formation and impacts of multiple stress on phosphorus acquisition

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There is urgent need for simple rapid screens of root traits that improve acquisition of nutrients and water. Temperate cereals produce rhizosheaths, a trait first noted on desert species over 100 years ago and thought to be limited to grass species of the Poales order. Here we screen association genetics populations of barley for rhizosheath weight and derive QTL and candidate genes. We assess whether rhizosheath weight was correlated with plant performance and phosphorus (P) uptake under combined drought and P deficiency. Rhizosheath weight was investigated in relation to root hair length, and under both laboratory and field conditions. We go on to perform a phylogentic study of angiosperm species to assess whether this trait is isolated to the Poales. Our data demonstrate that rhizosheath weight was correlated with P uptake under dry conditions and that the differences in rhizosheath weight between genotypes were maintained in the field. Rhizosheath weight also varied significantly within barley populations, was correlated with root hair length, and was associated with a genetic locus (QTL) on chromosome 2H. Putative candidate genes were identified. We demonstrate that a number of other angiosperm orders have rhizosheaths which include orders containing domesticated crop species. Rhizosheath weight is easy and rapid to measure and associated with relatively high heritability. Breeding cereal genotypes for beneficial rhizosheath characteristics is achievable and the same is possible for other crop species. Understanding of this trait could contribute to agricultural sustainability in nutrient and water-stressed environments.

O309

Importance of phosphorus (P) remobilization during grain filling in rice plant regarding the P regime

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Phosphorus (P) is a key nutrient for plants and deficiencies of P in cropping soils frequently limit plant growth. Given the increasing need for P fertilizer to meet the global food demand, and the finite nature of world rock phosphate reserves, security of P supply will become a priority in the next decades, particularly for staple crops such as rice. At maturity, P is principally found in the rice grains as a consequence of P loading into the grain, a process starting at grain filling (immediately after anthesis) with a rapid phase of P accumulation between 6-15 days after anthesis (DAA). However, the loading mechanisms involved remain unclear, particularly the contribution of exogenous uptake from roots post-anthesis *vs* remobilisation of P from vegetative tissues. Using a ^{33}P isotope tracer, we studied the uptake, distribution and redistribution of P during grain filling in rice plants (cv. IR64) that differed in P status. Plants were grown in hydroponic system from sowing to maturity and ^{33}P was spiked in the solution at 9 DAA. The distribution of ^{33}P among organs (root, stem, leaves, flag leaf, rachis, husk, grain) was determined at 3h, 24h and 120h after spiking. The ultimate aim is to understand the physiology of P loading into grains in order to reduce the P concentration of cereal grains and improve the P efficiency of cropping systems. The results are therefore discussed in terms of importance of vegetative P remobilisation *vs* post-anthesis P uptake of exogenous P.

O310

Is Phosphorus known by Malagasy rice producers: as a companion or as a threat against local environment?

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Even if about 65% of Malagasy farmers cultivate rice, the production is not sufficient to Malagasy population. Water management and low fertility of soil are cited among the major reasons of the low productivity. If water concern is associated to global weather, scientists have stated that Phosphorus (P) is the limiting nutrient of rice yields in Madagascar, especially in the major rice producer areas. Unfortunately, farmers do not know about the natures and the roles of the nutrients in fertilizer. They mostly apply organic fertilizer on field. Inorganic fertilizer is not widely applied due to a low return of investment which limits demand and its availability in the market. In parallel to the purpose that demonstrates the necessity to apply P fertilizer on rice fields, this work aims to make P known by farmers. Thus, experimental designs have been established following plot and territory scales in order to show the effect of P application on irrigated or on rainfed rice. P is applied as organic or mineral forms at the approximate dose 20 $kg.ha^{-1}$. Rice production has been assessed during improvised workshops. As results, after 4 years of interaction between farmers and researchers, it appears that farmers do not understand P as nutrient, as soil scientists or agronomists may distinguish many of them. They mainly define P as a fertilizer. Moreover, they perceive P role accordingly to its quantitative and qualitative effects on rice. As consequence, they are currently interested in applying to a wider scale, the farming system scale, the triple superphosphate which was the applied inorganic fertilizer during comparative trials with farmyard manure as organic matter.

O311

Towards the selection of phosphorus efficient rice varieties

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Where intensive rice cultivation with continuous application of phosphorus (P) fertilizers is practiced in the irrigated lowlands of Asia, soil P concentration is in a favorable level for rice cultivation. However, intensive P fertilization for rice would not be a viable option as the quantity and quality of the P fertilizers are decreasing gradually. Moreover, low-input rice based cropping systems exist in the rainfed lowlands often show P deficiency. Under such circumstances it is very important to identify rice varieties which can produce a higher biomass and yield at limited P availability. Moreover, identification of shoot and root characteristics enhancing P uptake and internal use are also of prime importance when introducing and improving rice varieties to be used in P limited soils. Therefore, an experiment was established in a low-P site (Colwell P of 1.7 mg P kg^{-1} air dry soil) at the rice research and Development Institute, Bathalagoda, Sri Lanka. Thirty six inbred rice lines obtained from the International Rice Research Institute (IRRI) showing the promise in relation to efficient P uptake and/or utilization characteristics, and forty four local inbred rice varieties recommended to be cultivated in Sri Lanka were used. Six weeks after transplanting three seedlings were harvested from each variety and replicate with the roots. Shoot and root growth were measured. When considering the shoot growth the best performing IRRI lines were IRRI-123, Kalubala Vee, Tsipala-421 and IR-8 while the best local varieties were Bg406, Bw363, Bg369, Bg400-1 and Bw452. Moreover, the best performing local varieties were producing 2.3 time higher biomass than that of best producing IRRI lines. The root mass ratio of the best performing IRRI varieties ranged from 16-38% while that of local varieties were 15-22%. The characteristics required for the greater growth response of above local and IRRI rice varieties need to be investigated further in order to understand the efficient P uptake and utilization mechanisms in rice.

O312

Challenges and opportunities on the use of bio fertilizers: examples from Senegal and Kenya

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Not only phosphorus (P) bio available in soil is very low but phosphate fertilizing efficiency is also low. Consequently, annual world P demand increases predicting phosphorus stock end in the coming 125 years. In addition to that, the high cost of chemical fertilizers obliges most Sub Sahara African smallholder farmers to do not use fertilizers which ultimately results in poor yields. In this paper, we present opportunities and challenges of using bio fertilizers as sustainable way of alleviating soil P deficiency effects in Kenya and Senegal. In Kenya where soil P deficiency has been identified as the biggest challenge of crop productivity increases, we share results on the use of commercialized arbuscular mycorrhizal inoculants to replenish soil P. While in Senegal known having huge quantities of P rock deposit and important quantities of feed stock material that can be charred (biochar), we present results on the capacities of biochar to improve P availability for plant cultivated in sandy soil. Results from both countries show that current expectations on the use of bio fertilizers are numerous and justified. However challenges on sustainable agriculture through the use of the called bio fertilizers especially mycorrhizal inoculants and biochar are still ahead.

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Posters

P301

Effect of phosphorus and soil on nodulation and production at flowering stage of different small faba bean varieties

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In order to evaluate faba bean nodulation and production at flowering stage under different phosphorus and soil conditions, two trials were conducted during 2013-2014 under field conditions in two different locations: experimental station (L1) and farmer's field (L2). Three Moroccan faba bean varieties (V) (Vicia faba minor) Alfia 5, Alfia 17 and Alfia 21 were combined with four phosphorus (P) rates (0, 20, 80 and 160 kg P_2O_5/ha). The experimental design was a split plot with four replicates where P was affected to the main plot and variety to the sub plot. At flowering stage, a sample of 0,5 linear meter of plants (shoots and roots) by sub-plot was harvested. Results show that in both locations P, V and P*V have significant effects on above ground dry biomass. For nodulation; in L1, P have a significant effect on nodule number and biomass while, V and V*P have no significant effect. The rate of 160 kg P2O5/ha gave the best nodules number and biomass per plant. In L2, nodule number per plant was significantly affected by the interaction V*P, while the nodule biomass was significantly affected by V where Alfia 17 and Alfia 21 gave the best nodule biomass per plant. For above ground dry biomass (AB): the models developed are respectively for L1 and L2: ABL1 = -0,81*P2 + 4,11*P + 11,46 (R^2 = 0,61) and (ABL2) = -11,25*P2 + 64,17*P + 61,83 (R^2 = 0,62). Under L1 conditions the best production was performed by treatments Alfia 5 and Alfia 17 with 20 kg P_2O_5/ha. While under L2 conditions, the best production was performed by treatments Alfia 17 and Alfia 21 with 80 kg P_2O_5/ha.

P302

Phytase activity produced by rhizobacteria isolated from extreme environments

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Rhizobacteria (bacterial communities associated with roots) that inhabit extreme regions produce enzymes adapted to those environments and provide some benefit to their plant host. Currently, rhizobacteria with the ability to produce phytase (myo-inositol hexakisphosphate phosphohydrolase) are being isolated from the rhizosphere of pastures and cereal crops. The goal of this study was to isolate and characterize phytase-producing rhizobacteria from Chilean extreme environments. Our results showed that the use of different culture media allowed the isolation of a wide variety of bacterial phenotypes, including those with motility, ability to form biofilms, pigmentation and production of endospores. In addition, two groups of phytase-producing rhizobacteria were isolated from natural hot spring environments and Atacama Desert. The strains were identified as member of thermophilic Geobacillus sp. and Bacillus sp. (natural hot spring) and Enterobacter sp. genera (Atacama Desert). The phytase produced by the after mentioned strains were identified as intracellular acid phytases. More precisely, the pytases produced by the thermophilic strains were most likely beta propeller phytases (BPP), since their activity was Ca-dependent and a phytase positive signal was obtained in a PCR reaction. The phytase activity produced by Enterobacter sp. strains, however, was Ca independent. Thus, this phytase is either a histidine acid phytase or a cysteine phytase. This study showed that Chilean ecosystems contains a wide rhizobacterial diversity and highlight our limited knowledge of their ecology, interaction with plants, and their potential as plant growth promoting rhizobacteria.

P303

Effects of a new phosphate fertilizer on P uptake and wheat yield

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Phosphorus (P) is the second main nutrient for plants, making P fertilizers essential inputs for crop yield and quality. As the world resource of easily extractable P is dramatically decreasing and over P fertilizations can be source of environmental pollution, there is a clear necessity to improve fertilizer's P use efficiency. Two experiments were carried out at Agroscope-Changins (Switzerland) and RITTMO-Colmar (France) to evaluate the P use efficiency of a new phosphate fertilizer (SSP-TIM) issue from a technology developed by TIMAC-AGRO compared to Simple Super Phosphate (SSP). Both experiments have been conducted in greenhouses, one in acidic sandy soil (RITTMO) and the second in neutral clay soil with a very high P fixing capacity (Agroscope-Changins).Five modalities were studied: Control, SSP and SSP-TIM fertilizers applied at 25 and 50 kg P_2O_5/ha. P uptake and biomass production were measured at different plant stages whereas the yield of wheat (grain and straw) and P concentration were determined at the end of the experiments and the P-use efficiency for both fertilizers and doses were calculated. In the acid soil, the SSP-TIM applied at 25 Kg P_2O_5/ha significantly increased wheat yield production by 19% compared to the SSP fertilizer while, in the clay soil, we observed a mean increase of P use efficiency of 5% when SSP-TIM fertilizer was applied. These results slightly vary depending on the dose of P fertilizers and the plant maturity. In the light of these experiments, it seems that the SSP-TIM fertilizer can be valuable in both soils, especially in cases of reduced P fertilization.

P304

Effect of phosphorus supply and pH on acid phosphatase activity in the rhizosphere of grasses cultivated in volcanic soil

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Phosphorus (P) is a limiting nutrient for pasture production in Southern Chile, mainly due to the high P fixation capacity of its volcanic ash derived soils. Under P deficiency, plants and microorganisms secrete acid phosphatase in the soil as a mechanism to increase P hydrolysis and its uptake. The aim of this study was to evaluate the effect of P fertilization and acidity condition on phosphatase activity in the rhizosphere of forage grasses cultivated in a Chilean Andisol. A greenhouse experiment with ryegrass or tall fescue plants was conducted in an acidic Andisol in the presence or absence of P and nitrogen fertilizers (nitrate or ammonium). At the end of the experiment, soil phosphatase activity, pH, and Olsen-P were determined in the rhizospheric soil. Plant biomass, P uptake, and root surface phosphatase activity were also assayed for both plant species. The results showed that soil phosphatase activity did not vary as a consequence of either P addition or pH changes derived from nitrate or ammonium supply. Nevertheless, the root phosphatase was inhibited at increasing P supply levels and pH. P uptake by tall fescue was about 67% higher than that of ryegrass at low soil P availability, which suggests that tall fescue was less sensitive to P deficiency than ryegrass. Acknowledgments: This work was supported by Chilean FONDECYT Project 1141247

P305

Role of aluminium on P availability in the rhizosphere of pastures growing in Andisols

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The main constraints for farming in Southern Chile is acidity condition of volcanic soils, which causes an increase in the content of aluminum (Al) reducing phosphorus (P) use efficiency, therefore, crop food quality and yield. In these soils, high inorganic P fixation and, in turn, low P availability and high Al soluble concentrations at low pH are the most important limiting factors in crop production. Thus, it is very difficult to separate the effects due to low P or high Al in plant nutrition because Al toxicity and P deficiency often coexist in acid soils. The objective of this research is clarify the role of aluminum on P availability in pasture rhizosphere. Soil rhizosphere samples (0-10 cm) associated to grassland species were collected from four different Andisols belong to PiedrasNegras (PN), Pemehue (PH) , Llastuco (LL) and Gorbea (GB) soil Series. We determined Al pyrophosphate, Al oxalate, pH, carbon and Olsen P, microbial P, total P, and inorganic and organic P fraction according to Hedley procedure. Furthermore, we determined soluble Al in each P fraction. The results shown a significant negative relationship between Al pyrophosphate and the inorganic available P fractions extracted with NaHCO3, NaOH and H2SO4,InAndisols,the Al-SOM complexes regulate P availability and clay fraction (oxides, allophane) stabilize P in organic form. Interestingly, microbial P content was increased by soil acidity, and consequently an enhancement of acid phosphatase activity is expected.

P306

Chemical nature of phosphorus in soils dominated by bracken and bluebell plants

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The role of plants in phosphorus (P) cycle in soil is of great importance and still not entirely understood. 31P NMR was used to assess phosphorus speciation, given as percentage of total P, in soil and plant samples collected in an area dominated by bracken (*Pteridium aquilinum*) and bluebells (*Hyacinthoides non-scripta*), in Snowdonia (UK). Samples were collected from April to September 2013 in order to cover the main lifecycle stages of these native plants. Total P in soil was between 1.5-2.2 g/kg, mainly sequestered as organic P (1.0-1.5 g/kg). Plant-available P ranged from 22 to 63 mg/kg. ^{31}P NMR showed that soil samples contained between 60-78% of organic P; specifically monoesters (54-73%) comprising mainly phytate (28-42%) and Scyllo-inositol phosphate (13-16%); diesters (1-6%); phosphonates (1-2%); and phosphonolipid (1-4%); The inorganically-bound P (22-40%) occurred as orthophosphate (21-40%) and pyro/polyphosphate (0-5%). The total P concentration in soil increased after bluebell flowering with phytate as the main P-containing species. This is notable as phytate was not detected in the plant samples, with the exception of bluebell bulbs (up to 46%) which are contractile and bury themselves deeper into the soil during flowering. Phytate release from the bulb at this period is hypothesized. Also, the main P species found in this acidic soil (pH 3.98-4.67) support high levels of fungal activity because of phosphonates and pyrophosphate, and polyphosphate detected. P was bound predominantly in inorganic form in both bracken and bluebell samples (up to 85%). Also detected were monoesters (12-25%) and diesters (about 1%).

P307

Phosphate solubilizing bacteria associated with arbuscular mycorrhizal fungi, beneficial symbionts of crop plants

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An important group of beneficial soil microorganisms is represented by arbuscular mycorrhizal fungi (AMF) which establish mutualistic symbioses with the roots of most food crops and play a key role in soil fertility and plant nutrition. AMF performance may be positively affected by functionally diverse bacteria associated with their spores, which differentially enhance nutrient availability to plant roots by different mechanisms, such as phosphorus (P) solubilization. In our work we utilized: i) a culture-independent approach, PCR-DGGE, to identify the diverse bacterial species associated with AMF spores; ii) a culture-dependent approach to isolate bacteria with functionally important traits, such as P-solubilizing activity. Sequence analysis of the major DGGE bands showed the occurrence of Arthrobacter, Bacillus, Paenibacillus, Pseudomonas, Rhizobium, genera including P-solubilizing strains. Isolation of the microbiota associated with Rhizophagus intraradices spores yielded 5.4±0.9-23±0.7 CFU of bacteria per spore. 374 strains were isolated in pure culture (135 actinobacteria, 189 heterotrophic, 27 N-fixing and 23 chitinolytic bacteria) and then functionally characterized for P-solubilizing, chitinase, nitrogen fixing activity and production of siderophores, indole acetic acid (IAA) and exopolysaccharides (EPS). Phosphatase and phytase activities were detected in 73% and 100% of Actinobacteria, in 74% and 83% of chitinolytic bacteria and in 44% and 52% of nitrogen-fixers. The most efficient strains, after molecular characterization, were identified as Sinorhizobium meliloti, Arthrobacter phenanthrenivorans, Nocardioides albus and Streptomyces spp. Such P-solubilising strains, alone or in combination with AMF, could be used as efficient biofertilizers and biohenancers in sustainable plant production systems.

P308

Quantifying phosphorus flows at different levels in China to identify potential measures to improve the management

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Phosphorus (P) as a finite natural resource is essential for food production to feed the increasing world population. The amount of P involved in food production in China has increased dramatically in the past decades, and has led to serious environmental pollution. In the present study, the P flows, P stocks and P utilization efficiencies (PUE) in the complete food chain at different levels in China have been estimated for the year 2010 with the static material flow analysis approach based on the law of mass conservation. The PUE of the arable land at national, regional (North China Plain), and county (Quzhou) levels were 26%, 26% and 20% with 4883 Gg P $year^{-1}$, 1752 Gg P $year^{-1}$ and 5144 Mg P $year^{-1}$ accumulated in the soil, respectively. The PUE of the livestock production at national, regional, and county levels were 5%, 8% and 23% with 2123 Gg P $year^{-1}$, 578 Gg P $year^{-1}$ and 516 Mg P $year^{-1}$ lost to the environment, respectively. In contrast, there is 1594 and 80 Gg P $year^{-1}$ deficit on grassland at national and regional levels, respectively. Improving the PUE in the arable land and the livestock raising industry sectors, on the basis of the actual demands combined with efforts to promote the recycling of organic manure and wastes, can significantly reduce the consumption and losses of P from the food chain, and will diminish the depletion of the limited natural resource. Given China's substantial share in global P production and consumption, this will make a substantial difference.

P309

Overexpression of a *Bacillus subtilis* phytase in *Arabidopsis thaliana* enhances its ability to mobilize P from phytate

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The low availability of phosphorus (P) is a major constraint to the growth and development of vegetable crops worldwide. In fact, 50-80% of total P in agricultural soils exists as organic P where phytic acid is the most dominant component, that is not available to plants unless hydrolyzed by specific enzymes called phytases. We are particularly interested to study a microbial phytase PHY US417 of Bacillus subtilis strain which was isolated in the Laboratory of Enzymes and Metabolites of Prokaryotes (LEMP) of the Centre of Biotechnology of Sfax (CBS). We plan to make use of this enzyme in the engineering of a Pi-enriched plant product for animal feeding, to meet the needs of the animal in this nutrient. On the other hand, we aim to develop biotechnological approaches to increase via this phytase, the ability of plants to mobilize soil P to improve crop production, hence reducing the use of phosphate fertilizers, which over time can cause environmental pollution problems especially eutrophication. We have demonstrated in this work that the PHY US417 phytase added to the medium has the ability to stimulate the growth of Arabidopsis thaliana plants in vitro under P-limited conditions. In addition, we engineered transgenic Arabidopsis plants overexpressing this phytase. The enzymatic tests revealed variable levels of phytase activity at pH 7.5 in these lines. Finally, physiological analyzes showed that overexpression of PHY US417 seems to improve (albeit modestly) growing plants submitted to P deficiency. All together, these results show that PHY US417 is active in Arabidopsis and can be exploited in other crops such as cereals.

P310

Arbuscular mycorrhizal colonization in maize genotypes grown under contrasted P-regimes in a long-term field experiment

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Most terrestrial flowering plants have the ability to establish symbiotic associations with arbuscular mycorrhizal (AM) fungi. The fungus improves the uptake of water and mineral nutrients in the host plant, mainly phosphorus and nitrogen, in exchange of photoassimilates. AM symbiosis not only promotes plant growth through facilitation of nutrient uptake, but it might also protect the plant from abiotic and/or biotic stresses. The benefits received by the AM symbiosis vary depending on the host genotype and the AM fungus species. In nature, as well as in crop fields, different AM fungi can be present in the soil or the plant, and affected by P availability or plant genotype. This has been little documented in field-grown crops however. In this study, we examined AM colonization in roots of a panel of maize genotypes grown in soils with contrasted P levels. We examined the relative level of colonization by 5 different AM fungi. Field experiment was carried out at the long-term P fertilizer trial of INRA-Auzeville (SW France). The field consisted in 4 P levels replicated in 4 blocks, ranging from P-deprived soils (P0, soil that had not been fertilized for 45 years), to soils that have been under excess P fertilization (P4, 4-fold the P offtake by crops). A total of 23 maize genotypes (selected for their contrasting root traits) grown in the two extreme P regimes (P0 and P4) were assessed. The level of root colonization was examined by microscopy observations of trypan-blue stained roots. AM colonization was further quantified by qPCR. Differences in susceptibility to AM colonization among the different maize genotypes grown under different P levels will be presented.

P311

Life Cycle Assessment (LCA) of phosphorus on AVP1 transgenic lettuce

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Human P usage is very inefficient. For example, about 80% of P mined for fertilizer, but only 1.5% of that is consumed by humans and 46% is lost from soil erosion and runoff, causing eutrophication. One means of improving agricultural P efficiency involves genetic engineering strategies to increase crop use of soil P so that results in reducing P fertilization rate. AVP1 transgenic romaine lettuce (Lactuca sativa cv. conquistador) had been engineered to improve dry tolerance and resistance, as well as nutrient use efficiency. The future scenarios for growing AVP1 transgenic crops are to reduce fertilization rate but not compromise yield. In this study, I used Attributional LCA, with kg nutrient/ha/yr as functional unit, to evaluate the environmental impacts by comparing wild type (WT) and AVP1 lettuce in California and Arizona (system boundary), as these two states produce 98% of lettuce over the U.S. I assumed that the biological effects from AVP1 gene were equal in head, leaf, and romaine lettuce. I also assumed that WT and AVP1 lettuce consume that same amount of water, while AVP1 lettuce requires more water in a shorter growth period to reach to equivalent yield as WT. Results showed that applying AVP1 lettuce would conserve 78% N and 55% P fertilizers applying to grow lettuce. It would also reduce 20 kgN/ha/yr emitted as ammonia to the air, 5.7 kgN/ha/yr as NO and N2O, 117 kgN/ha/yr as NO3 being leached out from the soil, 0.065 kgP/ha/yr into groundwater, and 0.23kg P/ha/yr into surface water. Applying AVP1 transgenic crops has large impact on reducing eutrophication potential and should be considered in future farm practices.

P312

Effect of AM fungi in the Al-P interaction in wheat cultivars grown in a split root system

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In developing countries, as Chile, which have limited access to P fertilizer, there is a need to develop plants that are Al tolerant and more P efficient. Then, an option is to mimic plants habitually growing in acid soils which surely have effective mechanisms related to Al tolerance and P deficiency. Therefore, the objective of this research is to understand the interaction Al-P-Arbuscular mycorrhizal (AM) symbiosis on the growth and development of some wheat cultivars when they are cropped in acidic soils. Several screening for Al tolerance and P efficiency were carried out with 40 commercial wheat cultivars habitually cropped in south of Chile. Such screening were performed in mineral solution under 0 and 200 uM of Al as AlCl3 and 20 and 200 uM of P as KH2PO4 as well as in pots to see the responses at liming (0.15 and 23% Al-saturation in soil) measuring the detrimental effect on principal root length and shoot/root P-Al concentration at 15 days of Al exposure and the Al and P concentration in shoot and root. After screening one Al tolerant and P efficient wheat cultivar ('Invento') and one Al sensitive and P no efficient ('Tukan') were selected and compared with "Atlas66" gold standard cultivar in Al tolerance. Then, a split root experiment was carried out under five treatments (+P,-P); (+Al,-Al); (+Al +P, +Al -P); (+MA, -MA); (+Al +MA, +Al -MA) and dry weigh, glomalin and root colonization were determined. The root mass was different between the cultivars being 'Invento' the smallest. P deficiency resulted in a decrease in root mass of all cultivars as also the lack of AM symbiosis. By contrast, 'Tukan' had only response to P appearing comparatively more dependent of the P fertilization. The addition of inoculum of AM fungi increased the GRSP concentration in the three cultivars although in different amounts. 'Invento' cultivar was more than twice that 'Tukan ' and more than triple the 'Atlas 66'. In conclusions, Al tolerant and P efficient wheat cultivars had higher response to mycorrhizal arbuscular propagules. It could suggest an positive effect of AM symbiosis in the Al-P interaction to consider in future selection of P efficient wheat cultivars in acidic soils.

P313

Long term organic phosphorus changes under tillage systems in Brazilian Cerrado Oxisols

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Organic phosphorus can be an important source for plants, reducing P fixation and increasing phosphate availability, mainly in undisturbed soils. The aim of this study was to evaluate the long term changes in soil organic P forms in Brazilian Oxisols, under two soil management systems. The study consisted of four soil management trials, established in Costa Rica-MS (CR) since 1994 (18º15'10"S and 53º12'41"W), Sapezal-MT (SA) since 2001 (13º56'33"S and 58º53'43"W), Luziânia-GO (LU) since 1992 (16º15'02"S and 47º37'02"W) and Tasso Fragoso-MA (TF) since 2001 (8º30'57"S and 46º3'47"W), all soils classified as Typic Hapludox (65.6, 45.2, 65.3 and 25.5, respectly for soils clay composition). The experiments were distributed in a randomized blocks design, being the treatments no-till (NT) conventional tillage (CT) and native vegetation (NV). The depths layers of 0-5, 5-10 and 10-20 cm were sampled in 2013, with four replications. The Hedley P fractionation procedure was used to identify organic P fractions in soil, using the following extractors: NaHCO3 0.5 mol L-1 (PoBIC), NaOH 0.1 mol L-1 (PoHID-0,1) and NaOH 0.5 mol L-1 (PoHID-0,5). The NT and CT systems resulted in accumulation of labile and moderately labile organic P fractions (PoBIC and PoHID-0,1) in all soil surface layers (0-5, 5-10 and 10-20cm), compared to native vegetation. Both NT and CT promoted accumulation of PoHID-0,5 in subsurface (10-20 cm) in clayey soils (CR, SA and LU). In TF soil (less clay), the organic P fractions was much lower than observed in clayey soils and cultivated areas were similar to NV, indicating that the recalcitrant organic P forms are not accumulated in soils with low clay level.

P314

Tillage systems changes in acidity and available nutrients in Brazilian Cerrado Oxisols

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The appropriate soil management is essential in tropical agroecosystems. The no tillage system promotes the maintenance of crop residues on soil surface and minimal change in its structure what can result in less soil acidity and increase in nutrients availability. The aim of this study was to evaluate the long term changes in soil pH and exchangeable levels of P, K, Ca and Mg in Brazilian Oxisols, under soil management systems. The study consisted of four soil management trials, established in Costa Rica-MS (CR) since 1994 (18º15'10"S and 53º12'41"W), Sapezal-MT (SA) since 2001 (13º56'33"S and 58º53'43"W), Luziânia-GO (LU) since 1992 (16º15'02"S and 47º37'02"W) and Tasso Fragoso-MA (TF) since 2001 (8º30'57"S and 46º3'47"W), all soils classified as Typic Hapludox (65.6, 45.2, 65.3 and 25.5, respectly for soils clay percentage). The experiments were distributed in a randomized blocks design, being the treatments no-till (NT) conventional tillage (CT) and native vegetation (NV). The depths layers of 0-5, 5-10 and 10-20 cm were sampled in 2013, with four replications. The pH (CaCl2, 1:2.5 soil:solution ratio), P, K, Ca and Mg (extracted with anionic exchange resin, 1:10 soil solution ratio) were analyzed. The soil pH in agricultural systems (NT e CT) was greater than in NV, what was obviously expected. NT system promoted a pH gradient in soil profile, with the highest value in the first 5 cm of the soil, what was not observed in CT. The soil P, Ca and Mg content in NT and CT systems were uniform in near surface layers (0-5 and 5-10cm), being higher than NV. The K level not changed in soil depths, regardless of management system.

P315

Severe P deficiency and P adsorption in soils of the highly populated region of South Kivu, Democratic Republic of Congo

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High population densities combined with a large dependence on agriculture is leading to severe land pressure in certain areas of South Kivu. Because of the political and economic situation, the use of mineral fertilizers is practically non-existent and the use of animal manure rare. While it is clear that soil fertility is directly related to food security and income in the densely populated areas, the region has been largely neglected by the international research community and little elementary information is available about the nature of the soil fertility constraints present. A study was undertaken at 2 sites in the Walungu territory to determine the occurrence and the degree of various soil nutrient deficiencies and toxicities. Soil samples were collected at 30 locations across the 2 sites and used to establish a nutrient omission trial using maize as a test crop. After 5 weeks, maize biomass in pots which did not receive phosphorus (P) was about 20% of biomass in pots amended with P, demonstrating severe problems of P deficiency. Nutrient disorders like potassium deficiency were also observed, but the effects of omitting other nutrients than P were far less pronounced. The P buffer capacity of the soils ranged from 15 mg P kg-1 soil up to as high as 214 mg P kg-1 soil. Under such conditions, P fertilizer use efficiency is likely to remain low due to processes of P adsorption and P fixation. In order to increase productivity on these soils, an integrated soil fertility management approach will be crucial including the use of organic materials to improve availability of added mineral fertilizers.

P316

Differences in P efficiency among soybean genotypes are attributed to variation in P uptake and not P utilization

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In view of the economic reality of smallholder farmers in sub-Saharan Africa and the scarcity of phosphorus (P) resources available, technologies are needed that increase the use efficiency of P fertilizers. This is especially the case for weathered, P-fixing soils where P fertilizer use efficiency may remain low due to strong P adsorption and fixation. One of such technologies is the selection and development of P-efficient genotypes. P efficiency may be the result of either the development of certain root traits leading to enhanced P uptake, or of certain mechanisms leading to enhanced P utilization (this is, more biomass produced with the same amount of P taken up). Twenty soybean genotypes were screened on 15 sites in Western Kenya at 3 P levels (no P, 20-26 kg P ha-1 and 50-60 kg P ha-1). In addition, 8 soybean genotypes were grown in a pot trial using a P-deficient soil at 2 levels of added P (low and high P). P efficiency was calculated as the ratio of biomass production at low or medium P supply to that at high P supply. In both the field and the pot trial, soybean genotypes differed significantly in P efficiency, and P efficiency was correlated with P uptake but not with P utilization. Although P utilization efficiency may play a more important role at higher levels of P supply, we conclude that breeding programs aiming at increasing soybean growth at suboptimal P supply should exploit genotypic variation in P uptake rather than P utilization.

P317

Effect of phosphorus deficiency on phytase activity of faba bean (Vicia faba)-rhizobia symbiosis

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Legume-rhizobia symbiosis provides the necessary nitrogen for plant growth and contributes to the improvement of soil nitrogen balance. However, this symbiosis is limited by many environmental constraints such as phosphorus (P) deficiency. Indeed, this major element is massively under insoluble forms in soil since it is strongly associated with aluminum, iron and calcium. Besides, the effect of P deficiency on phosphatases activities, particularly phytases has been widely studied in some N2-fixing legumes. The current study develops the impact of P deficiency on phytase activity in eight faba bean (Vicia faba)-rhizobia symbiosis. The experiment was carried out in a greenhouse on four faba bean varieties (Aguadulce, Alfia, Luz de Otono and Reina Mora) inoculated with two local rhizobia isolated from farmers 'fields in Al Haouz region. The P deficiency was applied by adding low KH2PO4 concentration (25µmol plant-1 week-1) to nutrient solution while the control received 125µmol plant-1 week-1. The plants were harvested at flowering stage and their growth evaluated. P content as well as phytase activities were assessed in nodules. The results showed a significant impact of phosphorus deficiency on plant growth and nodules P content for all the studied combinations. Besides, phytase activities were highly stimulated in nodules under P deficiency. A further analysis of a phytase gene transcription in nodules was performed using RTPCR method showed its localization in the nodule cortex.

P318

Plant uptake of phosphorus recycled from waste water and sewage sludge ashes

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The growing human population and urbanization result in greater phosphorus (P) fluxes from agro-ecosystems to consumers and finally into waste water. The direct application of sewage sludge is increasingly debated and alternatives to recycle P from waste water are needed. Options are the precipitation of struvite (MgNH4PO4.6H2O) either from waste water or from separately collected human urine or the recycling of P from sewage sludge incineration ash. In either way the recycling of P back to crop land requires that the plant availability of P in the recycling product is known. We studied P uptake by plants from struvite precipitated from synthetic human urine (MAP-syn), struvite precipitated from sewage sludge (MAP-ss) and from sewage sludge ashes (SSA) which underwent a thermo-chemical heavy metal removal (SSA-tc). We used radioisotope dilution to determine the P in Lolium multiflorum taken up from the fertilizer in the greenhouse using soils from arable fields. Relative fertilizer efficiency (RUE) is expressed as P uptake from the fertilizer relative to water soluble mineral P. The results show that P contained in the MAP-syn, MAP-ss and SSA-tc is readily available to plants on the slightly acidic soil, with a RUE of 90%, 100% and 90%, respectively. On the alkaline soil, P contained in MAP-ss and in SSA-tc had a RUE of 50% and 13%, respectively. Struvite represents a viable alternative P fertilizer. The significant lower relative efficiency of the SSA-tc fertilizer indicates that this fertilizer is not suited as P fertilizer in alkaline soils, unless its availability could be further promoted by biological P mobilization.

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Phosphorus balances and yield responses of crops as affected by phosphorus fertilization in China

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Sustainable agriculture emphasizes improving phosphorus (P) efficiency rather than solely depending on excessive application of chemical P fertilizers, but the historical dynamics of yield responses to P fertilization and P balances were not fully understood. The objective of the present study was to investigate soil P balances along with time in China, and analyze how P balances modified yield responses to P fertilization. The data sets were based on 82 long- and short-time experiments conducted in China over 30 years (1978-2013) as well as data of grain production and chemical P consumption from FAO and IFA. Grain production stagnated in the middle of 1990s while chemical P fertilization increased dramatically during the last decade. This caused great P imbalances. Before 1990, the P balances were negative while it became positive from 1990 to 2000, and about 60 kg P2O5 ha-1 year-1 was accumulated in soil during the last decade. Along with time, all crop yield responses to P fertilization increased at first and then declined afterwards, although P fertilization significantly increased crop yields compared to the control, and yield responses to P fertilization varied with crop species. Compared with low soil P fertility in 1980s, yield responses to P under high soil P fertility in 2010s was much lower, indicating a significant decline in yield response to P with increased soil P fertility. These results suggested that excessive P fertilization can be reduced without penalty of high crop yield through optimized P management strategies to improve P use efficiency.

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Application of biochar-blended-compost under low P soil in Brazil

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Biochar application has received increasing attention as a means to trap recalcitrant carbon and enhance soil fertility. Also, it has absoprtion capacity which retain P content of fertilizer in soil. The aim of our study is to evaluate the effect of biochar-blended-compost in different aspects (biochemical, chemical, microbiological). Hydrolytic enzymatic assays, such as β-glucosidase and phosphatase activities, are used for the assessment of soil quality. P content in soil and plant has been also evaluated. Microbial biomass in soil has been also examined. After observation of our results, the effect of biochar has impacted on the improvement of soil quality.

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Assessement of growth of common bean for biological nitrogen fixation efficiency under low P condition in Malawi

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In some parts of southern Malawi region the deficiency of P in soil bring the difficulty in cultivating maiz, beans, and other vegetables. Majority of low class of Malawian societies takes legumes as a good supply of protein, and common bean is considered as the indispensable material in their daily life. Other than nitrogen and carbon sources, P is an element of interest because of the dramatic effects observed due to P fertilizers when applied to nodulated legumes in low P soils. In order to improve legume yields, we investigated responses to rhizobial inoculation (CIAT 899 strain) and P fertilization and low under field conditions with 26 bean lines. Through several parameters of plant growth, we have resulted that the effect of P input on the common bean growth has been demonstrated generally in different parameters. The promotion of plants growth and increase on the pods weight has been undergone. Also, it stimulates the symbiosis in the soil.

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Phosphorus in the soil profile under conventional and no-tillage soil practices

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The minimum (MT) and no-tillage (NT) soil practices are discussed in last years and still more often used in agricultural practice. Conservation tillage practices affect a number of soil characteristics, among them also the phosphorus distribution in the soil profile. Changes in the P distribution in a soil profile can affect the P availability for crops. The field experiment with conventional CT – ploughing to 22 cm), MT (chiselling to 10 cm) and NT practices is carried out since 1995 at Prague – Ruzyn□ on Orthic luvisol, clay-loamy soil, pH = 7.0, average of rainfall and temperature - 472 mm and 8.4°C. The average of available P concentrations in the whole soil profile of 0-30 cm remained similar for all tillage practices (CT, MT, NT). However, P concentrations accumulated in the top soil layer 0-10 cm under MT and NT, whereas distribution of available phosphorus was more unified under CT. A decrease of pH which could affect P availability in soils was noted under MT and NT in the top layer. The P concentrations decreased in deeper soil layers under MT and NT. The root density of winter wheat also increased under MT and NT. Significant correlations between available P concentrations in soils and root density were obtained indicating the adequate utilization of phosphorus in the top layer by winter wheat under MT and NT. The lower P concentrations and P-availability for crops in deeper soil layers in MT and NT will be necessary to solve in future, particularly for deeply rooting plants. The P distribution and availability for crops under MT and NT could be affected also by drought due to P accumulation in surface layer.

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An initiative of sustainable phosphorus use in P- rich mining zone of lower Himalaya region of Pakistan

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Phosphorus from inorganic sources such as tricalcium P (rock phosphate), though constitutes the major proportion in soils of lower Himalaya regions of Pakistan, is mainly unavailable to plants. The need of available P in this zone, is deteriorating the natural ecosystem of the area via environmental pollution through mining and artificial P fertilizers. Despite the well-known effects of rhizosphere trophic relationships on N mineralization, almost no work has yet been done on P mineralization. We, therefore, hypothesized that the interactions between phosphorus solubilizing bacteria and bacterial grazer nematodes are able to improve plant available P use from abundantly present P source. We tested the hypothesis by isolating P solubilizing bacterial strains and growing them with Pine seedlings in sand containing tricalcium phosphorus as sole P source. The plants were grown alone or with a P solubilizing bacterial strain along with bacterial-feeder nematodes. The bacteria and the nematodes were isolated from same region of rich unavailable P zone of lower Himalaya. Interestingly the grazing of bacteria by nematodes enhanced plant P accumulation. Although plants increased the density of P solubilizing bacteria, these bacteria alone did not improve plant P nutrition as in the case of nematode predation. To our interpretations, the solubilizing bacteria locked up the phosphorus assimilating their biomass, which was delivered to plants mainly by bacterial grazers i.e. nematodes. Our results open an alternative route for better utilization of poorly available inorganic P to plants. In future we plan to introduce a combined inoculum (biofertilizer) of P solubilizing bacteria and their predator nematodes for the use of small farmers of lower Himalaya region of Pakistan which will ultimately help to lead the region using their P reserves in a sustainable way.

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Charge characteristics of nano–ball allophane as influenced by competitive adsorption of phosphate and oxalate

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Allophane as a variable charge mineral has unique characteristics: it has both negative and positive charges simultaneously. Oxalate (Ox) was chosen because it occurs ubiquitously in nature. A full understanding of the surface charge is essential for anion adsorption mechanism and has effect on plant nutrition and fertilizer needs as well as the environment. Studies on the change of surface charge characteristics properties of nano–ball allophane due to competitive adsorption of phosphate (P) and Ox are still lacking. Therefore, the purpose of this study was to know the change in charge characteristics of nano–ball allophane with competitive adsorption of Ox and P. Change in surface charge of nano–ball allophane samples with different Si/Al ratios and under various Ox and P adsorption ratios was examined. Cation exchange capacity (CEC) was found to increase with increasing pH, and after adsorption Ox and P, in both single and binary adsorbate systems. The increase in CEC was higher in single ox system than in single P system. In other hand anion exchange capacity (AEC) was found to decrease with increasing pH, and after adsorption of Ox and P, in both single and binary adsorbate systems. Moreover, the KnP(allophane sample with high Si/Al ratio) having higher CEC value as compared to KyP(low high Si/Al ratio) for all cases. The reasons behind the change in surface charges was the effect of increasing pH and, effect of the phosphate or/and oxalate compounds adsorption.

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Rice is more competitive than barnyard grass when soil phosphorus and moisture availabilities are limited

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Productivity of rice (*Oryza sativa* L.) is low due to constraints such as high weed competition, low phosphorus (P) utilization efficiency, and water scarcity. A pot experiment was conducted using rice-rice (four plants per pot), rice-barnyard grass (BG; *Echinochloa crusgalli* (L.) Beauv.)(two plants of each species) and BG-BG (four plants per pot) in combination, in order to study the impact of P placement (topsoil P; 0-5 cm, and subsoil P; 15-20 cm), and soil moisture management (continuous flooding - CF; i.e. 3 cm water level above the soil surface throughout the experiment), topsoil drying -TSD; i.e. top watering was stopped at the time of anthesis and the middle soil layer of the pot was kept moist through the capillary action maintaining a soil moisture gradient from bottom to top layers) and alternate wetting and drying -AWD; i.e. continuous flooding until tillering and then watered at 12 day intervals) on competitive effects of BG and rice. The P placement in subsoil reduced the shoot and root dry weights (DW), root length, root diameter and rooting depth of BG by 60-90% than those where P was placed on the topsoil, irrespective of the plant combination and the moisture treatment. In the case of rice, the same comparison showed reductions lower than 15%. Even though the root mass ratio (ratio of root DW and total plant DW) of rice was lower (0.25-0.38) than that of BG (0.37-0.62), rice roots penetrated to deep soil layers exploring subsoil-placed P and moisture under TSD condition (67% increment in root length), which enhanced the concentration of tissue-P and uptake of total P by rice plants hence the total biomass. The water-use efficiency (WUE ; g DW ml-1 H2O) of rice was greater (1.44 mg l-1) than that of BG (0.88 mg l-1), and was higher under AWD (25%) and TSD (50%) conditions than that under CF (1.16 mg l-1). Therefore, P placement in the subsoil enhanced the competitive ability of rice over BG especially under TSD condition coupled with higher WUE.

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Sequential changes occurring in the growth of rice when declining the soil phosphorus fertility

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Continuous application of phosphorus (P) fertilizers to rice has resulted in an accumulation of P in lowland rice soils. Therefore, rice plants do not show P deficiency symptoms even without the application of P fertilizers for several seasons. To date there is no reliable indicator to identify P deficiency in rice growing soils. Therefore, an efficient P management technique requires the understanding of gradual changes in the development and growth processes in rice to declining soil P fertility to ensure the sustainability in rice production and enhance the P fertilizer-use efficiency. In order to study this, a long term field experiment was conducted at the Rice Research and Development Institute at Batalagoda, Sri Lanka for four consecutive seasons with (T1- P2O5 45 kg ha-1) and without (T2- P2O5 0 kg ha-1) the application of P fertilizers. Other nutrients were applied as recommended. Soil samples were collected at the beginning of each season from the top 20 cm layer to study the soil P dynamics and plant samples were collected at the correct physiological maturity to study the growth and P uptake. Initial soil total P and plant available P (Olsen-P) concentrations were 345.3 µg g-1 and 13.8 µg g-1, respectively. During the first three seasons shoot dry weight (DW), plant height, soil solution and available P concentrations were similar between P fertilized and unfertilized plots. In the fourth season shoot DW and plant height were reduced in P unfertilized plots (36.9 g hill-1 and 97 cm) than those in fertilized plots (41.7 g hill-1 and 102 cm) while the grain yield was not reduced. Phosphorus concentrations (i.e. 1.6, 1.2, and 2.1 mg g-1 in T1, and 1.0, 0.76, 1.3 mg g-1 in T2, for green leaves, dead leaves, and panicles, respectively) and total P uptake were reduced even from the third season in P unfertilized plots than those in P fertilized plots. It can be concluded that even though there is no reduction in grain yield of rice, reduction in plant P concentration is a good indicator to identify phosphorous deficiency in paddy fields.

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The COMIFER method for P fertilization management

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Phosphorus management at field level must be simple and based on soil test as phosphorus bioavailability plays a prominent role in crop nutrition. It has also to take care of the availability of organic products or manure at farm level. The method proposed by COMIFER since 1993 to interpret soil test is based on a broad dialogue involving researchers as well as agricultural advisors. The method is based on laboratory research results and on a large set of field trials, conducted by all these actors. The interpretation procedure takes into account the crop sensitivity class. It is the major factor which leads the fertilization strategy. It uses two reference thresholds for every soil type and crop class combination. It also takes care of the availability of phosphorus due to fertilizers applications in previous years. The COMIFER method has had several evolution steps and is still nowadays the common basis for the various decision methods used in France. The method is updated by the COMIFER P-K-Mg group and is still evolving to and integrate new references (manure and slurry quality, new organic fertilizers,…) and adapt to new concepts. Present works deal with the use of more mechanistic phosphate dynamics principle to better integrate the role of soil buffer power in fertilizer rate calculation.

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The French COMIFER as an actor for efficient phosphorus use in agriculture

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Agriculture has a prominent role in phosphorus fluxes in France. The common interest is in using the resources in the most effective possible way to avoid environmental risks while preserving the economic competitiveness. The use of phosphorus is not regulated in France. Farmers are the ultimate decision-makers regarding P-flows toward agriculture. They need relevant and rather simple tools for decision. Stakeholders for decision support systems are numerous, from research to suppliers. To coordinate them, the COMIFER has been created in 1980. It promotes dialogue and applied research assessment to define rational procedure for decision. The COMIFER is an independent association; its members are split in 3 boards: public institutions, agricultural organizations and economic structures. It specificity is based on the publications provider realised with the consensus of all the members. The COMIFER manages several technical groups, one about P-K-Mg. For dissemination, the COMIFER organizes a congress every two years and proposes a web site where reference documents are downloadable. The P-K-Mg group deals with a scientific and technical monitoring of the state of the art and supports on-going works for the improvement of inputs management. He has published references and defined a simple and broadly used method for P management based on soil test interpretation. The Comifer has developed its cooperation with other structures closely related to fertility management at French national level. Now it also wishes to broaden its relationship at the international level to mutualize and harmonize the reflections, references and methods.

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Soil test phosphorus of a previously enriched soil incubated with duck manure solid and liquid fractions

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Phosphorus (P) reuse to reduce dependency on imports is currently under discussion. Thus, soil application of animal manures to meet crop P requirements asks for a reassessment of soil P testing, as these materials are not equivalent to mineral fertilizers. The effect of manure addition, soil P level and time on P extractability was evaluated by the Olsen and iron oxide paper strips (Fe-O) methods. Two soils with low P content were used, one of which had been amended with earlier with 107 mg P kg-1 as KH2PO4, referred to as S0 and S107, respectively. The two soils were then incubated aerobically with duck manure solid (SF) and liquid (LF) fractions applied at 85 mg P kg-1 for 112 days. Samples of S0 and S107 without manure were also incubated. For each treatment, at 5 sampling dates (7, 14, 28, 56, and 112 days), Olsen-P and Fe-O-P was determined on 3 replicates. P recoveries (% of added P) by the Fe-O and Olsen over time followed the same trend. An initial increase up to 14/28 days was followed by a sharp decrease with the lowest P recoveries observed at 56 days, and an increase at 112 days. For both manures, Olsen-P recoveries in S107 were lower than those observed in S0, whereas in the Fe-O method this trend was only observed at 56 incubation days. For both extraction methods and soil P levels, LF P recoveries were always significantly lower when compared to SF. Manure composition, soluble total C, soluble organic C, Ca and Mg, combined with the higher amount of LF added, may explain the different P extractability. However, the lower recovery of Olsen-P for the soil treated with manure than untreated soil requires further investigation.

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Quantification of in situ dissolution of phosphorus fertiliser granules using X-ray computed tomography.

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The rate at which fertiliser granules dissolve and release nutrients in soil is a primary factor regulating the availability of phosphorus (P) to crop plants. Simulation models used to predict root nutrient uptake from soil rely heavily on nutrient release curves when simulating nutrient depletion. Similarly, models used to predict rates of vertical leaching and run-off also need good estimates of granule dissolution rate. Current methods of measuring release rates are performed ex situ and therefore do not adequately capture the soil specific parameters such as its heterogeneity and the preferential flow paths that develop in a real soil. In this study, time resolved, non-destructive, 3D micro-focus X-ray computer tomography (CT) imaging was used to visualise and quantify the in situ rate and mechanism of fertiliser dissolution in an agricultural soil. Fast release (Triple superphosphate; TSP) and slow release (Crystal Green/Struvite; CG) fertiliser granules were placed in soil filled tubes. Weekly CT scans (12□m spatial resolution) of the tubes were obtained over 12 weeks. Preliminary results show that phosphorus rock-based fertilisers such as TSP are highly porous and the primary mechanism of dissolution involves water ingress into the core causing the granule to dissolve from the inside out. Conversely, CG has a very low intrinsic porosity and dissolves from the outside, in concentric layers. This behaviour is also seen in the presence of live plants. On-going work will help advance our understanding of how different types of P sources function in a soil/plant environment leading to improved fertiliser design and better informed plant-soil nutrient balance models.

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Rock phosphate impact on the productivity and biological properties of degraded soils in Burkina Soudano-sahelian zone

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The soils of Burkina have generally structural phosphorus deficiency and lead to a low yields for many producer. The deficiency is even more pronounced in degraded bare soils "Zipella" of the northern Region on witch farmers practice rehabilitation technique and production called "zaï". The study was conducted in the northern Region in Burkina to assess the impact of the use of rock phosphate in combination with organic amendments in zaï system on productivity and biological properties of degraded bare soils. This study was conducted on the Ferric Lixisol with a usual deep of 20 to 26 cm. The experimental design used was Fisher Blocks with 3 replications and 12 treatments. The results showed that the addition of rock phosphate manure and compost resulted in increased seed yields of about 60 to 70 % compared to manure and compost simple respectively to cowpea and sorghum. The increase in seed yields is about 75% compared to the control without amendment. The addition of phosphate has achieved seed yields of 1000 to 1300 kg.ha-1with cowpea and 1900 to 2300 kg.ha-1 for sorghum. The overall biological activity was also increased by the contribution of rock phosphate. Phosphate manure addition resulted in an increase in microbial biomass by 60% compared to manure simple and 85% compared to the control without amendment, respectively 68 mg.kg-1against 38 mg.kg-1 and 12 mg.kg-1. Highest amounts of soil respiration (CO2 evolved) were obtained with the combination of phosphate in manure. Our results show that the contribution of phosphate in zaï system improves productivity and biological properties of degraded bare soils.

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Comparative study of P-enriched compost, inorganic fertilizer and PGPR on growth and yield of wheat

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The present research was aimed to enhance the solubility of phosphorus (P) from rock phosphate through composting with poultry litter and Plant Growth promoting Rhizobacteria (PGPR). Primarily, the rock phosphate (RP) was composted along with poultry litter (PL) in pits (1.25×1.25×0.5 meter) for 120 days with three replications using Randomized Complete Block Design. The RP added PL had higher total P, available P, microbial biomass (C and P), and lower total organic carbon (TOC), total nitrogen and C/N ratio over PL alone. Inoculation of Pseudomonas sp. with RP added PL showed maximum increase in available P (41% of total P) followed by Proteus sp. inoculation (30% of total P) over un-inoculated treatment (23% of total P) on 120th day of composting. Subsequently, two year study was conducted to compare the prepared P-enriched composts (PECs) with inorganic fertilizer on wheat (Cv.GA-2002) with and without inoculation of PGPR (Pseudomonas sp. and Proteus sp.) The inoculation of Pseudomonas sp. showed significant ($P \leq 0.05$) increase (10%) on yield and yield components of wheat over un-inoculated treatments. However, PEC improved grain yield (36.35%), Dry matter yield (36.2%) and number of tillers (46%) over control. It can be concluded that the inoculation of Pseudomonas sp. can enhance P availability and the rock phosphate enriched compost can be used as alternate product for better crop growth and productivity.

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Agronomic Performance of Phosphorus-Based Application of Swine Manures under Long-Term Corn-Soybean Rotation

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With increasing interests in adopting phosphorus (P)-based manure application for environmental protection, a good knowledge of agronomic performance is needed to assure crop productivity with various manure addition in such approach. We evaluated the effects of three forms of swine manure (liquid, LM; solid, SM; and liquid manure compost, MC) on crop P uptake and agronomic P efficiency, compared with chemical fertilizer (CF) on a Brookston clay loam soil under corn-soybean rotation from 2004 to 2011. The grain yield for corn followed the order of LM>SM>MC, while it for soybean was in the order of LM=SM>MC. Similar patterns were discovered for total P uptake and grain P removal. Manure P source coefficients were 1.14, 0.85 and 0.74 for corn, and 1.0, 1.0 and 0.9 for soybean, for LM, SM, and MC, respectively. Apparent P agronomy efficiency (APAE) and cumulative P agronomy efficiency (CPAE) defined as the grain yield produced with each kg net P input in a given year-period since its 1st application, remained similar between LM and CF for corn. The APAE and CPAE decreased by 21 and 20% for SM and 31 and 36% for MC, respectively, relative to CF. For soybean, no P-source effects were found on CPAE, while APAE for MC decreased by 13% compared to CF. The values of CPAE decreased linearly with increases in net P input over time, regardless of crop species and P source. P-based application must be optimized on a manure form-specific base and take the long-term legacy P into consideration.

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Rock phosphate increased nodulation, growth and yield of Vigna unguiculata in sub-Saharan agrosystem of Burkina Faso.

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Cowpea plays a considerable role in the nutritional balance and rural economic of Burkina Faso. However, its farming is marked by yields instability related to drought and soil depletion of nutrients, particularly nitrogen and phosphorus. In this study factorial trials were carried out in 12 farmers' fields in the northern Soudano-sahelian region of Burkina Faso, in view to compare nodulation and growth of cowpea without and with rock phosphate (25% P and 10% Ca) applied at the dose of 313 kg ha-1. Although a large variation was observed between trial sites, the cowpea nodule dry weight increased from 21±2 without rock phosphate to 30±3 mg plant-1 with rock phosphate. The shoot biomass increased from 9±2 g to 13±1 mg plant-1, and grain yield from 564±1 kg ha-1 to 687±2 kg ha-1. However the benefit of the Burkina rock phosphate was much higher in trials where the nodulation of cowpea was the highest. It is concluded that the supply of Burkina rock phosphate could significantly improve the symbiotic nitrogen fixation and the yield of cowpea in sub-Saharan areas of Africa.

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The role of plant and bacterial organic anion production in plant access to insoluble organic phosphorus

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The inefficient use of phosphorus (P) in agricultural systems has led to the global depletion of mineral phosphate supplies and surface water pollution. External fertilizer requirements and nutrient loss could be minimized by improving crop access to native soil P. Phytate (IHP) is the dominant organic P compound in most soils and is converted to plant-available orthophosphate (Pi) by plant or microbial phytases. The bioavailability of insoluble IHP may be improved in the presence of low molecular weight organic anions (OAs) from plant or microbial sources. The influence of plant and bacterial OAs on the solubility and bioavailability of IHP was assessed in tobacco (Nicotiana tabacum) grown on insoluble P sources (IHP, Pi), which were either sorbed to goethite (Gt) or precipitated with calcium (Ca). Wild-type (WT) tobacco was transformed to over-express Peniophora lycii phytase (PHY) and Multidrug-And-Toxic-Compound-Extrusion-type transporters (CIT), leading to increased phytase activity (33-fold) and citrate exudation (2.6-fold), respectively. Consistent with exudate characteristics, PHY plants accessed 4-fold more P from Gt-IHP, whereas CIT plants incorporated 2-fold more shoot P relative to the WT. The PHY plant-line incorporated >20-fold more shoot P compared to other plants grown on Ca-IHP. Transgenic plants inoculated with Pseudomonas sp. incorporated >7-fold more P from Ca-IHP, suggesting a synergistic effect of plant exudates and microbial products on plant acquisition of insoluble organic P. A combined strategy of P solubilization and hydrolysis is therefore suggested as a suitable target for improving crop utilization of native soil P.

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A conceptual model of root hair ideotypes for future agricultural environments

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Phosphorus (P) commonly limits crop yield and is frequently applied as fertilizer derived from rock phosphate, a diminishing resource. Plants have evolved a number of mechanisms to improve P-acquisition, including the proliferation of root hairs. Through an understanding of these mechanisms it is possible to improve the P-efficiency of crops. Observations of interactions between root hair traits and P-acquisition made from experimentation utilising a genetically nearly identical mutant population of barley (Hordeum vulgare L.), along with conclusions taken from the literature have been synthesised to produce a conceptual model of root hair ideotypes. Understanding the impacts of root hair presence and length on P-limited yield and interactions with Arbuscular Mycorrhizal fungi allow us to postulate beneficial modifications to root hair traits and their implications for plant yield. Possible cost/benefit relationships of such traits are described, recommending potential ideotypes encompassing important traits associated with root hairs and P-acquisition which represent targets for research and breeding programmes in future crop plants. Using the model we have identified and focused on the potential to utilise low cost roots in improving phosphorus use efficiency. Screening has begun for roots with increased longevity, larger cells, reduced cell file number or aerenchyma which all have potential to improve P-acquisition at reduced cost to the plant. Given finite resources and an increasing global population, crop plants with such traits have the potential to play an important role in improving crop varieties and the long term sustainability of agriculture.

P337

Genetic variation under low phosphorus in West and Central African pearl millet inbred lines and testcrosses

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Pearl millet [*Cenchrus americanus* (L.) Morrone] is a food security crop for millions living in drylands of Africa and Asia. Its production on acid sandy soils of the Sahel is limited by erratic rainfall and poor soil fertility, especially low phosphorus (P) soils. We sought to elucidate the genetic variation in West and Central African landrace-derived inbred lines for grain yield under low P conditions, to determine their performance as inbred lines per se and in hybrid combinations, and to determine quantitative-genetic parameters to derive an appropriate breeding strategy for grain yield under low P conditions. We evaluated a total of 155 landrace-derived inbred lines as well as their testcrosses in four locations over two years under two treatments, high P (HP; with P fertilization) and low P (LP; without P fertilization). Results revealed significant effects for genotypes, P-level, genotype x P-level, as well as genotype x environment interactions. Grain yield reductions under LP treatment ranged from 7.9 to 35.5%, and 11.2 to 60.9% for inbred lines and testcrosses respectively, with positive mid-parent heterosis averaging 43.5% under LP. We conclude that direct selection of testcrosses under LP is more effective and that indirect selection for testcross performance from inbred line performance is not desirable.

P338

Genetic regulation of phosphorus homeostasis during grain filling in rice

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Phosphorus (P) is an essential plant nutrient because of its role in nucleic acids, phospholipids, ATP and other phosphor-esters. Ultimately, 70-80% of total plant P is mobilised to seeds during reproductive development which results in the removal of large quantities of P from fields in harvested seed and drives the need for continual P fertiliser inputs. At present, we have a poor understanding of the plant gene networks involved in P mobilisation into seeds as most research on P has focused on improving P uptake or understanding the gene networks involved in the response to P deprivation. We studied the physiological behaviour of P movement during grain filling and have found that grain P content reached a maximum 15 days after anthesis (DAA). We therefore used high-throughput RNA-seq to investigate transcript expression in the P source/sink tissue (i.e. flag leaf/grain) during the rapid phase of P accumulation (6-15 DAA). Differences in gene transcript levels and implications for P transport to developing grains will be discussed.

P339

Abiotic processes controlling the effects of citrate on phosphorus availability: study of a fertilized ferralsol

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Organic acids exuded by roots, especially citrate, can increase P availability in soils and thus facilitate P acquisition by plants. However, controlling processes are poorly known. In order to improve this understanding, we added different citrate concentrations (2, 10, 20, 50, 100, 250 and 500 µM as trisodium citrate) to water extractions performed with a fertilized ferralitic soil. We performed the experiments at T = 2°C in order to minimize the effects of biological activity. We measured dissolved inorganic P concentrations (available P) along with the concentrations of major solutes (Na, K, Ca, Al, Fe, Si and organic carbon) and pH. We also modeled aqueous speciation and determined mineral saturation indexes. Results showed that available P gradually increases with citrate concentration. Similar trends were observed with dissolved Al, Fe, Si, organic C, and Na. In contrast, pH decreased compared to control (i.e. 0 citrate) with addition of low citrate concentrations while it became more alkaline at higher citrate concentration. Dissolved K, Mg and Ca did not show monotonous variations as well. Dissolved K gradually decreased up to 250 µM of citrate. Dissolved Ca slightly increased with low citrate concentrations, vanished at intermediate concentrations (50 and 100 µM) and finally increased markedly at high citrate concentrations. Dissolved Mg exhibited intermediate variations. Multiple linear regression analysis showed that variations of P availability were significantly correlated with dissolved Si. This result along with these of the modeling suggested that available P was mainly controlled by dissolution of P-sorbing minerals, especially kaolinite

P340

Using phosphorus resources efficiently in the tropical soils

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Tropical soils are commonly highly weathered and poor in soil fertility. These soils generally contain low amounts of plant available phosphorus (P) and high fixation of P in terms of precipitation and/or specific adsorption to soil clay particles. Soil P reaction in these soils make it difficult for the plants to access the necessary amounts of P for high crop yields. Adequate use of P resources should consider the production of the right source and its use according to adequate nutrient stewardship, which for P needs to consider the fertilizer properties, the crop, the soil properties, and the fertilizer and soil management. Among other important management strategies, many studies have been showing that much better P fertilizer use efficiency can be obtained when adequate cropping systems are adopted. In Brazil research show that the use of certain types of forage grasses in the crop rotation significantly increase P fertilizer use efficiency. For example, the use of Brachyaria grass, as one of the crops in a diverse cropping system, almost doubled P use recovery, as related to when the grass was not in the rotation. Another important aspect of the adequate use of P is related to efficiently accessing the pool of bioavailable P in these soils, which in Brazil has been accomplished in many regions by the use of an exchange resin as an extractor for soil P. This paper will show several results related to how to manage P efficiently in agricultural systems of the tropics.

P341

Response of wheat under indigenous rock phosphate acidulates

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Phosphorus is the kingpin of Indian agriculture and good amount of phosphorus is consumed by wheat. High grade rock phosphate is required for manufacturing of phopshatic fertilizer manufacturing but Indian reserves are of low grade, resulted import. Scope is existing to use low grade rock phosphate directly in field but solubility is the limitation. To overcome this acidulates can be used which are the materials creates acidic environment surrounding to the root zone and helpful to dissolve rock phosphate and release phosphorus. Farmers of the country are small and they want to use indigenous materials as an acidulates. Considering the above facts field experiments were conducted in randomized block design with three replications, for four years ie. 2009-10 to 2012-13, to assess the performance of indigenous rock phosphate linked with different acidulates on wheat crop. Eight treatments were formulated from different combinations of rock phosphate with acidulates namely FYM, Gypsum, Phosphate solubilising, Bacteria, Pressmud, SSP, Pyrite. The treatments were 1) Single super phosphate (Chemical fertilizer), 2) Rock Phosphate 3) Rock phosphate plus gypsum , 4) Rock phosphate plus Single super phosphate , 5) Rock phosphate plus phosphate solubulizing bacteria (PSB @2 L/ha), 6) Rock phosphate plus FYM , 7) Rock phosphate plus Pressmud , 8) Rock phosphate plus Pyrite . All acidulate were mixed in equal ratio, just before sowing of the crop. Wheat variety PBW-550 was sown in second week of November and harvested in April during all the years. Results revealed that acidulated rock phosphate had non significant difference from chemical fertilizer during all the years except 2009-10. Rock phosphate acidulated with gypsum gave maximum wheat yield among the treatment tested during all the years. Hence it is concluded that in wheat crop acidulated low garde rock phosphate could be an viable alternative to chemical fertilizer i.e single super phosphate. Among the acidulated material gypsum is the better option.

P342

Phenotyping for drought and low phosphorus tolerance in tropical legume crops

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Water deficit and low soil fertility are the major environmental constraints to crop yield in the semi-arid regions of West and Central Africa where accessibility and affordability of fertilizer is an issue. Moreover, phosphorus is important for crop production but is inherently low in most of tropical soils. However, it is hypothesized that phosphorus improves root growth and number of nodules, which could result in increased nitrogen and water uptake, leaf expansion rate, canopy development, radiation interception, grain yield, and seed quality. Therefore, knowledge of drought tolerance and nitrogen fixation mechanisms induced by phosphorus may contribute to improve the management practices for the farmers land. Further, selection of plant genotypes that produce good yield under low-P soil or those with high-P response efficiency can be a low-input approach to solving this problem. Clearly, an integrated approach combining plant traits improvement and optimum land management are needed to revitalize the crops performance under climate change and degraded land conditions. In this presentation, we would like to describe some methodologies (dry-down, infrared-thermography, lysimetric system) and present some results from our work on the phenotyping of plants for water-use, nitrogen fixation and yield under progressive drying soil. Also, we will show how these techniques are well suitable and relevant for agronomical and physiological assessment of the effects of phosphorus on plants nutrition, growth, yield, and products quality. In prospects, we will be investigating on phosphorus efficiency in agriculture and its ability to improve the cropping systems and their productivity in the semi-arid regions.

P343

Can deficit irrigation techniques be used to enhance phosphorus and water use efficiency and benefit crop yields?

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Soil drying and rewetting (DRW) affects the forms and availability of phosphorus (P). Water soluble P has been reported to increase 1.8- to 19-fold after air-drying with the majority of the increase (56-100%) attributable to organic P. Similarly, in two contrasting soil types DRW increased concentrations of total P and reactive P in leachate, likely due to enhanced P mineralisation and physiochemical processes causing detachment of soil colloids, with faster rewetting rates related to higher concentrations of P. How these dynamics affect crop P acquisition and growth remains unclear. Sensing soil drying stimulates root-to-shoot signalling of the phytohormone abscisic acid (ABA) which causes partial stomatal closure and reduces water use (transpiration). Water deficit caused a greater accumulation of ABA in plants subjected to P deficiency which increased stomatal closure, suggesting increased sensitivity. This effect was blocked by kinetin, suggesting an interactive effect of ABA and cytokinins. Further studies are needed to understand interactions between P availability and phytohormone signalling during DRW. The research aims to guide deficit irrigation techniques to increase P and water use efficiencies and crop yields. Presented here are the results of two experiments, the first investigating whether DRW increases phosphate uptake by plants and affects the compositions of xylem sap (ions via ICP-MS and ABA via radioimmunoassay). The second reports the soil water content and matric potential thresholds at which DRW increases P availability. Future experiments will investigate how different sources of P (organic and inorganic treatments) respond to DRW regimes.

P344

Comparison of plant growth and root-released organic acids of major Norwegian crops under phosphorus deficiency

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Phosphorus (P) is an essential macronutrient for plant growth and development. The world population is expected to reach an estimated 9.2 billion by 2050, which means food production globally has to increase by 70% in order to feed the world. P deficiency is one of the major limitations to crop productivity globally. Root exudates play an important role in releasing soil P and increasing P availability to plants. Here, we compared the effects of P supply on plant growth and organic acids (OAs) secretion from the roots of rape, potato, wheat and barley (two dicots and two monocots), which are important crops in Norway, using hydroponic culture. Similarly with other reports, our results showed that P starvation caused different extents of phenotypical alterations like biomass reduction, anthocyanin accumulation, and increased root length and root/shoot ratio in all of the four crops. The results also showed that P deficiency induced exudates of malic acid, citric acid and succinic acid, but with some differences among different crops. The total amount of OAs released by plant roots is rape>barley>wheat>potato. Moreover, our preliminary results indicated that P deficiency induced a pronounced boron uptake in dicots (rape and potato), particularly in plant shoots. Interestingly, in our system, over-accumulation of boron by adding more exogenous H3BO3 inhibited P deficiency induced OAs significantly in rape. All these results suggest that different plant species have different physiological responses to P deficiency. Those results are also of importance for understanding genetic diversity and adaptation of crops to P deficiency, and for effective utilization of P in future agriculture. Our ongoing study on physiology and molecular analyses will provide more information about the relationship between P uptake and organic acids produced by plant roots.

P345

Growth and phosphorus nutrition of rice in response to dolomite application under iron toxicity

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Iron (Fe) toxicity is one of the most common nutritional disorders in lowland rice-cultivating systems, particularly under acidic soil conditions. Apart from the increased uptake of Fe under acidic soil conditions causing Fe toxicity and yield loss, phosphorus (P) uptake can also be reduced causing P deficiency. Hence, iron toxicity is referred to as a multiple nutritional disorder. Application of dolomite (CaMg(CO3)2) is generally practiced in upland cropping systems to alleviate soil acidity and enhance nutrient availability to crops. However, the growth response and nutrition of rice under Fe toxic soil condition have received little attention, and the growth and nutritional response of low-land rice to the application of dolomite is not known. Therefore, an experiment was conducted, in replicated farmer fields with the symptoms of Fe toxicity, with and without the application of dolomite for four consecutive seasons (2011-2013) using both Fe-toxicity tolerant and susceptible rice varieties bred in Sri Lanka. Dolomite application did not change the soil P dynamics (i.e. buffer capacity, soil solution P or the plant-available (Colwell) P concentrations), growth, yield or P nutrition of rice during the first two seasons of cultivation. After three seasons of dolomite application, tiller production, height, biomass and yield (by 200 kg ha-1) were enhanced only for the Fe-toxicity susceptible rice variety compared with those on plots without dolomite application. However, the growth and yield of the Fe-toxicity tolerant rice variety were similar on plots with and without the application of dolomite. Dolomite application did not increase soil pH and the availability of P for plants (Colwell-P). However, the soil solution P concentration increased. The increased growth and yield response of Fe-toxicity susceptible rice variety in response to dolomite application is promising. However, the underlying mechanisms, such as changes in soil P, calcium, magnesium and Fe availabilities, plant uptake and root growth responses in response to dolomite application need to be investigated further.

P346

From A to B: mechanisms in A (Aspergillus) to phosphate release for B (Barley)

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Phosphorus is an essential nutrient for plant growth and development, and deficiencies in soil phosphorus limit agricultural crop yields worldwide. Rock phosphate, the basic constituent of many inorganic phosphorus fertilizers, is an increasingly expensive resource with a low efficiency of use. Naturally-occurring fungal interactions with such sparingly-soluble phosphorus sources could enhance the release of soluble phosphate into the soil nutrient cycle and promote plant growth. This research aims to characterize the mechanisms involved in fungal phosphate solubilization, and examine the abilities of the fungus Aspergillus niger to enhance plant phosphorus uptake and growth under phosphorus-deficient conditions and in the presence of inorganic phosphorus sources, including rock phosphate. The results presented will include fungal growth and solubilization of phosphorus sources, phosphate mineral transformations and the underlying mechanisms, as well as the influence of such activities on growth and uptake of phosphates by plants. Our results varyingly show that soil fungi are able to solubilize sparingly-soluble phosphate minerals, including those in rock phosphate, and that this ability can be beneficial to plant acquisition of phosphorus. Future agricultural practices may benefit from greater understanding of the interactions between plants, fungi and phosphorus-containing minerals.

P347

Biosolids as a source of phosphorus in Australian agriculture

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The agricultural land application of biosolids (stabilised solid organic residuals from treated sewage sludge) as a source of nutrients for crop production is considered a long-term sustainable management option throughout many regions in Australia. Approximately 70% of the 330,000 tonne dry solids produced nationally are land applied per annum. The phosphorus (P) content of biosolids varies and is dependent on the wastewater treatment process, with mean total P values of 1.3-3.9% reported throughout Australia. It is estimated that approximately 6,000 tonne of P is returned to the soil annually in Australia from the land application of biosolids. Hence the recycling of P from biosolids is a useful substitute for inorganic fertiliser P and prevents the loss of P from the food chain. This paper presents findings for P availability in four biosolids products (dewatered mesophilic anaerobically digested, lime-amended, pelletised and alum sludge) relative to inorganic P fertiliser as investigated by combinations of field crop, laboratory and pot experiments in south-western Australia over several years. The risk of off-site movement of biosolids-P compared with inorganic fertiliser P at typical application rates was further examined on several soil types to assess the environmental implications of this practice in Australia. The effectiveness of biosolids-P compared to inorganic-P as a source of fertiliser in field experiments as measured by soil available P, uptake of P by shoots and crop yield was dependent on many factors over time including the soil conditions and biosolids type. Biosolids produced from wastewater treatment processes that used aluminium treatment to remove excess P had lower phytoavailability than those without chemical addition and pose additional challenges for land application as a source of P.

P348

Evaluating the impact of rising fertilizer prices on crop yields

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Due to tensions on fossil energy and phosphorus markets, the sharp rise in fertilizer prices observed during the last decades is expected to persist in the future, putting into question production pathways relying heavily on crop intensification. To evaluate how, in this context, economic choices may alter crop yields, we first construct different fertilizer price scenarios to 2050 based on an econometric relation with oil and gas prices, or on the continuation of recent trends. A scenario reflecting the possible depletion of phosphorus is also presented. The resulting changes in fertilizer price range between +0.8% and +3.6% per year over the 2005-2050 period. Once developed, these scenarios are tested into a global land use model incorporating an endogenous representation of the land-fertilizer substitution. In so doing, this paper shows that the crop yields in 2050 are reduced by 6%-13%, depending on the scenario, due to the supply-side response to rising fertilizer prices. To meet the demand for food and non-food products, the fall in crop yields implies a global increase in cropland area ranging from 100 to 240 Mha. On the other hand, the impact of phosphorus depletion on intensification and land use in 2050 appears to be relatively small. The sensitivity of the results is finally tested with regard to assumptions on food consumption, change in potential yield and nutrient use efficiency.

P349

P supply effect on photosynthetic performance and antioxidant responses in ryegrass cultivars grown under Mn excess

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We previously found that Mn-excess cause photosynthetic impairments, mainly in the Mn-sensitive cultivar of ryegrass. Also, our findings indicated that despite the increase of Mn in ryegrass tissues at increasing P supply, plant-growth inhibition caused by Mn-excess was decreased. We evaluated the P nutrition effect on photosynthetic performance of perennial ryegrass cultivars (Nui and Kingston) treated with increasing Mn under hydroponic solution. Two P treatments [100 µM (control) and 400 µM (high P); supplied as K_2HPO_4] in combination with two Mn concentrations [2.4 µM (control) and 350 µM (excess Mn), supplied as $MnCl_2$] at pH 4.8 during 10 days were performed. Results showed that despite P supply increased Mn tissue concentrations compared to control, P additions significantly reduced the detrimental effect of Mn excess on photochemical parameters (ΦPSII and ETR), mainly in Nui (Mn-sensitive). We also found that high P additions increased the superoxide dismutase (SOD) activity in both cultivars, mainly in Kingston (Mn-tolerant), decreasing the oxidative stress induced by Mn excess. We observed that shoot phenolic (TPH) content was slightly increased in response to Mn excess, mainly in the Mn-tolerant cultivar. Under high P, these Mn-induced TPH increments decreased may be due to its low Mn-stress level in plants. These results confirm that P alleviates Mn toxicity in perennial ryegrass reducing the negative effect of Mn on photosynthesis and oxidative stress. Moreover, it is postulated that the greatest absorption of Mn in plants exposed to high P suggests the possible inactivation of Mn through complexation P-Mn.

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Keynote presentations

K401

Dietary Phosphorus

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In this paper, we present information on phosphorus (P) as a nutrient and toxicant; the P content of foods, drinks, and other ingestants; estimates of P intake in several different regions of the world; and the associated consequences to human health from deficiencies and excess of P. P is an essential nutrient element, the major dietary sources being poultry, red meat, fish and dairy products. However, high levels of P are also found as ingredients and additives in foods and soft drinks, in vitamin and mineral supplements, and prescription medications. P deficiencies are rare, but research shows that excess intakes are a greater risk, with morbidity and mortality consequences. FAO/WHO recommendations for nutrient in human nutrition do not address P *per se*, but have suggested that they should be linked and equal to calcium requirements. Some national authorities have made P intake recommendations, e.g., Australia/New Zealand has set its Estimated Average Requirement for adults at 580 mg/day and its Recommended Dietary Intake at 1000 mg/day. The USA has set its Recommended Dietary Allowance at 700 mg/day for adults, its nutrient reference value at 1000 mg/day, and its tolerable upper limit at 4000 mg/day. P intakes continue to increase globally as a result of the growing consumption animal-source foods, highly processed foods, and excessive use of P-based agricultural chemicals. Future population and dietary pattern projections and scenarios for P will be presented in the context of sustainable diets and feeding the planet in 2050.

K402

Trends in Phosphorus use in Animal Feeds

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In grain-based animal feedstuffs, around 70-80% of the naturally occurring phosphorus (P) is bound in phytate (inositol hexaphosphate). As phytate is not efficiently degraded within the intestinal tract of monogastric animals, this phosphorus is excreted and may result in eutrophication of rivers and lakes. In addition, inorganic phosphates must be added to the diet to satisfy the animal's nutritional requirements, raising costs. To make phytate-bound P available for the animal, phytase enzymes produced by microbial fermentation started to be used in the 1990's and are now widely used in monogastric feeds. As phytate also is an antinutrient, it has a negative influence on the availability of other nutrients, including minerals (including zinc, iron and copper), protein and energy, and phytase supplementation can improve animal performance. In the last few years, new more efficacious phytases have been launched allowing a more complete destruction of phytate. This means an even lower use of dietary inorganic phosphate as well as the potential for improved animal performance. This paper will discuss the extent of phytase use in the global animal feed market, alternative phosphorus sources used in animal feeds, and how phytase use can impact feed costs. It will also outline how the phytases can differ in their characteristics and efficacy within the animal intestinal tract and how this can influence the productive value of poultry and swine feeds.

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Oral presentations

O401

The future of phosphorus demand: food, diet and equity

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This paper describes an analysis of the role of changing diets in the demand for phosphorus at the global level. Phosphorus is an element that is essential for agricultural production, and the requirement for phosphorus for animal products is significantly greater than for plant-based foods. The change in diets over time therefore has had, and is projected to have significant implications for global phosphorus demand. This paper will explore these impacts, and outline a framework for considering the potential outcomes of the current trajectory, and its biophysical and ethical limitations. It will describe a framework for managing a transition to a global sustainable phosphorus future, including the synergistic impacts associated with such a transition, including energy use and greenhouse emissions, water use and human nutrition and health. This will include consideration of 'contraction and convergence' scenarios in which a global per capita share of phosphorus resources is modelled. The institutional arrangements that would be required for such a significant departure from current management of this planetary resource will be explored.

O402

Phosphorus requirements for the changing diets of China, India and Japan

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The importance of reducing dependency on phosphorus imports is undeniable in the face of the dwindling supply of high-grade phosphate rock (P-ore), climbing phosphorus commodity prices, and the threat of trade limitations from P-ore suppliers. With geopolitical risks in many of the P-ore exporting countries and rising demand in booming economies with burgeoning populations, it is wise to determine the exact nature of P-dependency in order to increase awareness of the various risks involved and to seek new ways forward for phosphorus use. To that end, we analyzed the BACI trade statistics for 2005 to determine the dependency of Asian countries on phosphorus, in particular for P-ore, yellow phosphorus, chemicals, and fertilizers. The data revealed a complex set of patterns, with some countries relying heavily on just one or two countries to meet their commodity needs, and others drawing from a wide range of sources. In many cases, a strong dependency was noted on a country which itself was heavily dependent on another source for its commodity needs. Besides this, a clear tendency for P-ore producing countries to export value-added product at a higher cost rather than export ore is clear in the 2005 data. To prepare for the day when phosphate ore is inevitably in short supply, and to ensure a stable supply of phosphorus for both agriculture and industry, efforts need to be made to ensure that phosphorus is recycled efficiently in all societies, and to improve the use of phosphate fertilizers in agriculture.

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Session 5 – Phosphorus in our wastes

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Session 5 – Phosphorus in our wastes

Keynote presentations

K501

P recycling options for urban P

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Given the advancing urbanization and expectation of more than 70% of the global population living in cities by end of this century, urban nutrient management will play a crucial role for global food security. Urbanization leads to further dislocation of agricultural food production and human consumption with concentration of nutrients in such areas providing a wide spectrum of recovery and recycling opportunities. Nutrients from different waste streams are still waiting to be tapped and depending on the grade of technisation, simple solutions and high-tech approaches can be applied to close the nutrient cycle. Decentralized sanitation and urban farming provides the opportunity to close the loop on local level and to yield high quality food, grown by our own hands, whereas urban mining recovers nutrients from centralized and concentrated waste streams like wastewater, food wastes etc. to be recycled on regional or higher level. For the city of Berlin, wastewater, especially sewage sludge and organic waste have been identified to bear the highest recovery potential for phosphorus. The city's current recycling rate for phosphorus of only 8 % is intended to be increased dramatically within the next years. Different options for nutrient recovery and recycling from low- to high-tech will be implemented and the gap between supply and demand of and for secondary nutrients will be bridged to reach the goal of 90% P recovery and recycling.

K502

Recyling P in rural or peri-urban farming systems in Sub Saharan Africa and Madagascar

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Tropical soils have generally low available P content for plant production. Farmers developed traditional cropping systems based on organic matter and nutrient recycling contributing to the plant P nutrition. However, during last decades, when population and food needs have drastically increased, farmers have responded by extensive practices leading to the increase of cultivated land. Nowadays, trees in fallows or in parklands or pastoral feed resource for livestock that were the key factors of traditional agro-ecosystems viability tended to disappear and lead to a so-called mining agriculture in certain productive area. Chemical fertilizers to intensify crop production remains extremely low particularly in poor rural areas. In an other hand, farming systems that use large amounts of chemical fertilizers were generally confronted to soil pollution or degradation especially when crops residues did not return to soil, or when it was associated with large amount of organic inputs as in peri-urban horticulture systems. A solution to conciliate agricultural production development and natural resources conservation is to promote intensification of ecological processes in farming and cropping ecosystems. Agro-ecological practices aim to intensify nutrient recycling and more specifically P recycling at all scales of the systems : from the plant soil system to the landscape or the territory levels. Agricultural practices driving organic matter and nutrient recycling like agroforestry practices, legumes in crop rotation or association, crops livestock integration, domestic and municipal waste recycling are described and potential innovations are discussed.

K503

Towards closed loop phosphorus management: The UK Water Industry

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The UK produces around 11 billion litres of wastewater each day. Approximately 96% of the population are served by wastewater treatment works (WwTW), which are operated by 12 water and sewerage companies. The water industry receives in the order of 55 kt phosphorus annually, 60% of which is captured in the bio-solids (70% of which is recycled to agriculture) and the rest being discharged to receiving waters. By 2015, 639 WwTW (serving a population equivalent of 23 million) will be operating phosphorus removal processes to meet Urban Waste Water Treatment and Water Framework Directive commitments for nutrient sensitive receiving waters. One WwTw in the UK already operates a full-scale struvite recovery plant and another is planned for 2014-15. This paper will report on a 3.5 year project with the UK Water Industry in which we explored how the industry might move from phosphorus removal (legislation/pollution prevention driven) to phosphorus recovery (resource efficiency driven) in a bid to close the phosphorus management cycle.

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Food and phosphorus security: bridging the global – local gap

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Global resources are limited and researchers conjecture their productive lifespan. Rockström et al. (2009) identified nine planetary boundaries, of which three have already been crossed (phosphorus, biological diversity, and climate change). Such planetary transgressions can be delayed by bridging management of global resources to the national level (Nykvist et al., 2013). A desk study is presented about households' and local authorities' potential to contribute to reduce, reuse and recycle P-rich products. The 3R waste hierarchy is applied with data from EU statistics, Gustavsson et al., 2011 on food waste, and human excreta. Paper, garden waste and a shift to a more vegetarian diet are not included. Realistic recovery of 90 % of P in urine and in faecal matter (or in black water) is achievable in the long-term. 28 % of P can be saved by shifting to using other resources (17%) and to decrease food losses (11%). Another 32 % of mined P is saved by reusing/recycling food P, assuming that half of mined P is lost in food chain up to the consumption stage. Such measures increase P recovery from a low percentage to 89 %, which saves some 60 % of mined P each year. Food security is ensured for a longer period and the transgression of planetary resources boundaries is delayed by centuries. The necessary changes in infrastructure to achieve the above results will continue to the end of this century. Now is a window of unprecedented opportunity to design urban infrastructure since houses and infrastructure for an additional 5.5 billion new urban residents in the 21st century have not yet been planned. A win-win situation is imminent, providing both food security and reduced harmful emissions to air, water and soil.

O502

Valorisation of livestock manure into P-rich organic soil amendment for environmental and economic sustainability

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Livestock residues, such as pig manure, represent a more sustainable source of phosphorus (P) and other plant nutrients in comparison with the established synthetic fertiliser production processes. However, suitable technological solutions have not yet been provided to effectively make use of these nutrients to supply European fertilizer requirements. In the EC-funded project BioEcoSIM, pig manure is valorised into slow-releasing mineral fertilisers, P-rich organic soil amendment and reclaimed water. In this way, the negative environmental impacts in intensive livestock regions and high energy costs for synthetic fertiliser production are reduced. Raw pig manure after acidification is mechanically separated into a liquid (90.7% w/w) and a solid fraction (9.3% w/w). From the liquid fraction, P salts are precipitated (struvite and calcium phosphate) with P content 5.3% w/w. The solid manure fraction is thermally treated to produce biochar, which can be used as soil amendment, together with the recovered P salts. Because the nitrogen (N) content in the solid and liquid fractions is considerable, i.e. 5.3 g $N\text{-}NH_4$/kg and 3.5 g $N\text{-}NH_4$/kg, respectively, the N recovery as ammonium salts is a suitable process. The discharged process water will be disinfected, if needed, to ensure its safe use for irrigation or livestock production. A comprehensive characterisation of the mass streams in the process was carried out, including mass balances for macro-, micronutrients and pollutants. The implementation of the results will help fulfil the need for economically viable and environmentally benign practices in European agriculture to move towards a more resource-efficient and circular economy.

O503

A regional-scale soil phosphorus balance for exploring mineral fertilizer substitution potentials – the case of Norway

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The substitution of mineral phosphorus (P) fertilizer used on agricultural soil with recovered P from P-rich waste sources can be one important step towards increased P sustainability. To be able to see where opportunities for P recovery and recycling can be explored within a country, we need to spatially disaggregate the national material flows. This work aims at identifying the potentials for substituting mineral P fertilizer with P-rich waste sources, using Norway as a case study, disaggregated into its 19 counties. For this purpose, a material flow analysis approach was utilized with mineral fertilizer, animal manure and wastewater sludge as input flows to agricultural soil. Exports from agricultural soil included plant yields and losses of P through erosion and run-off. Average numbers for 2009-2011 were used. Considering the total amount of P in inputs and outputs, results show that all counties had a positive soil balance. There is a great theoretical potential in substituting mineral P fertilizer with manure P within counties if manure P is distributed to balance soil P exports. The substitution potential in wastewater sludge is much smaller, due to a lower absolute amount of P captured and a lower P plant availability from chemical precipitation. There is however a greater potential in wastewater yet to be exploited illustrated by the total amount of P in untreated wastewater. In conclusion, the regional soil P balance shows that a minority of the counties would still need to import P fertilizers if the full potential in their own manure and wastewater P was exploited and distributed well. The feasibility of this is yet to be explored.

O504

Sustainable airport cities - closing the phosphorus cycle at Amsterdam Airport Schiphol

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Recovery and reuse of phosphorus is a matter of great importance for Europe. The water cycle at Schiphol Airport (serving 50 million travelers per year) is comparable to that of a small city with significant wastewater flows and opportunities for recovery and local reuse of phosphorus. The goal of this project is two-fold: promote corporate social responsibility between aviation and water sector and use innovative technology for phosphorus recovery from wastewater with the application of recovered phosphorus locally as a fertilizer. The Waste Water Treatment Plant (WWTP) at Schiphol consists of an activated sludge system without primary sedimentation and chemical phosphorus removal with iron salts. Several streams (centrate, digested sludge, and fecal deposit from airplanes) at WWTP Schiphol were characterized for free phosphate content using standard methods. These data were used to construct a mass balance of phosphorus. High free phosphate concentrations (>100 mgP/L) were found in centrate from sludge digestion and the fecal deposit stream originating from airplanes. Phosphorus is recovered by crystallization with added magnesium and ammonium (present in the streams) as high quality struvite granules ($MgNH_4PO_4.6H_2O$) in a pilot installation (10 m^3/h). The recovery potential for this WWTP is about 11 kg P per day of struvite, based on 75% efficiency. Produced struvite will replace artificial fertilizer currently used at the Schiphol premises. This project shows that recovered phosphorus can be reused locally as a fertilizer, contributing to a reduction of the environmental footprint of the waste water treatment process and operations at Schiphol Airport.

O505

Phosphorus cycling in Montreal's food system and through urban agriculture

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Cities are a key system in anthropogenic P cycling as they concentrate both P demand and waste production. Urban agriculture (UA) is proposed as a way for urban environments to contribute to increase P recycling by recycling cities' high-P waste into very local food production. However, we have a limited understanding of the role UA currently plays in the P cycle of developed cities, its potential to increase P recycling, and what factors are most important in realizing that potential. In my research, I used Montreal, Canada as a case study to quantitatively explore the role of UA in the urban P system. I used substance flow analysis to quantify P flows both for the whole island of Montreal and the UA sub-system for 2012, obtaining P data and information on UA practices through 164 surveys with local UA practitioners. In 2012 Montreal imported 3.5 Gg of P, of which 2.63 Gg ultimately accumulates in landfills, 0.36 Gg are discharged to local waters, and 0.09 Gg are recycled through composting. Although there are clear provincial policies that mandate cities to increase composting and waste recycling, Montreal is not on track to meet the policy objectives. I found that current UA contributes 0.44% of the P consumed as food in the city, but UA recycles 73% of the P-waste produced in UA. Thus, although UA is a small subsystem, it may prove to be a valuable asset to increase urban P sustainability by becoming a catalyst of increased city recycling.

O506

Phosphate fertilizer effect of thermally processed sewage sludge ash compared to triple superphosphate

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The global geogenic phosphate reserves will be exhausted within the following 320 years. The P-recycling of sewage sludge represents one possibility of permanent P-supply. Because of low P-contents, heavy metal contamination and high pathogenic risks, the usage of untreated sewage sludges in agriculture has to be regarded critically. Therefore, different processing methods for sewage sludge have been developed, in order to increase the P-concentration, to remove harmful contaminations and to produce P-fertilizers. In a pot experiment, maize was cultivated on a sandy soil (soil born P (CAL) 1.14 mg P/100g soil) fertilization effects of untreated sewage sludge ash (USSA), glown phosphate (GP1 + GP2), steel mill slag + sewage sludge ash (K+P) and triple superphosphate (TSP) were determined in three fertilization levels (0.18, 0.35 and 0.52 g P/pot, 6000 g of soil). Over all fertilization levels the USSA (7.25 g DM pot^{-1}) show yields comparable to the unfertilized treatment (8.35 g DM pot^{-1}). GP1 (35.22 g DM pot^{-1}), GP2 (39.35 g DM pot^{-1}), K+P (32.75 g DM pot^{-1}) and TSP (36.11 g DM pot^{-1}) shows significant higher yields over all fertilization levels. At the end of the trial GP1 (3.7 g P 100 g^{-1} soil), GP2 (3.58 g P 100 g^{-1} soil), K+P (3.94 g P 100 g^{-1} soil) and TSP (3.93 g P 100 g^{-1} soil) show significant higher P contents in soil in comparison to unfertilized variant (1.75 g P 100 g^{-1} soil) and USSA (1.75 g P 100 g^{-1} soil). This study shows that it is possible to produce a P-fertilizer from sewage sludge ash which leads plants to a dry matter yield, like a triple superphosphate. Treated sewage sludge ash can be an alternative to mineral P-fertilizers.

O507

Is there a potential for phosphate recycling in the mineral fertilizer production?

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The main driver for closing the phosphorus (P) loop and increasing the recovery from waste streams is the pressure P use has on the environment. Different sources present opportunities to recover phosphates such as sewage sludge ashes (SSA), meat and bone meal ashes (MBMA) and struvite. The main challenge is to include these streams in the existing production processes without jeopardizing quality and plant-availability. Firstly, the different P-rich flows were quantified and characterized, i.e. total P2O5 content, chemical characteristics (heavy metals, iron and aluminium content). Secondly, pilot-scale and plant-scale testing was performed at ICL Fertilizers sites in Amsterdam. Multiple routes for P fertilizer production are available. Given the chemical resembles of the P forms in mono-incineration ashes and in rock phosphate, direct acidulation of ashes is the most straightforward production process. The best results were obtained using MBMA, followed by aluminium-based SSA and finally iron-based SSA. For recovered P to be used in the production process of mineral P fertilizers the supply of the raw material needs to be constant in terms of quantity and needs to have a more or less constant quality and P content. It should be guaranteed that the products are produced via mono-incineration, in order to secure absence of unexpected contaminations. Recovered P streams which minimally impact the existing production scheme are preferred. Both meat bone and meal ashes and sewage sludge ashes offer recycling potential. This recycling is an elegant way to prevent landfill and diffuse waste of phosphate.

O508

P-recovery from waste water: comparative assessment of P-recovery potential, removal of pollutants and costs

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National P-balances show considerable but often unexploited P-rich flows as e.g. waste water. Direct sewage sludge application in agriculture would be the most simple and appropriate method to recover P from waste water. But due to potential environmental risks as heavy metals (HM), acceptance is decreasing. Thus, numerous technologies have been developed to recover ideally great amounts of plant available P with reduced environmental risk. This work outlines the efficiency of 18 technologies with respect to recovery- and depollution potential as well as costs. For tracking P and selected heavy metals within the recovery approaches, material flow analysis was chosen as appropriate instrument. In combination with costs for the necessary resources and known investment cost, economic assessment was performed. Selected results are: recovery rates from process water are low, the products are not contaminated with HM and these approaches can be economically. For higher P-yield, sewage sludge respectively its ash has to be processed. But further procedural effort and resource demand is necessary which is often not in reasonable relation to the recovery rate, especially for direct recovery from sewage sludge. For greatest P-yield sewage sludge ash has to be treated, showing recovery potential of ca. 85 % related to waste water. Depending on the requested level of depollution, the P-recovery potential decreases with greater removal of HM and costs increase from economically for approaches without HM removal to costs of 4-7 €/kg P. This knowledge is instrumental for further concepts on the sustainable use of P, closing interrupted nutrient loops and reduce economic dependencies.

O509

Potential and bottleneck for recovery and recycling of P in steelmaking slag : Focusing China, India and Japan

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The potential for a new supply of phosphorus to ensure that supply matches demand in the future is explored in the context of steel making slag. In this study, a simple means is applied to identify the potential for as-yet untapped phosphorus resources to be extracted from steel making slag. The importance of phosphorus in agriculture and in the chemical industry demands that the full potential of this strategic resource, which exists only as a trace element in nature, is realized. Of the 338,045 kt of phosphorus traded in 2005 in steelmaking resources in the largest 15 transactions, 300,436 kt were contained in the trade of iron ore. That is, 88.9% of the phosphorus traded in these transactions can be attributed to the trade of bulk and powdered iron ore, with exports from Australia and Brazil accounting for 69.4% and 29.0% of that trade, respectively. China and Japan account for 53.0% and 26% of the imports of phosphorus in steel making resources of the total of the top 15 transactions, which is equivalent to almost 80%. The largest three quantities of phosphorus traded in iron ore were the 69,634 kt imported by China from Australia, the 48,372 kt imported by Japan from Australia, and the 42,801 kt imported by China from India. By analyzing the flow of phosphorus in steelmaking resources and examining the steelmaking data for China, India and Japan, we estimate the quantities of phosphorus that could be extracted from the steelmaking slag, providing a value-added resource to the steel-making industry. The bottlenecks to realizing the full potential of recovered phosphorus are also discussed.

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Phosphate recovery from iron phosphate rich sludge

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Ecological, geopolitical and economic concerns demand a more sustainable use of phosphate (P). During waste water treatment, huge amounts of P are eliminated by adding iron (Fe) to form insoluble iron phosphate compounds (FeP) that settle in the sludge. P recovery from FeP sludge, in a concentrated form, is not yet economical feasible. We envisage a biotechnological process, to recover P and Fe from FeP sludge. Our approach is based on natural P mobilising mechanisms well-known from soils and sediments. Key for P and Fe recovery is to understand the complex iron biogeochemistry that affects P binding and mobilization. Accordingly, our first experiments revealed distinct patterns of P release from different FeP upon sulphide addition. In the wastewater plant, FeP formed initially experience drastic changes in a variety of parameters (e.g. oxidizing and reducing conditions) that transform these compounds. The lack of information on these types of FeP makes it difficult to design experiments and develop thermodynamic models. Thus, the first step towards a recovery process is to characterize the FeP and Fe compounds that form at different stages of the wastewater treatment process. Methods will be developed to sample, separate and analyse sludge under anaerobic conditions. Characterisations of solid compounds include Mössbauer spectroscopy, SEM-EDX, XRD and TEM. Identifying FeP allows to find the stage where, thermodynamically and chemically, the most favourable iron phosphate compound exists for introducing a successful Fe and P recovery process. The developed methods bundle can be applied to other research fields as well. Up to now, despite intriguing differences, accurate characterizing of iron compounds and FeP has often been neglected.

P502

Synergy effects of phosphorus recovery and copper (II) enrichment during struvite precipitation

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Phosphorus removal and recovery from wastewater has been of great concern for several decades. A common approach of such practice is through the precipitation of struvite ($MgNH_4PO_4 \cdot 6H_2O$). In the present research, we investigated the synergy effects of heavy metal enrichment in the struvite precipitation during the P recovery process, which has generally been overlooked in the previous studies. Synthetic phosphorus-rich wastewaters with a variety of copper (II) concentrations were designed and batch experimental reactions were conducted under different pH or temperature conditions. Response surface modelling (RSM) was applied to assist in the understanding of relative significance of reaction factors. The P removal rate increased with the increase of Cu concentration (5 to 400 mg/L) or pH (6.5 to 10), with a slight decrease when pH further increased to 11.5. Temperature had minimal influence on the P removal rate. As for the Cu enrichment process, more than 98% of the Cu(II) was seen to be present in the precipitation for all cases. X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), 31P-NMR, and ICP-MS were jointly utilized to further determine the composition and structure of the precipitants in the batch experiments with various initial Cu concentrations, and hence help the elucidation of possible Cu enrichment mechanism in struvite. The surprisingly high Cu enrichment rate (even at low initial Cu concentration and / or pH) and corresponding enrichment mechanisms indicate that heavy metal is a possible source for contamination during P recovery, which may hinder the re-use of struvite as slow-release fertilizer. On the other hand, these findings demonstrate the feasibility of an innovative technique towards advanced and integrated treatment of phosphorus and heavy metal.

P503

Impact of wastewater components on phosphorus removal by oil shale ash in model systems

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Sustainable phosphorus management employs strategies for reuse, recovery and recycling of phosphorus. P retention from waste water is crucially important and for this purpose local cheap sorbent materials should be favoured like oil shale ash (OSA) in Estonia. High P binding efficiency of Ca-rich OSA in aqueous environment has been shown by earlier studies. However, the impact of various components in municipal wastewater to P retention efficiency and the nature of immobilized P is neither thoroughly understood nor studied. The aim of this study is to detect the mineralogical and chemical composition, crystals size and water solubility of the precipitate that forms, when leachate of OSA is mixed with P containing solutions (orthophosphate, polyphosphate and bio-phosphorus organic compounds) and their mixtures with urea and washing-up liquid “Fairy”. The precipitates were studied by chemical, XRD, FTIR, Thermal, and SEM (EDS) analysis. The main component of the precipitate of orthophosphate containing solutions is carbonate substituted Ca-hydroxyapatite, in polyphosphate (washing powder) solution additional Ca-polyphosphate is formed. The P-organic compounds (Na-phenyl phosphate and Na -glycerol phosphate) alone do not precipitate in the studied conditions, while “Fairy” does not impact the chemical composition of precipitates. The precipitates obtained with the addition of urea (1.7%) contain some organic water soluble complexes that increase the solubility of P. Precipitation of calcite and urea in minor quantities are also followed. Crystallinity of precipitates is very fine to amorphous depending on additives in the mixture. The biggest impact gives polyphosphates.

P504

Use of saline - sodic soils for sorption of inositol hexaphosphate

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The wastewater discharge from urban, agricultural and food industries, as well as liquid manures generated in intensive livestock systems are point sources of organic phosphorus (P), particularly inositol hexaphosphate (IP6). Sorption could be used as a process treatment to remove organic compounds, and it would be interesting to evaluate the use of low-cost materials, such as desert soils for IP6 sorption from liquid solutions. Kinetics of IP6 sorption, pH effect and sorption isotherms were examined in batch experiments in four desert saline - sodic soils: Antofagasta (AN), Mejillones (ME), Aguas Blancas I (ABI) and Aguas Blancas II (ABII). Sorption kinetics of IP6 was well described by Elovich equation, and sorption capacities were in decreasing order: ABII > ME > ABI > AN. In addition, IP6 sorption capacity in AN, ME and ABI was strongly influenced by the solution pH, but in ABII it was not pH-dependent. The maximum IP6 sorption capacity was in increasing order: ABI < AN < ME < ABII. ABII soil is recommended for IP6 removal; in this soil IP6 sorption was not depending on solution pH, and the precipitation and sorption of IP6 were associated with Ca2+, Mg2+, and minerals such as montmorillonite and vermiculite

P505

Struvite precipitation in raw swine slurries in semi-continuous lab scale reactor - preliminary results

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Nitrogen (N) and phosphorus (P) are vital nutrients for plants and crops but their excessive release from agricultural sources and diffusion into the environment is also the cause of major concerns such as water eutrophication. This study applied struvite (MgNH4PO4*6H2O) precipitation for N and P removal and recovery from raw swine slurries with high organic and ammonia contents. Struvite precipitation was carried out in a laboratory scale reactor (6L) working in semi-continuous mode, evaluating the effect of pH and air stripping as a pre-treatment. MgO and H3PO4 were used as additional sources to reach equimolarity between NH4+, Mg2+, and PO43-. Results showed the feasibility of struvite recovery from high loaded complex matrices as swine slurries: at pH 9.5, E%N-P was 85% on average, whereas precipitation was detected at pH as low as 6 (around 40%); however, at pH > 7 results were comparable to those found at pH 9.5. The air stripping as a pre-treatment slightly enhanced the N removal, allowed to reduce the alkali (NaOH) dose for pH adjustment, and facilitated the pH regulation due to the reduced alkalinity. Struvite crystallization resulted as fast as the proper mixing between the elements was achieved. Runs were also carried out at different T but no tangible differences were noticed between 20 and 50°C. Mg was found as the limiting factor for precipitation: if higher efficiency is the target, more Mg must be supplied or different methods for Mg addition must be considered. Finally, experiments must be carried out to enhance the release of P from biomasses in order to enhance the soluble P available for struvite crystallization and reduce the external addition.

P506

Phosphorus recycled from pig manure and food industry effluents: experiences from bench to semi-industrial pilot scales.

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The main sources for P recycling are animal manure and wastewater and the best way to close the loop is to produce a fertilizer which can substitute mineral fertilizers produced from ore. This can be achieved by producing products containing struvite ($MgNH_4PO_4$, $6H_2O$) and calcium phosphates as a form available for plants. In the both cases P crystallization is the key step of the process. The Phosph'OR project (2010-2014), funded by the French agency for research (ANR) gathered together four academic research institutes and four small enterprises to share and develop knowledge about P crystallization in the aim to design two recycling processes producing struvite or biological granules enriched with calcium phosphate, from high loaded organic effluents such as animal manure or food industries wastewater. The influence of mineral composition and organic matter on competition between struvite and calcium phosphates precipitation had been studied both in synthetic and real wastewater. A model allowing predicting the influence of process parameters on chemical reactions and kinetics is under development. Two lab scale and two semi-industrial scale pilots producing struvite and biological granules enriched with calcium phosphates identified as hydroxyapatite had been tested. The P efficiency of the recycled products compared to commercial triple superphosphate (CaH_2PO_4) and pure struvite and hydroxyapatite ($Ca_5(PO_4)_3OH$) had been assessed by a pot experiment and soil incubations studies. The economic and environmental assessment of the processes (ACV) compared to reference scenarios of effluent management has been carried out. The purpose of this presentation is to give an overview of the most impacting and relevant results obtained during this collaborative research program.

P507

Technical and policy options for recovering phosphorus from the 3 most prominent phosphorus waste flows

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In the EU28 member states, three major waste flows are estimated to contain 6.2 million tonnes or approximately 95% of all phosphates (as P2O5) in waste: farmyard manure (5 million tonnes), sewage sludge (750,000 tonnes) and animal by-products (450,000 tonnes). Recovery options are, however, different as are current waste disposal and reuse practices. P in farmyard manure is quantitatively used but largely ineffectively due to distribution problems. About 50% of P in sewage sludge is used, but efficiency is not high either. Eventually, all P from animal by-products of category one is irrecoverably lost in construction materials or depleted in lignite/coal ash due to combustion in cement and power plants. All waste flows have one problem in common: nutrients are highly diluted preventing the transport to regions where they could be used effectively. Whereas water removal is the main challenge in farmyard slurries and sewage sludge, P is deliberately diluted in construction materials because of misdirected incentives. Appropriate technical solutions must not consume relevant amounts of energy and materials to avoid offsetting the phosphorus yield by CO2 emissions and secondary waste flows. Dewatering equipment should be easy to operate at a scale which is suitable to waste amounts of one or several cooperating farms. Energy generation by anaerobic digestion and thermal or hydrothermal gasification may compensate the treatment expenses and even generate an additional revenue flow to farmers. Different technical options have been investigated for their sustainability and economic feasibility. A modified legal framework is recommended to avoid misleading incentives.

P508

Waste phosphorus recycling through a pedological engineering process

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After more than half a century of high application of phosphorus (P) fertilizers in agriculture, the P resource is progressively depleting. This P deficiency forces the development of P-recycling strategies. Urban wastes and industrial by-products might present high potential to be recycled as P fertilisers. In urban areas, pedological engineering proposed recently to mix technogenic materials in order to create fertile organo-mineral constructed Technosols for plant cultivation. The present study proposes a methodology to select waste materials in order to optimise mixtures for P uptake by ornamental plants. Focusing on P phytoavailability, complementary chemical (Ptotal/POlsen) and biological (plant test) approaches have been applied. Ten waste materials were selected for their abundance and their fertility potential: sewage sludge, sewage sludge-green waste compost, green wastes, street sweeping wastes, paper mill sludge, bricks, concrete, rubble, track ballast and excavated acidic earth material from a deep horizon. Total P concentrations in pure materials ranged from 0.17 to 104 g.kg-1 dry matter (DM) and available P (Olsen method) ranged from 0.017 to 4.9 g.kg-1 DM. As a comparison, P total concentration in natural soils is ranging from 0.1 to 3 g kg-1 DM. The P status of contrasted organo-mineral mixtures were characterised and was compared to those of the pure waste materials. For example, the mixture 80/20 (v/v) of bricks (Ptot/POlsen 0.7/0.03) and compost (21.0/0.96) resulted in an optimised P fertility (3.4/0.10). Evaluation of P uptake by two contrasted plants (Rye-Grass and Rape) was done by measuring the total P content of the shoots after 8 weeks of growth. The best accumulation of P has been observed in the rape for the mixture of excavated earth material and green wastes (75/25 v/v). The perspective of this work will be to develop a decision support system to optimise the P recycling in urban environments. Besides that, Phyto-P-Mining - the use of plants to extract P from wastes and by-products - is promising in terms of waste P recycling and the closure of local-nutrient and good cyclings.

P509

Ashes from low-temperature gasification as sustainable phosphorus fertilizer

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The use of agricultural residues and urban waste for bioenergy generation and the subsequent return of residuals to agricultural soils is a step towards closing nutrient cycles, which is especially important for nutrients produced from non-renewable resources such as phosphorus (P). Low-temperature gasification is an innovative process efficiently generating energy from different biomass fuels and at the same time hygienizing potentially hazardous organic waste streams (as e.g. sewage sludge), thus facilitating a safe soil application of the residual ash fraction. In our study, different ash products originating from low-temperature gasification of various biomass fuels were tested for their P-fertilizing potential in pot experiments with spring barley as a test crop. An indirect 33P dilution approach was furthermore used to determine the fraction of plant P derived from selected ash amendments. The results showed that some ashes could substitute mineral P fertilizers to a certain extent, and that the feedstock used was of extreme importance for the subsequent plant-availability of P in the ash. Ash resulting from gasification of wheat straw showed the best P fertilizer effect. When sewage sludge chemically precipitated with Fe or Al salts was gasified, the tested plants were generally not able to take up the P from the ash, while ash from gasification of biologically treated sludge performed better as P fertilizer. Gasification of waste materials and the subsequent use of the resulting ashes on agricultural fields could be an applicable strategy for the concurrent generation of bioenergy and re-circulation of P to soils.

P510

Mining phosphorus from the centrate of sludge dewatering process

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A system was studied to recover phosphorus from the phosphorus rich centrate after dehydration process of sludge in wastewater treatment. The study included mineralization to recover phosphorus, development of a device for the recovery and application of the device in the field, and feasibility as a fertilizer. Calcium chloride was the most efficient agent for mineralization among magnesium chloride, calcium chloride, and calcium hydroxide tested. A part of the supernatant and the mineral in the mineralization tank was recycled. The optimal recycling ratios were 0.7Q and 0.01~0.02Q for the supernatant and the mineral, respectively. 95% of phosphorus could be recovered from the centrate with rapid mixing (120 rpm) and alkaline condition (pH 8.0). The device consisted of reactor for phosphorus mineralization and settling with a system to recycle the supernatant and the mineral from the settling tank. The optimal operating conditions can be changed with the characteristics of centrate of a wastewater treatment plant. The feasibility of the recovered phosphorus as a fertilizer was confirmed by fertilizing fields with gourd, castor bean, cabbage, and white radish. The harmful heavy metals in the soil fertilized with the recovered mineral and in the plant were within the standard or not detected. With the system, an important resource could be recovered and the amount of sludge could be reduced. In addition, coagulant to remove phosphorus from the effluent to meet the standard could be reduced.

P511

Phosphorus recycling from wastewater using biochar produced from anaerobically digested materials

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A reliable source of phosphorus (P) is essential for the stability of global food supply, but the natural P cycle has become "broken" by human activity. An innovative, more sustainable P cycle connecting recovery with re-use must be realised. The utilisation of treated waste products to both recover phosphate from wastewater and return it to soil presents a sustainable solution to this P cycling imbalance on a local scale. Biochar is a charcoal analogue produced by pyrolysis under oxygen-limited conditions from a wide variety of biomass materials and is used as a soil additive. To date, biochars produced from anaerobic digestate (AD) represent the only biochar materials to exhibit significant phosphate sorption properties. These materials may be sustainably generated, as energy co-products are produced in both the anaerobic digestion and pyrolysis processes. In current work, biochar materials produced from AD sewage sludge (slow pyrolysis, 450°C) demonstrated high P sorption capacities (4.7 – 5.7 mg P g-1) in initial batch sorption experiments. Repeated exposure to high concentrations of P (24 h x 5; 3 g l-1), resulted in even higher cumulative sorption values (19.2 – 26.3 mg P g-1). To test the viability of these materials in a flow-through filter system, column sorption experiments have been performed using solutions of K2HPO4 and simulated sewage. The bioavailability of P contained in, and captured by the materials has been assessed using laboratory methods (2% formic acid extraction, Olsen P, Mehlich 3) and these results compared to plant P uptake in a pot experiment. Our results indicate these materials may be used to contribute towards a sustainable P system.

P512

Towards Raman Chemometrics for Polyphosphate Accumulating Organisms

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Polyphosphate Accumulating Organisms (PAOs) are bacteria that remove phosphorus from wastewater in the Enhanced Biological Phosphorus Removal (EBPR) process. This process constitutes one platform for phosphorus recovery and recycling onto land. Operating EBPR to optimise performance and stability remains a challenge, however, due to poor understanding of these bacterial ecosystems. Raman microscopy is an analytical technique used to obtain vibrational spectra that represent the biochemical composition of a sample. Previous studies have used Raman spectra to characterise soils and to type bacteria. As a culture-independent technique capable of reporting the biochemical fingerprint of single, live cells, our aim is to demonstrate the contribution Raman microscopy can make to further our understanding of EBPR. Herein, we report the development of Raman microscopy as a chemometric tool for quantitative characterisation of PAOs. Raman spectra of bacteria from EBPR communities in both a lab-scale sequencing batch reactor and a full-scale plant were captured. In agreement with earlier publications, we observed that the principal metabolites: polyphosphate, glycogen and polyhydroxyalkanoates are readily identifiable in the Raman spectra. At the time of writing these spectra are being data-mined using multivariate statistical approaches to extract robust, quantifiable parameters that can be used to characterise PAOs.

P513

P Recycling from Sewage Sludge and Animal meal - AWINA spreader wheel incineration

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Since 22 Years the AWINA spreader wheel Technology is used for burning difficult biogen residues. Sewage sludge or animal meal can be burned in these combustion units. 24 AWINA "biomass Boilers are working in Europe. 3 Combustion Units are burning sewage sludge with the AWINA spreader wheel Technology since 3 years in Germany according to the 17. BimschV and "TA Luft". (Straubing 1MW & Altenstadt 2x 4 MW). The ash is used as a fertilizer or sold to the fertilizer industry. The Technology is available from 1MW (3600 tons of dried sewage sludge/year) - 10 MW (36.000tons of dried sewage sludge/year). Also the Technology is tested for the monocombustion of animal meal or many other difficult and phosphor rich materials. There was no Marketing for this Technology until October 2013. So the Inventor Andreas Wilde began the restart in October 2013. Information in English or German is available at www.awina-technik.at/cms/index.php/en/.

P514

Phosphorus management and recovery from wastewater as struvite

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Sustainable use of phosphorus (P) has become increasingly important over the last years since it is a scare and essential resource for life development. Moreover, concentrations of phosphorus reaching wastewater treatment plants (WWTPs) represent an important route of phosphorus losses. The main objective of this work (funded by LIFE+2012), developed between 2013 and 2016, is to prove at pre-industrial scale the viability and sustainability of the integral good management of phosphorus at WWTPs including its recovery as struvite by crystallization. The project will assess El Cidacos municipal waste water treatment plant (Calahorra, La Rioja, Spain), operating enhanced biological phosphorus removal (EBPR) and anaerobic digestion of sludge. A plant model will be used to optimise P-removal and P-recovery as struvite and a stirred struvite precipitation reactor will be designed, constructed and implemented in the plant for the recovery of struvite from the high phosphorus concentrated supernatants. The morphological and agronomical aspects of the recovered struvite will be analysed and evaluated, with characterization and agriculture application assays. An economic study will assess the overall economic impact of the P-recovery implementation, both on plant operation and through the value of the recovered fertiliser product. It is expected to recover up to 30% of the WWTP incoming phosphates, which will reduce phosphorus in sludge decreasing 10% sludge production and 15% operational costs.

P515

Effects of water conservation and recycling on phosphorus recovery from municipal wastewater in Australia

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Per capita water consumption declined by 25-36% while recycled water use increased by 10% in Australian capital cities from 2000 to 2009. Assuming constant per capita phosphorous loads, these changes present an opportunity for phosphorous recovery as struvite from reverse osmosis concentrate generated at water recycling plants. An assessment using a multi-parametric model for 50,000 equivalent population wastewater recycling plant found a reduction in specific power for struvite recovery from RO concentrate from 590 to 170 kWh/kgP as per capita water consumption declined from 300 to 50 L/p/d. The effect of phosphonate antiscalants used in RO systems at concentrations of 0 to 30 mg/L reduced the rate constant from 2.5 to 1.7 h-1 for phosphorous recovery from synthetic solutions and altered the rhombic struvite precipitate in 1L jar tests. However, this effect was less pronounced in a 5L bench reactor at higher struvite saturation levels (SI 1.8) indicating the technical feasibility of struvite recovery from RO concentrate. However, analysis of wastewater catchments with reported declining water consumption over the 2000 to 2012 period found per capita phosphorous loads declined in 11 of 12 catchments. A Life Cycle Analysis considering the impacts of introducing phosphorous recovery into existing infrastructure found struvite recovery from solids dewatering streams was preferred over recovery from RO concentrate and over direct land application of biosolids at centralised plants. The separation of urine for fertiliser reduced the global warming potential of decentralised systems, although resulted in an increase in soil salinization and terrestrial ecotoxicity potentials.

P516

Apples farming with the urine from the School UDDTs

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For promoting the awareness of the value of human waste, I have been running a very profitable and succefull business by selling apples and cherries grown with the urine collected from the 31 shools UDDTs blocks in Tianshui City, Gansu Province China. The net profit was around 0.8 million Yuan with a turnover of 3 million Yuan during last 3 years.

P517

Possibilities of phosphorus recovery from industrial sewage sludge ash

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Phosphorus is an element that cannot be substituted. While phosphorus is highly abundant in nature, it is one of the least biologically available nutrients. Nowadays alternative phosphorus source are in wide demand because of its natural reserve depletion and localization of important phosphate reserves in unstable world regions. Phosphate rich waste is one of such alternative for fertilisers' production. Increasing number of incineration plants functioning in Poland creates possibilities of developing recovery methods from, now easily available waste, sewage sludge ash. A significant amount of iron present in the Polish ash disqualifies the possibility of its utilisation in thermochemical methods (iron does not form volatile chlorides) or in the metallurgical method (maximum acceptable iron concentration could not exceed 1%). Proposed by Cracow University of Technology solution transfers unwanted waste into phosphorus products-fertilisers. It was shown that there is a possibility of phosphorus recovery from industrial sewage sludge ash by its further utilization in the extraction processes with the use of inorganic acids, both nitric and phosphoric. Phosphorus recovery efficiency depends on the ash properties, sewage treatment and combustion technology as well as used extracting agent. In some cases is greater than 92%. Research results characterised obtained extracts for further production of NP and NPK fertilisers. Proposed technology will be a source of useful phosphate products enriched with microelements like Zn and Cu as well as a source of mineral additives for building industry.

P518

Phosphorus recovery from ISSA and biochar: Comparing chemical and physical characteristics

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Across the EU in 2010, 11.5 million tonnes of sewage sludge was produced. 20% of this was incinerated, producing an incinerated sewage sludge ash (ISSA) rich in phosphorus. This ISSA has been recognised as an important and viable source for the recovery of phosphorus. Thanks to the extensive research into the recovery of phosphorus from ISSA using several inorganic acids and varying liquid to solid ratios, this is now a well-known and proven process. However, the use of incineration in the UK is in decline due to high operating costs. Pyrolysis is now being viewed as a promising alternative, but economics are still a barrier to its uptake. The viability of the process can be substantially improved if the residues from pyrolysis are transformed into marketable products. Pyrolysis gases can be used as fuels, while chemicals can be recovered from pyrolysis liquids. The solid residue from pyrolysis has been investigated as a soil amendment. However, there is a lack of research into the recovery of phosphorus or other nutrients from biochar using the same methods as those employed for ISSA. The current research examines the physical and chemical characteristics of biochar compared to ISSA. Methods used to characterise the ISSA and biochar include XRD, XRF, SEM and sequential acid leaching. The recoverability and bioavailability of phosphorus from biochar in comparison to ISSA will be discussed in order to determine the viability of this waste stream as a novel source for the recovery of phosphorus.

P519

Options for phosphorus recovery and recycling from Wastewater in China

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Phosphorus and its compounds are irregenerable and non-replaceable limited resources. The currently explored and economically feasible global reserves may be depleted within generations. Phosphorus recovery from wastewater and sludge, as well as from animal residues is considered more and more as reasonable option to increase the value chain efficiency of this precious resource. China is a big country with a large and growing population and limited farmland area per capita. To produce enough food for feeding the population is of vital importance for the country. In year 2001 phosphorus was identified as one of the most important 20 minerals after 2010, which cannot meet the development of national economy by Ministry of Land and resources of the People's Republic of China. With the current wastewater treatment capacity of 53,3 billion m^3/year in China, 400,000 metric tons of phosphorus could be recovered from wastewater and sludge every year. Sludge management options need to be most ecologic, including social acceptance, economical and technical feasibility. Adapted from the European's experience and with regards to available and feasible technical solutions, a Material Flow Analysis (MFA) and Life-cycle assessment (LCA) for specific cases in China will be conducted to quantify the P recovery potential in waste water (the environmental system). The main goal of this research is the analysis of sustainable P-recovery technologies from wastewater with regards to the specific conditions and requirements in China. Case specific recommendations for the best suitable technologies for future P-recovery in China will be given.

P520

A holistic approach to the use of a slurry tanker - a tool to precipitate phosphorus from slurry and sewage

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SyreN system uses the technique of acidification (sulphuric acid) to change ammonia (gas) to ammonium (salt) during application of slurry. This reduces the emission of ammonia with up to 70% and eliminates airborne eutrophication. The method also applies the correct amount of sulphur as sulphate fertilizer. SyreN+ system adjusts the amount of ammonium nitrogen in slurry during application through addition of anhydrous ammonia and binding it as ammonium in the soil – thereby reducing leaching of nitrogen to aquatic environment. SyreN Crystal system uses precipitation to reduce / adjust the amount of Phosphorus in slurry directly in the slurry tanker. A slurry tanker is only used 2 month pr. year. In the 10 month period, the slurry is loaded batch wise to the tanker where pH is adjusted and magnesium chloride is added. Before and after the precipitation, the slurry tanker is measured for weight. The weight increase of the slurry tanker reveals how much struvite is precipitated. The struvite in the slurry tanker is then dissolved using a 70% sulphuric acid-slurry solution mixed by SyreN system. This causes the struvite to dissolve into a 10 % phosphorus acid solution or a NPKS of 4-28-0-9 + 10 Mg, or a starter fertiliser to be used directly to replace mineral phosphorus. Excess phosphorus may be economically and profitably redistributed to areas with low animal intensity. The use of fertilizer industry raw materials and recycled phosphorus direct in farming, optimises slurry logistics, economy and reduce/eliminate negative environmental effects from slurry application. The system is turning a pollution problem of global scale into a profitable fertilizing solution.

P521

Closing the Loop; Waste to Resource. The risks and benefits of soil amendment on sandy soils, Australia

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The soils of the Swan Coastal Plain, on which much of the Perth, Western Australia metropolitan area is located, are some of the oldest in the world. They are extremely infertile, have poor nutrient retention and low water holding capacity. In a drying climate many current land management practices, especially horticultural industries and the rapid urbanization of land, may not be sustainable in terms of water usage and nutrient retention. Organic soil amendment materials, particularly those produced by recycling green waste and animal manures, appear fundamentally sound. However, they usually lack minerals such as aluminium, calcium and iron, which prevent phosphate from leaching in some Western Australian soil types. Inclusion of a small amount of these minerals in the form of clays, loams or industrial wastes such as “red mud”, can greatly enhance the phosphate adsorption capacity of the amended soil. The benefits of using compost and recycled organic waste for soil amendment have been clearly demonstrated. However before the use of these materials can be considered “sustainable”, it is necessary to consider the properties of the soil to which they are being applied. With correct guidance, education and regulation, the use of such products for improving the quality of soils on the Swan Coastal plain, Perth Western Australia plain can be achieved.

P522

Efficient use of crop residues for preparation of P-enriched compost

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Phosphorus is an element that is widely distributed in nature and occurs together with nitrogen (N) and potassium (K), as a primary constituent of plant life. Phosphorus plays a series of functions in the plant metabolism and is one of the essential nutrients required for plant growth and development. Under continuous cultivation, P inputs, in particular water-soluble fertilizers, must be added to either maintain the soil P status of fertile soils or increase that of soils with inherent low P fertility. Phosphorus is low to medium in most of the alkaline swell-shrink soils of Vidarbha region of Maharahstra (India). The P-enriched composts may be useful in these circumstances. In view of the above background the experiment was conducted at Dr. P. D. K. V., Akola (India) during 2011-12. The P-enriched compost was prepared from crop residues with rock phosphate. Chemical and biological changes during decomposition of crop residues were recorded. The prepared compost was analyzed for various chemical properties. The results revealed that, the microbial count (i.e. bacteria, fungi and actinomycetes) was increased up to 60 days of composting, thereafter the count was decreased. Among the different levels of rock phosphate used for preparation of P-enriched compost, 12 per cent rock phosphate favoured the growth of bacteria and actinomycetes, whereas, fungal count was increased with the relatively lower levels of rock phosphate. Among the crop residues used for preparation of P-enriched compost, wheat straw found beneficial in increasing bacterial and actinomycetes population of P-enriched compost. The P-enriched compost prepared from cotton stalk + 12 per cent rock phosphate also found beneficial in increasing the total N, ammoniacal nitrogen, nitrate nitrogen, total phosphorus, citrate soluble phosphorus, water soluble phosphorus, sulphur, zinc, manganese, and fungal count. The phosphocompost prepared from wheat straw (C: N ratio: 20.67) and cotton stalk (C: N ratio: 19.19) along with 12 per cent rock phosphate was found equally beneficial in maintaining lower C: N ratio. The suitability of prepared compost was assessed by conducting field experiment on soybean based cropping sequence along with various treatments. The results revealed that application of 100 % RD + in situ soybean straw (50 % RD + 50 % P through PC to soybean) recorded significantly highest grain (26.83 q ha-1) and straw yield (40.52 q ha-1) of wheat and grain (24.83 q ha-1) and straw (32.21 q ha-1) yield of chickpea followed by 75 % RD + in situ soybean straw (50 % RD + 50 % P through phosphocompost to kharif) (24.67 q ha-1).

P523

Phosphorus availability of a French thermally conditioned sewage sludge assessed by isotopic labeling techniques

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Phosphorus in urban sewage sludge is a potential source of P for agriculture if it is plant-available. In that case it could be an alternative to mineral P fertilizers known as non renewable source. However, to manage TCSS it is necessary to have an accurate assessment of its P fertilizing value. This work aimed to assess and compare the plant availability of P in TCSS and triple superphosphate (TSP). A pot experiment with a mixture of ryegrass and fescue was carried out for 2 months on a P-deficient and slightly acidic soil in which 50 mgP.kg–1 was applied as TSP and TCSS. The 32P–labeling of soil P was used to accurately quantify the P taken up by plants from the different P sources and to evaluate interactions after applying P-TCSS on P taken up from soil. In parallel, soil incubations were conducted on the same treatments to analyze soil respiration and soil microbial dynamics. In comparison to the control (no P applied), shoot and root biomass productions, and plant P nutrition increased with TSP and TCSS application. The contribution of TCSS and TSP to plant nutrition was 55.2% and 55.7%, respectively and the relative agronomic effectiveness of TCSS was 64%. This decrease is explained by the carbon associated with the 50 mgP.kg-1 applied to soil. This carbon initiates a priming-effect with a high microbial activity marked by high soil respiration and high P content in microbial biomass which competed for plant-available P and delayed the root and shoot growth. As a consequence, P taken up from soil and TCSS decreased both. In conclusion, this study shows that it is possible to substitute TSP by TCSS.

P524

A robust high-throughput on-site assay to dose phosphate in industrial processes

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The preservation of phosphate resources has become a major stake in our society. As a consequence, the European parliament has implemented an ambitious policy of recovery and recycling of phosphate. However, the lack of on-site accurate assay to dose phosphate inhibits proper optimization of industrial recycling processes. Therefore, we have developed two analytical assays by combining absorbance detection and high-throughput analysis (microplate format). The methods, based on the use of chromogenic reagents and performed on a microplate, enable up to 96 simultaneous measurements of inorganic phosphate or polyphosphate contents in 5 to 30 minutes. The assay has been validated for both high range concentrations (from 10 to 260 mg PO_4 /L; industrial phosphate concentration) and low range concentrations (from 0.05 to 1 mg PO_4 /L; wastewater treatment and discharge). It is much less sensitive to interferences commonly found with other methods on industrial samples.