ABSTRACT BOOK
Organic Phosphorus Workshop 2023

November 27 – December 1
Pucón, Chile.
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PROLOGUE

Humanity faces many urgent challenges, including food security, environmental degradation, and climate change. The maintenance of current global food production, as well as future increases driven by projected population growth, are strongly dependent on continued inputs of phosphorus, mainly in the form of mineral fertilizers derived from phosphate rock. Global phosphate rock resources are finite, and there is an acknowledged urgent need to improve phosphorus use efficiency in agroecosystems to meet increasing demand. Organic forms of phosphorus account for up to half of the total phosphorus present in many agricultural soils. The nature and dynamics of organic phosphorus in soil play a major role in determining phosphorus bioavailability and plant productivity, and optimisation of biological phosphorus cycling has the potential to contribute significantly to improving phosphorus use efficiency. Long-term inputs of phosphorus have resulted in the accumulation of significant quantities of legacy phosphorus in agricultural soils which in turn has contributed to increased diffuse phosphorus transfer and accelerated eutrophication of many waterbodies. Biological processes also play a vital role in determining the mobility and bioavailability of phosphorus in sediments.

By Leo Condron
Executive Organising Committee
Organic Phosphorus Workshop 2023
Soil organic phosphorus as key driver for P cycling in soil-plant systems

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Organic forms of P are central to the operation of global P cycles and are a key driver for P-cycling and P-balance in biological-based systems. Understanding of organic P dynamics within terrestrial soil-microbe-plant systems is of particular importance for addressing issues of productivity and sustainability in both natural and managed agro-ecosystems. Diversity and functionality of soil organic P evolves with soil pedogenesis and is intimately associated with the formation and functionality of soil organic matter (SOM), albeit with relatively poor understanding. Soil organic P typically constitutes around 50% of the total P in most soils but may represent more than 80% in natural and un-disturbed grassland systems, especially in the absence of agronomic interventions that includes fertilizer P inputs and cultivation. The chemical nature of organic P in soil and its speciation is routinely investigated using NMR–P spectroscopy which has indicated a strong predominance of phosphomonoesters. Within this, inositol hexaphosphates (IHP), phospholipids (as glycerophosphates) and mononucleotides (in addition to nucleic acids as diesters) are the major identifiable forms, with IHP (primarily as myo and scyllo isomers) typically accounting for ~10 to 15%. The monoester pool is further constituted by a large pool (up to 50%) of ‘unresolved’ organic P (identified by a broad monoester peak) that occurs as high molecular weight material that appears to be more closely associated with a broader component of SOM. A major challenge in recent years has been to understand the bioavailability of soil organic P and the role of specific plant and/or microbial phosphatases (e.g., phytases) and non-specific acid and alkaline phosphatases in mineralizing different pools and forms of organic P. For example, phytases in particular have been shown to be effective in mineralizing soil organic P, with their capacity to release orthophosphate being enhanced significantly by the presence of organic anions. More recently we have shown that identifiable fractions of IHP and the monoester broad-peak were reduced by ~90% and ~50%, respectively, in soils treated with phytase and citrate. This provides new insight to understanding of organic P dynamics in soil and more generally to link it with C cycling. Moreover it provides new opportunity to understand the role of organic P as a potential source of P for plant nutrition.

Keywords: accumulation, speciation, NMR, diester, monoester, inositol hexaphosphate, phytate, phosphatase, phytase, organic anion, microbial

References:
Session I. Role and function of soil organic phosphorus in sustainable land management

KEYNOTE

Interactions in the rhizosphere – implications for the bioavailability of organic phosphorus

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Plants and soils are the fundamental basis on which ecosystems function and are the foundation of agricultural sustainability. Interactions at the interface between plant roots and soil, known as the rhizosphere, underpin crop productivity, soil sustainability and a host of environmental processes. The defining challenge of our generation is to be able to achieve food security and environmental sustainability in a world with increasing human population and a changing climate. Plant growth is limited by soil P availability, so turnover of organic phosphorus (Po) represents a source of P for ecosystem function and, critically, P supply affects crop production1. Plants produce a myriad of carbon compounds from their roots which influence the biochemistry and form and function of the rhizosphere microbiome in fundamental ways. Carbon additions to soil have been shown to alter the environment for microbial recruitment, growth and function and in cohort with root traits, such as root hairs, and mycorrhizal hyphae can have a profound effect on the microbiome and its function2. Indirectly, these rhizodeposits can alter the chemical and physical environment of the rhizosphere in which the microbes grow and reproduce. However, components of rhizodeposits also act as specific signals which influence specific functions of microbes, such as fructose activating bacterial phosphatase enzyme production and altering organic P mineralisation3. This makes for an exceptionally complicated environment that varies from the bulk soil in many ways. Recent research highlighting the interactions between components of root exudates on the availability of organic P along with interkingdom interactions between roots, mycorrhizal fungi and the hyphosphere microbiome have illustrated the complexity of the rhizosphere with respect to organic P availability2. In this keynote presentation I will investigate and illustrate the critical interactions taking place in the rhizosphere which impact the availability of organic P and therefore have consequences for agricultural sustainability.

Keywords: Biochemistry, Interkingdom interactions, Microbiome, Phosphatase, Rhizosphere,

Acknowledgements: The contribution of TSG to the research highlighted and presented is supported by Scottish Government through the RESAS programme.

References

Oral presentations

**Organic phosphorus biogeochemistry differs in rhizosphere compared to bulk soils in long-term wheat fertilization trials in Saskatchewan, Canada**

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Organic phosphorus (P) is a significant proportion of total P in many agricultural soils. Organic P biogeochemistry, including P speciation and the processes governing P cycling, will be affected by proximity to roots (rhizosphere), crop rotation and fertilization. Rhizosphere and bulk soils were sampled in Swift Current, SK, Canada from long-term (from 1967) annual wheat plots (AW) with nitrogen (N) and P fertilization, with P fertilization alone or with no P from 1995, and from long-term (from 1982) plots with lentils and wheat (WL) in alternate years with N and P in the wheat phase only or with no P from 2008. Samples were analyzed for a range of P pools including total and organic P, soil test P and sequential fractionation, and P speciation was determined by P-NMR and P k-edge XANES spectroscopies. Soil processes were examined with anion-exchange membranes (AEM) and P enzyme activity assays (acid and alkaline phosphomonoesterase, phosphodiesterase), while qPCR was used to estimate the abundances of fungal and bacterial communities and P cycling genes (PhoC, PhoD and pqqC). Statistically, there were no significant interactions of treatment*position. Total P, soil test P and AEM P concentrations were lower in treatments where P fertilization ceased, but did not differ with position (bulk versus rhizosphere soils). Organic P concentrations were significantly lower in AW plots without N and P, and in bulk versus rhizosphere soil. Activities of all three enzymes were higher in rhizosphere than bulk soils, as were gene abundances by qPCR, but only the activity of acid phosphomonoesterase differed with treatment (lower in AW plots without N and P). Many organic P compounds (determined by P-NMR) differed with crop/fertilizer treatments, but only orthophosphate diesters differed in bulk versus rhizosphere soils. Many differences with fertilizers were related to soil acidification from long-term N fertilization, which altered soil cations, particularly calcium and aluminum. However, there were no significant differences in soil pH and cations in rhizosphere versus bulk soils. These results highlight the importance of geochemical and biological processes, and proximity to roots for soil organic P cycling in annual cropping systems.

**Keywords:** annual crops; rhizosphere; fertilizers; phosphatases; spectroscopy
Land use impacts on soil aggregate distribution, organic carbon, and phosphorus forms in Brazilian Ferrasols

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Soil aggregate stability can serve as an indicator of soil quality and has implications for soil organic carbon (SOC), as well as inorganic and organic phosphorus (P) fractions and forms. In this study, we examined the interplay between water-stable soil aggregates, SOC, and P forms across diverse land use scenarios in two Brazilian experimental sites marked by distinct soil clay content. Our results underscore the substantial impact of varying land use practices on the distribution of water-stable aggregates in clayey and sandy Ferrasols (Oxisols). In clayey Ferrasol, conservation-oriented approaches like integrated crop-livestock (ICL), no-tillage (NT), and native vegetation (NV) exhibit a prevalence of large aggregates, contrasting with conventional tillage (CT) which favors microaggregates. A parallel trend is noted in sandy soils, where ICL, integrated crop-livestock-forest (ICLF), and pioneer pasture (PP) display higher ratios of large aggregates (~45%) compared to CT (30%). In terms of SOC in clayey Ferrasol, ICL and NT mirror NV's in SOC concentrations (~2.4%), serving as a positive control for agricultural SOC stocks. Conversely, CT records lower SOC values across all aggregate size classes (1.5% to 2.0%) in comparison to other land use systems. In sandy Ferrasol, SOC values vary less among different land uses for large and macroaggregates (2.3% to 3.0%). However, microaggregates exhibit lower SOC concentrations for CT and PP (2.1% and 1.5%, respectively), while the clay+silt fraction retains higher concentrations across all land uses (2.5% to 4.2%). For P forms in clayey Ferrasol, no significant differences emerge among aggregate size classes for monoesters. Similar trend surfaces for orthophosphate accumulation. Pyrophosphate accumulation is notably higher in ICL across all aggregate sizes. In sandy Ferrasol, no distinct patterns are observed for aggregate size classes and P species. CT displays elevated orthophosphate concentrations in all three aggregate size classes (75 to 95 mg kg⁻¹), whereas ICL accumulates more pyrophosphate compared to other land uses (2.1 to 2.4 mg kg⁻¹). This study provides comparative data between soil aggregation patterns in diverse land uses, highlighting the significance of conservative systems, and their associations with SOC and P forms.

Keywords: Soil texture, Phosphorus forms, Land use, Ferrasols, Oxisols.

Acknowledgments: To the University of Queensland and the School of Agriculture and Food Sustainability for equipment facilities.
Evaluating soil organic phosphorus forms in long-term organic and conventional tea cultivation systems in Sri Lanka

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As the world’s second-most consumed beverage after water, tea is a perennial crop of major socio-economic importance in many countries. Young shoots are harvested regularly, prompting fertilisation to play a central role in promoting the growth and quality of tea. While phosphorus (P) is applied in lower proportions than nitrogen (N) and potassium (K), many physiological and metabolic processes are highly dependent on P availability – thereby affecting tea yield and quality. Insights on the organic forms of P (Porg) that dominate in soils, however, represent a neglected aspect of understanding P cycling in tea cultivation systems. A deeper knowledge of the chemical nature of soil Porg in such systems may help enhance our understanding of its transformation in soil and availability for the plant. Moreover, while organic fertilisation provides numerous benefits for soil quality, its impact on P cycling has yet to be elucidated for tea systems. We aimed to apply solution 31P nuclear magnetic spectroscopy (NMR) integrated with a spectral deconvolution fitting approach to quantify soil Porg forms in a long-term organic and conventional tea field trial in Sri Lanka (TRIORCON). Each plot has received P in the form of tea waste, neem oil cake, compost or Eppawala Rock Phosphate since 2000, resulting in significantly different microbial community compositions between the treatments. Accordingly, the chemical nature of Porg in each topsoil is hypothesised to differ, reflecting the respective forms of fertiliser inputs. In general, NaOH-EDTA extracts of topsoils receiving tea waste showed higher contents of total P (356 mg kg⁻¹) and molybdate reactive P (202 mg kg⁻¹). Molybdate unreactive P – taken as Porg – was highest in plots treated with neem oil cake (166 mg kg⁻¹). Preliminary results, however, demonstrate that the topsoil of all treatments displays similar Porg forms that vary only in concentration. Overall, our findings reveal that the input type does not modify Porg – and showcases the predominant role of soil processes in governing organic matter decomposition and P transformation.

Keywords: tea; organic farming; long-term field experiment; 31P NMR spectroscopy; organic P forms

Acknowledgements: To the Swiss National Science Foundation (SPIRIT programme), grant number 194252.

Session II. Nature and biogeochemistry of organic phosphorus in water and sediments

KEYNOTE

Microbial community functional potential and mechanisms for recycling organic phosphorus in soils

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This talk will address two important processes underpinning organic phosphorus (P) cycling in soils. First, we will explore microbial enzymes and mechanisms involved in the generation of bioavailable P from the soil environment. What, if any, relationships exist between P cycling activity and the diversity of functional genes or microbial species in a given environment has been largely unresolved. We revealed that in response to organic P and inorganic P inputs, microbial community phylogenetic and functional gene diversity have divergent, but significant, associations with P cycling activity. Next, we explore organic sources of P for use in crop production including biochar, manure, and compost. Microbial community responses to these inputs as well as their potential to provide synergistic benefits will be discussed.

Keywords: Soil microorganisms, phytase enzymes, functional potential, organic amendments
A preliminary assessment of the quantity and speciation of organic phosphorus in acid sulfate soils

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Acid sulfate soils (ASS) cover large areas globally. Agriculturally used ASS deliver high crop yields in the tropics. These soils have often a low phosphorus (P) availability compensated by high P fertilizer inputs. However, little information can be found on organic phosphorus (P$_{org}$) quantity and forms in ASS. We sampled the A1 horizons of ten ASS profiles, including eight agricultural upland ASS either affected by flooding or not (ASS$_{ag}$) and two ASS under natural vegetation both affected by flooding (ASS$_{nat}$) in the Vietnamese Mekong Delta in 2022. We extracted P$_{org}$ with NaOH-EDTA and determined P$_{org}$ forms using $^{31}$P liquid-state NMR spectroscopy. The data were related with other soil properties. We found that P$_{org}$ content varied between 9.4 to 144.4 mg P kg$^{-1}$ soil, accounting for 3 to 16% of total P, respectively. In ASS$_{ag}$, P$_{org}$ was significantly correlated to total carbon (r=0.95, p<0.001), amorphous iron (r=0.95, p<0.001), total P (r=0.85, p<0.01), and resin extractable (available) P (r=0.83, p<0.05). The results suggest that for ASS$_{ag}$, flooding did not have an effect on the above-mentioned relationships, and agricultural practices affecting total carbon and available P will have an effect on P$_{org}$ content. myo-IP$_6$ and phosphodiesters were present across all soils. Whereas, different combinations of pyrophosphate, neo- and scylio-IP$_6$, and phosphonate were found in different samples with neo-IP$_6$ being absent in ASS$_{nat}$. These forms of organic P will be quantified for the conference. In addition, phosphatase activity will be analyzed to assess hydrolysability of P$_{org}$ forms. In summary, our study contributes valuable insights into P$_{org}$ quantity and forms and their drivers in ASS$_{ag}$ as well as in ASS$_{nat}$. However, the current discussion is based on a small sample size of A1 horizons. In a next step, we will expand our analyses to the second horizon from the same profiles.

Keywords: Organic phosphorus; phosphorus speciation; NMR spectroscopy; acid sulfate soils; Vietnamese Mekong Delta.

Acknowledgments: To the Swiss National Science Foundation and Vietnam’s National Foundation for Science and Technology Development, grant number IZVSZ2.203317, for the funding.
Transport of other phosphorus in legacy phosphorus agricultural catchments

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Phosphorus (P) loss from P-saturated (legacy P) agricultural catchments is a significant contributor to water quality deterioration in downstream water bodies. We established and instrumented a network of 15 small agricultural catchments in Maryland, USA, to determine P losses from catchments with Maize-Soybean crop rotations. The selected catchments have soil test P levels (Mehlich 3-P) greater than 150 mg/kg (environmental threshold value used in Maryland to guide P applications), with several catchments above 500 mg/kg. The accumulation of legacy P in these catchments is due to the long-term use of poultry manure and dairy manure. The major pathways of water and P transport in these catchments are overland flow (surface runoff), tile drainage (leaching through the soil profile), and open ditches (subsurface lateral flow). The sites were instrumented with H-flumes in overland flow catchments and water control structures in tile drainage and open ditch catchments. Flow meters, rain gauges, and ISCO autosamplers were used to target flow-weighted sampling on a per-event basis. Samples were analyzed for orthophosphate P (PO₄-P), total dissolved P (TDP), and total P (TP). The P forms between TP and PO₄-P comprise dissolved unreactive P (DUP), particulate reactive P (PRP), and particulate unreactive P (PUP); these forms are collectively referred to as other P in this work. Previous research has suggested that DUP likely consists of organic P soluble in water, whereas PRP likely consists of inorganic P sorbed to soil particles, and PUP likely consists of organic P sorbed to soil particles. In one catchment, we used Fourier Transform-Ion Cyclotron Resonance-Mass Spectrometry (FT-ICR-MS) to investigate the changes in the molecular characteristics of DUP. We found that in DUP pool, more-bioavailable compounds (comprising amino sugars, carbohydrates, lipids, and proteins) were 4–31%, whereas less-bioavailable compounds (comprising lignin, tannins, condensed hydrocarbons, and unsaturated hydrocarbons) were 69–96%. This presentation will focus on the transport of other P in legacy P catchments, in three distinct flow pathways, over a range of flow and temporal scales. We will discuss concentration-discharge (C-Q) relationships of other P and research needed to investigate the complicated biogeochemistry of other P in flowing waters to address water quality deterioration in agricultural catchments.

Keywords: Legacy P catchments; other phosphorus; agricultural catchments; eutrophication

Acknowledgments: US Department of Agriculture-National Institute of Food and Agriculture and Maryland Department of Agriculture for funding the facilities, personnel, and various projects.

References:
Tuesday 28, November

Session I. Role and function of soil organic phosphorus in sustainable land management

KEYNOTE

Impact of Chemical and Organic Phosphorus Fertilizers on P availability, Bacterial Diversity and Pasture Production

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Phosphorus (P) is a critical nutrient in agroecosystems, and its effective management is essential for global food production. This study aimed to assess the influence of chemical and organic P fertilizers on bacterial diversity and composition in Andisol, located in Southern Chile. A long-term experiment (2016-2022) was conducted to examine the effects of various P sources on DM (Dry Matter) pasture production microbial diversity and functionality. Manure addition changed physical-chemical soil, increasing the soil pH, increasing the microbial diversity and increasing the P-ase activity. We observed an increase DM production with organic P source. Notably, the study revealed significant alterations in bacterial abundance and composition based on the applied P source. Moreover, different P fertilizers influenced the expression of P-cycling-related bacterial genes, such as phoD, phnK, pqqc, and gcd. However, when treatments were grouped according to their P source, distinct changes in microbial composition were evident, with specific taxa being highlighted based on the treatment and dosage. Consequently, this study demonstrates the influence of contrasting fertilization schemes on microbial diversity and abundance, which correlates with nutrition and plant growth variables. These preliminary findings lay the foundation for identifying key variables, including nitrogen (N), phosphorus (P), and carbon (C), that affect plant growth and production. By employing a multifactorial model for optimizing nutrient turnover in pastures and controlling the "natural soil bioreactor," this research paves the way for developing sustainable strategies for N fertilization and enhancing overall agricultural productivity.

Keywords: P-cycling-related bacterial genes (phoD, phnK, pqqc, gcd), Bacterial diversity and composition, Nutrient turnover in pastures, Sustainable fertilization strategies.

Acknowledgments: To the Scientific and Technological Bioresource Nucleus (BIOREN) for equipment facilities, Regular ANID Project No.1230084 and collaborators: Dr. Leyla Parra, Dr. Cecilia Paredes, Dr. Patricio Barra, Dr. Michel Abanto, Dr (c). Benjamin Leyton-Carcaman, Dr. Paola Duran and Dr. Rolando Demanet.
Oral presentations

Legacy effect of drought with organic phosphorus amendments labeled with $^{33}$P radioisotopes on calcareous and carbonate free soils.

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Determining of the legacy effects of drought and alternate wet and dry cycles on the decomposition of organic phosphorus (P) amendments in different soil types is a prerequisite to increase resource efficiency, reduce dependence on mineral fertilizers and lead to more sustainable crop production under changing climate. Two soils types, calcareous (Calc+) and carbonate-free (Calc-), were subjected to three moisture treatments prior to wheat seeding: 1) drought (30% water holding capacity (WHC)), 2) 8 weeks alternate wet and dry, and 3) optimum conditions (70% WHC). In parallel, mineral and organic P fertilizer (cowpea residue) were labeled with $^{33}$P to trace the allocation of applied P in Calc+ and Calc- soils into different P pools (Olsen P; microbial polar lipids, shoot and root biomass). In Calc+ soils, biomass increased significantly more under organic P than under mineral P in all moisture regimes. In contrast, organic P fertilization had no effect on biomass in Calc- soils except under optimal moisture conditions. $^{33}$P recovery in the Olsen P fraction was significantly higher (31%) under mineral P fertilization compared to organic P fertilization (11%) in Calc- soil. It is noteworthy that, organic P fertilization resulted in an average increase of 24% and 45% in MBC and MBN, respectively, compared to mineral P fertilization. Increasing moisture had a decreasing effect on the incorporation of $^{33}$P into microbial P-lipids under organic P fertilization on both soils. The $^{33}$P incorporation into microbial P-lipids was 59 - 91% higher with organic P fertilization than with mineral P in both soils. The results revealed that microbial immobilization of $^{33}$P (59-91%) displayed a conversion of organic P to microbial P potentially available for plant growth. Organic P enhanced microbial growth fostering microbial immobilization in both soils even under drought. We thus found a legacy of pre-sowing moisture regime on microbial P transformation with no implications for plants. Organic P fertilization does not only foster an enhanced plant P uptake, but also alleviates the drought stress in both soils.

Keywords: $^{33}$P–labelled radioactive isotopes, pre-planting moisture treatment, sustainable agriculture

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Changes in phosphorus fractions within submerged pastoral soils associated with critical source areas

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Critical source areas (CSAs) play a crucial role in transporting nutrient enriched overflow from pastoral lands to nearby freshwater bodies. They are often subjected to short-term but repeated submergence during the winter season. Generally, phosphorus (P) is released from soils upon submergence through a collection of complex hydrological and biogeochemical processes. The P dynamics and the potential of CSAs to release P upon short-term submergence during winter have not been previously studied in New Zealand. A field study was conducted on two dairy farms with Recent Soil (Fluvents) and Pallic Soil (Aqualfs) in New Zealand to investigate the release of P and changes in organic (Po) and inorganic (Pi) P fractions under CSA submergence resulting from winter rainfall. Ten porewater samplers were installed within the CSAs on the two farms. Porewater was collected from 2 and 10 cm depths below the surface within 24 hours after five rainfall events over a period of two months. Soil samples (0-10 cm) were collected at the beginning, at the middle and at the end of the experiment. The initial soils were assessed for soil texture, Olsen P, total organic carbon, and P sorption capacity. Water samples collected during the study were analysed for dissolved reactive P, pH, dissolved organic carbon, selected cations and anions, and alkalinity. In situ measurements were conducted to determine the redox potentials of the two soil depths. Our assessment will encompass the measurement of water, NaHCO3 and NaOH extractable Po and Pi, HCl extractable Pi and residual P fractions of different depths of soils. Further, geochemical modelling will be employed to examine potential changes to P species. The mechanisms of P release in CSAs will be presented by combining the temporal changes of P fractions in soils.

Keywords: Critical source areas; inorganic phosphorus; organic phosphorus; Pallic Soil; Recent Soil

Acknowledgments: Financial support from the World Bank funded AHEAD Scholarship (AHEAD/PhD/R3/Agri/336) of Sri Lanka and the Kathleen Spragg Agricultural Research Award, New Zealand for the PhD study.
Drivers and barriers for the adoption of phosphorus and nitrogen recovery technologies in nutrient-intensive regions: a case study of Flanders, Belgium


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Phosphorus (P) and nitrogen (N) are essential for all life forms. Their demand – in the form of fertilizer, feed, and food – is constantly growing due to a rising global population. The production and use of mineral fertilizers lead to severe environmental impacts, and many countries depend on imports. High-income regions have contributed the most to the historical transgression of the planetary boundaries, and therefore have a big responsibility to take mitigation measures. Flanders, in Belgium, is a nutrient-intensive region with a large potential for N and P recycling from concentrated waste streams like manure, food processing waste, and sewage sludge. The possible recycling technologies that can be used to achieve a more circular economy in this region are manifold. However, this transition requires the involvement of different actors, and the drivers and barriers behind their decision behavior are not yet understood.

We identified more than 200 stakeholders and conducted exploratory interviews with environmental coordinators of companies in different food processing sectors and livestock farmers, to identify drivers and barriers for the adoption of N and P recovery technologies. We found that companies that collaborate with technology providers, consultancies, or universities have a deeper knowledge of nutrient recovery technologies. Policy-makers should work with these organizations, knowing that their advice has a big influence on key stakeholders. Improving the corporate image through environmental measures is a nice-to-have, but not necessarily a driver for change. Efficiencies increase with installation size, therefore reducing costs. Collaborations between companies in the same sector are thus necessary to facilitate a more centralized treatment process. The focus here should be regional to avoid high transport costs. Some companies reported getting more revenue from producing energy from their wastes than from selling these high-value products for food or feed production. Subsidies based on the ladder of Moerman could help revert this situation. Legislation that is constantly changing acts as a barrier to technology adoption, since companies consider these investments risky when the political situation is unstable.

Keywords: circular economy; nutrient recovery technologies; actors’ choice behavior.

Acknowledgment: To the Research Foundation - Flanders (FWO) for funding the NutriChoice project (1S57224N).
Effect of intercropping and seed treatment on soil P availability, microbial communities and functions in the rhizosphere

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In agroecosystems, where monocultures prevail, there is limited understanding of the influence of diversified cropping (e.g. intercropping) and chemical inputs on biological soil P cycling. Seed treatments are commonly recommended as a routine management practice in conventional agriculture but the impact on soil functions are largely unknown. Field experiments at the AAFC Harrington Research Farm on Prince Edward Island, Canada evaluated the influence of monocultures vs intercropping (e.g. pea/mustard, pea/barley) and the effect of seed treatment vs no treatment on soil biological communities, predicted functions and P availability. We hypothesized that (1) intercropping would result in more diverse bacterial communities compared to monocultures, and (2) seed treatments would negatively affect soil P availability and soil biological communities and functioning related to P turnover. Bulk and rhizosphere soil samples were collected in July and August from 2019-2021 and analysed for H2O extractable-P, Mehlich-P, pH, moisture and phosphatase activity. Rhizosphere bacterial communities were characterized by 16S amplicon sequencing and processed using Dada2 pipeline and PICRUSt2 for functional predictions. Seed treatments resulted in significant increases in Mehlich-P and predicted functions in bacteria categorized as phosphatases, phosphodiesterases, and phosphorus mineralization. There were temporal differences in H2O extractable P in rhizosphere samples but no differences among the treatments. Crop type did not influence any of the measured soil parameters, except soil NO3 between the early and late season sampling. There was no effect of crop or treatment on any bacterial diversity indices but there was a change in communities between the early and late sampling times. Contrary to our hypothesis, nutrient availability and associated predicted functions in bacteria increased with seed treatment vs. no treatment. Relationships with soil P availability and fungal, protozoan and general eukaryotic communities within these systems is also being explored.

Keywords: available P, phosphatase; microbial community
The Role of Organic Phosphorus in Land Management: A Critical Component for Sustainable Agriculture and Environmental Stewardship

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Organic phosphorus (P) is an essential component of soil fertility and plays a vital role in land management for sustainable agriculture and environmental conservation. This abstract highlights the significance of organic phosphorus in the context of nutrient cycling, plant growth, and soil health. It also explores the challenges associated with its availability and efficient utilization in modern land management practices.

Organic phosphorus in soils originates from various sources, such as decomposing organic matter, microbial activity, and residues from plants and animals. This pool of phosphorus serves as a crucial reserve, replenishing and sustaining plant nutrition throughout the growing seasons. Furthermore, organic phosphorus acts as a buffer against rapid phosphorus depletion, reducing the risk of nutrient imbalances and long-term soil degradation.

One of the key aspects of organic phosphorus management is fostering an environment conducive to its efficient mineralization and transformation into plant-available forms. Soil microorganisms, particularly phosphatase-producing bacteria and fungi, play a pivotal role in this process by breaking down organic phosphorus compounds and releasing inorganic phosphate ions, which are readily taken up by plants.

Incorporating organic farming practices and adopting conservation agriculture techniques can enhance organic phosphorus retention in soils. Crop rotations, cover cropping, and reduced tillage methods facilitate nutrient cycling, improve soil structure, and promote organic matter accumulation, leading to higher organic phosphorus content in the soil profile. Moreover, understanding the dynamics of organic phosphorus and its interactions with other nutrients is essential for optimal nutrient management. Balancing phosphorus inputs through appropriate fertilization strategies and avoiding over-application is crucial to prevent nutrient runoff, which can lead to water pollution and eutrophication of aquatic ecosystems.

In conclusion, organic phosphorus holds a pivotal position in sustainable land management. By emphasizing its role in nutrient cycling, promoting organic farming practices, and optimizing fertilization strategies, farmers and land managers can enhance soil health, bolster crop productivity, and contribute to a more environmentally conscious approach in agriculture. Embracing the significance of organic phosphorus in land management represents a critical step towards achieving food security, preserving natural resources, and ensuring a sustainable future for generations to come.
Session III. Interactions between the biogeochemistry of organic phosphorus and other elements in terrestrial and aquatic ecosystems

Oral presentations

Seasonal variation and release of soluble reactive phosphorus in an agricultural upland headwater in central Germany

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Soluble reactive phosphorus concentrations (SRP) in agricultural headwaters can display pronounced seasonal variability at low flow, often with the highest concentrations occurring in summer. These SRP concentrations often exceed eutrophication levels but their main sources, spatial distribution, and temporal dynamics are often unknown. The purpose of this study is therefore to differentiate between potential SRP losses and releases from soil drainage, anoxic riparian wetlands and stream sediments in an agricultural headwater catchment. To identify the dominant SRP sources we carried out three longitudinal stream sampling campaigns for SRP concentrations and fluxes. We used salt dilution tests and natural 222Rn to determine water fluxes and sources in different sections of the stream, and sampled for SRP, Fe and 14C-DOC to examine possible redox-mediated P mobilization from riparian wetlands and stream sediments. The fraction of dissolved organic P (DOP), calculated as the difference between TDP and SRP, was insignificant in stream water. Stream water SRP concentrations, fraction of SRP within total dissolved P (TDP) and dissolved organic carbon (DOC) radiocarbon ages matched those in the groundwater entering the gaining section in the upper headwater. Pore water from the stream sediment provided evidence of reductive mobilization of SRP but the exchange fluxes were probably too small to contribute substantially to SRP stream concentrations. We also found no evidence that shallow flow paths from riparian wetlands contributed substantially to the observed SRP loads in the stream. Groundwater is the main long-term contributor of SRP at low flow and agricultural P is largely buffered in the soil zone. We argue that the seasonal variation of SRP concentrations was mainly caused by variations in the proportion of groundwater present in the streamflow, which was highest during summer low flow periods. Accurate knowledge of the various input pathways is important for choosing effective management measures in a given catchment, as it is also possible that observations of seasonal SRP dilution patterns stem from increased mobilization in riparian zones or from point sources.

Keywords: Soluble reactive phosphorus; stream sediments; riparian wetlands; P mobilization; eutrophication
Organic forms of P (Po) are critical to the nutrition of organisms associated with highly weathered, low fertility soils. The conversion of rapidly cycling, low molecular weight (LMW; <1000 Da) forms of Po to PO$_4^{3-}$ prior to plant uptake represents a critical bottleneck to the soil P cycle. The broad chemical composition of soil Po, including the LMW Po pool, is well known to the level of compound class (e.g., phosphomonoesters, phosphodiesters, phosphonates) thanks to two decades of $^{31}$P nuclear magnetic resonance NMR spectroscopy research. However, within these compound classes, there may be substantial variation in the way LMW Po compounds are cycled and accessed by soil organisms due to specificity of hydrolytic enzymes and variable C:N:P stoichiometry of LMW Po forms. High-resolution, compound-specific data is needed to account for this variation and thereby enhance our knowledge of LMW Po dynamics. To this end, we combined a classic soil P extraction with a novel liquid chromatography–mass spectrometric workflow to quantify specific LMW Po compounds in several low-fertility Australian soils. The extractable LMW Po pool was comprised of at least 40 phosphorylated organic compounds, which included sugar phosphate, phosphorylated amino acid and nucleic acid Po species alongside phospholipid derivatives and other LMW phosphorylated intermediates and by-products. Another ~20 putative metabolites containing phosphorylated moieties were detected through tandem MS. Microbial cells were a major source of LMW Po compounds, and the composition of LMW Po forms differed between the intra- and extra-cellular pools. The composition of LMW Po was evidently shaped by soil parent material, with both biotic (i.e., microbial composition) and abiotic factors (i.e., P fertility and mineralogy) likely mediating this effect. Our analytical workflow will be further developed to expand coverage of targeted LMW Po analytes and to explore the degree by which the composition of non-phosphorylated metabolites (i.e., associated with key metabolic pathways) may be either correlated with, or driving LMW Po dynamics in soils.

**Keywords:** Organic Phosphorus; Metabolomics; LC-MS

**Acknowledgements:** This work was supported by a Discovery Grant from the Australian Research Council (DP200102565). This research was facilitated by access to Sydney Mass Spectrometry, a core research facility at the University of Sydney.
In soils, the formation, mineralization, and modification of soil organic phosphorus (P) species are influenced by chemical processes and biotic interactions. We investigated how the composition of organic P species in basalt-derived soils is constrained by the prevailing soil properties. The soil properties on the Hawaiian archipelago are a result of soil formation under distinct gradients in rainfall and substrate age as described by the soil process domain concept of Chadwick et al. Within a soil process domain, the pedogenic processes controlling the soil properties are well studied. Across the Hawaiian archipelago, we sampled 12 different sites, each developed under a different combination of rainfall (ranging from 200 to 4000 mm m$^{-2}$) and substrate age (ranging from 0.05 to 4100 kyr). With this sampling design we covered two sites of each soil process domain. This design allowed i) a quantitative identification of specific organic P species representative for certain pedogenic processes (emblematic P species) and ii) linking changes in the P speciation to soil genesis. Organic P speciation was performed on sieved (<2 mm) topsoil samples (O and A horizons) previously extracted with NaOH-EDTA using liquid-state $^{31}$P nuclear magnetic resonance (NMR) spectroscopy. P species were identified based on their known chemical shift position or by spiking the sample with known P species. In order to quantify the identified P species, the extracts were previously spiked with a known amount of methylene diphosphonic acid, and the P-monoester region spectrally deconvoluted and fitted, as described by Reusser et al. Preliminary results show that absolute amounts of extractable P are highest in the intermediate stages of pedogenesis. P-monoesters show highest relative amounts in highly weathered soils. The relative amounts of phosphonates, poly-P, pyro-P, P-diesters and certain P-monoester species appear to be more similar in soils of a common soil process domain than in soils of the same substrate age or rainfall regime. The next step aims to clearly define these P speciation characteristics emblematic for each soil process domain.

Keywords: Organic phosphorus; liquid-state $^{31}$P NMR; P speciation; Soil process domains.

Acknowledgments: To Laurie Mauclaire Schönholzer, and Daniel Zindel for technical support.

References:
Colloidal particle size and elemental distributions in the glacier foreland soil chronosequence of New Zealand’s Franz Josef Glacier

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Glacial foreland soils may on millennial time scales loose substantial amounts of nutrients via leaching or colloidal translocation. In this study we quantified the change of mobilizable colloids and associated nutrients changes during such progressive long term soil formation. Top- and subsoil samples from seven sites along the Franz Josef chronosequence, New Zealand (range: 0.06-120 kyr) were collected. Water-dispersible colloid content (WDC) was analyzed via asymmetric flow field-flow fractionation coupling a UV detector, a dynamic light scattering detector, an organic carbon detector, and an inductively coupled plasma mass spectrometer. Nano (0.6-30 nm), fine (30-240 nm), and medium sized colloids (240-500 nm) were separated and analyzed for elemental content distribution associated with these varying colloidal size particles. 31P-Nuclear Magnetic Resonance Spectroscopy was used to determine P species contained in bulk soil, colloidal and aqueous fractions. Colloidal organic carbon (OC), P, and Ca concentrations reached their highest values in youngest topsoils (60 and 500 yr) and declined in older soils (1-120 kyr), with lower values in the subsoil than the comparable topsoil. Therefore, OC and P were lost over time during the soil development. Colloidal Si, Al, and Fe contents were the highest in the young subsoils (60 and 500 yrs), but lower in these young topsoils, and in the old subsoils (1-12 kyr). Topsoils generally contained relatively higher proportions of the nano-colloid fraction compared subsols for respective elements, regardless of the site age. Within the topsoils, P was mainly present as P-Ca in nano colloids, as P-Ca-OC in fine colloids and as P-OC-mixture of clay mineral, Fe/Al (hydr)oxides and Ca in medium colloids. Colloidal P in subsoils was uniformly associated with Ca, Fe, Al, and Si in all the three size fractions. Orthophosphate and orthophosphate monoester were the dominant P species. Compared to WDC relatively more diesters were present in the bulk soil with more pyro-P and poly-P forms in the aqueous phase. We concluded that soil depth (i.e., pedogenic horizon) was generally a more important driver of colloidal size distribution and associated nutrient content than soil development duration and related external environmental controls.

Keywords: Water-dispersible colloids, elemental content, glacier soil chronosequence, soil profile, 31P-Nuclear Magnetic Resonance spectroscopy.
On organic phosphorus and are we asking the right questions for a hungry World with a changing climate?

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It is 84 years since W. J. Dyer first isolated phytin on soil and this will be the fourth of the series of organic phosphorus workshops, 20 years since the first of this series was hosted in Switzerland. In 2016 I co-hosted the previous Organic Phosphorus Workshop in the Lake District of Northern England, and at the end of the meeting I reflected, with co-authors, on the state of the subject and where it had got to and where it needed to go next. At this time of writing, in 2016, my learned mentor A. F. ‘Tony’ Harrison wrote:

“I feel strongly there is a need to broaden the perspective of the current research. I feel there is a big missing dimension. Imagine there is a big box of knowledge labelled ‘Research on Soil Organic Phosphorus’. From what I have seen in the Organic Phosphorus Workshop 2016, most if not all of your research topics seem to start off inside this box. Most projects seem to get ever deeper into this box looking at details of increasing complexity. Other research projects also start off inside the box, but try to look outwards towards trends with external factors, such as across ecosystems, plant successions or pedogenetic developments. I think that at least some of you should start your projects off from outside the box and look in. What do I mean? Some of you should start, for example, by addressing the important environmental issues of our time”

Now seven years have passed and I will re-appraise this statement in context with the latest findings of the new Workshop. I will consider how our World is changing rapidly, in terms of climate and the needs of agriculture, and will critically consider if we are best meeting the needs of modern society.

Keywords: Organic phosphorus, climate change, soil, plants, aquatic systems.

The complexity of soil organic phosphorus and its close association with soil organic matter

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Phosphorus (P) is an innate constituent of soil organic matter and a key element in nutrient cycles of terrestrial ecosystems. In general, pools of organic P comprise the majority of P in soil and is an important source of P to living organisms. However, the chemical nature of soil organic P remains unclear which is of concern when attempting to address global issues of declining soil organic matter and diminishing rock phosphate reserves needed for agricultural production. Historically, research on the chemical nature of soil organic P has largely focused on that of recognisable biomolecules (e.g., inositol phosphates, phospholipids, and nucleic acids). This has greatly improved our understanding of the P cycle, and led to improved outcomes for agroecosystem management. Nevertheless, there is increasing evidence to show that a large portion of the organic P in soil remains unresolved. This is partly due to the available techniques used to assess soil organic P over time, but also due to fundamental differences in the interpretation of data, most notably that relating to solution $^{31}$P NMR spectra on alkaline soil extracts. A holistic view on soil organic P, covering more than a century of research and a diversity of approaches, combined with recent advances and a multidisciplinary approach, has revealed new insight on the chemical nature of soil organic P. An emerging view is that about half to two-thirds of the organic P in soil is comprised of phosphomonoesters (R–O–PO$_3$) in large molecular weight material (> 5 kDa), which differ to that of recognisable biomolecules. Whilst initial studies indicated this pool could be observed as a single broad peak in NMR spectra, recent evidence shows the composition of this pool to be chemically and structurally complex with several components of varying molecular weight. Furthermore, this large pool of organic P appears to be closely associated with soil organic matter, particularly via ester bonds. Whilst it is apparent that a large portion of soil organic P is chemically and structurally complex, obtaining a clearer view remains challenging, which has been and continues to be the case for soil organic C. Nevertheless, this will be essential for us to better understand the processes governing the accumulation of soil organic P, its association with soil organic matter, and the processes of C and P cycling/turnover governing the supply of P to plants. This will necessitate a multidisciplinary approach and a diversity of techniques used across soil organic P and organic C.

Keywords: complex, inositol phosphates, large molecular weight, NMR, phosphomonoester, phytate, soil organic matter, speciation, unresolved organic P

References:


Implementing sustainable agricultural practices fostering soil carbon sequestration rely on (1) increasing plant-derived organic matter inputs and/or (2) reducing soil carbon losses. Both processes may concern inorganic and organic forms of P, which are strongly involved in soil organic matter formation and decomposition through microbial carbon and nutrient requirements. In this talk, I will present the biogeochemical processes leading to soil organic carbon and co-comittant organic P accumulation. I will discuss the effects of different P forms and their influence on soil organic matter stabilisation processes in contrasting soil types. I will investigate the effect of organic as well as inorganic amendments in acid and carbonate containing soils and their effect on both organic and inorganic carbon persistence. Sustainable agricultural practices, in particular the use of legumes to replace inorganic N fertilisation and their effect on organic P pools and soil organic matter biogeochemical composition and turnover will be presented. Innovative solutions focusing on increasing soil carbon stabilisation while reducing inorganic P fertilisation by applying organic P sources for sustainability of agricultural systems will also be discussed.

Keywords: 3-5 keywords. Carbon sequestration, organic amendments, sustainable practices
Assessing vegetative filter strip for environmental remediation with the SWAT model

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This study addresses water quality within a watershed and the impact of various factors, such as agriculture. One of the most significant factors is the presence of phosphorus (P), which contributes to water body eutrophication. In agricultural watersheds, phosphorus can originate from animal waste or fertilizers, and effective management practices can help mitigate its negative impact. In this context, this work aims to quantify the benefits of utilizing vegetative filter strips (VFS) as a management practice to remediate an intensive agricultural watershed. The proposed methodology quantifying the organic phosphorus dynamics is the Soil & Water Assessment Tool (SWAT). A case study is presented for an irrigated agricultural watershed in northern Uruguay, where primary land uses include rice, soybeans, and livestock. The advantages of implementing VFS are assessed using the SWAT model. Water quantity simulations are calibrated and validated through a moving window procedure using the Kling-Gupta Efficiency. Phosphorus predictions are validated by analyzing the relationship between water discharge and phosphorus loads. Scenario analyses demonstrate a reduction in the magnitude and frequency of elevated phosphorus concentrations. These SWAT models allowed to simulate various phosphorus dynamics scenarios to quantify and/or quality impacts for watersheds. The results are promising and could integrate Ecohydrology concepts, towards the understanding of the importance of remediation of high-impact agricultural watersheds.

Keywords: filter strips, buffer zones, SWAT, irrigation

Acknowledgment: ANII postgraduate scholarship.
Organic phosphorus in legacy phosphorus agricultural soils: Insights from chemical and spectroscopic techniques

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Agricultural soils with a long-term history of organic waste (e.g., manures, biosolids) applications (termed legacy P soils) have accumulated significant amounts of inorganic and organic P.¹,² Organic P pools in legacy P soils are least understood and are often disregarded due to the presence of sizable inorganic P pools. We investigated organic P in legacy P soils from the Mid-Atlantic, USA, using chemical (water extractable P [WEP], Mehlich 3-P, P fractionation) and advanced spectroscopic (XANES, ³¹P NMR) techniques. Organic WEP (WEPo) in poultry litter-amended (PL-amended) soil was 21% of total WEP at 1:10 and 7% at 1:100 solid-to-water ratio³, equivalent to 1% of Mehlich 3-P and 0.35–0.57% of total P.³ Acid phosphatase activity (AcP) in most soils ranged from ~0.5 to 8 μmol pNP g⁻¹ hr⁻¹ with dairy manure-amended soils 2–7 times greater AcP than PL-amended soils. High AcP in these legacy P soils with reserves of phosphononoesters (e.g., 13–24% phytic acid identified with XANES²) may indicate the potential of these soils to provide inorganic P to plants.³ ³¹P NMR data for the legacy P soils are being collected, which will provide insights into the organic P pools. This presentation will discuss the variability and forms of organic P determined with chemical and spectroscopic methods and how these are affected by the history of organic wastes application in legacy P soils.

Keywords: organic P, legacy P soils, Mid-Atlantic USA, XANES, ³¹P NMR

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On the prediction of phosphorus fluxes in the Santa Lucía basin under a variable climate using SWAT model

Gelós, M. 1, 2, Kok, P. 1, 2, Hastings F. 1, 2, Nervi E. 2, 3, Alonso 2, 4, De Vera, A. 4, Terra, R. 4, Navas, R. 2, 5, Vervoort, W. 2, 6, Baethgen W. 2, 7

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Freshwater in the Santa Lucia River basin, which is known to have high nutrient levels, has experienced important eutrophication events since 2013. For the last three continuous years, La Niña has triggered the magnitude and frequency of droughts affecting the water supply for half of the country population. Moreover, predictions for the upcoming years include three years of drought followed by one year of excessive rainfall. Weather generator tools and environmental models can be used as supportive tools when analysing the effect of climate variability in water quality.

The Soil Water Assessment Tool (SWAT) has been implemented, calibrated and validated using a dense network of hydrometeorological stations and a relative long dataset. Land management was determined with experts, and a soft calibration of nutrients was performed using observed data. The results indicate that the model is sensitive to synthetic climate bias by documented ENSO indices, having an impact in water quantity and leading to changes in phosphorus loads.

The main contribution of this work is to demonstrate how the model can be used as a supportive tool to evaluate the impact of climate conditions in phosphorus dynamics. The results will be useful in the future to assess adaptation measures to climate variability and climate change regarding water and soil quality.

Keywords: Climate variability; nutrient dynamics, soil and water quality.

Acknowledgments: Grupo de modelación integrada de cuencas (GMIC_uy), INIA FPTA 358 and the Ministry of Enviroment of Uruguay.
Cultivating flooded rice as a treatment technology to mitigate phosphorus loads and improve soil and environmental quality from agricultural watersheds

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During summer months (June-August) more than 202 km² of fallow sugarcane land is available for rice (Oryza sativa) production in South Florida, USA. The net value of growing flooded rice in the region as a rotational crop with sugarcane far exceeds its monetary return. Soil conservation, pest control, and phosphorus (P) load reduction are only some of the benefits. With no P fertilizer applied, rice cultivation in Florida can potentially function as a sink for P because of particulate settling and plant P-uptake, while harvested whole grain rice can effectively remove P from a rice field per growing season. A controlled experimental plot was designed to quantify the reduction in P concentration and loads between inflow and outflow over a 110-day rice cultivation cycle. Daily water samples were collected from inflow and outflow over a six-week period once a permanent flood was established. Inflow water P concentration was manipulated weekly, from 0, 0.075, 0.22, 0.50, 0.22, and 0.075 mg/L P. Approximately 160 L of water was treated daily. On average, 28% reduction in total P (TP) concentration and 51% reduction in soluble reactive P (SRP) was observed between inflow and outflow, corresponding to significant P load reductions using this treatment technology. Soil health benefits include increased water holding capacity, and reduced active carbon compared to fallow fields. A significant increase in Mehlich-3 P content was observed at soil depth of 15-30 cm after rice cultivation, probably resulting from the root biomass structure. In addition, P load reductions were increased over the flood depth. Future research work includes (i) evaluating P use efficiency in crop management by identifying and selecting rice varieties tolerant to low P inputs; and (ii) greenhouse gas assessment associated to flooded rice cultivation in the region.

Keywords: rice cultivation, water quality, Histosol, treatment technology, phosphorus

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Session IV Advances in methodology to investigate and quantify organic phosphorus dynamics

KEYNOTE

Recent advances in measuring compositions and tracing sources of organic phosphorus compounds

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Understanding biogeochemical processes involving phosphorus cycling in soils and waters requires novel techniques that can go beyond operationally defined methods and connect sources and pathways of transformation. This talk presents a series of recent advances in analytical techniques aimed at developing tracers using mass spectrometry (IRMS and MS-MS) and mass spectroscopy (NMR and Raman) methods in phosphorus compounds, including adenosine triphosphate (ATP), inositol phosphate, and glyphosate. Major highlights include NMR and Raman-based methods of quantifying phosphate oxygen isotope exchange, which can resolve the temporal evolution of five isotopologues of phosphate in enzyme-catalyzed reactions. NMR-based method enabled the detection of isotope exchange at bridging and non-bridging oxygen sites in ATP, which allows identifying primary and secondary isotope effects during synthesis and hydrolysis. Orbitrap mass spectrometry-based method for measuring isotopes enabled measuring structural and position-specific ‘intact’ isotopes in an inositol ring- thus directly connecting phytate and its dephosphorylated products. Collectively, these results highlighted the potential of an isotope-centric approach for connecting sources and products of phosphorus compounds in the environment.

Keywords: Organic phosphorus cycling; isotope effect; sector and orbitrap mass spectrometry.

Acknowledgments: National Science Foundation (NSF); US Department of Agriculture (USDA)
Simultaneous Tracking of Multiple Organic Phosphorus Transformation by Enzymes and Soil Minerals: New Advances Enabled by High-Resolution Mass Spectrometry

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Extracellular phosphatases secreted by plant roots, fungi, and bacteria catalyze the release of inorganic phosphate (Pᵢ) from the dephosphorylation of organic phosphorus (Pᵢorg) compounds. This natural enzymatic process represents a promising approach to engineer nutrient recovery towards addressing phosphorus needs for agricultural productivity. Understanding enzyme activities for multiple Pᵢorg substrates in a mixture is important for predicting enzymatic phosphorus recycling from realistic organic mixtures such as agricultural soils or organic wastes. However, it is challenging to assign Pᵢ in enzyme assay solutions to a specific substrate from a mixture of Pᵢorg substrates. To overcome this challenge, we have developed an analysis protocol involving high-resolution mass spectrometry to monitor simultaneously Pᵢorg substrates and their organic by-products. Using this protocol in an enzyme assay with a phytase from the fungus Aspergillus niger, we were able to assign the time-dependent production of Pᵢ to the sequential transformation of different Pᵢorg types present in a mixture containing phytate, ribonucleotides, and sugar phosphates. Specifically, we found faster dephosphorylation rates for the multi-phosphorylated compounds (phytate, di-phosphorylated sugars, and di- and tri-phosphorylated ribonucleotides) than the monophosphorylated compounds (monophosphorylated sugars and monophosphorylated ribonucleotides). These findings provide new insights on the activity hierarchy exhibited by a fungal phosphatase during dephosphorylation of different Pᵢorg types, with important implication for the extent of enzymatic Pᵢorg recycling. We have now applied our mass spectrometry-based approach to probe multi-substrate Pᵢorg dephosphorylation by other phosphatase enzymes and by reactive soil minerals.

Keywords: Organic phosphorus; enzyme; phosphatase; phytase; Aspergillus niger.

Acknowledgments: This research is supported by a grant from the U.S. National Science Foundation (CHE 1709626).

Microorganisms are a key driver of phosphorus (P) cycling within soils, influencing plant P availability by 1) storing P within their biomass, 2) mineralising non-plant available organic P, and 3) solubilising inorganic P forms. It has often been reported that phosphate-solubilizing microorganisms (PSM) may improve P availability in soil, forming a basis for the development of bio-inoculants with selected microbial strains. Although many published studies report ‘positive effects’ of such PSM inoculants on plant growth, most of these studies have been conducted under controlled conditions. Field experiments frequently fail to demonstrate positive responses (reviewed in Raymond et al. 2021). I propose that there is currently insufficient evidence that PSM inoculants mobilize sufficient P to change the crops’ nutritional environment under field conditions; the current focus in which PSM solubilize P ‘for the plant’ should be re-adjusted. Although specific microorganisms have the capacity to solubilize P and to generally mobilize unavailable P forms, they probably do so to meet their own needs. This means that the role of PSM is more likely one of slowly introducing small amounts of P into the soil-plant system through turnover of the microbial biomass (biological P cycling). Research should therefore focus on obtaining a mechanistic understanding of microbial P mobilization as a component of soil system, and on how the microbial community as a whole can be directed towards more benefits for plant P nutrition.

Carbon (C) availability is one of the main limitations of microbial activity in soils. The increase in labile C (i.e. glucose) in soil systems has been shown to increase microbial activity and P availability in soil. In practice, organic fertilizers provide a pool of labile C such that their addition may influence the functional role of microorganisms. However, addition of organic fertilizer may also affect soil structure and create “hot-spots” for microbial P cycling. I will discuss how long-term addition of organic inputs affected soil structure and influenced microbial P cycling. Understanding the functional role of microorganisms in P cycling and developing management to enhance plant P availability remains a significant challenge for the future.

Keywords: Organic phosphorus; soil microorganisms; organic fertilizer; soil structure.

Acknowledgments: To Novo Nordik Fonden (NNF) for funding part of the research, grant no. NNF21OC0071454 in the call "Plant Science, Agriculture and Food Biotechnology - Postdoctoral Fellowships 2021". I would also like to thank all people with whom I have worked (and still working) on this topic: Carsten W. Müller, Astrid Oberson, Federica Tamburini, Jakob Magid, Frederik van der Bom, Emmanuel Frossard, Alan Richardson, Michael Bell, Peter Kopittke, Dorette Müller-Stöver, Lars Stoumann Jensen among others.
Phosphorus (P) is an essential plant nutrient that is typically deficient in medium to highly-weathered soils. Because of its high fixation to soil clays, farmers often supplement P through the use of fertilizers in rates higher than plant needs, contributing to the accumulation of Legacy P. Many soils in North Carolina contain high legacy P, meaning that repeated applications of P have led to P tied up to soil particles in less available chemical forms, despite large concentrations of available P in the soil. Plant uptake of legacy P can vary based on the genetic capabilities of the plant. This study evaluates genetic differences of P uptake by measuring kinetic differences and root morphological differences of three different and distinctive genotypes of corn: B 73, NC 358, and CML 530.

Varieties B 73, NC 358, and CML 530 were evaluated for differences in kinetics of P by measuring influx at 0, 1, 2, 4, 7, 12, 18, 24, and 32 hours. It was found that early influx of P was highest for CML 530, second highest for NC 358, and lowest for B 73, indicating the first are more efficient taking up P. Total P influx over the course of 32 hours also remained the greatest for CML 530, and lowest for B 73. Roots of each of the varieties were scanned using WinRhizo to determine differences in root morphology. Total root length was greatest for CML 530, and smallest for B 73. These results demonstrate potential in future genetic and phenotypic selection for developing varieties to perform best in soil with high legacy P.

**Keywords:** Legacy phosphorus; plant genetics; root morphology; plant nutrition

**Acknowledgments:** Thank Science and Technologies for Phosphorus Sustainability (STEPS) for funding such valuable research in soil phosphorus
The organic phosphorus content, phosphomonoesterase activity, bacterial phosphomonoesterase gene abundance, and total bacterial community of sediments from anthropogenized lakes and rivers of southern Chile respond to spatiotemporally.

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Phosphorus (P) cycling by microbial activity is highly relevant in the eutrophication of lakes and rivers. In this context, the contents of organic (P_o) and inorganic (P_i) phosphorus, the activity of phosphomonoestersases (Pase), the abundances of bacterial Pase genes (phoD, phoC, and phoX), and high-throughput sequencing (HTS) of 16S rRNA gene (Illumina Miseq platform) were studied for superficial sediments of the anthropogenized Budi Lake and Imperial and Toltén rivers in Chile. Our results showed spatiotemporal variations in P fractions, Pase activities, and Pase gene abundances. In general, our results showed higher contents of P_i, P_o, total P, and Pase activity in sediments from the more anthropogenized sampling sites in summer compared with those values in less anthropogenized sampling sites in winter. Higher abundances (gene copy g^-1 sediment) of phoC, phoD, and phoX genes were also found in sediments from the more anthropogenized sampling sites in summer compared with those values in the less anthropogenized sites in winter. Our results also showed a positive correlation between P contents, Pase activities, and abundances of bacterial Pase genes, independent of seasonality. The principal component analysis (PCA), beta diversity, and alpha diversity showed clear differences among sampling sites and seasons for both rivers; however, temporal differences for Budi Lake were slighter. Results demonstrated significant differences and positive correlations with anthropogenic impact. The present study provided information on the microbial activity involved in P cycling in sediments of Budi Lake and Imperial and Toltén rivers, which may be used in further research as indicators for monitoring the eutrophication of lakes and rivers.

Keywords: Organic phosphorus; Phosphomonoesterase; Bacterial community; Eutrophication.

Acknowledgments: To the Scientific and Technological Bioresource Nucleus (BIOREN) and Laboratorio de Investigación en Salud de Precisión for equipment facilities, and National Research and Development Agency of Chile (ANID) projects FONDECYT (postdoctoral no. 1201386 and Iniciación no. 11230308), NSFC190012, and REDES190079.
Despite the importance of phosphorus (P) as a macronutrient, the factors controlling storage of P in soils and the implications of soil organic carbon (OC) sequestration for P storage are not yet well understood. Therefore, two meta-analyses were conducted that explore sequestration of P and C in different pools of terrestrial ecosystems.

In the first meta-analysis, I analyzed the distribution of organic and inorganic P (OP and IP) as well as OC among soil particle size fractions depending on geographical location of the soil, climate, soil depth, and land use. In the second study, I synthesized results about the relationship between C and P in soil organic matter and other ecosystem pools and discussed implications of OC storage in terrestrial ecosystems for P sequestration.

In conclusion, the first study shows that OP is strongly enriched in the clay size fraction relative to OC, and that OP is more persistent in soil than OC, which is most likely due to strong sorptive stabilization of OP. The second study shows that the storage of OC in mineral soils leads to the sequestration of large amounts of OP since soil organic matter in mineral soils is very rich in P.

**Keywords:** Organic phosphorus; organic carbon, particle-size fractions, interaction of carbon and phosphorus cycling, organo-mineral interactions, carbon sequestration.

**References:**

Phosphorus-cycling microbial communities in organic and upper mineral soil horizons across a temperate rainforest chronosequence

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Microbial community structure and function were assessed in the organic horizon and upper mineral soil across a ~4000 year dune-based soil chronosequence at Big Bay, New Zealand, where the proportional contribution of organic soil in the profile increased with time. We hypothesised that the organic and mineral soils would show divergent community evolution over time with a greater dependency on functionality of phosphatase genes in the organic soil layer as it developed. Structure of bacterial, fungal and non-specific acid and alkaline phosphatase-harbouring communities were examined in both soil horizons across 3 dunes using amplicon sequencing, network analysis and qPCR. The soils showed a decline in pH and total phosphorus (P) over time with increase in acid and alkaline phosphatase activity. The organic horizon harboured a more complex microbial community compared to mineral soils, with greater network connectivity and wider diversity of Class A (phoN/phoC) and phoD-harbouring communities. Bacterial diversity declined in both horizons; however, over time, with enrichment of Planctomycetes and Acidobacteria. More complex fungal communities were evident in the youngest dune, transitioning to a dominance of Ascomycota in both soil horizons. Identified hub bacterial taxa correlated with acid phosphatase activity, total soil carbon (C) and total nitrogen (N). Higher phosphatase activity in older dunes was driven by lesser diverse P-cycling communities, especially in the organic horizon. Development of the organic layer had a significant impact on various soil properties as compared to the underlying mineral soil. This was associated with major differences in the composition, structure and potential functionality of the resident bacterial and fungal microbial communities, including those harbouring different phosphatase genes. Future work associating differences in microbial community structure and function with above-ground differences in plant communities and plant dependency on P uptake will further our understanding of soil P cycling by microbial communities and their wider contribution to ecosystem dynamics.

Keywords: biological P cycling, pedogenesis, amplicon sequencing, co-occurrence networks

Acknowledgments: This research was supported by funding provided by Lincoln University (L. Condron) and Natural Sciences and Engineering Research Council (Canada) Discovery Grant (K. Dunfield).
Thursday 30, November

Session V. Interactions between the biogeochemistry of organic phosphorus and other elements in terrestrial and aquatic ecosystems.

KEYNOTE

Role of soil biology and organic phosphorus in improving phosphorus use efficiency in agroecosystems

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Inputs of phosphorus in the form of water-soluble mineral fertilizers derived from phosphate rock are required to increase and maintain the productivity of managed ecosystems (agroecosystems). In most cases only a small proportion (10-25%) of the fertilizer phosphorus is utilized by plants during the growing season following application. This low level of phosphorus use efficiency is mainly attributed to adsorption of inorganic and organic phosphorus on oxide surfaces, which substantially reduces bioavailability and results in significant ongoing accumulation of residual or legacy phosphorus in soil. Organic and biotic forms of phosphorus account for up to half of the total phosphorus present in most agricultural soils, and biological and biochemical processes play an essential role in determining the bioavailability of phosphorus at the plant-soil interface (rhizosphere). Ongoing advances in our understanding of how rhizosphere properties and processes influence phosphorus dynamics and bioavailability highlight potential pathways to improve overall phosphorus use efficiency. Biological phosphorus dynamics in the rhizosphere are primarily driven by the supply of readily-available energy in the form of soluble organic carbon contained in root exudates. The quantity and composition of exudates produced by plant roots are determined by a combination of factors including plant species/variety and environmental conditions that govern plant growth. This presentation will describe and discuss recent research relating to the key processes that drive biological phosphorus dynamics in the rhizosphere, together with options for optimizing biological phosphorus cycling in agroecosystems. The latter will mainly concern arable cropping systems and include assessment of the potential use of green manure/cover crops, intercropping, microbial inoculants, and soil amendments to improve phosphorus use efficiency.

Keywords: fertilizers; phosphorus use efficiency; rhizosphere;
Reactive soil minerals as abiotic catalysts for organic phosphorus transformation

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Plant and microbial phosphatases are considered to play a critical role in the dephosphorylation of organic phosphorus (Porg) compounds. In fact, in P cycle models, only this enzymatic process is included for the production of inorganic phosphate (Pi) from Porg. However, recent reports assert that reactive soil minerals such as iron (Fe) and manganese (Mn) oxides, which are well known adsorbents of P-containing species, are capable of catalyzing Porg dephosphorylation. It is imperative to determine the extent of this mineral-mediated organic P transformation towards a comprehensive understanding of P cycling. Using adenosine triphosphate (ATP) as a representative Porg compound, we determined the catalytic reactivity of two common oxide minerals, an Fe oxide (goethite) and a Mn oxide (birnessite). We employed high-resolution liquid chromatography-mass spectrometry for simultaneous quantification for each dephosphorylation organic byproduct: adenosine diphosphate (ADP), adenosine monophosphate (AMP), and adenosine1, in conjunction with UV-Visible spectroscopy for quantification of Pi. Collectively, our analytical protocol allowed us to determine with high accuracy the extent of catalytical reactivity by each mineral. The mineral reactivity rates were within one order of magnitude of reported enzymatic activity rates, thus highlighting the importance of re-evaluating the role of reactive soil minerals within the P cycle.

Keywords: Organic phosphorus; mineral catalysis; reactive soil mineral; abiotic transformation.

Acknowledgments: This research was supported by a grant from the U.S. Department of Energy(DESC0021172).

Emerging phosphorus relations of the novel plant-fungal symbiosis: feremycorrhiza

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Feremycorrhiza (meaning “nearly mycorrhiza”) is a newly discovered symbiosis between plants and the Australian native fungus *Austroboletus occidentalis* in which the fungal partner may confer significant growth and nutritional benefits to host plants without colonising their roots. *A. occidentalis* is a basidiomycete and phylogenetically related to ECM fungi. Our work with 33P-labelled phosphate revealed that fungal hyphae transfer nutrients to the host but do not extend far beyond the rhizosphere. Further recent work has identified that *A. occidentalis* can mobilise water-insoluble P compounds (CaP, FePO₄ and AlPO₄) and that phosphate solubilization is linked with exudation of organic acid anions by hyphae. The fungus converts solubilized P into long-chain inorganic polyphosphates. *A. occidentalis* does not have the capacity to utilize complex organic matter and lignocellulosic substrates as a carbon source, relying on hexoses such as glucose. Generally, its exudation of enzymes is weak with the exception of alkaline phosphatase. Preliminary evidence suggests alkaline phosphatases may be produced in abundance. In this paper we will explore recent advances and findings in the phosphorus physiology and nutrition for both plant and fungus in feremycorrhiza symbiosis.

**Keywords:** mycorrhizal symbiosis, fungal phosphorus nutrition, phosphatases, carboxylates

**Acknowledgment:** the authors would like to thank CERES, UK for funding part of this work and Aysha Hales-Henao and Alana Rogers for their invaluable assistance with laboratory and controlled environment growth room studies.
Interconnection between abiotic and biotic processes controlling P cycling in redox affected soils

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Organic P cycling in soil is strongly controlled by abiotic processes, including adsorption, precipitation and coprecipitation, which lead the element to be the most inaccessible nutrient for most plants. All these abiotic processes determine the selective stabilisation of inositol phosphates with respect to the other organic P species, linked to their high affinity for iron oxide surfaces, which hamper their degradation and control their fate in soil. Thus, the proportion of different organic P species and the retention by the solid phase is governed by Fe cycling. However, different environmental factors, such as Eh/pH changes, may strongly modify the stability offered by abiotic processes and favour microbial redox-driven transformations and plant responses to improve P bioavailability. In soils experiencing reducing conditions, such as paddies, P compounds may indeed be released into the porewater solution following microbial-driven reductive dissolution of Fe (hydr)oxides and easily migrate to the rhizosphere replenishing the depletion zone determined by plant P uptake. On the other hand, aquatic plants can create a heterogeneous spatial distribution of O₂ and cause the coprecipitation of Fe and P on root surfaces. The formed coprecipitates, the so called Fe plaques, may retain both inorganic and organic P forms and their mineral composition is a function of P species, P/Fe ratio and O₂ rate fluxes. Whether these plaques act as source or sink of P to plants is still matter of debate.

This presentation will show the most recent findings on the main factors that control inorganic and organic P coprecipitation/dissolution at both lab ad field scale and the chemical and mineralogical composition of the formed plaques. Furthermore we will evaluate how the composition and mineralogy of coprecipitates control the release of P. Finally the response of plants to utilize these plaque as source of P will be explored considering also the effects of changing water management technologies. These results will be then used to define new agricultural decision support systems to improve water and nutrient management technologies, fine-tune resource utilization and environmental protection for a greater sustainability of rice agrosystems.

Keywords: anaerobic soils, Eh, oxygen gradient, iron plaque, plant P availability, rice

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Organic Phosphorus (OP) Hot Spots in the Atacama Desert

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Soil biogeochemical cycles in the Atacama Desert (Chile) are mainly controlled by geochemical factors because of its arid to hyper-arid nature. Organic (OP) and microbial P are limited, and soil P is predominantly present as inorganic P (IP) bound to calcium. The aim of this study was to identify specific factors and locations within the Atacama Desert which lead to OP hotspots (defined as locations with much higher OP concentrations than the whole soil). Our own field and lab studies point to four such settings.

Firstly, the coastal fog ecosystems, in Morro Moreno National Park (1), e.g., soil OP can be up to 19 to 26% of Total P (TP) (average of 622 mg TP kg\(^{-1}\)), meanwhile reaching 433 mg OP kg\(^{-1}\) (35% of TP) at 500 masl in Paposo, another fog oasis. Secondly, presence of seabirds, soils at nesting sites have TP contents varying between 700 and 1,300 mg P kg\(^{-1}\), with higher and more variable OP contents (30-550 mg P kg\(^{-1}\)) compared to other desert soils. The highest TP, IP, and OP in garuma gulls (Leucophaeus modestus) nesting sites are recorded in the nearby guano traps, bones, and gull carriions. Thirdly, plant rhizospheres exemplified in the “Yungay Oasis” for S. foliosa and D. spicata, here OP tends to increase with depth reaching values of 57.9 and 66.5 mg P kg\(^{-1}\)respectively at 20 and 25 cm depth. In control soil, OP remains constant up to 20 cm deep, where OP increases from 29.6 to 64.6 mgP kg\(^{-1}\). Finally we associating OP with enhanced organic carbon (OC) content. As in the Atacama Desert OC generally increases with depth (2), so does OP, for example in deep soils (Yungay area) below 2 m depth OP peaks of (40 - 87 mg kg\(^{-1}\)) were observed. Our work suggests that specific locations at the Atacama desert such as: deeper soil, more carbon rich vegetated parts, coastal fog ecosystem, soils from bird colonies may with high proportional OP content in relation to TP.

Keywords: Atacama Desert, hyper-arid soil, phosphorus cycle, plant-soil interaction


References:
3) Fuentes et al. (2022b). EJSS https://doi.org/10.1111/ejss.13217
Sustainable production of food for increasing world population (8 billion in November 2022) is a significant and multi-faceted challenge. Supplying crops with optimal amounts of phosphorus required for crop growth is increasingly problematic because of the scarcity and uneven geographic distribution of non-renewable phosphate rock and environmental pollution associated with use of phosphorus fertilizers (e.g. eutrophication).

Soil organic phosphorus, even though representing a major part of the total phosphorus in many soils, has received relatively little attention. Biological turnover of organic phosphorus has to be considered together with soil carbon cycling. The use (recycling) of organic soil phosphorus can be enhanced by optimizing plant-microbial facilitation (and minimizing competition) in the rhizosphere, bearing in mind that low phosphorus and/or carbon availability may limit organic phosphorus mineralization. Organic phosphorus in the particulate organic matter is likely a more important source of available P (after mineralization) than organic phosphorus in the mineral-associated organic matter in some soil-plant systems. The C:P stoichiometric ratio declines substantially with the distance from the root surface, making organic phosphorus mineralization in the rhizosphere faster than in the bulk soil. The improved use of organic soil phosphorus is essential in sustainable intensification of food production.

**Keywords:** crop nutrition, organic phosphorus, microorganisms, soil organic matter, rhizosphere
Carbon-based nutrient sources including biosolid, manure, and compost are increasingly used in mainstream agriculture including arable, grazing and horticultural farming systems to increase carbon storage in soil, thereby improving soil health productivity. There have been increasing interests in the conversion of these carbon-based nutrient sources into biochar in order to reduce the rate of decomposition, thereby enhancing carbon sequestration in soils. However energy is required to initiate the pyrolysis process during biochar production which can also lead to the release of greenhouse gasses. Alternative methods can be used to stabilize C in composts and other organic residues without impacting their quality. Addition of clay materials to carbon-based nutrient sources have been shown to decrease the rate of decomposition, thereby increasing the stabilization of carbon. The objective of the study is to examine the effect of stabilization of carbon in carbon-based nutrient sources using clay materials on the transformation and bioavailability of phosphorus and nitrogen in soil. A number of carbon-based nutrient sources including biosolid compost, farmyard manure, fish manure, horse manure, pig manure, poultry manure, and spent mushroom compost and food waste compost were used in this study. The effect of allophanic clay on the stabilization of C in these organic amendments was examined by monitoring the release of carbon-dioxide using respiration experiments. The effect of carbon stabilization on the fertilizer value of these carbon-based nutrient sources was examined by monitoring bioavailable nitrogen (i.e., potentially mineralizable nitrogen) and phosphorus (i.e., Olsen P), and plant uptake of these nutrients using a plant growth experiment. The results have indicated that while clay addition achieved carbon stabilization in carbon-based nutrient sources, it did not negatively impact the fertilizer value of these nutrient sources.

Keywords: Carbon-based nutrient sources; organic phosphorus; organic nitrogen; mineralizable nitrogen; bioavailability

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1. Oyetunji, O., Bolan, N. & Hancock, G. (2022), A comprehensive review on enhancing nutrient use efficiency and productivity of broadacre (arable) crops with the combined utilization of compost and fertilizers Journal of Environmental Management. 317, 115395
Session I. Role and function of soil organic phosphorus in sustainable land management

**Poster presentations**

The potential of mineral-treated biochar to remove phosphate from wastewater to use it as an alternative phosphorus fertilizer source.

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Although biochar has been used to remove phosphate from wastewater, the efficiency is low because biochar usually possesses a negative surface charge. Mineral-coated biochar is suggested to enhance the removal of phosphate from wastewater; however, it is unclear whether phosphorous (P) adsorbed to mineral-coated biochar are readily available for plants across a wide range of soil pH. Hence, this study is aimed to: (i) determine whether the type of cation influence phosphate removal efficiency of mineral-coated biochar, (ii) elucidate whether the inter-play between soil pH and coated-cation govern P availability from P-laden mineral-coated biochar, and (iii) determine the effect of P-laden mineral-coated biochar addition on soluble soil P fractions. Accordingly, coffee husk biochar was coated with different minerals, namely (i) MgCl2 (MBC), and (ii) FeCl2 (FBC. The uncoated biochar (UBC) was used as a control. The results showed that MBC increased phosphate removal from manure wastewater by 35%, and FBC by 25%, compared to UBC (p < 0.001). The maximum P adsorption capacity (Q_m) was 10 mg P g⁻¹ for MBC and FBC, and 5 mg P g⁻¹ for UBC (p < 0.001). Mineral-coated biochar increased P uptake by twofolds under acidic soil (pH = 4), by 60% – 90% under moderately acidic soil (pH = 6), and by 40% – 75 % under alkaline soil (pH = 8) compared to untreated biochar. Similarly, mineral-coated biochar increased water-soluble P, microbial biomass P, and plant biomass compared to UBC. Overall, P release from MBC decreased with increasing soil pH, but on the contrary, it tended to increase for FBC, illustrating that soil pH – and – cation interaction should be considered while designing P-loaded mineral-coated biochars for slow-releasing fertilizer.

**Keywords:** Treated biochar; microbial P; P Uptake; soluble P; soil pH; wastewater

**Acknowledgments:** To Ethiopian Institute of Agricultural Research for funding as an MSc research grant, and to African Plant nutrition Institute for awarding this project as a recipient of 2021 young African phosphorus fellowship award.
Soil aggregation is the process by which soil particles bind together, forming aggregates or clumps. It is a vital process that influences soil structure and stability. However, soil aggregation also affects the deposition of organic and inorganic forms and fractions of nutrients like phosphorus (P) in the soil. In this context, the soil aggregation distribution, organic P ($P_o$), and carbon/phosphorus relationship (C/P) were studied by evaluating different land uses in two experimental areas with contrasting soil textures in Brazil. The findings indicate that different land uses on the clay Oxisol have a significant impact on soil aggregation distribution. Specifically, there is a greater tendency for the formation of large aggregates (>9.52 µm) compared to microaggregates (2 – 0.25 µm) and individual particles, such as clay+silt (< 0.25 µm). Integrated systems, such as integrated crop-livestock (ICL), exhibit a distribution pattern similar to that of native forest (NV). In the case of the sandy Oxisol, a higher distribution within macroaggregate (9.52 – 2 µm) classes was observed, particularly in agricultural systems such as integrated crop-livestock-forestry system (ICLF), (ICL), and no-till (NT) when compared to NV and extensive pasture (EP). The distribution of $P_o$ in clay oxisol indicates that it tends to accumulate in smaller soil fractions like clay+silt and microaggregates, particularly in NT and ICL systems. However, no clear relationship was observed between soil aggregation distribution and $P_o$ in the sand oxisol. Nevertheless, NT and ICLF showed higher accumulations of $P_o$ compared to other land uses. Through logistic regression analysis, microaggregate categories within clayey Oxisols exhibit a higher likelihood of $P_o$ accumulation. Conversely, lower levels of $P_o$ accumulation are observed in the larger aggregate class of these soils. In contrast, sandy Oxisols display a significant tendency for $P_o$ accumulation within the clay + silt fraction. Land use has the potential to modify its own biogeochemistry, thereby influencing the dynamics of $P_o$ in the soil. These findings offer valuable insights into how different management systems can enhance the availability of P in agricultural systems.

**Keywords:** Organic phosphorus, Land use, Oxisols.
Assessing the promotion of phosphatase activity by soil organic phosphorus concentration in pastures growing in Andisols under inorganic and organic management

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Andisols are well known as high phosphorus (P) retention soils. Accordingly, the development of crop production is a difficult task due to its low P availability which led to yearly P fertilization. Naturally, plants uptake P from the soil by root release of phosphatases enzymes playing a crucial role in organic P mineralization. Recently, it have been stated that organic P availability might enhance the activity of phosphatase in soil. We aimed to assess the promotion of phosphatase activity by soil organic P concentration in pastures growing in Andisols under inorganic and organic management. Soil core samples were collected in paddocks receiving organic (ORG) and inorganic (NPK) fertilization. We sampled a total of 5 sites comprised two paddocks (ORG and NPK) each, including four replicates per paddock. Soils were physicochemically characterized and phosphatase activity, as well as, P fractionation analyzes were performed. The data collected was analyzed by analysis of variance, following normality and homogeneity tests. Additionally, the relationship between variables was determined by principal component analysis (PCA). Soil available inorganic and organic P was significantly higher in soils receiving organic amendments as compared to inorganic fertilizers. Organic fertilizers sources highly increased soil organic carbon, and soil organic matter. In addition, phosphatase activity was highly reduced from a 20 to 63% in soils receiving NPK management as compared to ORG. Furthermore, shoot biomass in two sites managing with NPK was 7-9% less than ORG sources, while NPK was higher than ORG in the other three sites from 9.5% to 23%. We found that organic P in soil was placed in the same dimension of phosphatase activity in PCA, where sites were clearly separated by soil P fractions, while treatments showed a similar behaviour. We concluded that Andisols managed with organic fertilizers were able to maintain biomass production as compared to inorganic sources. However, organic amendments enhance the conditions of plant growth. Additionally, soil phosphatase activity was promoted by the input of organic P. Thus, organic sources could ensure food security and recover soil quality.

Keywords: Organic phosphorus; phosphatase activity; organic pasture management; Andisols.

Acknowledgments: To the Scientific and Technological Bioresource Nucleus (BIOREN) for equipment facilities, and FONDECYT projects n°3210228; 1181050, 1201257.
Biowaste materials have been proposed as viable sources for producing organo-mineral fertilizers (OMF). However, due to variations in raw materials and composting conditions, the chemical properties of organic materials exhibit significant variability. This variability could extend to OMFs, potentially leading to unpredictable interactions between soil and the organic and inorganic components of OMFs. This study aimed to assess whether OMFs derived from different biowaste materials would differentially impact nitrogen (N) and phosphorus (P) availability in soils, consequently affecting nutrient use efficiency by maize (Zea mays). Green compost (GC) from pruning residues, municipal solid waste compost (MSWC) and manure based vermicompost (VC) were combined with diammonium phosphate, ammonium sulfate and urea to achieve an OMF with a targeted content (%) of organic carbon (Corg), nitrogen (N), and phosphorus (P) at 7.5-10-2.1, respectively.

These OMFs underwent a 10-day incubation without plants, as well a 30-day pot trial involving maize cultivation. Additionally, a peat-based OMF and a mineral fertilizer treatment served as controls. Post-incubation, no differences were observed in N-NH₃, NO₃, Norg, or total N levels between the four OMFs and the mineral control. Nevertheless, MSWC and VC demonstrated a substantial reduction (76-94%) in the combined water and bicarbonate extractable P, with MSWC showing a smaller decrease (19%) relative to the mineral control and peat-based OMF. Furthermore, GC, MSWC, and VC OMFs increased the residual P (34-41%)—typically linked to the organic P fraction in soil—compared to the mineral control and peat OMF. This rise in the organic P fraction was correlated with a reduction in P use efficiency (16-21%) and dry matter production (-2 mg DM kg⁻¹ soil), compared to the mineral control and peat OMF. This finding suggested that OMF immobilized P did not mineralize within the 30-day timeframe. Biowaste-derived OMFs affected differently available P in soil, but all them have the potential to increase the organic P fraction in soil, potentially decreasing P fixation to soil minerals. However, it is advisable to avoid using these OMFs for short-term crops due to the observed reductions in P use efficiency.

**Keywords:** biowaste; organo-mineral fertilizer; nutrient availability; residual phosphorus.

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**References:**
Soil Nutrient Dynamics affected by Grassland–Cropping Rotations and Boosted by Nitrogen Fertilization

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Grassland-cropping rotations offer several benefits to the farming system, including nutrient cycling and soil fertility improvements. However, the effect of the frequency of rotation of grassland within grain crops is not fully understood. Therefore, the objective of our study was to analyze the long-term effects of integrating grassland sequences within rotations of arable crops on the dynamics of soil nutrients leaching (particularly phosphorus [P]) and tissue export, and contents of soil carbon (C), nitrogen (N), P, potassium (K), calcium (Ca), and magnesium (Mg), in the Lusignan national long-term observatory, western France. Five treatments were distributed in randomized complete blocks, with four replications: i) pure arable crop rotation of maize/wheat/barley; ii) rotations of maize/wheat/barley followed by three years of mowed grasslands (C3G3); iii) rotations of maize/wheat/barley followed by six years of mowed grassland (C3G6); iv) rotations of maize/wheat/barley followed by six years of mowed grassland under low N fertilization rate (C3G6N-); and v) a long-term mowed grassland (G). All treatments decreased the soil surface P, K, Ca, and Mg contents in 43%, 63%, 9%, and 28%, respectively. The rotation systems with the presence of grassland and high N fertilization had the highest nutrient export, especially P, due to the higher biomass production. On the other hand, they also had the highest soil organic carbon (SOC) content and the lowest soil N leaching, 269% lower than the purely agricultural system. Therefore, grassland-cropping rotations with nitrogen fertilization prove to be viable options for improving soil fertility and reducing nutrient losses. However, the monitoring and replacement of nutrients should be done frequently, so that soil fertility and crop productivity are not compromised. N fertilization plays a key role in the dynamics of macronutrients in the soil, by increasing the production of grassland biomass, nutrient export, and their depletion in the soil.

Keywords: soil organic matter; phosphorus leaching; grassland; crop rotation; Lusignan observatory.

Acknowledgment: We acknowledge technical staff from the SOERE long-term observatory and funding by INRAE, CNRS INSU and the region Nouvelle Aquitaine.
Evaluation of the solubilization capacity of inorganic phosphates by bacteria isolated from rhizospheric soils of the commune of Lonquimay.

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Phosphorus in the soil is crucial to ensure optimal plant growth. It is reported that plants obtain phosphorus from the soil in the form of phosphate ions, but it is often limited in quantity and not readily bioavailable to roots. Therefore, the application of microorganism such as bacteria is an alternative that seeks to increase the bioavailability of inorganic phosphorus to plants. The objective of this research was to evaluate the phosphorus solubilization capacity of bacteria isolated from rhizospheric soil, the native petrophytum caespitosum plant, endemic to Lonquimay. Said phosphate solubilizing capacity was evaluated qualitatively, following the methodology of Nautiyal. Ten bacteria were selected to evaluate the phosphate solubilizing capacity, using the solid culture medium with phosphate (NBRIP) whose composition per liter was 10 g of glucose, 2.5 g MgCl₂, 0.25 g MgSO₄, 0.2 g KCl, 0.1 g (NH₄)₂SO₄, and 15% agar, pH 7.0) supplemented with 2 g Ca₃(PO₄) and with FeO₄P. The medium was sterilized at 121°C at 1 atm for 15 min in an autoclave and then poured into sterile 121-mm Petri dishes. Once solidified, they were inoculated according to the numbered order on the plate. The preparation and inoculation of the plates was done under the laminar flow chamber. The cultures were allowed to grow for 5 days at 28 °C, in an incubator. The results obtained showed that 27% of the strains showed phosphate solubilization activity, the bacteria C4r (Pseudomona sp) had formation of a halo in the medium supplemented with Ca₃(PO₄), which are indicative of the solubilization capacity of the bacteria from the Ca₃(PO4) phosphate source. In conclusion, the biotechnological importance of phosphate solubilization by native soil bacteria lies in the fact that it could be an alternative to some synthetic growth promoter, covering multiple areas of application. These bacteria play an essential role in improving phosphorus bioavailability in soils, which has positive implications for both agricultural production and environmental sustainability.

Keywords: Inorganic phosphorus; solubilizing bacteria; bioavailability.

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References:
Strigolactones modulate the plant response induced by sparingly available inorganic and organic phosphorus forms

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Phosphorus (P) is an essential nutrient for plant growth, actively engaging in primary cellular metabolic processes while serving as a structural component of key biomolecules. Soil processes encompassing adsorption, precipitation, and coprecipitation can limit P bioavailability. This, in turn, leads to restrained plant growth and excessive use of P fertilizers, with adverse impacts on the environment and progressive depletion of P reserves. In response to the challenges posed by P limitation in soil, plants orchestrate intricate adaptations that include an array of growth, development, and metabolic adjustments, aimed at increasing P-acquisition and utilization efficiency. Recently, strigolactones (SLs) have emerged as newly defined hormones that mediate multiple levels of morphological, physiological and biochemical changes in plants as part of the P acclimation strategies to optimize growth. Therefore, understanding the soil processes affecting P availability and P acquisition strategies by plants can contribute to improved agronomical practices, fine-tune resource utilization and environmental protection, and the development of plants with high P use efficiency for enhanced agricultural productivity.

Therefore, we present recent advances in elucidating the role of SLs in the complex P signalling pathway, with a special focus on their role in controlling the release of P from sparingly accessible inorganic and organic P forms present in soil.

Keywords:
Root exudates, root morphology, phosphate, inositol phosphates, agricultural productivity, resource utilization

Acknowledgments: This study was partly carried out within the Agritech National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors’ views and opinions, neither the European Union nor the European Commission can be considered responsible for them.
Maize and soybean intercropping facilitates soil organic phosphorus transformation driven by phosphatase activity in red soil under different phosphorus application rates

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Intercropping facilitates phosphorus (P) turnover and enhances P acquisition. However, the underlying mechanism of intercropping promotes P transformation in red soil is poorly understood. Here, we present a long-term field experiment of maize/soybean intercropping under different P application rates (0, 60, 90, and 120 kg P ha⁻¹) in red soil to investigate the potential transformation mechanisms of soil organic P (Po) using sequential extraction. The results revealed that compared with monoculture maize, maize/soybeans intercropping significantly enhanced P uptake by 45.5% to 76.8% at all P application rates. Simultaneously, varying rates of P application led to a substantial increase in the content of soil labile P pools by 14.4% to 82.1%, coupled with a decrease in the content of non-labile P pools by 6.6% to 11.5%. In which the labile Po increased by 9.7% to 98.8%, and moderately-labile Po decreased by 9.8% to 18.8%, the non-labile Po decreased 7.1% to 11.8% (except P120). In addition, intercropping at various levels of P application resulted in a substantial augmentation in acid phosphatase activity (ACP) ranging from 9.5% to 13.4%, as well as an increase in alkaline phosphatase activity (ALP) ranging from 19.9% to 28.6%, as compared to monoculture. Structural equation modelling (SEM) showed that intercropping could raise soil P bioavailability by boosting ACP and ALP activities which directly or indirectly affect Po turnover. Hence, the enhanced of P bioavailability of the maize/soybean intercropping probably resulted from a complex effect of transforming non-labile P pools into labile P pools and moderately-labile P pools by increasing phosphatase activity in red soil. These results reveal the mechanisms of organic P turnover through diversity planting patterns.

Keywords: maize/soybean intercropping; P transformation; phosphatase activity.

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Impact of high intensity cropping on soil organic phosphorus fractions in Himalayan plains of Chenab-Ravi basin

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Phosphorus is a major part of DNA, RNA, and ATP, and is essential for genetic information and energy transfer in cells. Soils contain inorganic, organic, and soil solution P, with organic P being the most common at 20-80%. P fractions in soil vary in mobility, bioavailability, and chemical behaviour, and can change in certain conditions. Cropping intensity has significant impacts on nitrogen and phosphorus pools. We studied the impact of intensified cropping systems (with long history of >4 years) under five diverse cropland ecosystems on nitrogen and phosphorus pools in relation to changed substrate availability and fertilizer application. The treatment details include: T₁-Basmati rice-Wheat -Cowpea, T₂- Basmati Rice-Potato—Wheat-Mixed Fodder (Maize+ Cowpea + Charnii), T₃-Basmati Rice-KnolKhol-Potato-Greengram, T₄- Basmati Rice- Radish- Green onion-French bean vegetable-Okra and T₅-Rice- Fenugreek- KnolKhol-Green onion-Dry Onion-Black gram. The samples were taken from three depths i.e 0-5, 5-15 and 15-30 cm in kharif season. The value of available phosphorus and labile organic phosphorus showed significant difference at 0-5 cm soil depth with the highest value in T₂- Basmati Rice-Potato-Wheat-Mixed Fodder. Moderately labile phosphorus was highest under T₂ (156.08 mg kg⁻¹) at 0-5 cm and at 5-15 cm the highest value was also recorded in T₂ (151.30 mg kg⁻¹). The maximum values of non–labile organic phosphorus was obtained in T₅- Basmati Rice- Radish- Green onion-French bean vegetable-Okra (37.02 mg kg⁻¹) at 0-5 cm soil depth. The application of organic manures along with fertilizers and their decomposition released organic acids and boost various phosphorus fractions. At regional scale, more diversified cropping system appears to be promising cropping practices that sustains nitrogen and phosphorus show clear soil sustainability.

Keywords: Fractions, Cropping intensity, phosphorus fractions, randomized, labile phosphorus, manures.

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Organic P dynamics in paddy soils and their role in rice P uptake

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In rice soils the chemical speciation of phosphorus (P) is largely controlled by iron (Fe) cycling. If in aerobic soils P is strongly retained by metal (hydr)oxide surfaces, in anaerobic paddies, P compounds may be released into the porewater solution following microbial-driven reductive dissolution of Fe (hydr)oxides and re-precipitate when redox conditions change. These processes involve both inorganic (Pi) and organic P (Po) and are affected by the total P content, although the extent and mechanisms underpinning Po redox-driven changes have been scarcely investigated. Moreover, organic P compounds may be, in parallel, hydrolyzed by soil enzymes, feeding the Pi pool and creating a very dynamic and complex system that affects plant P availability. Thus, this study aimed to determine the composition and distribution of Pi and Po forms before and after rice cultivation under flooding conditions in soils differing for their total P content.

Three groups of paddy soils with low, medium, or high P content were subjected to a sequential chemical extraction to investigate the distribution of Pi and Po into soluble (0.1 M CaCl2), exchangeable (anion exchanging resins), redox-sensitive (acid ammonium oxalate), and residual pools before and after 60 days of rice cultivation. On the same soil samples, the organic P composition and its changes after cultivation were determined by 31P NMR spectroscopy, along with the activity of soil phosphomonoesterase.

The results showed that the amount of Pi and Po pools was related to the total soil P content, although differences between high and medium P soils were much higher than between medium and low P soils and largely varied according to the strength of each extractant. Organic P composition was also related to total P content, although the abiotic redox-driven processes and the plant responses to limited P availability differently contributed to organic P turnover. Inositol phosphates, the predominant Po form in the high P soils, resulted preferentially stabilized by Fe-P coprecipitation phenomena, whereas in low P soils glycerolphosphate and mononucleotides dominated in the soils before cultivation and decreased with rice growth, likely due to enzymatic hydrolysis to respond to plant needs.

Keywords: paddy soils, organic phosphorus, 31P NMR, chemical extraction, P pools

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Biotechnological strategies for improving phosphorus availability in agroecosystems

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The main concern worldwide is how to maintain food security by growing rate of the global population. Considering that have been estimated a growth of 30% of the global population by 2050 (9.2 billion people). In this context, nitrogen (N) and phosphorus (P) nutrients as fertilizer play a key role to support commercial-scale production of crops food. Considering that P is a finite resource and continued inputs are required to maintain the productivity of agroecosystems under sustainable scenario. The aims of this research were 1) to enrich available P content in manure stabilized waste by biotechnological processes and 2) to develop biofertilizer strategies to improve P plant acquisition from soils based on P enrich manure-bacteria-enzyme complexes. According to enrich P in stabilized manure, cattle dung was inoculated with natural inoculum (microorganisms from cattle dung). Four Biofertilizer were developed from the enriched P-available compost. B1: beads of compost; B2: beads of compost + bacteria consortium, B3: beads of compost + Phytase-complex (QUANTUM BLUE EXP, E. coli 1,000 U g-1), and B4: beads of compost + bacteria consortium + Phytase-complex. The aerobic degradation conducted showed an increase of total P about two fold, the labile P (water+bicarbonate fractions) was maintained around 40% and a significantly reduction of residual fraction was observed. In addition, pot experiments showed an outstanding effect in shoot P from biofertilizers regarding to conventional fertilization. Moreover, there was not significant differences on dry matter yield between conventional fertilizer, B3 and B4. Finally, our preliminary results may suggest the development biofertilizers as a suitable and competitive alternative to conventional fertilizer enhancing the plant P acquisition.

Keywords: P acquisition; biofertilizer; compost; food security; P recourse

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Red guano: an interesting phosphorus source on hazelnut growth plants

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Due to the favourable agroclimatic conditions for hazelnut cultivation, Chile is key targeted to increase I+D+i in the field of nut production, considering a medium to long-term vision that allows to close the gaps of sustainability fruit crops. From 2021/22 season, the Laboratory of Physiology and Nutrition in Fruit Trees (LFNF), has been implemented an experiment to determine the effect of phosphorus (P) application from red guano and phosphate rock in a hazelnut orchard grown in Campo Experimental Maquehue, Universidad de La Frontera (38°50'25.27"S, 72°41'50.80"W) La Araucanía Region. The treated trees correspond to cultivar Bossio (fifth leaf) under conventional production system. In this context, the trees growing in field conditions were performed under three treatments: Control (T0), red guano at 3 Mg ha⁻¹ (T1) and phosphate rock at 220 kg P ha⁻¹ (T2). For 2021/22 season, there was no significant difference on new branches length (cm) between T0 and T1, but those trees treated with T2 showed a 27% increased. Whereas, 2022/23 season T1 and T2 showed a 28 and 44% over T0 respectively for branches and diameter. In the case of tree height (m), for 2021/22 season, both phosphorus treatments showed a 16% (T1) and 36% (T2) higher height than in T0. Red guano was an interesting P source on hazelnut by improving the vegetative structure growth, although in a lesser extension in comparison to phosphate rock. Finally, evaluations continuing for a third season to obtain more conclusive results.

Keywords: Organic amendments; phosphorus supply; hazelnut; vegetative growth; Fertilizer transition.

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Influence of land management and biogeochemical processes on phosphorus leaching in a temporary grassland under temperate climate conditions

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Incorporation of temporary grassland into arable cropping systems offers numerous benefits for addressing the agricultural productivity–environmental sustainability dilemma. Previous studies revealed that both pure crop and grassland systems reduced soil total phosphorus (P) stocks without adversely affecting plant yield after 13 years. On the other hand, soil organic P stocks increased significantly in pure grassland, with changes in specific P compounds1. In temperate agricultural system, vertical leaching is a primary nutrient loss pathway, critical for assessing the resilience of the crop-grassland rotations under varying management and fertilization scenarios. Thus, this study aimed to elucidate the mechanisms behind nutrient leaching dynamics in the long-term crop-grassland rotations across different management and fertilization regimes. To this end, we used a long-term field experiment that was established since 2005 in the Lusignan national long-term observatory, western France, on Cambisol with a temperate climate. The experiment comprised five treatments distributed in randomized complete blocks with four replications, varying in grassland duration (3 or 6 years) and the presence or absence of N fertilization. Zero-tension plate lysimeters at -105 cm depth were installed in two of the four blocks for each treatment in 2004, collecting drainage water between 2005-2019 (62 draining events). Leachates from each event were analyzed for nutrients and ions, including P, NO3-, Ca, K, Mg, etc. Soil humidity before each event and soil redox conditions during each event were assessed using daily temperature, evapotranspiration, precipitation, high-frequency soil volumetric water content, and drainage duration data. We linked leachate chemistry to the soil response to rewetting and soil redox conditions, along with land management and fertilization regimes, to mechanistically explain the temporal and spatial variations in the leachate chemistry. The results evidenced that rewetting of dry soils was the primary driver of P variations in leachates in this temperate site, with pure crop fields exhibiting higher variability due to stronger soil dryness. This study provides a mechanistic understanding of nutrient leaching dynamic in the crop-grassland rotation system, aiding predictions of their resilience to future climate changes, including altered precipitation and global warming.

Keywords: temporary grassland; nutrient leaching; soil phosphorus; dynamics.

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Session II. Nature and biogeochemistry of organic phosphorus in water and sediments

Internal phosphorus loading in a chain of eutrophic hardwater lakes (Canada)
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Sediments can act as a source or sink of phosphorus (P) for the water column of lakes. In eutrophic hardwater lakes, high sediment calcium (Ca) concentrations may control sediment P fluxes. However, relatively little is known about the importance of redox processes across Ca-rich lakes, and key geochemical factors controlling the process in hardwater. Using intact sediment cores from a chain of eutrophic hardwater lakes in Saskatchewan, Canada, we quantified sediment P fluxes under varied conditions, and measured sediment organic (P_o) and inorganic (P_i) phosphorus pools via sequential fractionation and solution P-31 nuclear magnetic resonance spectroscopy. Concentrations of total Ca, magnesium, manganese, iron and aluminum cation pools in sediments were also determined. Results indicated that sediment P flux rates were significantly higher in sediment cores incubated under hypoxic conditions than oxic conditions. Changes in season had no significant effect on internal P loading. Redox-sensitive-bound phosphate was the only sediment P fraction that significantly differed among the lakes, with an inverse relationship to sediment P fluxes. High concentrations of internally generated P_o forms and organic matter in surface sediments appear to play a key role in internal P loading in these lakes. However, sediment Ca appears to have an overriding effect on sediment P, partially masking the impact of redox control on internal P loading in these hardwater prairie lakes.

Keywords: Sediment phosphorus; biogeochemical processes; calcium; sediment cores; P-NMR.

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Session III. Interactions between the biogeochemistry of organic phosphorus and other elements in terrestrial and aquatic ecosystems

How wildfires affects phosphorus dynamics and biota in spatial subsystems of streams and rivers

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Fluvial ecosystems, or freshwater ecosystems with constant flow, are one of the most threatened by climate change. Through spatial structure, there are four spatial subunits in fluvial ecosystems: the central surface stream, hyporheic, parafluvial, and riparian zones. In the case of wildfires, physical settings can be altered, including flooding and mass movement, changes in sediment erosion, nutrient transport/deposition, modifications to channel morphology, and alterations to water temperatures in fluvial ecosystems. The aim of this study is to review the scientific literature on wildfires and the effects of post-fire periods on phosphorus dynamics and associated biota in the four geomorphological subunits of rivers and streams worldwide. The synthesized Boolean algorithm used was: Title: = ("wildfire*" AND "phosph*" AND "biot*" AND stream* OR parafluvial OR hyporhe* OR riparian). Both original research and review papers published between 1970 and 2022 were considered, generating 26,551 records. Finally, only 87 articles were taken into account because they are related to geomorphological subunits and specifically address the effects on phosphorus dynamics and associated biota. The most remarkable results are as follows: i) Depending on the heat intensity reached by the fire and the speed of propagation, can also lead to changes in nutrient transfer processes, laminar flow, erosion, and the arrive of harmful substances such as ash, smoke, and debris. ii) Each subunit presents its own response mechanisms regarding phosphorus increase, depending on the areas adjacent to watercourses and the geometric form of basins. iii) The phosphorus cycle as a transmitter of nutrients from high areas affected by combustion to riparian, hyporheic, and parafluvial subunits in large rivers has been well reviewed, however, compared to the main channel stream, information on these subunits is mostly scarce. iv) Climatic, vegetational, hydrologic, and geologic aspects are associated with both the increase in total phosphorus and the recovery time in post-fire periods, as well as with changes in the structure of biotic communities structure. Long-term monitoring of the rate of change in phosphorus levels, understanding the model species that represent each subunit, and determining the duration of post-fire periods are important issues that need to be addressed immediately.

**Keywords:** climate change; phosphorus export; wildfires and post-fire periods; geomorphological subunits of rivers; fluvial ecosystems.

**Acknowledgments:** Thanks to ANID (Agencia Nacional de Investigación y Desarrollo) scholarship, grant number 21210601 and FAPESP-UFRO Nº2020/06982-3.
Despite extreme water limitations, there is evidence of past and present life forms in hyper-arid climates like the Chilean Atacama Desert. We hypothesize in Coastal Cordilleria of the Atacama life is predominantly sustained by fog, leaving a biological fingerprint in the microbial cycling of soil phosphorus (P). To test this hypothesis, we collected topsoil samples (0‒10 cm) from 54 subsites nearby plant (< 10 cm) and further away (1 m) along aridity gradient from the coastal to the inland region of the Atacama Desert. Satellite-based detection showed that Pacific fog entered the desert to a distance of 10 km from the coast, whereas inland sites (10‒23 km from the coast) received water primarily through infrequent rainfall events. We performed sequential P fractionation and determined oxygen isotope composition of HCl-extractable phosphate ($\delta^{18}$O$_{\text{HCl-Pi}}$) to assess microbial imprints on soil P cycling Total P (Pt) concentration was found to exponentially rise from < 340 mg kg$^{-1}$ to a maximum of 1021 mg kg$^{-1}$ at the hyper-arid sites ≥ 10 km away. This trend was accompanied with increasing quantities of inorganic P (Pi), whereas the organic P (Po) contents fluctuated. The $\delta^{18}$OP values of HCl-extractable Pi (mainly present as Ca-P) exhibited a negative correlation with its contents. Soil $\delta^{18}$O$_{\text{HCl-Pi}}$ values decreased exponentially with increasing distance from the coast from 18‰ to a minimum of 10 ‰ at sites ≥ 10 km away (< 5% fog occurrence frequency). This highlighted that fog, left an isotopic microbial fingerprint in soil phosphates, with 27‒81 % of Ca-P resulting from a re-precipitation from biologically cycled phosphate in the fog-affected areas. Intriguingly, the presence of plants did not significantly affect Ca-P pool sizes and their $\delta^{18}$O$_{\text{HCl-Pi}}$ signatures, in line with the assumption that plant growth patterns reflect more recent water abundance and not the past biological imprint. We conclude that biological P cycling in the hyper-arid Atacama Desert is predominantly mediated by fog, which also controls apatite dissolution rates and related occurrence and spread of microbial life in this extreme environment.

**Keywords:** Atacama Desert; Soil P; Fog; Hyper-aridity; Phosphate-oxygen isotope
N:P Ratio and the Nature of Nutrient Limitation in some natives species from Southern South America.

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Temperate rainforest ecosystems are known for their diverse and unique plant communities, which are adapted to growth in a wide range of edaphic conditions. Little is known about the nutrient limitations that shape these ecosystems, especially concerning nitrogen (N) and phosphorus (P), the two main elements that limit plant growth. This study aims to investigate the N:P ratio and its relationship to nutrient limitation in native plant species inhabiting temperate rainforests from southern South America. For this, we collected leaves of several species (among trees, bush, climbers and ferns) and soil samples in four collection sites. The leaf N and P concentrations and the soil chemical properties were determined. The leaf N:P ratio was used as an indicator of N or P limitation, where values < 10 indicate N limitation, values > 16 indicate P limitation, and values between 10 and 16 indicate that plant growth is equally limited by N and P. The results showed that N:P ratio for plants varies depending on species, plant classification, growth form, and soil type where they grow. The plant communities growing in the site with the lowest soil N:P ratio showed mainly P limitation. In contrast, the plant communities growing in the site with a balanced soil N:P ratio showed N limitation or co-limitation by N and P. Sites with higher soil N:P ratio showed that about 50% of the tested species presented co-limitation by N and P in their leaves. Among growth forms, Hemiparasite and Mosses are more limited by N, whereas other growth forms are co-limited by N and P. Overall, this study contributes valuable information regarding N or P limitation in native plants of Southern South America. Understanding the nature of nutrient limitation can aid in the conservation efforts of these unique ecosystems, for example, by managing these species in their production.

Keywords: Acid soils; Native species; South of Chile.

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Phosphorus speciation in a Brazilian Cerrado Oxisol under long-term tillage and phosphate fertilization management

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Unraveling fertilizer's long-term conversion within soil P forms is essential for optimizing P sustainability in agriculture. In this study, we investigated P speciation in Brazilian Cerrado Oxisol under different management systems using a combination of P fractionation, P K-edge X-ray absorption near edge structure (XANES) spectroscopy, and solution 31P nuclear magnetic resonance (31P-NMR) spectroscopy. Topsoil (0-5 cm) samples were obtained from soils under two soil management (conventional-CT and no-tillage-NT), two sources of P (triple superphosphate-TSP and phosphate rock-PR), two rates (22 and 44 kg ha⁻¹ year⁻¹ of P) and two controls (0 in CT and NT) in a long-term (22 years) field experiment. The total P concentrations ranged from 1,102 to 454 mg kg⁻¹, with high contribution of occluded P (42 to 75%), mainly in controls. In NT, compared to CT, the P concentrations was higher in all P pools: 100 vs 25 mg kg⁻¹ for labile; 265 vs 140 mg kg⁻¹ for mod-labile; and 487 vs 331 mg kg⁻¹ for non-labile. Also, the NT increased organic P (POHID) (93 vs 63 mg kg⁻¹, NT vs CT). The highest POHID (114 mg kg⁻¹) was verified in NT with application of 22 kg ha⁻¹ year⁻¹ of P, regardless of source; and the lowest was observed in control-CT (30 mg kg⁻¹). Based on XANES results, the predominant P compounds were P-Fe (up to 64%) and P-Al (up to 46%), except with highest P dose by PR in NT, where P-Ca represented 36%; and highest contribution of organic P was found in control-NT (12%). According to the 31P NMR spectra, orthophosphate and monoesters were the dominant P species, but small amounts of diesters and pyrophosphate were also found. Phosphorus addition decreased orthophosphate diesters. The organic P and P bioavailability are affected most by soil management. Our integrated approach utilizing P fractionation, XANES, and 31P-NMR provided valuable insights into how soil management affects soil P forms in the long term, offering key strategies to enhance P availability in agricultural systems.

Keywords: P fractionation, XANES, 31P NMR, P species.

Acknowledgment: This research was supported by São Paulo Research Foundation (FAPESP) grant #2020/09593-8 and #2022/07795-8.
Applying β-propeller phytase gene as marker to explore the occurrence of Bacillus velezensis FZB42-like strains during germination of vegetables.

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Under favorable environmental stimuli (light, temperature, water, and soil nutrients), coordinated biochemical and molecular processes are triggered during seed germination, where endophytic bacterial communities in seeds rapidly respond and adapt. In this context, phytate (myo-inositolhexakaphosphate) represents the main storage form of organic phosphate (Po) in seeds and studies have reported diverse soil- and plant-associated Bacillus able to release inorganic phosphates (Pi) from phytate by β-propeller phytase activity. We have also preliminarily observed the presence of Bacillus velezensis FZB42-like strains, a recognized PGPB, as part of seed microbiomes in some vegetables traditionally commercialized and exported. However, the role of seed-borne Bacillus on cycling and releasing Pi from Po during the seed germination and early stage of growth of plants remain largely unexplored.

Here, we used specific primer set for Bacillus β-propeller phytase gene to explore the occurrence of Bacillus velezensis FZB42-like strains during germination of Lactuca sativa (lettuce) and Solanum lycopersicum (tomato) by qPCR. In general, our preliminary results did not show positive reactions for Bacillus velezensis FZB42-like in DNA extracts of seeds and seedlings (7 days after germination). In contrast, positive reactions were observed in DNA extracts of seed-borne Bacillus velezensis FZB42-like strains (S-30, S-23 and P-28), but not in seed-borne strains belonging to other taxonomic affiliations (Paenibacillus sp. strain P-81, Arthrobacter sp. strain P-56, and Stenotrophomonas sp. strain P-96). When seeds were inoculated with Bacillus sp. strain S-30 by liquid-soaking (2h in 0.8% NaCl at 0.5 McFarland turbidity), germinated, and grown for 7 days, positive reactions were observed in L. sativa and S. lycopersicum seedlings. Interestingly, a higher growth was observed in S. lycopersicum seedling inoculated with Bacillus sp. strain S-30. Here we preliminary demonstrated that specific primer set for Bacillus β-propeller phytase gene can be useful to monitor the Bacillus velezensis FZB42-like strains during germination and early stages of vegetables. Further, assays will be displayed to explore the expression of β-propeller phytase gene of endophytic bacteria during germination in absence and presence of phytate or another substrate containing Po.

Keywords: Bacillus, germination, phytase, seeds, vegetable.

Acknowledgment: FONDECYT project no. 1201386 and 1221228.
Phosphorus (P) cycling in rice soils has always been related to the reductive dissolution of iron (Fe) oxy(hydr)oxides occurring during continuous flooding (CF). However, the oxygen leaks from rice roots create a redox gradient in the rhizosphere, which causes the coprecipitation of the released Fe and P with formation of Fe plaque on rice roots surfaces. The latter can retain both inorganic (Pi) and organic (Po) forms as a function of mineral composition, but the extent and the mechanisms of retention remain largely unknown. Water saving practices can further influence Fe plaque mineral composition, with changes on Pi and Po retention mechanisms and their availability to rice plants.

The effect of water saving techniques on Fe plaque mineral composition and P retention/release mechanisms was thus investigated. Rice plants were grown in mesocosms filled with a P-limited soil and subjected to CF or alternating wet and dry (AWD) practices. Fe and P release into the soil porewater was periodically measured during plant growth. Rice plants were collected in the main phenological stages and Fe plaque separated from roots. Fe plaque mineral composition was evaluated by sequential extraction with acid ammonium oxalate and dithionite–citrate–bicarbonate, and P forms characterized and quantified by FT-IR and synchrotron based XANES spectroscopy.

Under CF, high levels of Fe(II) and P were found in the porewater solution, whereas AWD decreased the Fe(II) release, proportionally more than P. As a result, Fe plaque formed under AWD had a higher P/Fe ratio and were mainly composed by poorly Fe (hydr)oxides, while CF led, surprisingly, to the formation of a predominant crystalline phase. Both Pi and Po forms were detected in the Fe plaque with greater amounts of Po forms (mostly inositol hexaphosphate) in CF than AWD, probably related to their higher affinity for poorly Fe (hydr)oxides than Pi. Conversely, AWD caused a greater retention of Pi, which was in turn highly correlated to plant P uptake. Our results indicate that water saving practices can affect not only Fe plaque mineral composition, but also the retention/release of Pi and Po forms, thus strongly impacting P availability to rice plants.

**Keywords:** iron plaque, paddy soils, organic phosphorus, XANES, FT-IR

**Acknowledgments:** Research carried out in the framework of the project "Fosforo in risaia: equilibrio tra produttività e ambiente nell’ottica delle nuove pratiche agronomiche" funded by Regione Lombardia d.d.s. March 28th - n. 4403.
Phosphorus Deficiency Induces Upregulation of Organophosphorus Compound Uptake Proteins by Phosphobacteria: Insights from Proteomics

Barra, P.J., Delgado, M., Durán, P., Rodríguez, R., Mendez, I., Becerra, N., Saldivar, M., Claverol, S., Mendoza, J., and Mora, M.L.

Acidic soils in southern Chile, including Andisols and Ultisols, are characterized by a high capacity for phosphorus (P) fixation. Consequently, these soils often exhibit substantial total and organic P content but limited P availability for plant nutrition, leading to reduced crop yields. Phosphobacteria have shown the potential to enhance plant growth in acidic soils by increasing P availability through solubilization and mineralization. However, the enzymatic mechanisms employed by these bacteria to release organic P retained in the soil remain incompletely understood. This study used label-free quantitative proteomics to evaluate the response of three Al-tolerant phosphobacteria, Enterobacter sp. 198, Enterobacter sp. RJAL6, and Klebsiella sp. RCJ4, to P deficiency. These strains have previously demonstrated their ability to enhance plant growth under conditions of P deficiency and Al toxicity, common stressors in acidic soils.

The strains were cultivated in mineral media with varying P concentrations, sufficient P+ (1.40 mM) and deficient P (0.05 mM). Total proteins were extracted during the late exponential phase of growth and subjected to high-throughput proteomics analysis. More than 1,800 proteins were identified in each treatment and strain. The results confirmed that a main strategy of plant-associated bacteria to acquire and compete for P is to produce enzymes responsible for the mineralization of P-containing organic (organophosphorus or organophosphates) compounds, such as alkaline phosphatase, as well as transporters involved in the uptake of organophosphorus compounds such as phosphomonoesters, phosphonates, and glycerol-3-phosphate. The knowledge generated in this study is crucial for understanding bacterial behavior in acidic soils, which in turn will be important for developing efficient biofertilizers for crops grown in acidic soils.

Keywords: Phosphobacteria; Proteomics; Acidic soils; organophosphorus compounds

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References:
Selenium (Se) is an essential micronutrient with significant implications for plant growth and human nutrition. In recent years, biofortification by using Se nanoparticles (SeNPs) has emerged as a promising alternative to conventional Se fertilizers. However, the interaction between Se and other essential nutrients in crops of key foods still remains unclear. Phosphorus (P) is an essential nutrient for the growth of plants and exhibits comparable ionic chemical characteristics to Se. Therefore, the generation of comprehensive studies concerning the associations of P and Se becomes necessary as the existing literature is limited and presents contradicting findings regarding the correlation between these inorganic elements in wheat plants. Thus, the aim of this study was to evaluate the availability of Se and P in the soil-plant system in response to SeNPs application in wheat plants to elucidate the possible effect on the uptake of both elements. The experiment was conducted using pots filled with an Andisol under greenhouse conditions from November to March 2023. Wheat seeds (*Triticum aestivum* L. cv. Fritz) were pelleted with Se at a concentration of 2 mg per kg soil, utilizing different Se sources (Na₂SeO₃) as inorganic Se control and two biogenic SeNPs: E-SeNPs and B-SeNPs, respectively. After harvest, total Se and P levels were determined in plant tissues and soil, according to Kumpulainen et al. and Sadzawka et al., respectively. Results revealed that the interaction between Se and P in roots and shoots was evident. Supplying selenite led to decrease the concentration and accumulation of P, but increased Se levels in roots. Alternatively, the addition of B-SeNPs resulted in an increase in root phosphorus (P) content with a slight inhibition of selenium (Se) absorption by the roots. Moreover, it was observed a proportional relationship between Se and P levels in shoots in all cases. No significant changes were observed in the Se and P concentration of soil and grains. We conclude that there is a strong competition between P and Se based on their availability to plants, being that different according to the Se source applied and plant samples analyzed. Our findings improve our understanding of the interaction of P and Se in plants and our ability to more effectively regulate the nutritional quality of wheat grain via the application of P and Se fertilizers in agricultural practice.

**Keywords:** selenium nanoparticles; phosphorus; availability; biofortification; *Triticum aestivum*

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Organic phosphorus evolution through soil incubation with N and its relation with C mineralization

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In soils, crop production often is limited by low P availability despite of high total P contents, mainly in the form of organic P, which is sorbed strongly to the mineral phase. The aim of this study was to examine the possibility of mobilizing this organic P by addition of N fertilizer. To this end we used urea application to soil and investigated carbon mineralization, and the distribution of organic and inorganic P forms during 60 day under laboratory incubation. Urea increased C mineralization in soils during the 1st day by a 40%, with no further effects until day 60. The proportion of labile P fractions (NaHCO₃-Pᵢ and Pₒ) was higher at the 1st day (4% in average), and relative labile P (NaOH-Pᵢ and Pₒ) was higher at the 7th day and residual P was higher at the end of the experiment (60%), denoting the P immobilization into less available P fraction in the time. However, in soils receiving N fertilizer, exhibited an higher NaHCO₃-Pᵢ that was incremented from 100 to 160 mg kg⁻¹ from day 1 to 60. Also soils in with N addition, NaOH-Pₒ was higher at day 60, but residual P proportion was lowered from 53 to 48%. Meanwhile, soil acid phosphatase activity was highest at the middle of the experiment (day 15) and enhanced with N addition by an 30%. Organic P showed a negative correlation with C mineralization at day 1 (r=-0.58, P<0.05), but a strong positive correlation at day 60 (r=0.90, P<0.01). Furthermore, we observed an higher C/N proportion at the 3rd day of incubation for the residual C:N:P molar ratios for control soils but the highest C/N ratio at day 60 for the N added soils. N/P ratio was greater at the middle of the experiment (days 7-15), as well as C:P ratio (days 7-30). N addition enhanced C/N, C/P and N/P ratios, indicating that PE affected residual N fractions together in a further extend as P. Therefore, we concluded that addition N fertilizer induced mobilization of legacy P, through a priming effect, but this effect has been reversed in time together with an organic P accumulation.

Keywords: phosphorus; nitrogen; soil incubation; soil respiration, phosphatase activity.

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Gevuina avellana Mol. (Proteaceae) regulates its P uptake through the exudation of organic acids and the up-regulation of genes related to the production and transport of organic acids and P transporter.

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Proteaceae species feature as plants with remarkable ability to thrive in soils extremely poor in phosphorus (P). In Chile, Gevuina avellana (Proteaceae) grows in a wide variety of soil environments, including young volcanic substrates very poor in P. We conducted an experiment to evaluate the morphological, physiological, and molecular mechanisms involved in the P acquisition of G. avellana plants. For this, G. avellana plants were separated into two groups of 12 plants each to perform two different P treatments: 1) high P (100 µM) or low P supply (5 µM). After 120 days, morphological responses (i.e. relative growth rate (RGR)), photosynthesis rate, mineral concentrations (Nitrogen (N), Manganese (Mn), Iron (Fe), Copper (Cu) and Zinc (Zn)) in different plant organs and carboxylates exuded by roots were evaluated. Additionally, the relative expression of genes involved in the production and transport of organic acids (PEPC, CS, MDH, ALMT, MATE) as well as P transporters (PHT1.14) were assessed in leaves and roots. The results showed no significant differences in RGR, photosynthesis rate, and mineral concentrations in most plant organs. However, the carboxylate exudation (oxalate) by roots was significantly higher in P-starved plants. Besides, the relative expression of the MATE gene was significantly higher in leaves, and PHT1.14, PEPC, and MATE genes were significantly up-regulated in the roots of plants grown under P deficiency. We concluded that G. avellana plants self-regulate the P uptake to maintain an elevated P concentration when P is deficient, either by increasing the exudation of oxalate by its roots, activating phosphate transporters and genes related to the production and transport of organic acids.

Keywords: phosphorus-deficiency, native plants, cluster roots, carboxylate exudation

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Influence of MeJA application on the relationship between Al and P concentration in highbush blueberry under Al toxicity and water deficit

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The combination of aluminum (Al) toxicity, phosphorus (P) deficiency, and water deficit has increased attention due to climate change. In acidic soils, high Al levels and low P coexist, provoking a significant decrease in plant growth, crop yield, and fruit quality. Highbush blueberry (Vaccinium corymbosum) is an important crop in southern Chile, being affected by these combined stresses, reducing its productivity. The methyl jasmonate (MeJA) application could activate plant resistance mechanisms against these stresses. Our objective was to determine the relationship between Al and P concentration in highbush blueberry under Al toxicity, water deficit (WD), and MeJA application. Star cultivar was exposed to control (low Al saturation, 80% field capacity), control+MeJA-50μM, Al (85% Al saturation, 80% field capacity), Al+MeJA, WD (low Al saturation, 50% field capacity), WD+MeJA, Al+WD, and Al+WD+MeJA in an Andisol. Relative growth rate (RGR), Al concentration, P concentration, water potential (Ψw), and relative water content (RWC) were determined in leaves and roots. RGR and Ψw significantly improved with the MeJA application. Al was higher in roots than in leaves and it increased in treatments with Al and without MeJA compared to control, strongly decreasing at 7 days with MeJA application; while, P was higher in leaves than in roots, decreasing its concentration in treatments with Al and without MeJA application. A significant negative correlation was found between Al and P. In conclusion, Al interferes with P uptake in the Star cultivar of highbush blueberry under Al and WD treatments, making the MeJA application a good alternative to revert it.

Keywords: Andisol, drought, growth, highbush blueberry, phosphorus, toxic aluminum

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The ability to quantify organic phosphorus (OP) turnover in soils and to identify the factors that control it is crucial for understanding ecosystem processes and biogeochemical cycles. However, the rate at which OP decomposes and the overall residence time of OP compounds in soil are still poorly understood due to the lack of reliable methods to understand OP mineralization under natural conditions. Towards this, we propose a novel approach of compound-specific isotope analysis to determine the isotopic signature of OP compounds, and based on this calculate the mineralization of OP and its persistence in soils. This approach will open up new possibilities for studying the phosphorus cycle in terrestrial ecosystems.

For this purpose, the OP sample was extracted from the soil with 0.25 M NaOH, filtered, and purified by ion exchange chromatography. The OP compounds collected were then dephosphorylated using HCl. The dephosphorylated samples were derivatized and the acetylated samples were then characterized and analyzed for their carbon isotopic composition using a GC-MS-IRMS system. We also analyzed two pure compounds (≥98%) of phytic acid sodium salt hydrate (from rice) and D-myo-inositol-1,2,3,4,5,6-hexakisphosphate (from Zea mays) to determine the correction factors accounting for the isotope fractionations associated with the derivatization process. Our initial results from the soil sample show the presence of various phosphomoesters such as inositol phosphates and glucose-6-phosphates as discernible sharp peaks in the GC-MS spectra. Furthermore, the carbon isotopic composition (δ¹³C) of the pure compounds indicates no additional isotopic fractionation other than the addition of a new functional group during the derivatization process. We are currently evaluating the efficiency of the developed protocol by estimating the total loss of samples during extraction, purification, dephosphorylation, and derivatization of OP.

**Keywords:** Carbon isotope, Compound-specific isotope analysis, Inositol phosphates, Organic phosphorus
Session V. Interaction between biotic and abiotic phosphorus dynamics in soils and sediments

Microbial interaction and phosphorus availability in long-term soil management systems

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Soil microorganisms directly influence the biogeochemical cycle of phosphorus (P). Through the process of mineralization, they convert organic phosphorus (Po) into inorganic phosphorus (Pi), which is readily absorbable by plants. The aim of this study was to assess the impact of soil microbiota on available soil P levels. The experiment was conducted in the Brazilian Cerrado, on an Oxisol (Latossolo). The experimental design followed a randomized block design with split plots, comprising three replications. The main plots consisted of two soil management systems - no-tillage (NT) and conventional tillage (CT) - while the subplots were assigned to different cover crops (millet, brachiaria, and sunn hemp), with fallow used as a control treatment. We analyzed labile P and organic P levels, acid phosphatase activity (ACP), and the abundance of bacterial genes (phoC and phoD). Labile P levels in the soil were higher in the CT and fallow treatments compared to the NT and cover crop treatments. However, no significant effect of the treatments was observed on organic P levels. The abundance of the phoC gene was higher in the NT treatment compared to CT, whereas the phoD gene showed differences due to cover crop species, with brachiaria and fallow exhibiting the highest and lowest gene abundances, respectively. In contrast to labile soil P, ACP was higher in the NT treatment compared to CT. Among the soil management systems, cover crops showed higher ACP compared to fallow. These results highlight increased enzymatic activities under conditions of lower P availability. Our findings revealed a significant correlation between ACP and labile P levels (p = 0.0295*, R² = 0.20), indicating that ACP explains 20 % of P availability in the soil. This study is pioneering in evaluating the abundance of the phoC gene in Brazilian tropical soils and provides essential insights into the biological activity and its contribution to P availability in cultivated areas under different soil management systems.

Keywords: Organic phosphorus; microbiological activity; bacterial phosphatase; Oxisol (Latossolo).
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Effect of using a biochar-based sustained release fertilizer on phosphorus availability in acid soils.

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Soil is crucial for agricultural productivity and food security, as it provides essential nutrients, water, and support. However, soil acidity has emerged as a primary constraint in agricultural settings, leading to deficiencies in nutrients such as phosphorus (P) and nitrogen (N) by enhancing the mobility of metal(loid) such as aluminum (Al). The loss of N in soils is primarily due to volatilization and leaching, while phosphorus forms insoluble or low-solubility compounds when interacting with other elements, resulting in the fixation or retention of this nutrient. Unfortunately, significant conventional fertilization is often required to counteract this deficiency, which poses detrimental environmental effects. In this context, innovative fertilizer is an exciting option for increasing nutrient efficiency in degraded soils. The work aimed to develop and characterize a biochar-based sustained-release fertilizer (BCRF) impregnated with N and P for degraded soils. We also evaluated the BCRF effect on wheat growth and its contribution to the fertility of acid soils, comparing it with similar products and conventional fertilization methods. Soil incubation experiments were conducted to measure the soil's reaction to the BCRF treatment, emphasizing pH, N availability, Al immobilization, and P availability. Simultaneously, a greenhouse trial evaluating the effect of BCRF in a spring wheat cultivar (Pantera) was implemented. Our results revealed a variety of responses during soil incubation. BCRF exhibited superior performance in N-NH₄, almost doubling the NH₄ concentration while consistently showing elevated P availability. Its application decreased the Al content without compromising extractability and augmented the aboveground biomass. In addition, BCRF yielded more spikes and seeds without negatively affecting grain yield. BCRF increased grain N content by 38% and P by 33% compared to control. Furthermore, BCRF retrieved more N and P from the aerial biomass than the control. While BC-NP surpassed traditional fertilization in P extraction, no marked difference was observed in N extraction. In conclusion, our study identified a fertilizer with physicochemical traits parallel to previously documented solutions and observed its commendable influence on plant growth, outperforming other reported alternatives.

Keywords: Plant production; Smart fertilizer; Inmovilization of Al.

Acknowledgments: National Research and Development Agency of Chile (ANID) through Fondecyt project no.1211387.
Phosphorus (P) is an essential nutrient for life on Earth, but is one of the less abundant in the lithosphere, making it a limiting nutrient, due turnover of organic P is essential for community structure and ecosystem processes. Between parallels 22°S and 26°S lies the hyper-arid core of the Atacama Desert, considered as a unique place as be at the dry limit of life on Earth. Within this hyper-arid core is situated the Yungay Oasis, that, defying the harsh environmental conditions, supports shrubs and salt-grass. Our purpose is to enhance the understanding of the phosphorus cycle in hyper-arid environment, specifically the interaction of plant-soil in adverse conditions. Two plant species were sampled in the Oasis, *S. foliosa* and *D. spicata*. Sampling was done horizontally every 10 cm from 0 to 50 cm of distance and vertically near the root every 5 cm from 0 to 25 cm depth, additionally, bare soils were sampled as control. Physico-chemical and SEM-EDS analysis were performed, including total phosphorus (Pt), inorganic phosphorus (Pi) and organic phosphorus (Po) by the extraction method proposed by Saunders and Williams. Horizontally, *S. foliosa* showed higher Pt and Pi than *D. spicata*, possible due to the decomposition of organic matter coming from their leaf. Pt and *S. foliosa* and *D. spicata* tends to be higher than the control soil in the entire profile, possibly indicating root-induced changes by plants to acquire P. Nevertheless, Pt, Pi and Po in the control soils increase at 20 cm depth, which is consisted with previous finds in the area. The secretion of protons, phosphatases or phytases to mobilize Po by enzyme-catalyzed hydrolysis, can lead to a pH reduction in the rhizosphere soil, which is in concordance with our findings. Additionality, P-Ca-Cl-C minerals could be found at 5-10 cm depth in *D. spicata* soils, also indicating a possible weathering of bedrock of source to P uptake. We conclude that even in harsh environments it is possible distinguish P cycling coming from the interaction between plants and hyper-arid soils.

**Keywords:** Atacama Desert; hyper-arid soil; phosphorus cycle; plant-soil interaction.

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Genotype-Specific Phenological Responses to Phosphorus and Water Availability in Winter and Spring Wheat Genotypes

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The relationship between phosphorus (P) availability and water deficit stress is a significant challenge for global wheat production. This study aims to explore the adaptability of different wheat genotypes to varying P and water conditions, focusing on phenological parameters. Plants were grown under controlled conditions on an Andisol with soil P-concentration of 3.4 mg P kg⁻¹ (-P), which was enriched to 30 mg P kg⁻¹ (+P). Irrigation was applied at two levels: well-watered (+W) and 30% +W (water-stressed, -W). Wheat was grown until the end of its phenological cycle.

The results show that both winter and spring genotypes are differentially sensitive to P and water limitation. Winter genotypes showed significant delays, ranging from 40 to 127 days, in reaching the strongly erect leaf sheath stage (Feekes stage 5) under low P and water-stressed (-W-P) conditions. On the other hand, spring genotypes showed an 11-day delay under low-P but adequately watered conditions and a 16-day delay when both low-P and water-stress conditions were applied. Interestingly, spring genotypes under water-stressed but P-sufficient conditions accelerated phenology by 10 days on average. The complex interplay of phosphorus availability and water stress on the phenology of different wheat genotypes is revealed in this study. These findings provide a basis for developing targeted nutrient and water management strategies tailored to the specific adaptive responses of winter and spring wheat genotypes. Further research should focus on elucidating the genetic mechanisms behind the observed phenotypic variation, which will provide additional avenues for optimizing nutrient and water use in wheat cultivation.

Keywords: Genotypic difference, phosphorus scarcity, water deficit stress

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Effects assessment of ZnO and CuO engineered nanoparticles on the physicochemical properties of an volcanic ash and inorganic phosphorus availability

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The use of engineered nanoparticles (ENPs) of copper and zinc oxides (CuO, ZnO) in pigments, cosmetics, agrochemicals, among other applications, has shown great growth in the last years. As a result, ENPs are being increasingly incorporated into the environment, putting agricultural soils at risk because ENPs are highly reactive due to their large surface area–to–volume ratios; modifying the physicochemical properties of soil and the availability of important nutrients such as inorganic phosphorus (IP) (Suazo-Hernández et al., 2023). The objective of this study was to evaluate the effect of CuO and ZnO ENPs on the physicochemical properties of soil and the availability of IP in soil derived from volcanic ash. We monitored changes in the adsorption of IP in soil in the presence of 1% ENPs of CuO and ZnO (% w/w). We used pH tests (pH 3.5–10.5), adsorption isotherms and desorption studies, which were carried out with 0.5–g samples of soil and solutions of 6.47 mmol·L⁻¹ of IP (pH axis) and 0.08–6.47 mmol·L⁻¹ of IP (isotherms) at pH 5.5; 0.01 M NaCl was used as a supporting electrolyte. We carried out the desorption studies; 0.01 M NaCl at pH 5.5 without IP was used as an extracting agent. The results showed that 1% ENPs of CuO and ZnO generated changes in the physicochemical properties of soil, such as changes in pH, electrical conductivity, percentage of organic matter and the concentration of Cu and Zn. We noted an increase in IP adsorption over the range of pH; the increase was greater for ZnO ENPs than CuO ENPs. The IP adsorption isotherms for the control soil and soil with both ENPs yielded a better fit to the Langmuir–Freundlich model than Freundlich and Langmuir models. Finally, the desorption studies revealed that less IP was released in soils with 1% of either ENP compared with the control soil. This study demonstrated the potential impact of ENPs on physicochemical properties and IP availability in soils derived from volcanic ash.

Keywords: Emerging pollutants, Inorganic elements, Agricultural soil

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Sustainable Alternatives for Phosphorus Fertilization: Arbuscular Mycorrhizal Fungi, Phosphorus-Impregnated Biochar, and Crop Uptake Efficiency.

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Phosphorus (P) availability in soils, especially those inherently deficient in P, is a pressing concern in global agriculture. Addressing this challenge, the current study delved into two separate but complementary approaches: the intrinsic root traits of wheat cultivars and the application of phosphorus-impregnated biochar. In the first approach, two wheat cultivars, "TCRB14" and "STKI14," were investigated for their P uptake abilities in P-deficient soils. Biomass production served as a primary metric, with TCRB14 showing superior outcomes, suggestive of enhanced P acquisition. Further examinations revealed TCRB14's propensity for increased arbuscular mycorrhizal colonization, possibly facilitating better nutrient absorption. The rhizosphere of TCRB14 also demonstrated elevated oxalate concentrations, potentially aiding in P mobilization. In contrast, STKI14 displayed increased, albeit not statistically significant, acid phosphatase activity. Root morphology studies illuminated TCRB14's advantageous features: longer, broader, and more branched roots, likely contributing to its P uptake efficiency. Separately, the application of phosphorus-impregnated biochar was assessed as an external intervention. Preliminary findings indicated that this biochar not only provided a controlled P release but also showed potential in moderating soil pH and enhancing cation exchange capacity. Such attributes could offer dual benefits: immediate P supply and improved soil health, facilitating more sustained nutrient availability. Conclusively, this research highlighted both inherent plant attributes and external soil amendments as pivotal in addressing P deficiency challenges. As sustainable agricultural practices become paramount, insights from such studies offer a roadmap for integrative strategies, encompassing crop breeding and innovative soil management techniques.

Keywords: Phosphorus availability; Root morphology; Arbuscular mycorrhizal colonization; Phosphorus-impregnated biochar.

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Effect of Rock Phosphate and Lemon Peel Application on Soil’s Available Phosphorus Forms.

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Rock Phosphate (RP) is the raw material used to produce inorganic fertilizer because it is rich in phosphorus, whose main characteristic is low solubility in water. The phosphatic fertilizer industry uses high acid concentrations at high temperatures to solubilize phosphorus (P) from RP, causing great harm to the environment during production. As an option, citrus peel could be a potential strategy to solubilize P from PR since within its components are organic acids, which can convert insoluble P into soluble P forms. Therefore, the present study was conducted to examine the effect of lemon peel and RP on soil available P forms. For that, a soil incubation were carried out using an Andisol mixed with RP at equivalent field doses of 50-100-200 kg ha⁻¹ and fresh (F) and dry (D) LP at doses of 0.5, 1, and 2 g. The incubation was maintained for 60 days. The P fractionation was carried out for 200 kg ha⁻¹ RP and 2 g of FLP and DLP treatments. To determine the P fractions in the soil, the Hedley sequential fractionation was carried out. Our results indicated that the content of easily-available, moderately-available, and non-available Pi and Po varied notably among treatments. Compared to the control, the concentration of NaHCO₃-Pi on day one increased by 16%, 24%, and 22% when RP, RP+FLP, and RP+DLP were added. While for day 60, these treatments increased by 13%, 15%, and 17% respectively. Moderately-available Pi (NaOH-Pi) had the same content in both incubation periods. However, moderately-available Po decreased in all treatments by 25%, 20%, 12%, 29%, and 22% under RP, FLP, DLP, RP+FLP, and RP+DLP respectively, compared to the control on day 60. HCl-Po content showed a significant decrease in all treatments compared to the control. Besides, non-labile P had a remarkable reduction in the treatments that contained lemon peel at the end of the incubation time.

Keywords: Phosphorus fractionation, lemon peel and rock phosphate.

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Assessment of the activity and gene expression of intracellular acid phosphatase in ryegrass plants grown under different organic amendments and mineral P fertilizers

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An important strategy of plants to maintain cellular phosphorus (P) homeostasis under P limitation is the induction of both intra- and extracellular activity of phosphatases (APases). Among them, intracellular purple acid phosphatases (PAPs) are the major class of plant APases that play an essential role remobilizing P inorganic (Pi) from cellular reserves, or hydrolyzing Pi from P organic compounds in apoplast and rhizosphere. Even though it has been reported that organic amendments (OAs) can increase soil P availability by promoting the activity of extracellular APases, little is known about the role of OAs on the function of intercellular APases. This study aimed to analyze the effect of OAs and mineral P fertilizers on the activity and gene expression of intercellular APases in ryegrass plants cultivated on an Andisol with low available P. A pot assay was performed using two OAs (Cattle manure; CM and Poultry manure; PM) and two P sources as reference (Phosphate rock; PR and Triple superphosphate; TSP) in combination with two nitrogen (N) doses (as urea; 100 and 200 mg kg soil−1). Four weeks after imposing the treatments, the intracellular APase activity and the gene expression of PAPI in roots were analyzed. As result, all treatments decreased the APase activity with respect to control irrespective of N level. Regarding the OAs, CM and PM reduced the APase activity by about 22% at 100 mg N kg soil−1, which was consistent with the down-regulation of PAPI expression induced by both OAs at the same conditions. Similarly, a decrease in APase activity by about 34% with CM and 29% with PM was observed when the highest N dose was applied. A similar trend in APase activity was observed with PR and TSP application at the same N regime. Nevertheless, CM increased the transcript levels of PAPI under 200 mg N kg soil−1, whereas the expression of this gene was decreased by PM, PR and TSP supply.

Keywords: Organic amendments; Intracellular APases; PAPI

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The impact of organic amendments on soil P availability, phosphorus use efficiency and the gene expression of phosphate transporters in ryegrass plants

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Phosphorus (P), a non-renewable resource, highlights the critical need to explore and develop alternative P sources to support sustainable agriculture. Although organic amendments (OAs) such as animal manures are considered a cost-effective and environment-friendly strategy to increase soil P availability and plant production, few studies have focused on investigating the influence of OAs on P use efficiency (PUE) and gene expression of P transporters. This study examined the impact of different OAs, and mineral P fertilizers as reference, on the PUE and gene expression of P transporters in ryegrass plants grown under two N levels. A pot experiment was conducted on an Andisol with low available P by using ryegrass plants (Lolium perenne L.) cv. Base. Two OAs (Cattle manure; CM and Poultry manure; PM) and two P sources (Phosphate rock; PR and Triple superphosphate; TSP) were applied in combination with two N doses (as urea; 100 and 200 mg kg soil-1). Plants were harvested 30 days after the initiation of treatments, and Olsen-P, P content and dry weight of plants were evaluated. Additionally, the gene expression of P transporters PHT1;1 and PHT1;4 in roots were analyzed. Between OAs, only PM increased P soil availability respect to the control by about 2.1-fold and 2.2-fold at either 100 or 200 mg N kg soil-1 added, respectively. Similarly, soil P was positively influenced by PR and TSP under different N regimes. Consequently, PM, PR and TSP-treated plants showed a better P uptake as well as PUE over the control. Accordingly, PM enhanced shoot P content up to 2.3-fold when the highest N level was applied, which was accompanied by a significant increase of dry matter production by about 83%. Compared to control, all treatments decreased the gene expression of PHT1;1 and PHT1;4 irrespective of N supply. Interestingly, regarding the OAs, PM-amended plants showed a more noticeable down-regulation of these P transporters under both N doses.

Keywords: Cattle manure; Poultry manure; Phosphate rock; PUE; Phosphate transporters.

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Soil phosphorus availability alternation after rice paddy converted to rice-crab culture in the Jianghan Plain, China

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China has recently seen a significant shift from traditional rotations of rice and dry-season crop (RRD) to integrated rice-crab culture (IRCC) characterized by markedly different water management and fertilization regimes. Previous studies showed that long-term consecutive IRCC cultivation can lead to soil phosphorus (P) fertility degradation. However, the precise factors governing this phenomenon remain underexplored, and it remains unclear whether the decline in soil P fertility is influenced by the initial RRD soil’s property or the IRCC cultivation duration. To this end, we collected topsoils (0-20 cm) from China’s five largest crab-producing counties in the Jianghan Plain. We sampled three replicates of IRCC plots of contrasting duration in each county and adjacent RRD plots (>20 years) as controls. We assessed general soil properties and soil organic P (OP) composition, inorganic P fractions, Olsen P, and extracellular alkaline phosphatase activity (APA). Our data showed that compared to RRD, IRCC reduced soil total P (TP) and OP levels and increased soil organic carbon (SOC) and total nitrogen. IRCC did not significantly alter soil P composition, with orthophosphate monoesters, orthophosphate diesters, and phosphonates dominating soil OP, while ferric P, calcium P, and residual P dominating inorganic P fractions. Olsen P decreased in early years after IRCC installation and increased in plots with longer durations, while APA showed a converse trend. Multiple linear regression indicated that Olsen P changes were primarily influenced by initial RRD soils’ clay and available potassium contents, the TP changes, and IRCC duration ($r^2 = 0.519$), while APA changes were controlled by initial RRD soils’ APA, Olsen P, and clay contents and the SOC changes ($r^2 = 0.666$). Combined redundancy analysis and variation partitioning showed that initial RRD soils’ chemical and physical properties explained much more of the variance of Olsen P and APA changes (50.4%) than IRCC duration (4.0%). Our results underscore the importance of considering initial RRD soil properties when converting RRD plots into IRCC for sustainable IRCC cultivation.

Keywords: rice paddy; organic phosphorus; inorganic phosphorus; phosphorus availability; integrated rice-crab culture.

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