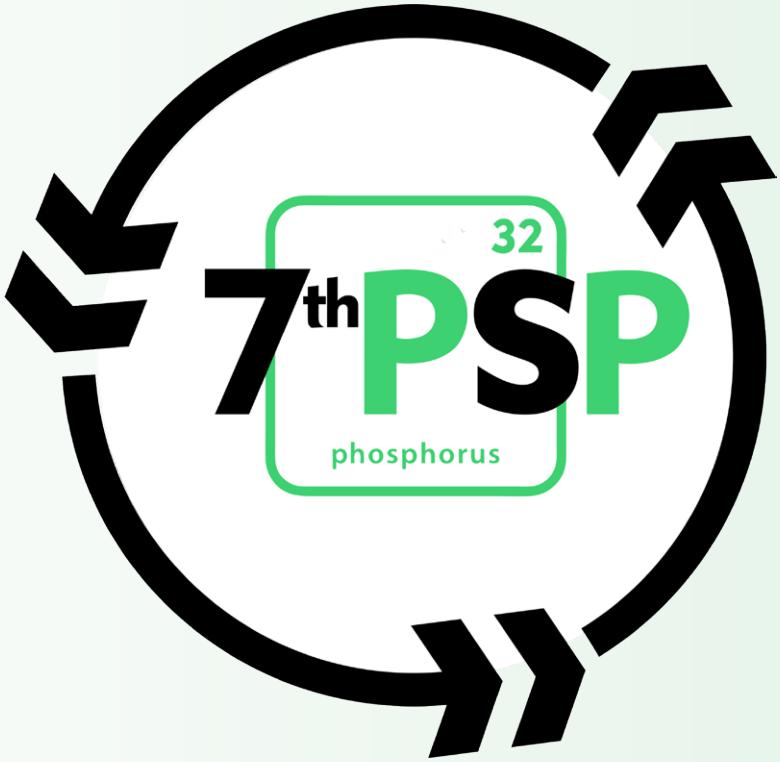
Book of abstracts



Phosphorus in Soils and Plants Symposium

Towards a sustainable phosphorus utilization in agroecosystems

FACULTAD DE AGRONOMÍA

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URUGUAY

Published By

The organizing committee of the 7th Symposium on Phosphorus in Soils and Plants (PSP7)-National Agricultural Research Institute and School of Agronomy, Universidad de la República, Uruguay

Editorial Processing: Silvia Garaycochea, Diego Michelini

The National Agricultural Research Institute and School of Agronomy, Universidad de la República, Uruguay welcomes the 7th Symposium on Phosphorus in Soils and Plants (PSP7) "Towards a sustainable phosphorus utilization in agroecosystems"

Monday 3 to Friday 7, October 2022 in Montevideo, Uruguay

On behalf of the International Scientific Committee and Local Organizing Committee, it is a pleasure for us to welcome you to the 7th Symposium on Phosphorus in Soils and Plants (PSP7) – "Towards a sustainable phosphorus utilization in agroecosystems".

After more than 20 years from its departure point in Beijing 2000, the Symposium lands for the second time in South America, where it will tackle the issues of the current P cycle, in the agroecosystems of the region but also of the world. On one hand, many agroecosystems in the world, such as South American one, face phosphorus scarcity for sustaining economically viable levels of primary and secondary production. On the other hand the systematic addition of P for attaining those levels of productivity has put under consideration how to manage high phosphorus which gives rise to problems of eutrophication mostly in aquatic ecosystems. That dichotomy of the phosphorus cycle in these agroecosystems pushes both the scientific society and the agricultural sector to join to look for sustainable solutions. Therefore, it is fundamental to congregate actors from different sectors in the PSP7 such as the academia, educative sector, private sector, government and other stakeholders, from the region and the world. The scope of the topics will range from **fundamental insights** of phosphorus biogeochemical cycles to **applications** such as crop breeding, fertilizer development, soil management and performance of environmental impact assessments. The conference also aims to attract many scientists from **developing countrie**s where phosphorus scarcity is a major issue.

The themes of PSP7 are:

Theme 1: Phosphorus forms, availability and cycling in soils

Theme 2: Phosphorus acquisition by plants and microorganisms

Theme 3: Phosphorus utilization and signaling in plants

Theme 4: Sustainable intensification of phosphorus supply in food production

Theme 5: Impact of phosphorus on environmental quality and on biodiversity

We want to express our gratitude to all the people who made this event possible. To our institutions for the support provided for the organization, the International Scientific Committee for spending their time in selecting the abstracts and discussing the program content, to the keynote speakers who showed their interest and availability to contribute with this event. Also, we want to thanks to the sponsor, fundamental contribution to reach the success. We would like to thank the Local Committee who worked with us since 2019 in organizational matters.

We hope you enjoy the symposium

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7th PSP phosphorus

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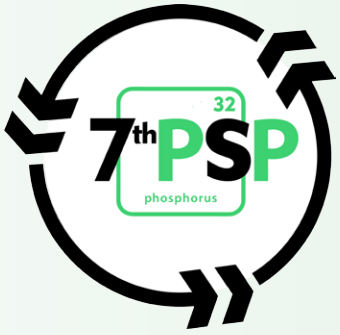


abstracts

Theme 1 - Phosphorus forms, availability and cycling in soils
Keynote presentation

Interaction between phosphorus cycle and the cycles of carbon and nitrogen in soils

Marie Spohn

Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU), Sweden

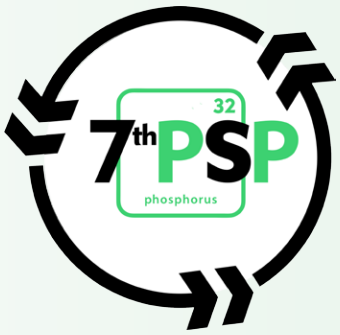
In this talk, I will present results of several studies showing that cycling and storage of phosphorus (P) in soils is closely related to the dynamics of nitrogen (N) and carbon (C).

The first part of the talk will concentrate on organic P storage in terrestrial ecosystems, and particularly in soils. Results of several studies will be presented showing that organic P is strongly associated with minerals in soils, more strongly than organic C and N. Implications of these findings for P and C cycling and avenues for future research will be discussed.

The second part of the talk will focus on mobilization of P by microorganisms from organic and inorganic soil P pools. I will present results from several studies that elucidate the relationship between microbial P mobilization in soils and the availabilities of P, N, and C.

The third part of the talk will be about mobilization of P from organic soil pools by plants. Results about the interactions between N and P dynamics in soils will be shown.

Taken together, these studies indicate that the interrelatedness of the P, N, and C cycles needs to be considered for a comprehensive understanding of P forms, availability and cycling in soils.



Theme 1 - Phosphorus forms, availability and cycling in soils
Oral presentation

Soil organic and resin-P in areas under pasture intensification and sugarcane expansion in Southeast Brazil

Luiza P. Canisares and Luiz A. Martinelli,

Centro de Energia Nuclear na Agricultura/USP, Piracicaba, São Paulo, Brazil

Sugarcane plantations and pastures are the two main land cover/use of the Southeast region of Brazil. These agricultural activities are extremely important once the global demand for biofuels and the consumption of livestock is globally increasing. Brazilian livestock production is based on the use of low-input pastures, which are largely not properly managed, compromising the profitability and sustainability of this activity. On the other hand, sugarcane is a high-input agricultural crop. The intensification of low-input pastures and the conversion of degraded pasture areas into sugarcane crops its two options that have been adopted. However, the environmental consequences of these land-uses intensifications were not fully evaluated. Phosphorus (P) is a key element in the tropics, agricultural practices have the potential to alter P availability. Here, we evaluated how land-use intensification affected soil P dynamics. In both sites (Brotas and Sorocaba), the concentrations of soils organic P and P-resin at 10 cm depth were compared with their respective areas of native vegetation and among land uses. P-resin showed the highest concentration in the sugarcane followed by intensive grazing, in both experimental areas, probably due to the fertilization performed in these areas. Unexpectedly, organic P showed the highest concentration in the unfertilized extensive grazing soil plots, probably due to the constant addition of cattle manure, and lower erosion.

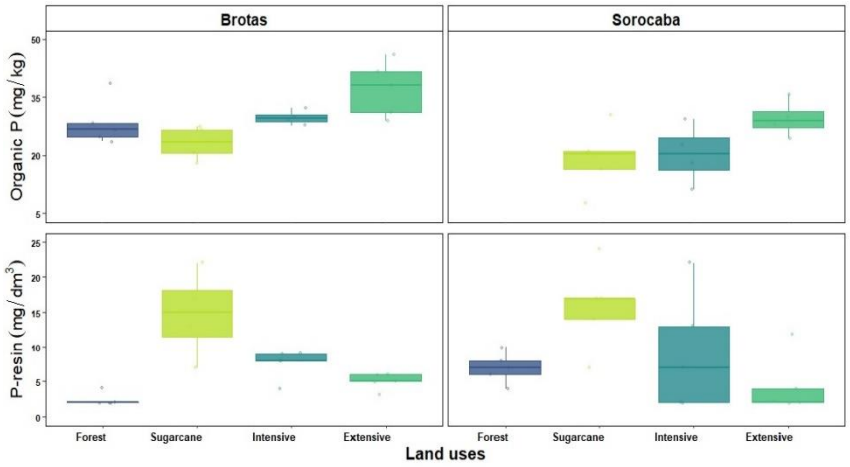


Figure 1. Concentrations of organic P and P-resin in soils under forest, sugarcane, intensive pasture, and extensive pasture in two sites – Brotas and Sorocaba.

Deciphering the transformation and fate of the freshly applied P in a calcareous soil by enriched oxygen isotopic labeling technique

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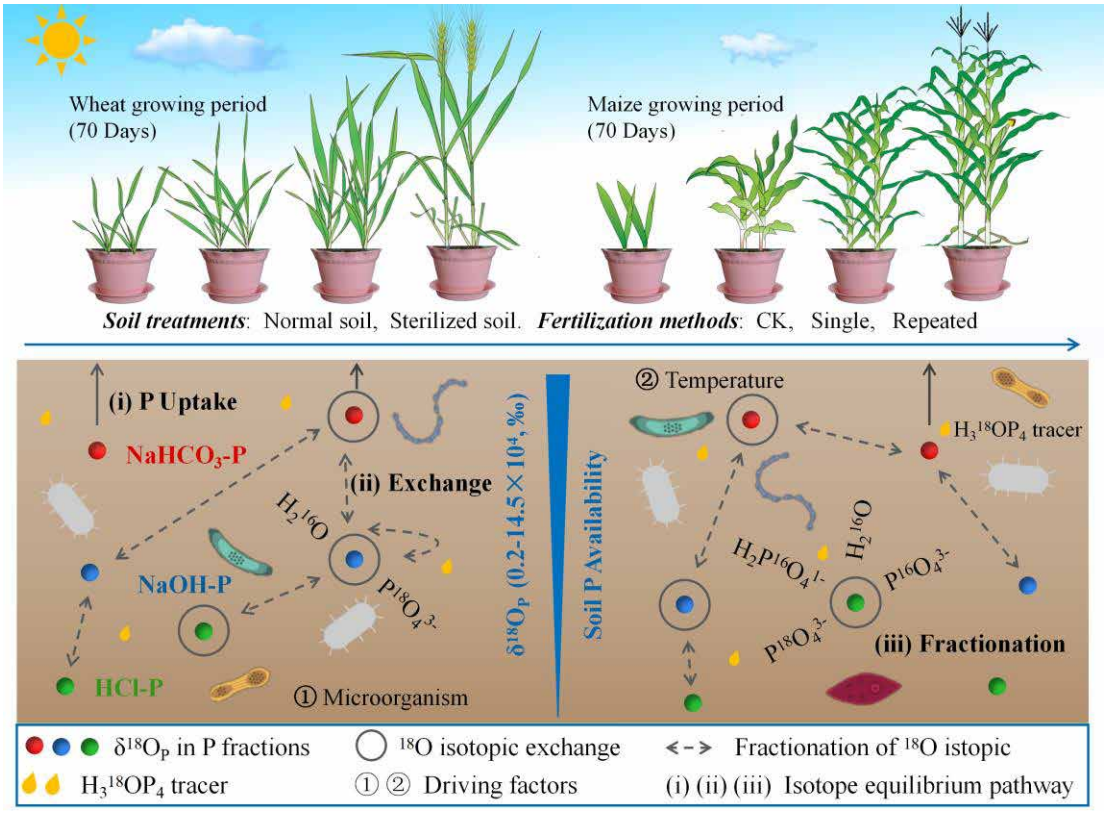
Different P fertilization methods significantly impact on the transformation and distribution of the applied-P in soils and influences its bioavailability. However, knowledge about how different P fertilization regimes affect the chemical nature and partitioning of the freshly amended-P in soil remains incompelte. Herein, we carried out a pot experiment to explore the fate and transformation of applied P in a calcareous soil by using enriched stable oxygen isotope labelling (^{18}O-P) coupling with Guppy's sequential extraction method. The dynamics of Olsen-P, different P fractions and the values of $\delta^{18}O_P$ of $NaHCO_3$-P, NaOH-P and HCl-P were assayed. The allocation of the added-P in soil-plant system also was analyzed by P mass balance approach. Three treatments included (i) CK, unfertilized control; (ii) single application ($H_3P^{18}O_4$, 118 kg P ha^{-1}); (iii) repeated application. We found that repeated P application significantly increased Olsen-P in both sterilized and normal soils. In wheat season under the repeated P application, about 72.5% of the freshly applied-P was held in labile (resin-P, $NaHCO_3$-P) and moderately labile forms (NaOH-P), the rest (27.5%) was recovered in HCl-P and residual-P forms. In contrast, more than 51.4% of the applied P appeared in HCl-P and residual-P forms in the single application. Moreover, in the normal soil, the $\delta^{18}O_P$ values of $NaHCO_3$-P (13.6×10^4 ‰) and NaOH-P (8.4×10^4 ‰) in the repeated P application were 253.0% and 795.4% higher, respectively, than in the single P application. Similar results were also observed in the sterilized soil, indicated that repeated P application facilitated to increase P availability through blocking the transformation of the spiked-P to recalcitrant fractions. Moreover, P mass balance analysis revealed that the supply of phosphate fertilizers through repeated method favored to the applied-P distributed in $NaHCO_3$-P and NaOH-P rather than HCl-P and residual-P pools. Consequently, remarkable greater agronomic performance of wheat and maize (biomass) and higher PUE were achieved in repeated P application. The partial least squares path modeling (PLS-PM) result further proofed above phenomena, which showed that agronomic performance was directly and positively influenced by labile P ($p <$

0.05), moderately labile P and $\delta^{18}O_P$ equilibrium, while non-labile P were directly and negatively related to agronomic performance. Our findings highlights that repeated P fertilization significantly increased soil P availability by retarding the applied P conversion from labile to recalcitrant forms. Also, our findings demonstrated that highly enriched oxygen isotopic labeling approach (^{18}O-PO_4) can be considered as a promising method for better understanding the dynamic transformation and fate of the applied P in calcareous soil.



Accumulated effects of contrasting phosphorus balances in the evolution of soil available phosphorus

Agustín Núñez, Valentina Rubio, Javier Moreira

[1] INIA La Estanzuela
[2] Private Consultant.

Sustainable phosphorus management requires fertilization strategies that avoid both under- and over-fertilization to minimize plant P deficiency while preventing excessive P accumulation and water contamination. While national information is available about critical P levels above which no responses to P fertilization are expected, less is known about the evolution of P availability under different P balances. Our objective was to evaluate the relationship between P balance (P fertilization minus P removal in grain) on the evolution of soil P availability (P Bray I analysis). We installed four experimental sites with contrasting initial P values: low (12.4 µg g^{-1}), high (41.6 µg g^{-1}), and optimal (18.5 and 20.5 µg g^{-1}). Each site received two contrasting fertilization treatments: no P fertilization vs fertilization rates to reach and maintain soil P Bray I between 16 and 20 µg g^{-1}. Averaged over 5 years, the lack of fertilization resulted in negative P balances that ranged between −11 and −19 kg P ha^{-1} yr^{-1} in each site. In three of the sites these negative balances resulted in a decrease in soil P levels ($p < 0.01$), but the magnitude of the decrease was site-dependent, and a loss of 1 µg g^{-1} P Bray I was observed every 5 to 12.5 kg P ha^{-1} of accumulated negative balance. The P balance of the fertilized treatments varied depending on the initial values of each site (which defined the fertilization rates) and was between −10 and +9 kg P ha^{-1} yr^{-1}. Interestingly, we did not find a significant relationship between positive P balances and soil P. Our results suggest that losses of P availability in response to negative balances are site-dependent and that neutral P balances do not always result in stable soil P levels, highlighting the importance of frequent monitoring of soil P availability.

Phosphorus depletion in Vertisols sub-surface – which fertilizer management strategy?

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Phosphorus (P) fertilizer applications are becoming increasingly important to maintain crop productivity in Northeastern Australia, due to increasing soil P depletion, particularly in sub-surface. A common application method is the use of concentrated deep P bands. Vertisols are an important cropping soil in the region, and are characterised by a wide range of physical and chemical properties that are likely to affect the behaviour of this applied P.

We collected topsoil and sub-surface soils of nine contrasting Vertisols and investigated the dynamics of applied P, including Soil P tests, P sorption curves, and the kinetics of potentially plant available P after application of different mineral P fertilisers (monoammonium phosphate [MAP] and diammonium phosphate [DAP], applied to the sub-surface soils at a rate of 50 mg P kg^{-1}). Further, we incubated depleted sub-surface soils with different amounts of MAP and DAP and evaluated P desorption and inorganic P speciation (using K-edge XANES).

The P sorption varied strongly among the Vertisols, which contrasted with other included soil types. The potentially plant available P decreased rapidly when low rates of P were applied, until an equilibrium was reached at approximately 30 d after fertilizer application. The degree of P saturation was a primary determinant of P recovery in these soils. A greater P application rate to sub-surface soils increased P recovery and resulted in more labile inorganic P forms, whereas P fertilizer type did not strongly affect the potentially plant available P.

The data suggest that the efficiency of P fertilisers in supplying P to a crop will decrease with greater depletion of soil P reserves. Effective P fertiliser strategies in Vertisols should therefore be based on enriching smaller volumes of soils, which may offer avenues to improve crop P utilization.

Does the fertilization strategy affect long-term legacy phosphorus dynamic?

Stefania C. Appelhans [1,2,3]*, Leonardo E. Novelli [1,2,3], Ricardo J.M. Melchiori [3], Pedro A. Barbagelata [2,3]

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[3] *INTA EEA Paraná, Argentina.*

Phosphorus (P) imbalances of agricultural systems are a global problem because it has environmental and economic impacts, like eutrophication or low crop productivity. When fertilizers are applied to increase soil available P, some fractions become in non-available P forms and reduce P use efficiency (PUE). Legacy P includes labile and moderately labile P fractions that could become available for crops under long-term P fertilization and affect the PUE. Our aim was to evaluate long-term legacy P dynamic and PUE with different P fertilization strategies and rates in fine and loam texture soils of Entre Ríos, Argentina. Using long-term P fertilization experiments under no-till in two contrasting soil types (a Mollisol and a Vertisol), we evaluated a combination of three initial (0, 100, and 200 kg P ha-1) and four annual P fertilization rates (0, 12, 24, and 36 kg P ha-1) applied as triple superphosphate. Annually, soil samples were collected at 0-5 cm, 5-10 cm, and 10-20 cm soil depth, and Bray1-P concentration was measured. Long duration effects of the initial P fertilization on Bray1-P were reordered in the Mollisol in comparison to the Vertisol, although annual P fertilization increased Bray1-P before in deep layers in the Vertisol. After 10 years, the stratification of Bray1-P was twice in the Vertisol than in the Mollisol. The annual P fertilization rate required to maintain the Bray1-P level was similar for both soils when no P was applied at the beginning of the experiment. Our results suggested that the use of the build-up fertilization strategy with a one-time high P fertilization rate and then using the residual legacy P reduce the PUE compared with annual P fertilization feeding crops needs.

Theme 1 - Phosphorus forms, availability and cycling in soils Poster Session

Close contact between vermicompost and mineral fertilizers in soil improves an early uptake of mineral phosphorus by ryegrass

Tomas Sitzmann[2] , Laura Zavattaro, Barbara Moretti[2] , Carlo Grignani[2], Astrid Oberson[1]

[1] *Lindau,Switzerland*

[2] *Turin,Italy*

Organo-mineral fertilizers (OMFs) are made by mixing organic and mineral fractions. OMFs have shown higher nutrient use efficiency than mineral fertilizers, but the reasons are unclear. In this study, we tested if the close contact in a mixture of vermicompost and mineral fertilizer solution that emulates grains of OMFs affects Italian ryegrass (*Lolium multiflorum*) nitrogen (N) and phosphorus (P) uptake. A greenhouse pot experiment was performed using calcareous soil. The treatments were mixtures with two C-N-P ratios, 7.5C-20N-10P and 7.5C-20N-10P. Controls were non-fertilized soil (0C-0N-0P), only N fertilizer (0C-20N-0P), only P fertilizer (0C-0N-10P), and N and P fertilizers (0C-20N-10P), plus two treatments with only compost (7.5C-0N-0P and 15C-0N-0P). Vermicompost was added to two holes per pot, and above it was added potassium phosphate solution (^{33}P = 0.6 mCi), and 4 hours later ammonium sulfate solution (atom% ^{15}N = 5%), at a dose corresponding to 300 kg N ha-1 and 65.5 kg P ha-1. Ryegrass was harvested after 4 and 8 weeks. In both cuts, treatments fertilized with both N and P had higher biomass and NP uptake. In the first harvest, 7.5C-20N-10P had higher biomass than 15C-20N-10P and 0C-20N-10P (2.0 vs. 1.6 and 1.6 g); a similar trend was seen in P uptake from fertilizer (3.1 mg P kg^{-1} soil vs. 2.6 and 2.5 mg P kg^{-1} soil, respectively). No significant differences between these three treatments were found for N uptake nor biomass and P uptake in the second cut, although the trend was that by increasing the C content in the soil, the NP uptake decreased, probably by a microbial immobilization of nutrients. These results show that small amounts of vermicompost are capable of increasing P availability in an early ryegrass stage. However, increasing quantities of organic C did not result in an increased protection effect on P.

Effect of fertilization history on p fixation

Facundo Borges[1], Marcelo Ferrando[2], Robin Cuadro[3], Andrés Quincke[3]

[1]ANII Uruguay Fellowship, [2] Departamento de Suelos y Aguas, Udelar Uruguay, [3] INIA Uruguay

Phosphorus is a relatively immobile nutrient, subject to fixation processes by the soil. P fixation affects the P requirement factor (PRF), i.e. the P rate required to raise agronomic soil test P by 1 mg/kg. Several factors inherent to the soil type affect P fixation. However, a given soil may show changes in its P fixation, as the soil accumulates P additions. These changes in P fixation should be taken into account so that fertilizer recommendations do not overestimate optimum P rates. Two important soil-forming materials for agricultural and livestock production in Uruguay are the precambrian shield and Quaternary sediments. A general research objective is to improve the soil-specific recommendations for P fertilization. The specific objective is to study the effect of previous P fertilization on P fixation according to soil type. We used a set of stored soil samples from previous experimental P fertilization trials, which belong to the two above-mentioned materials. No P fertilizer had been applied previous to establishment of trials. Samples of contrasting treatments were selected according to the P rates applied for 3 years. Soil P fixation will be determined using P retention indices, which represent a more practical and simple method than traditional adsorption isotherms. Basically, the soil is placed in a solution with known initial P concentration. After a certain agitation time the final P concentration in the solution is determined in order to obtain by subtraction the amount of P retained by the soil. It is expected to find evidence supporting that PRF estimation should take into account P fertilization history. This would lead to better adjusting recommended fertilizer P rates, reducing costs and the risk of P losses to runoff.

Effect of long-term phosphorus fertilization on phosphorus fractions and organic carbon in the central semi-arid region of Argentina

Lucila Alvarez[1] and Elke Noellemeyer[1]

[1] *Facultad de Agronomía, Universidad Nacional de La Pampa - Argentina*

The phosphorus (P) supplied through fertilizers can accumulate in the soil, resulting in low yield response and fertilizer efficiency. Labile forms become more stable over time, leaving little available P for crops. The objective of this work was to evaluate the accumulated effect of six years of different rates of phosphorous fertilization on P fractions, organic carbon (OC) and wheat yield. Labile forms like AEM-P (P extracted by anion exchange membrane) and NaHCO3–P and non-labile fractions of P like HCl-P were determined according to the Hedley method (Tiessen and Moir, 2006). The OC content was determined by Walkley and Black, available P by the Bray Kurtz N°1 method, and wheat yield was measured at physiological maturity. The experiment was carried out in a sandy loam soil located in La Pampa, Argentina (36°02'22.0'' S; 64°11'09.9'' W), with three P fertilization rates: Control (P0), 60 kg ha-1 (P60) and 120 kg ha-1 (P120) of monoammonium phosphate (MAP) in a strip design with two replicates. Soil samples were taken with five sub- samples from the 0-10 cm layer. Analyses of variance was performed with the Tukey test ($p<0.05$). Wheat yield increased by 124% in P60 and 145% in P120, compared to P0, without significant differences between P60 and P120. The OC increased significantly from 15.0 g kg-1 (P0) to 17.0 g kg-1 (P60) and 17.5 g kg-1 (P120). Available P and the three P- fractions increased with the P rate, and the labile fractions (AEM-P and NaHCO3-P) were more affected than HCl-P (Figure 1). The accumulated effect of fertilization improved the availability of phosphorus and increased organic carbon, which in turn, results in more favourable conditions for P solubility and improved physical condition of the soil.

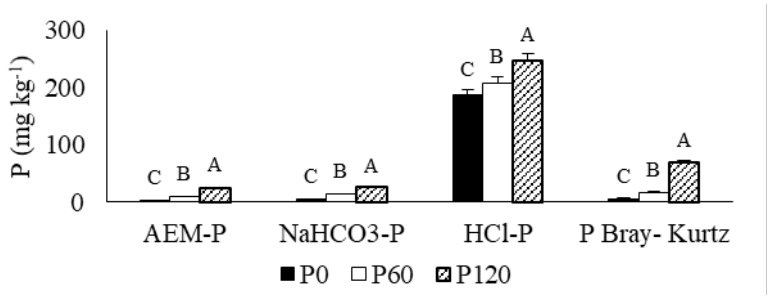

Figure 1. Phosphorus fractions and P Bray Kurtz (mg kg^{-1}) in P0, P60 and P120.

Legacy soil phosphorus management for improved crop production profitability and sustainability with reduced phosphorus loading to Lake Erie

Zhang, T.Q., Wang, Y.T. and Jia, Y.

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Optimum management of soil legacy P (SLP) can be an effective way to improve crop production profitability and surface water quality. An on-going field study has been started since 2019 to address knowledge gaps, based on which to develop BMPs for best use of SLP. In a clay loam soil, soil test P (STP, Olsen P) reduced linearly with P drawdown (i.e. utilization of SLP; PDD). A critical STP level was observed at 10.3-12.3 mg kg^{-1} in 2019 (corn), 2020 (soybean), and 2021 (winter wheat), below which crop yields increased with increases in STP under PDD. In this case, fertilizer P addition would be required to achieve optimum grain yield. Once STP reached the critical levels, further SLP increase did not increase crop yields. Moreover, fertilizer P additions did not increase crop yields compared to PDD, indicating that SLP is as crop-available as freshly added P. It seems that P addition is not required in the clay loam soil when STP is above 10.3-12.3 mg kg^{-1}, which, however, are lower than those recommended in Ontario. A sandy loam soil is also included in the study, but a different story was told: STP remained similar over the three PDD cropping years; crop yields were similar among different SLP levels under PDD, but fertilizer P additions increased corn yields by 15-18% despite high SLP levels (> 25 mg Olsen P kg^{-1}). It seems that the sandy loam soil may need a booster of fertilizer P to compromise the temporal shortage of soil available P, due to low diffusion P supply resulted from low soil water connectivity, to ensure optimum crop growth even when SLP is very high. Relative to fertilizer P additions, PDD decreased soil P losses in runoff water by 30%. Our results are useful for developing BMPs for best use of SLP and fertilizer P re-application strategies and technologies.

Relations between Bray-1 and citric acid soil P tests as affected by soil properties

Andrés Quincke[1] and Robin Cuadro[1]

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Fertilizer recommendations for P are mostly based on soil testing. For arable, moderately acid soils, the Bray-1 P test is the most widely used extractant for evaluating plant available P in Uruguay. However, this soil P test has shown a reduced reliability on calcareous soils and on soils fertilized with sparingly soluble P sources such as rock phosphate. In a previous study on a range of soil physicochemical properties, the citric acid soil P testing procedures performed better than Bray-1 assessing plant available P for leguminous pastures. The present study aims at better understanding the correlation between these two methods under different soil conditions. The Bray-1 and citric acid methods were compared using three data sets where soil samples were analyzed for both P tests and additional chemical properties such as pH in water, cation exchange capacity and texture. The data sets were (1) crop rotation and tillage trials on arable soils (fertilized with soluble P sources), (2) legume pasture P fertilization trials (fertilized with both soluble and sparingly soluble fertilizers), and (3) soil samples from soil surveys of commercial fields. Sampling depths were 0-15 or 0-7.5 and 7.5-15cm. Soil analyses were performed at the Soil, Plant and Water Testing Laboratory at La Estanzuela (INIA, Uy). Briefly, the procedure the Bray- 1 test was using a 3.56 : 25 (m-v) soil:solution ratio and an extraction time of 5 min, while the citric acid P test was determined using a 5 :50 (m-v) ratio and an extraction time of 30 min. We will analyze and report on the soil factors that modulate the regression functions and correlations between the two tests.

Theme 2 - Phosphorus acquisition by plants and microorganisms
Keynote presentation

Plant-Soil-Microorganisms interactions: Enhancing phosphorus acquisition of maize and sorghum in tropical soils

Sylvia Morais de Sousa Tinoco.

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Marginal soil fertility, soil acidity, aluminum toxicity, and low nutrient levels, especially phosphorus (P), are major limiting factors to cereal production in highly weathered tropical soils. Chemical fertilizers have been instrumental in the intensification of agriculture. However, if applied in excess, they can contaminate the environment, and can significantly increase the production cost. Cereals receive almost half of the world"s phosphate fertilizer applications. Therefore, plant P use efficiency (PUE) should be increased, aiming a more sustainable agriculture. One alternative is to use less soluble P sources associated that are more efficient in PUE. In addition, the symbiosis between P with plant genotypes solubilizing bacteria and/or arbuscular mycorrhizal fungi and plants can contribute to increase the acquisition of this nutrient and promote the growth of cultivated plants. Other factor essential for the plants to more effectively forage for P in the soil, increasing P acquisition under low soil P availability is the root system architecture (RSA) alterations leading to longer and thinner ageotropic lateral roots in the topsoil (where P levels are highest) . To date, there are not many genes that directly link root morphology and P acquisition, particularly in crop species cultivated in soils with low-P availability. A receptor-like cytoplasmic kinase gene named PHOSPHORUS-STARVATION TOLERANCE 1 (PSTOL1) is the first gene candidate to P efficiency (tolerance to low soil P) identified. This gene is responsible for a major quantitative trait locus for rice root P uptake. We have identified and characterized the homologous of this gene in maize and sorghum. In parallel, we showed that the most productive maize and sorghum genotypes have higher root angle and area, increasing foraging on the soil surface and P acquisition. Moreover, we showed that the crop type, genotype and fertilizer type are the main factors affecting the grain yield, root system, genetic diversity and abundance of microorganisms. Thus, the combined use of less reactive P sources, which could be more soluble over time by the physicochemical processes and soil microbiota activity, together with more efficient genotypes might reduce the amount of soluble phosphate fertilizers applied annually to crops.

Theme 2 - Phosphorus acquisition by plants and microorganisms
Oral presentation

Crop type determines how root system architecture and microbial diversity indices relate in different phosphate fertilization conditions

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Synthetic phosphate fertilizers are frequently used in agriculture; however, their overuse can increase production costs and cause negative environment impacts. Soil phosphorus (P) availability can be increased by the contribution of the rhizosphere microbiota associated with the plant root system. This work aimed to generate and validate a more robust method of identifying root system architecture traits from maize and sorghum plants grown under different phosphate fertilization conditions and associate them with microbial genetic diversity indices and grain yield. Four commercial genotypes of maize and four of sorghum were cultivated for two seasons under seven treatments, no addition of P fertilizer, rock phosphate (Itafós and OCP) and triple superphosphate with 50 and 100 kg P_2O_5 ha^{-1}. During flowering time, the root system was collected according to the Shovelomics method, analyzed by the modified Digital Imaging of Root Traits (DIRT) system and the bacterial genetic diversity indices were calculated. Modifications in the image pre-processing step made the analyses via the DIRT platform less error-prone. A decision tree was trained and a simpler and more understandable classifier was defined, based on only two root traits (area and solidity), which was more effective than the original methodology. The type of crop followed by the genotype and fertilizer were the main factors that affected the root system, grain yield, genetic diversity and abundance of microorganisms. The most productive genotypes had higher root angle and area, increasing foraging on the soil surface and P acquisition. The combined use of less reactive sources, that couldn't be more soluble over time by the physicochemical processes and soil microbiota activity, together with more efficient genotypes could reduce the amount of soluble phosphate fertilizers applied annually to crops.

How much P uptake is required for achieving maximum maize grain yield? Luxury consumption, implications for yield, and impact of P uptake on grain quality and partitioning of nutrients

Chad J. Penn

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Current agronomic phosphorus (P) recommendations are based on empirical relationships between soil test P (STP) concentrations and crop yield. Due to its empirical nature, the recommendations often result in either over- or under-application of fertilizer P. More precise P fertility recommendations will improve agronomic and economic efficiency, as well as reduce potential for P losses to the environment. We propose adaptation of the Barber-Cushman nutrient uptake model for use in determining optimum STP concentrations that are unique to each set of soil conditions and crop. This entails a mass-balance approach to soil P supply and plant P uptake. In addition to the overall approach, we present the results of the first series of experiments intended to determine the minimum mass of P uptake by maize, required for achieving maximum yield. Corn was grown to full maturity under optimum conditions in a highly controlled growth room utilizing sand-culture hydroponics. Quartz sand was used in order to precisely control available nutrient concentrations of treatments. Averaged across three maize hybrids, a minimum uptake of 580 mg P was required to achieve maximum grain yield. Maize exhibited a two-step P luxury consumption with respect to both max grain and biomass production i.e. max grain yield was achieved at 580 mg/plant, with further P uptake no longer increasing grain yield but still increasing total biomass until uptake of 730 mg P/plant. Further P uptake occurred after 730 mg/plant, but with no increase in total biomass. Excess P uptake decreased grain yield due to less Cu, Zn, and Fe being translocated from roots to grain, which reduced grain protein content.

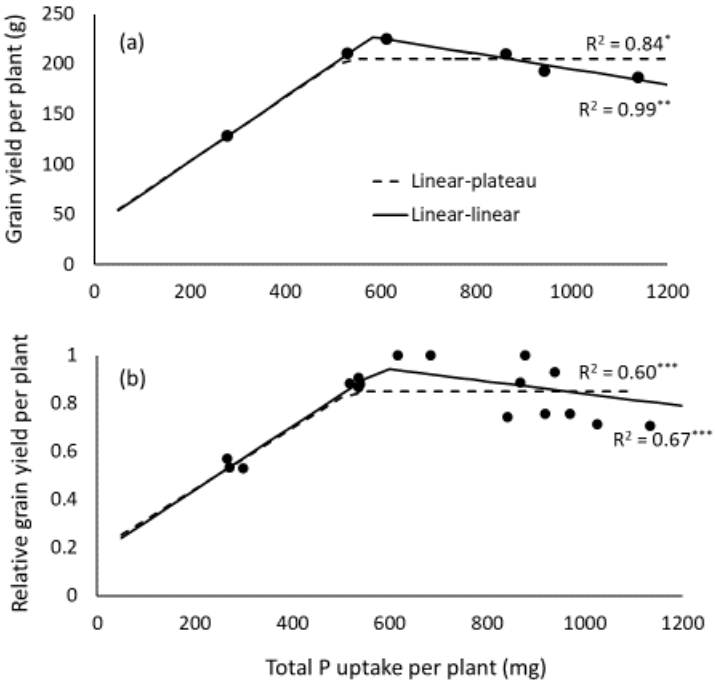

Figure 1. *Breakpoint analysis by linear-plateau and linear-linear modelling of the relationship between total phosphorus (P) uptake and grain yield, presented for yields averaged across hybrid (a) and relative yield for each hybrid (b).*

Soil phosphorus and water distribution interact with root architecture: trade-offs and interactions in complex environments

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In Northeast Australia, phosphorus (P) reserves are becoming increasingly stratified in the topsoil, whilst subsoils are being depleted. Because the topsoil is prone to rapid drying, 'deep bands' (0.1-0.3 m) are used to improve subsoil P access. Here, spatio-temporal interactions between root system architecture (RSA), P placement and water will determine crop productivity. Further, breeders are selecting for rooting traits that may enhance access to deep water, but it is unknown how these genotypes will function in complex soil environments.

Our goal was to quantify how heterogeneous distributions of water and P affect crop productivity and the potential of RSA to improve P use. We conducted a series of experiments with durum wheat and sorghum genotypes with contrasting root angles (wide=shallow *vs* narrow=deep) in controlled and semi-controlled conditions. We used rhizoboxes and a custom-built automated lysimeter system to control water dynamics in different parts of the soil profile. Experimental treatments involved various P distributions (low-P, deep-P, topsoil-P, starter-P, mixed-P) and soil water dynamics (constant, topsoil drying, drying/rewetting). Genotype responses were assessed based on biomass, grain yields, phenological development, root length and distribution, and total P uptake.

Consistent with their selection, the genotypes presented greater early-season root intensities at depth or in the topsoil, but these differences diminished later-season. Genotypic differences were negligible without P applications, which were the overall dominant driver. Early P access was essential for crop growth and development, and P close to the seed (Starter P, stratified P) boosted early root development such that soil exploration, and the odds of roots intercepting a P band, were improved. Although shallow roots could improve uptake of stratified P, topsoil drying diminished this comparative advantage. We note common plastic root responses to the placement of P, with the resulting improved plant P status boosting overall root system growth and development.

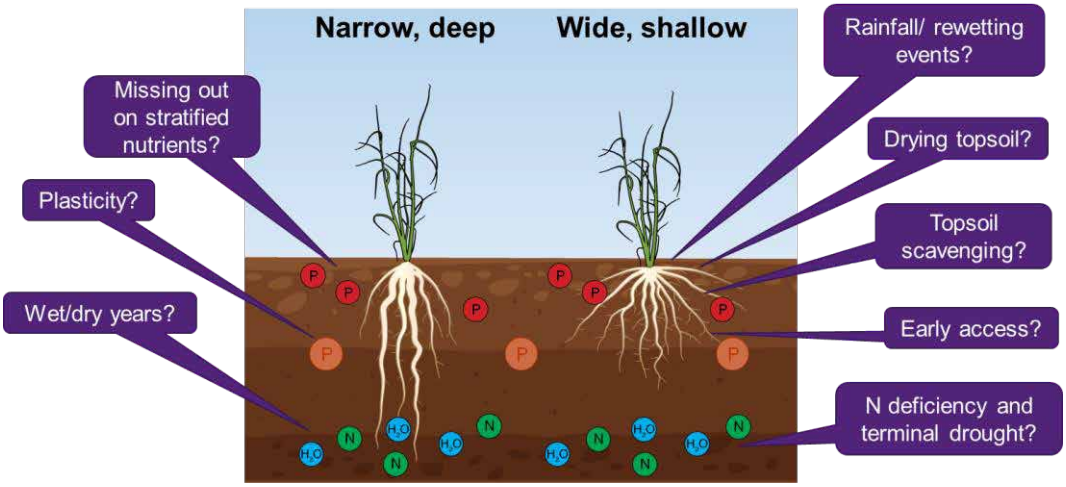

Figure 1. Many uncertainties remain about how 'designer' genotypes will function in complex environments (adapted from van der Bom et al., 2020)

Phosphate-solubilizing microorganisms for improved crop productivity: a call for action

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Phosphate-solubilizing microorganisms (PSM) are often reported to have positive effects on crop productivity through enhanced phosphorus (P) nutrition. Most studies that report 'positive effects' of PSM on plant growth have been conducted under controlled conditions, whereas field experiments more frequently fail to demonstrate a positive response (reviewed in Raymond et al. 2021). We have observed that many studies use experimental designs that are not suitable to verify if the mechanisms associated with P solubilization seen *in vitro* are responsible for and/or can be translated to improved crop P nutrition in complex soil–plant systems. We therefore call upon the scientific community to use more rigorous experimental setups and designs to evaluate the effects of PSM inoculation, to understand the underlying mechanisms that are responsible for the observations, and discuss the viability of inoculating PSM at field scale. We propose that there is currently insufficient evidence that PSM mobilize sufficient P to change the crops' nutritional environment under field conditions. The current concept, in which PSM solubilize P 'for the plant' should thus be revised. Although PSM have the capacity to solubilize P, we believe they do so to meet their own needs, and thus that their role is more likely that of slowly introducing small amounts of P into the soil-plant system through turnover of the microbial biomass (biological P cycling). Therefore, the existing concept of inoculation with PSM is unlikely to deliver a reliable strategy for increasing crop P nutrition. A further mechanistic understanding is needed to determine how P mobilization by PSM as a component of the whole soil community can be manipulated to become more effective for plant P nutrition.

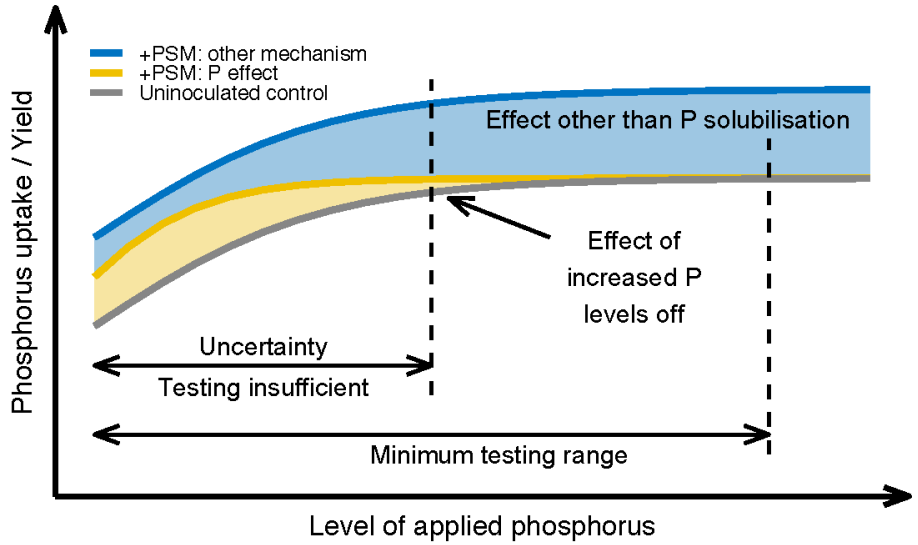

Figure: Conceptual representation of a crop response curve (P uptake, yield or biomass) with three productivity scenarios: 1. Uninoculated control (greyline); 2.Inoculation with PSM) in which P solubilization is the mechanism responsible for increased crop productivity (yellow line); 3. Inoculation with PSM in which a mechanism other than P solubilization must be responsible for increased crop productivity (blue line). Coloured shading indicates that the magnitude of the crop response can vary. Testing of an inoculant for beneficial effects to a crop will require the use of a minimum testing range in which different levels of P are included to cover the full response curve. If a response to inoculation is observed at the saturation end of the response curve, an effect other than P solubilization must be responsible for the gain in crop productivity. Not including the full range will lead to uncertainty with regards to the responsible mechanisms, hence testing would be insufficient. From Raymond et al. 2021)

Phosphorus mineralizing Bacillus co-inoculated with rhizobia interact with phosphorus fertilization to improve soybeans yield and affect bacterial rhizospheric community

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As most agricultural soils in the Southern hemisphere, Uruguayan soils where soybeans (Glycine max L.) are sown are low in available phosphorus (P). Therefore, the addition of phosphate fertilizers, a non-renewable and imported resource, is required. Often overlooked, soil organic P may count for 30-50% of total soil P, and it contains small rapidly cycling pools that can provide available P for crop uptake. Co-inoculation of soybeans with rhizobia and phosphorus-mineralizing bacteria (PMB) holds promise to improve P-uptake, crop yield, and sustainability. This study investigates the co-inoculation of soybeans with rhizobia and PMB Bacillus strains with and without addition of P fertilizer on plant P uptake and crop yield. The effect on the indigenous rhizosphere bacterial community in the field is also analyzed. The experiment was conducted at the experiment station INIA-La Estanzuela, Colonia, Uruguay, in a low available P soil without and with P-fertilization (7.7 and 15 µg g-1 of available P, respectively). The treatments were (1) Soybean seeds inoculated with Bradyrizhobium elkanii (control); and (2) Soybean seeds co-inoculated with Bradyrizhobium elkanii and formulated dried spores of either Bacillus megaterium ILBB592 or Bacillus pumilus ILBB44. The bacterial soybean rhizospheric communities were analyzed 30 days after sowing, using Illumina MiSeq sequencing of the bacterial 16S rRNA gene. The results showed that the P uptake and yield were increased by combining P addition and co-inoculation with Bacillus. P addition had an effect on the bacterial rhizospheric community increasing Actinobacteria and reducing Proteobacteria relative abundances, in comparison with the unfertilized plots. In contrast, when both P fertilization and Bacillus were added, the relative abundance of Actinobacteria were reduced and Proteobacteria increased. These results show that co-inoculation of P-mineralizing Bacillus and rhizobia has a synergistic effect on soybean growth and phosphorus nutrition and on the bacterial communities of the soybean rhizosphere.

FUENTE DE FINANCIAMIENTO: Proyecto - ALI_1_2014_1_5046, ANII

Theme 2 - Phosphorus acquisition by plants and microorganisms
Poster Session

Biological transformation of phosphorus in agricultural soils

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Despite relatively modest phosphorus (P) requirement, phosphorus deficiency set the second place in the world agriculture. Taking into account the depletion of phosphate rocks and quick fixation of applied P in soil, the understanding of microbial P mineralization (enzymatic release of orthophosphate or another organic P intermediates) and immobilization (utilization of soil solution orthophosphates during microbial metabolism) is of highest interest. Stoichiometry of C:P in residues governs mentioned processes: mineralization occurs if the C:P ratio of residues is 200:1 or less, while at C:P > 300:1 there will be not enough P in the residue to facilitate complete degradation, and immobilization occurs. Further, viruses may be one of the major drivers of mortality among bacteria in soil. Viral infection turns over the microbial population by cell lysis, thus releasing immobilized nutrients including P for root uptake. Microbial necromass consisting of the residue mixtures of initially intracellular and extracellular biomolecules may be an important source of labile organic phosphorus. As the global ratio of C:N:P for microbes (60:7:1) is narrow compared to other soil P stocks, it makes microbial necromass an ideal source of nutrients, especially under P deficiency. Besides, P solubilizing microorganisms may facilitate plant P nutrition. Phosphorus solubilization occurs mainly in the rhizosphere, which is microbial hotspot and zone of P uptake. The release of organic acids produced by bacteria and fungi, as well as decrease in pH are the most probable mechanisms to solubilize various forms of inorganic phosphates. Overapplication of both inorganic and organic P-containing materials may result in potential offsite degradation of water quality. Meanwhile, environmental initiatives like C sequestration may lead to co-sequestered P in soil, which requires more P input.

Effect of phosphate fertilization on nitrogen use efficiency of forage pastures 2. Annual Ryegrass

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Pasture response to N fertilization and the nitrogen use efficiency (NUE) is highly conditioned by the phosphorus (P) availability and soil water. The objective of the study was to evaluate the effect of NP fertilization on the NUE of annual ryegrass, in two growth periods. Two experiments were installed on a Clay loam, Vertic Argiudoll soil (P level citric acid methods: 4.3 mg kg-1; pH= 5.8) in Uruguay. P levels were applied at sowing (0, 15, 30 and 45 kg P ha-1) and six levels of N (0, 40, 80, 150, 300 and 600 kg N ha-1) were applied on 15 June (winter experiment, E1) and on 24 august (spring experiment, E2). The accumulated biomass (BA) was evaluated during periods June-August (80 days, main air temperature 11.5 °C, precipitation 143 mm) and September-November (60 days, main air temperature 17.0 °C, precipitation 264 mm) for E1 and E2, respectively. The NUE was calculated as (BANx-BAN0)/Nx (x is the N level of treatment and N0 the control for each P level). In both periods, the NUE decreased with increasing N levels. In E1 (Figure 1a) N and P application increased the NUE ($p<0.05$) without interactions between nutrients. There were significant differences in the P treatments compared to the control, without differences between the levels applied. The N40 level was the one with the highest NUE in the two growth periods. In E2 (Figure 1b), no significant differences were observed between P levels. Additional information is being analyzed to explain the different responses found between the two periods evaluated.

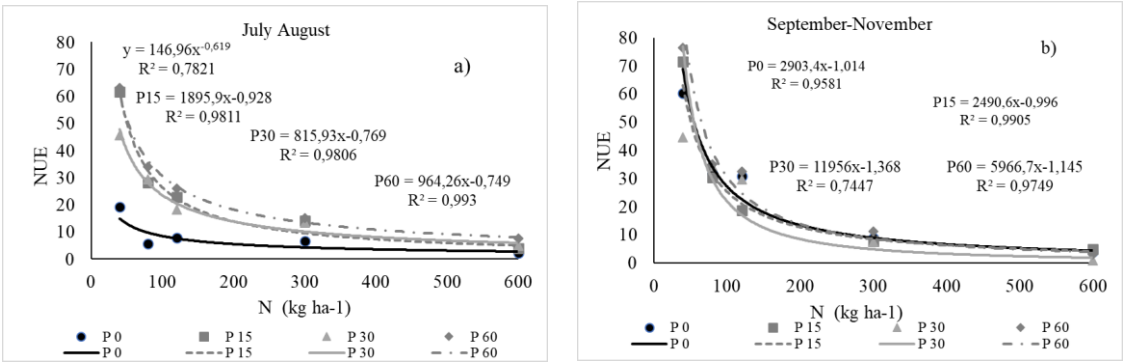

Figure 1. Nitrogen use efficiency by growth period evaluated (a: June-August; b: September-November) in relation to N applied and potential models adjusted for each P treatments.

Evaluating plasticity of root p acquisition strategies in four plants species of grasslands of Uruguay

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Natural grasslands are environmental and economically relevant ecosystems in Uruguay. They harbor a high diversity of plant species, including those belongs to Fabaceae, Asteraceae, Poaceae and Cyperaceae. This flora has developed different strategies to surmount the low availability of phosphorus of most of its soils. Strategies are based in tackling two P drawbacks: low solubility and poor mobilization. The objective of this work was to study strategies of different species of natural grasslands plants and evaluate its relationship with phosphorus availability.

A greenhouse assay was performed using four plant species (Adesmia bicolor, Baccharis genistelloides, Cyperus aggregatus and Paspalum notatum) and four levels of phosphorus (added as K2HPO4 0, 20, 80 and 160 µgP/g) with 6 replicates each. Leaf dry weight, leaf nutrients (N, P, K, Zn and Mn) and root phosphoesterases activities (mono and diesterases) were quantified in harvested plants, four months after sowing. For all species, plants produced more biomass and showed more leaf P content with the addition of 80 µgP/g in comparison to no P added. Furthermore, the addition of 160 µgP/g produced the same or even a negative effect than 80 µgP/g. There were no difference within P added nor plant species in remain nutrients quantified. A. bicolor showed the highest phosphatases activity but without differences among levels of P. The other species were plastic regarding to P availability, C. aggregatus and P. notatum produced more phosphoesterases when no P was added than with 80 µgP/g, whereas B. genistelloides produced more phosphomonoesterase at 160 µgP/g than with less P added. Our results shows that phosphatase production depends not only on plant species identity, but also on P availability for growth. To complement this work, two more phosphorus-acquisition strategies will be quantified: root carboxylates exudation (by HPLC) and symbiosis with fungi (percentage of root colonization).

Fe-P solubilization by *Talaromyces helicus* (L7B) is influenced by nutrients availability

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Phosphorus (P) is an essential nutrient for plant growth and development. It is found as insoluble forms in soils but can be solubilized by soil microbiota. Here, we studied the fungal strain *Talaromyces helicus* (L7B) as iron phosphate (FeP, 7g/l) solubilizer under different nutritional conditions: 2 concentrations (low:0,1g/l, high:1g/l) of inorganic-N (Ammonium Nitrate:AN and Ammonium Sulphate:AS) and organic-N (Asparagine:A and Tryptophan:T), and 10g/l of Carbon (Glucose:G, Saccharose:S, Fructose:F). LB7 was grown in liquid medium and agitation for 96h and biomass, soluble P, pH, phosphatases, and organic acids (OA) production was measured. Biomass production was highest with F (regardless N) and high-AN (regardless C). Fungal growth was accompanied by pH decrease, particularly with inorganic-N sources. High-N-F lead to high solubilization. High-T-F combination produced the highest solubilization (722,41±118,84 ug P/ml). Organic-N sources (low concentration), regardless C sources, produced low solubilization, while with inorganic-N sources (low) the solubilization rates depended on the N-C combination. The lowest FeP solubilization was present in low-T-G, coinciding with the lowest pH decrease, biomass and phosphatases production. The highest total-OA was produced in high-AS-S (1,8767±0,3791mM) coinciding with high pH decrease; the lowest was produced in high-A-F treatment where scarce pH decrease was found. Formate was the highest-OA produced with inorganic-N with G and S, while with F the major OA produced were gluconate and succinate. Citrate was the highest OA in all organic-N sources treatments, except for A-S (pyruvate) and T-F (acetate). Here we showed that *T. helicus* can solubilize FeP, and that this solubilization depend directly on nutrients amount and quality. It seems that the two most important mechanisms involved in this process are the OA release (particularly citrate and formate) and pH drop. The better understanding of fungal P solubilization and the nutritional conditions that affect this process could bring a better use of soil resources.

How do phosphorus deficit and drought affect the phenological development of wheat? A look into the future of phosphorus-water scarcity

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The current scientific evidence shows that phosphorus (P) mitigates the adverse effects of water deficit stress. However, there is little information on how drought and low soil P concentrations affect the phenological development of wheat. This study investigates the combined effect of P and water limiting conditions on wheat growth and phenology.

Ten wheat genotypes, including old and current cultivars, were screened. Plants were grown under controlled conditions on an Andisol with soil P-concentration of 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% of +W (water-stressed, -W). Wheat phenological stages were recorded during the entire growth period using the Feekes scale.

The wheat genotypes showed differences in growth and development in response to P and water limiting conditions. The single -P produced a long delay in the plant development, especially in the early growth stages. The number of days required to reach the leaf sheaths strongly (F5 stage) varied from 40 to 105 days in -P condition among genotypes. This effect was more evident when imposed -W-P; the number of days required to reach the F5 stage was delayed by 60 to 127 days. The single inadequate irrigation (-W) produced a growth delay of 4.9 to 21.8 days in the wheat genotypes subjected to -P and +P treatments, respectively, to reach the F5 stage. The growth delay subsequently postponed the reproductive stage and reduced yield components.

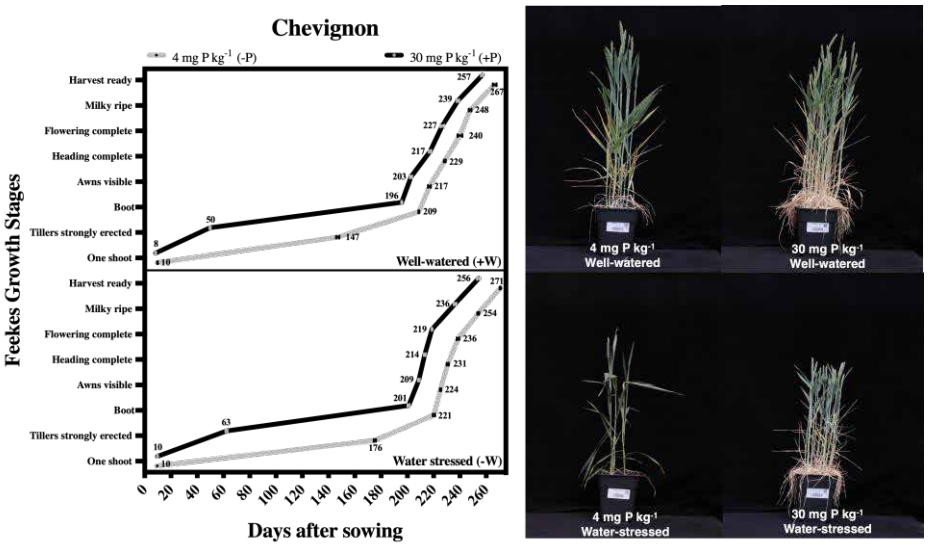

Figure 1. Wheat Feekes growth stages of Chevignon genotype were evaluated under two irrigation conditions (+W; and -W) and two P concentrations (4 mg P kg^{-1}, -P and 30 mg P kg^{-1}, +P).

Impact of grassland farm management and fertilizer practices on the interactions between phosphorus and micronutrients in relation to forage uptake

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The quantity and availability of nutrients in soils for uptake by forage plants greatly impact the yield and nutritional quality of forage. Results from a pot experiment showed that the uptake of phosphorus (P) along with other macronutrients, such as nitrogen (N), from soils had a synergistic effect on the uptake of copper (Cu) and zinc (Zn) in perennial ryegrass (*Lolium perenne*), two elements essential to both plants and animals. However, the uptake of P appeared to be antagonistic to the uptake of selenium (Se), an essential element to animals but not to plants. To investigate whether this effect could be observed at the field scale, a field experiment was carried out at the North Wyke Farm Platform (NWFP), a grassland livestock production research platform investigating the sustainability of (a) monoculture perennial ryegrass systems, (b) a mixed sward of perennial ryegrass and white clover and (c) maintenance of permanent pasture. Replicated (n=3) small plots within the fields under the different pasture management were applied with either: (a) control (with no urine or dung applied) (b) cow urine (at a rate of 5 L m^{-2}) or (c) cow dung (at a rate of 20 kg m^{-2}). Preliminary results showed that, similar to the pot experiment, the uptake of Cu and Zn were highly related to grass yield, which was significantly influenced by the availability of macronutrients, including P, regardless of the farm management and fertilizer practices. However, the uptake of Se did not follow the trend of grass yield and was significantly different between the systems. The monocultured perennial ryegrass system had significantly lower Se content in the grass than the other two systems, regardless of the fertilizer practices. However, soil P did not appear to be the major factor that drove the differences of Se concentration and content in the herbages.

Inoculantion effect of phosphate-solubilizing bacteria on microbiota of mayze rhizosphere cultivated with different phosphate fertilization conditions

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The use of bioinoculants for sustainable agriculture has grown in many regions worldwide. BiomaPhos® is a bioinoculant composed of two P-solubilizing *Bacillus* strains (CNPMS B2084 and CNPMS B119). Our aim was to evaluate the effect of inoculation with BiomaPhos® and phosphate fertilization on microbial communities of maize rhizosphere. Field experiments were carried out at Embrapa Milho e Sorgo Experimental Station in Brazil, in the 2019/2020 and 2020/2021 seasons. The maize genotype DKB390 was inoculated with and without BiomaPhos® and submitted to three P-fertilizer treatments: without P-fertilizer addition (P0); Rock phosphate (RockP) or triple superphosphate (TSP) at a rate of 120 kg of P_2O_5 ha^{-1}. Genetic diversity was assessed during flowering time by T-RFLP and taxonomic groups identified using the MiCA3 software. In the 2019/2020 harvest, no significant differences were observed in bacterial or fungal diversity among treatments. In 2020/2021, there were significant differences in both bacterial and fungal communities between inoculated and non-inoculated samples from RockP and bacterial communities from P0. The most abundant bacterial families in the first and second seasons were *Streptomycetaceae* (34.6% and 40.4%), *Micrococcaceae* (15.14% and 12.0%) and *Methylobacteriaceae* (10.9% and 13.7%), respectively. Furthermore, there was a significant increase in the abundance of the families *Rhizobiaceae*, *Sphingnomonadaceae* and *Brucellaceae* and a significant reduction in the relative abundance of the families *Clostridiaceae*, *Geobacteraceae*, *Micrococcaceae* and *Pseudomonadaceae* in the second season. The most abundant fungal families in the first and second seasons were *Saccharomycetaceae* (38.2% and 49.8%) and *Tremellaceae* (23.1% and 40.7%), respectively, with significant increase in abundance of both families and the reduction of the families *Davidiellaceae*, *Phaeosphaeriaceae* and *Trichocomaceae* in the second season. The results indicated that the microbial communities' structure of maize cultivated under P0 and RockP were different between non-inoculated and inoculated treatments in the second season.

Intra-root facilitation between fine root structures and parent roots allows rice to take up p from strongly p-sorbing soils

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Upland rice (*Oryza sativa*) is adapted to strongly phosphorus (P) sorbing soils. The mechanisms underlying P acquisition, however, are not well understood, and mathematical models typically underestimate observed P uptake. We present two recent models exploring root growth and P uptake in rice from strongly P-sorbing soils. Both models included crown roots and two types of lateral roots present in rice: larger L-type laterals comparable to other cereals, and small S-type laterals with determinate length unique to rice. Models assumed root hairs to develop on all root classes. The 3-D root growth model by Gonzalez et al. (2021) allowed us to estimate costs (P invested in growing a root) and benefits (P taken up by that root) of different root classes. Simulations relating costs and time needed to recover that cost through P uptake suggest that producing nodal roots represents a considerable burden to a P-starved plant, with more than 20-times longer pay-off time compared to S-type laterals and root hairs, which recover their cost within a day of their formation. The second model by Kuppe et al. (2022) simulates fast- and slowly reacting soil P and the P-solubilizing effect of root-induced pH changes. Simulations predict that the zone of pH changes and P solubilization around a root spreads further into the soil than the zone of P depletion. A root needs to place laterals outside its depletion- but inside its solubilization zone to maximize P uptake. S-type laterals and hairs growing on them are the key root structures to achieve that. Thus, thicker roots facilitate the P uptake by fine lateral roots and only this inter-root facilitation in combination with P solubilization allows for matching simulated with observed P uptake.

Involvement of hormones in function and development of cluster roots of white lupin (*Lupinus albus* L.)

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White lupin (*Lupinus albus* L.) is highly tolerant under phosphorus (P) deficiency. They form unique morphological roots, so-called cluster roots (CRs) under P deficiency, which contribute to P absorption by the expansion of root surface area and P mobilization activities. Previous studies have implied that several hormonal functions are involved in the function and the development of CRs. However, understanding of the effects of hormone on CRs is not enough. Here, the focus was on mRNA accumulation involved in the hormonal function on CRs, followed by the effects of ethylene on CR morphology and gene expression for P acquisition.

According to a reanalysis of public RNA-Seq data, genes related to the hormone functions were differentially expressed among three developmental stages of CRs, confirming that the function and the morphology are implied to be modulated by several hormonal functions. In particular, *ACC oxidase* genes and an *ACC synthase* gene, which are responsible for ethylene synthesis, were up-regulated in the CRs maturation-dependent manner. In turn, the morphology and gene expression were determined in CRs 10-days exposed by ethylene-related reagents (an ethylene synthesis inhibitor, $CoCl_2$, and an ethylene precursor, ACC). As a result, the elongation of rootlets in CR was promoted when CR was exposed by Co^{2+}, and some genes for P absorption (*acid phosphatases* to hydrolyze P-containing organic compounds, *citrate synthases* and a putative *citrate transporter* to mobilize P contained in inorganic compounds, and a *phosphate transporter*) were enhanced in ACC-treated immature CRs. It is suggested that ethylene works as a possible regulator for the rootlet elongation and transcription of genes for P acquisition in CRs. Since recent studies have provided novel insights on the morphological alteration under factors application such as flavonoids and a peptide, the relationship between ethylene and these factors are considerably important perspectives.

Root hair and root-specific transcriptome reveals low phosphorus response in *Cicer arietinum*

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Root hairs (RH) are a single-cell extension of root epidermal cells and are involved in phosphate (Pi) acquisition. Root hair length and density increase under low phosphorus (LP) availability, thus expanding the total root surface area for Pi acquisition. However, details on genes involved in RH development and response to LP are missing in an agronomically important leguminous crop, chickpea. To elucidate this response in chickpea, we performed tissue-specific RNA-sequencing and analyzed the transcriptome modulation for RH and root without RH (Root-RH) under LP. Root hair initiation and cellular differentiation genes like RSL TFs and ROPGEFs are upregulated in Root-RH, explaining denser and ectopic RH in LP. In RH, genes involved in tip growth processes and phytohormonal biosynthesis like cell wall synthesis and loosening (cellulose synthase A catalytic subunit, *CaEXPA2*, *CaGRP2*, *CaXTH2*), cytoskeleton/vesicle transport, and ethylene biosynthesis are upregulated. Besides RH development, genes for LP responses like lipid and/or pectate remobilization and acid phosphatases are induced in these tissues summarizing a complete molecular response to LP. Genes preferentially expressed in RH are mainly concerned with RH development and primarily include various RSL TFs. One of the RSL TF (CaRSL) is significantly associated with RH length in normal conditions in our chickpea GWAS study, which shows that CaRSL is an RH preferential RSL and plays a crucial role in regulating RH length in normal conditions. Also, RH displayed preferential enrichment of processes involved in symbiotic interactions, which provide an additional benefit during LP in the form of microbe-associated solubilization and acquisition of P. In conclusion, RH shows a multi-faceted response that starts with molecular changes for epidermal cell differentiation, RH initiation in Root-RH, and later induction of tip growth and various LP responses in elongated RH.

Screening of southern chilean quinoa genotypes reveals large variability in phosphorus acquisition capacity under restricted conditions

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Phosphorus (P) fertilizers are made from a non-renewable natural resource that will become scarce in the future, affecting global food production. Thus, reducing P-fertilizer inputs while increasing food nutritional quality has been posited as a major challenge to decrease human undernourishment and ensure food security. In this context, quinoa has aroused interest over the last years as a promising crop due to its ability to tolerate different stress conditions and grow in marginal soils with low nutrient content, in addition to the exceptional nutritional quality of its grains. Despite the above, there is scarce information about P management and acquisition efficiency in quinoa cropping. Therefore, the objective of this work was to evaluate biomass production, P acquisition, and some root traits, such as root biomass, rhizosphere pH, carboxylate exudation, and acid phosphatase activity of thirty quinoa accessions conserved on Germplasm Bank of Instituto de Investigaciones Agropecuarias (INIA)-Carillanca grown under low P availability (Olsen-P: 8 ppm). After 12 weeks, a large genotypic variation was observed among accessions, with P acquisition ranging from 0.15 mg to 17.8 mg per plant. Mean shoot biomass production varied more than 1400% among accessions and was directly correlated with P accumulation on shoots (r=0.91). Despite showing high intra-specific variability in root traits, only root biomass production significantly correlated with P acquisition (r=0.72), suggesting that root growth/morphology rather than its biochemical activity possesses a key role in the P nutrition of quinoa. Further studies are being conducted to evaluate root morphological parameters and other traits that could be used for selecting genotypes adapted to P-restricted conditions.

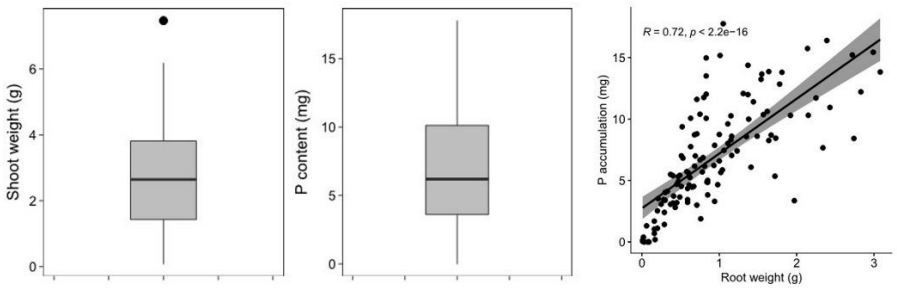

Figure. Shoot biomass production, P content per plant, and Pearson correlation analysis between P accumulation and root biomass production of 12 weeks old quinoa plants grown under low P.

Theme 3 - Phosphorus utilization and signaling in plants. Keynote presentation

Live transcription imaging of plant Pi starvation response

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Plants are sessile organisms constantly adapting to ambient fluctuations through spatial and temporal transcriptional responses. Here, we implemented the latest generation of MS2 RNA labelling system and combined it with microfluidics to rapidly change environmental conditions. MS2/MCT system is based on a fusion between GFP and the coat protein of bacteriophage MS2 (MCP-GFP), which recognizes a specific RNA stem-loop inserted in multiple copies into a reporter RNA. This enabled quantitative measurements of the transcriptional activity of single loci in living Arabidopsis plants, providing direct visualization of transcriptional regulation within entire organs. Using phosphate responsive genes as model, we found that active genes displayed high transcription initiation rates and frequently clustered together in endo-replicated cells. We also observed large differences between alleles of single cells and in agreement, intrinsic noise was larger than extrinsic variations. Moreover, we established that the transcriptional repression triggered in roots by phosphate, a crucial macronutrient limiting plant development, occurred with unexpected fast kinetics in the range of minutes, and with striking heterogeneity between neighboring cells. Access to single cells RNA polymerase II dynamics within live plants will benefit the study of numerous signaling processes.

Theme 3 - Phosphorus utilization and signaling in plants. Oral presentation

Membrane lipid remodeling for improving phosphate use efficiency in rice

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Membrane lipid remodeling, which involves the hydrolysis of phospholipids (P-lipids) to release Pi for essential cellular processes, and concomitantly, synthesis of non-Pi lipids like galactolipids and sulpholipids to compensate for a loss of phospholipids is essential for survival under Pi deficiency. We report, that lipid remolding is a conserved strategy in diverse rice genotypes to cope with P deficiency. Monongalactosyl diacylglycerol (MGDG) and digalactosyl diacylglycerol (DGDG) represent the most abundant galactolipids in the chloroplast and aid in membrane lipid remodeling, allowing the Pi utilization from the phospholipids' hydrolysis. A Pi deficiency responsive rice MGDG synthase gene, *OsMGD3* was characterized for its roles in Pi deficiency adaptation. Here, we show that Pi status of the plant and a transcription factor, OsPHR2 are involved in the transcriptional regulation of *OsMGD3*. We used overexpression (OE) and CRISPR/Cas9 generated knockout (KO) lines of *OsMGD3* to explore its potential role in rice adaptation to Pi deficiency. *OsMGD3* KO lines displayed a poor Pi deficiency tolerance while OE lines had improved PUE compared to WT. Both OE and KO lines have changed root architecture and altered membrane lipid remodeling, especially in roots. Our study revealed that OsMGD3 is involved in Pi deficiency-induced membrane lipid remodeling and also influences root architecture for Pi acquisition.

Subcellular phosphorus distribution controls plant growth under high CO_2

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Changes in the ongoing climate are bound to bring in radical shifts in atmospheric gases (for example, CO_2 – an anthropogenic pollutant), which can jeopardize the nutritional quality and food production. While the photosynthetic rate is enhanced by elevated atmospheric CO_2, resulting in increased biomass production under high CO_2 catalyzes a general drop in the accumulation of essential plant nutrients, including phosphorus (P). Despite a decline in nutritional status, better plant growth is baffling and counterintuitive, leading to the following poignant question: how do plants grow better in spite of meager P nutritional status? We will present our recent results demonstrating that elevated atmospheric CO_2 tightly regulates the transport of P at the subcellular level, which controls growth, and that this adaptive mechanism is conserved across evolutionary distant plant species. Our results lead to establishing a mechanistic framework to improve the P nutritional status of crops under elevated CO_2 without compromising the final yield. Therefore, our results should be of interest to PSP7 participants as sustainable food production against the backdrop of soaring CO_2 levels across the world is almost a daily preoccupation and discussion.

Low phosphate root1 (lpr1), a bacterial-type ferroxidase from *arabidopsis thaliana*, tunes iron-dependent phosphate sensing during root development

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Optimal plant growth critically depends on numerous edaphic resources. Access to inorganic phosphate (Pi), a principal intermediate of energy and nucleotide metabolism, profoundly affects photosynthesis, biochemical and cellular activities, and thus plant performance and crop yields. However, in most soils and agricultural production systems, antagonistic interactions of Pi with associated metal compounds (foremost Al and Fe) severely restrict Pi bioavailability, which guides local root development to maximize Pi interception and uptake. Growing root tips, the hotspots for Pi capture, scout the essential but immobile mineral nutrient. However, the mechanisms monitoring external Pi availability are unknown. We recently showed (Naumann et al., 2022) that *LOW PHOSPHATE ROOT1 (LPR1)* of *Arabidopsis thaliana*, which is one key determinant of Fe-dependent Pi sensing in root meristems, encodes a novel ferroxidase of high substrate specificity and affinity (apparent K_M ~ 2 µM Fe^{2+}). LPR1 typifies an ancient, Fe-oxidizing multicopper protein family that evolved early upon the bacterial land colonization. The ancestor of streptophyte algae and embryophytes (land plants) acquired LPR1-type ferroxidase from soil bacteria via horizontal gene transfer, a hypothesis supported by phylogenomics, homology modeling, and protein biochemistry. Our molecular and kinetic data on LPR1 regulation indicate that Pi-dependent Fe substrate availability determines LPR1 activity and function. Guided by the metabolic lifestyle of extant sister bacterial genera, we propose that *Arabidopsis* LPR1 monitors subtle concentration differential of external Fe availability as a Pi-dependent cue to adjust root meristem maintenance via Fe redox signaling and cell wall modification. We further hypothesize that the acquisition of bacterial LPR1-type ferroxidase by embryophyte progenitors facilitated the evolution of local Pi sensing and acquisition during plant terrestrialization.

Naumann et al. (2022) Current Biology 32:2189-2205

A member of the CYBDOM protein family plays a dual role in phosphate starvation responses and iron homeostasis

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Phosphate is an essential macronutrient required for plant growth. However, it is present at suboptimal levels in many terrestrial ecosystems. To ameliorate this limitation, plants have evolved developmental and physiological mechanisms known as phosphate starvation responses (PSR). One of the main PSR in *Arabidopsis thaliana* is a restructuration of the root architecture, which includes a reduction in primary root growth resulting in a shallower root system better adapted to explore the nutrient-rich topsoil. Intense research over the last years has shown that this developmental change is dependent on the accumulation and redistribution of iron (Fe) at the root tip, which in turn, participates in Fenton reactions and generates reactive oxygen species (ROS) that affect meristem function and cell elongation. We have recently determined that the ER resident chaperones CNX1 and CNX2, participating in ER protein quality control, are involved in this process. Arabidopsis *cnx1cnx2* mutant lacking the two CNXs showed a Fe-dependent hypersensitive root phenotype upon phosphate starvation due to a reduction in meristematic cell divisions, which was correlated with higher levels of iron in the root. A proteomic analysis showed that a member of the cytochrome b561 and DOMON domain-containing protein family (CYBDOM), named CRR, was strongly downregulated in the *cnx1cnx2* mutant. Biochemical and molecular assays performed in yeast and *in planta* showed that CRR is a plasma membrane-localized ascorbate-dependent ferric reductase whose expression levels modulates iron distribution pattern in the root, affecting meristem function and cell elongation. While *crr* mutant showed a reduced root growth under phosphate deficiency, lines over-expressing CRR were completely insensitive. Moreover, CRR activity was shown to be critical for iron toxicity tolerance since it determines the transport rate of iron from root to shoot. Altogether, our results uncovered new molecular players underlying root developmental responses to phosphate starvation and their relation with iron homeostasis.

Theme 3 - Phosphorus utilization and signaling in plants. Poster Session

Applications of crispr/cas9 technology for gene editing in rice

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Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-associated protein 9 system (CRISPR/Cas9) has emerged as the method of choice for site-directed mutagenesis in plant genes. This system consists of a guide RNA that contains sequence complementary to the target gene and a Cas9 protein which is an endonuclease that makes double stranded cut at the site marked by gRNA. The applications of CRISPR/Cas9 using single and multiple gRNAs have been successfully utilized in targeting different plants to alter agronomic traits including tolerance to biotic and abiotic stresses. Here, we have adopted different strategies to create loss of function mutants and precise editing of genes involved in rice tolerance to phosphate deficiency response. Our results demonstrate a high rate (up 80%) of targeted mutagenesis in a rice galactolipid synthesizing gene, OsMGD3. In another approach, we used a multiplexing CRISPR/Cas9 strategy to re-architect promoter of a phosphate transporter gene *OsPHO1*. The promoter of *OsPHO1* has two W boxes which are putative binding sites for the WRKY transcriptional factors that acts as negative regulator for its expression. In this system, we intended to use the multiple gRNAs cloned in a single Polycistronic-tRNA-gRNA (PTG) gene to remove those W-boxes present in the promoter of *OsPHO1*. Although efficiency was low, gene-edited plants displayed a W-box less promoter and consequently, enhanced expression of OsPHO1. Together, these findings demonstrate applications of CRISPR/Cas9 technology in efficient gene-editing in rice for crop improvement using single or multiple gRNAs.

Root-Expressed *OsPAP3b* Enhances Secreted APase Activity and Helps Utilize Organic Phosphate

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Phosphate deficiency leads to induction of purple acid phosphatases in plants, which dephosphorylates organic phosphorus complexes in rhizosphere and intracellular compartments. In this study, we demonstrate that *OsPAP3b*, a PAP encoding gene, is low Pi responsive and gets induced preferentially in roots. The expression of *OsPAP3b* is negatively regulated with Pi supply. Interestingly, OsPAP3b was found to be localized to the nucleus and cytoplasm. Furthermore, *OsPAP3b* is transcriptionally regulated by OsPHR2 as substantiated by binding assay. We also demonstrated, through *in-vitro* biochemical assays, that OsPAP3b is a functional acid phosphatase with broad substrate specificity. Overexpression of *OsPAP3b* in rice led to increased secreted APase activity and improved mineralization of organic P sources reflected in their better growth compared to wild type, when grown on organic P as exogenous P substrate. Under Pi deprivation, *OsPAP3b* knockdown and knockout lines showed no significant changes in terms of total P content and dry biomass. However, the expression of other PSR genes and the levels of metabolites were found to be altered in the overexpression and knockdown lines. In addition, *in-vitro* pull down assay revealed multiple interacting partners of *OsPAP3b.* Our data collectively suggest that *OsPAP3b* can aid in organic P utilization. The APase isoforms behavior along with nuclear localization suggests its additional role possibly in stress signaling. Considering its wide variety of functions *OsPAP3b* could be potential target for improving low Pi adaptation in rice.

The *cis*-Golgi ERD1 phosphate transporters harboring the EXS domain are essential for numerous aspects of plant growth and development

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Cell wall synthesis and protein glycosylation require nucleotide diphosphate-sugar import into the Golgi, which must be counterbalanced by inorganic phosphate (Pi) export. While numerous Golgi nucleotide-sugar transporters have been characterized, transporters mediating Golgi Pi export are poorly understood. We used plant and yeast genetics to characterize the role of two *Arabidopsis thaliana* proteins possessing an EXS domain, named ERD1A and ERD1B, in Golgi Pi homeostasis. ERD1A and ERD1B both localized in *cis*-Golgi and were broadly expressed in vegetative and reproductive tissues. We identified ERD1 orthologs in algae, bryophytes, and vascular plants. Expressing *ERD1A* and *ERD1B* in yeast complemented the *erd1* mutant phenotype of cellular Pi loss via exocytosis due to failure in Golgi Pi export, and the Arabidopsis *erd1a* mutant had a similar apoplastic Pi loss phenotype dependent on exocytosis. *ERD1A* overexpression in *Nicotiana benthamiana* and Arabidopsis led to partial mis-localization of ERD1A to the plasma membrane and specific Pi export to the apoplastic space. Arabidopsis *erd1a* had defects in cell wall biosynthesis, which was associated with reduced shoot development, hypocotyl growth and tensile strength, root elongation, pollen germination, pollen tube elongation, and fertility. We thus identified ERD1 proteins as Golgi Pi exporters that are essential for optimal plant growth and fertility.

Uptake and utilization of phosphorus by cluster root forming woody plants grown in poor nutrient soils in western Japan

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Part of plant species forms 'cluster roots' (CRs) and copes under P impoverished environments. CR-formation is advantage in increase of root surface areas and mobilization of unavailable P forms. Since the nutritional characteristics of CR-forming plants had been mainly focused on native plants in southern hemisphere, ecophysiological information for CR-forming plants in northern hemisphere were lacking. This study aimed to characterize uptake and utilization of P by CR-forming woody plants grown in poor nutrient soils in western Japan.

Miyajima Island in Hiroshima was the main field of this study. There are two CR-forming plants in Miyajima: *Helicia cochinchinensis* (Hc; Proteaceae), and *Myrica rubra* (Mr; Myricaceae). Young, matured, and senescing leaves were collected from mature trees of Hc, Mr and other evergreen trees in spring to analyze P and N concentration ([P] and [N], respectively). [P] of mature leaves of Mr was the lowest among tested plants (in average, 0.265 mg-P/gDW). Interestingly, [P] of senescing leaves of Mr was also the lowest, 0.035 mg-P/gDW in average, suggesting that P remobilization efficiency of Mr was extremely high.

To clarify sexual differences in nutrient translocation, [P] and [N] of leaves were compared between male and female plants. [P] of senescing leaves was significantly low in female than in male, although it was similar level in young and mature leaves. [N] was similar level regardless of sex. This fact suggests that the senescing leaves play a role of P source for fruits of Mr in female plants.

As the result of cultivation experiments, it was suggested that phosphatase activities in the rhizosphere of CRs of both plants contributed to organic-P mobilization. Moreover, numbers of CR were positively correlated to carboxylate exudation rate in Hc. Contrastingly, exudation rate of malate and citrate of Mr was very low than that of other CR-forming species.

Theme 4 - Sustainable intensification of phosphorus supply in food production Keynote presentation

Role of legacy phosphorus in sustaining intensively managed agroecosystems

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Inputs of phosphorus (P) in the form of mineral and/or organic fertilizers to managed ecosystems inevitably results in the accumulation of “residual” or “legacy” P in soil. This occurs primarily as a consequence of adsorption of soluble inorganic P onto metal oxide surfaces, as well as some precipitation of sparingly-soluble P minerals. In addition, added inorganic P may be retained in soil as organic P by various biological immobilisation pathways. The extent and nature of legacy soil P are determined by a combination of factors including the quantity, form, and duration of P inputs, soil properties (pH, metal oxide form and content, organic matter), and overall P-use efficiency related to the type and relative intensity of land-use and management. Rapid food production growth since the 1940s in North America, Europe, and parts of Asia, South America, and Australasia relied on availability of low cost P inputs derived from phosphate rock deposits, while the development of intensive grain-fed indoor meat production systems (e.g. pigs, poultry) resulted in the disposal of waste P onto land. Phosphorus use efficiency was very low in many of these systems which resulted in the accumulation of significant quantities of P in many agricultural soils, and levels of plant-available P in soil often exceeded agronomic optima. High levels of P input also resulted in enhanced diffuse transfer of P from land which adversely impacted the quality of many waterbodies via accelerated eutrophication. However, the cost of P fertilizers has increased dramatically in recent years, and become more volatile. Accordingly, there is an urgent need to improve the overall agronomic efficiency of P inputs in order to maintain or even increase food production with reduced inputs, which is also relevant for increasing food production in current low P input systems with rapidly increasing populations. Enhancing mobilization and utilization of legacy soil P has the potential to make a significant contribution to improving P-use efficiency in agroecosystems. This presentation will describe and discuss the extent and nature of legacy soil P, together with options and challenges-limitations associated with enhanced legacy P mobilization. These include the development and use of novel plant varieties or combinations of plant species (e.g. mixed species grassland), the inclusion of specific green manures in crop rotations, and microbial inoculation of plants (e.g. mycorrhizae) and soil (e.g. P-solubilizing bacteria).

Theme 4 - Sustainable intensification of phosphorus supply in food production
Oral presentation

Which organic materials to apply on fields with high phosphorus levels?

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To level off or decrease soil phosphorus (P) contents in order to protect surface and groundwater, P application is restricted in many countries and regions. This restriction has a severe impact on the amount of organic matter (OM) that can be applied on these fields. Organic amendments can ameliorate soil quality and enhance carbon (C) sequestration, but also contain P. In this study, three ongoing projects testing which type of organic amendment is preferable in order to limit P application and maximize OM application, are reviewed.

Vanden Nest (2015) advises to use compost from vegetal debris over farmyard manure for application on high P fields. However, annual application of plant-based farm compost in the BOPACT field trial in Belgium, resulted in an important P enrichment and increased P leaching compared to soil without compost application. The ongoing characterization of composts from varying origin in the project Soilcom shows that there is a large variation in OM and P contents in composts, with fivefold variation in the organic C:P ratio.

In addition to compost, residues from nature conservation management can serve as organic amendment. Materials as soft rush and heathland biomass have organic C:P ratios that are 2 to 9 times larger than compost, although the stability of the OM in the residues may be lower than that in compost. The second year results of the field trials of the project Bi-o-ptimal@Work confirmed the results of the first year (Amery et al., 2021), i.e. that these residues can replace the commonly used farm yard manure as organic amendment without hampering crop yields.

At the formulation of bio-innovative fertilisers for the Rustica project, a high C:P ratio is also targeted for some regions. In conclusion, carefully selecting organic amendments is crucial to increase soil quality while minimizing soil P enrichment.

Phosphorus and ph levels as indicators of soil health on dairy systems in Uruguay

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Current sustainability challenges of production systems require comprehensive answers with a multidimensional approach. The objective of this study is to select indicators that allow quantifying the productive-economic, social, and environmental evolution of dairy systems transitioning towards agroecology through a co-innovation approach. Six farms were characterized by assessment of descriptors on the three areas of sustainability. A diagnosis based on the information collected was made to identify and rank critical points and, in turn, propose a system redesign, without neglecting its original strengths.

In this framework, key indicators that could affect (positively or negatively) soil health (see table below) were identified: pH values showed possible acidification (between 3 and 18% below undisturbed soil levels), and phosphorus accumulation above the regulated environmental limits in Uruguay (31 ppm Bray). The simultaneous evaluation of these and other indicators from different dimensions of sustainability allows the proposal of redesigns that could reverse situations of environmental risk while sustaining the economic and social viability of the systems.

Table 1. System health indicators

Dimension	Group	Indicator	Farm					
			1	2	3	4	5	6
Environmental Soil	Biologic	ACI	-0,57	-0,21	-0,21	-0,35	-0,43	-0,18
		RI	-0,68	0,02	-2,03	-0,22	-0,55	-0,41
		PI	-0,16	-0,08	0,11	-0,04	-0,04	-0,05
	Physical	PRI (0-15cm)	0,01	-0,23	-0,34	-0,30	-0,34	-0,44
		PRI (15-45cm)	-0,16	-0,22	-0,20	0,01	-0,02	-0,21
	Chemical	OMI	-0,05	-0,05	-0,04	-0,15	-0,27	-0,05
		pHI	-0,18	-0,06	-0,16	-0,08	-0,05	-0,03
		P (ppm)	27,9	29,6	61,4	14,7	42,3	17,9
Environmental System level	Pesticides	EI (mam)	0,47	0,05	0,05	0	0,85	0,42
	Biodiversity	EII	2,4	3,2	2,5	2,6	2,4	2,6
Economic- productive*		KI (U$S/ha/year)	337	34	720	-31	107	173
		Prod. (lt/ha/year)	4564	5717	14742	3128	9780	3824
		Rel. I/O	0,74	0,91	0,80	0,84	0,89	0,76
Social		CTA (hr/year/pBC)	6,3	5,7	6,6	5,5	5,0	3,5

Ref.: ACI: Active Carbon Index; RI: Respiration Index; PI: Protein Index; PRI: Penetration resistance Index; OMI: Organic matter index; pHI: pH Index; P: Phosphorus; EI (mam): Mammalian ecotoxicity Index; EII: Ecosystem Integrity Index; KI: Capital income after rent; Prod.: milk productivity; Rel. I/O: Input/Output Relationship; CTA: Calculate Time Available.

*average of three years 2018/2019 to 2020/2021

Is it possible to diagnose the contribution of phosphorus from agro-industrial by-products?

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The main advantage of using residues from agricultural and agro-industrial production as soil improvers is the transformation of an environmental liability into a valuable product for plant nutrition and soil restoration. Since P fertilizers are mainly extracted from deposits, which are expected to be shortly depleted, it is very important to look for alternatives for reusing P from these materials. The question then arises regarding the possibility of predicting the availability of P from these sources. In the Department of Soils and Waters, of the Faculty of Agronomy, Udelar, individual characterizations of manure, industrial by-products and sanitary sludge have been carried out, which show a variety of results in terms of availability of nutrients once applied to the soil. The objective of this work was to determine the potential contribution of P from organic materials and to identify the causes of the differences between materials, which is directly related to their use efficiency. For this, the information from 11 evaluation experiments of organic materials, covering 20 different materials, was collected. In these studies, the increase in soil P availability was determined with the application of materials using the Bray No.1 method, calculating the required amounts of P and material to produce an increase of 1 mg/kg in the analysis value. The P content of the materials varied from 5 to 49 mg/kg (average of 19 mg/kg). The material requirement to produce the 1 mg/kg increase in the analysis value was in the range of 94 to 1365 kg/ha (dry basis) with an average of 602 kg/ha. Although for some materials it was possible to identify characteristics of their composition to diagnose their potential contribution of available P, in other cases it was not possible, for which the generation of specific indices for this purpose is proposed.

Phosphorus deficit increases the production risk to a greater extent in wheat than in maize and soybean

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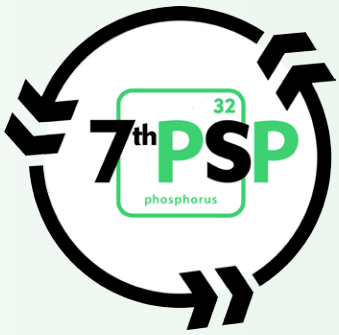
The production risk approach allows the estimation of the probability that the yield of a cropping system falls below a certain threshold. By comparing this probability between different crops or agronomic practices, it is possible to choose between different interventions to mitigate the effects of risk and foster resilience. Our objective was to compare the effects of long-term P fertilizaton on production risks in maize, wheat, and full season (FS) and double cropped (DC) soybean. Evaluations focused on a long-term experiment being conducted in five farms located in the Northern Pampas Region of Argentina since 2000, comparing +P (with P) and -P (without P) treatments. The effect on yield (tn ha-1) and production risk calculated by the probability (%) of yields falling below critical levels every 0.1 tn ha-1 were estimated. As expected, the four crops presented higher yields with P application, the average response was 1.17, 1.03, 0.30 and 0.44 (tn ha-1) for maize, wheat, FS soybean and DC soybean, respectively. The relative risk plots contrast graphically the agronomic production risks of one fertilization treatment versus another taken as reference, in our case -P and +P. The absence of P fertilization differentiated two groups. The lower production risk was verified for maize and both soybean crops (FS/ DC), which presented small differences between them. The wheat curve remained clearly separated from the first group, showing a greater concavity which indicates a higher production risk. In all cases, the -P treatment presented the highest production risk with a yield probability below the mean of 61, 69, 59 and 64% for maize, wheat, FS and DC soybean, respectively. For the +P treatment these values were reduced to 40, 33, 41 and 42%. Obtained results allowed the quantification of the differential impact of P fertilization on the production risk of the main Pampean crops.



Theme 4 - Sustainable intensification of phosphorus supply in food production Poster Session

Assessment of p mineralization from pelletized and non-pelletized compost through an incubation experiment

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The mineralization of compost in the soil can be affected by the sources of the composted organic materials and by their physical form. This work evaluated the mineralization of P after the addition of compost to the soil through an incubation experiment under controlled laboratory conditions for 7 weeks. The composts used were obtained from two different sources: pig slurry (CS) or the dry fraction of the digestate obtained after the anaerobic digestion of the pig slurry (CD). These composts were use in two different physical forms: pelletized (PE) and non-pelletized (NPE). The soils used in the experiment were a dystric Regossol and a dystric Cambissol. The experimental design was completely randomized with 5 treatments each one with 3 replicates. The treatments were: control without fertilization (C); non-pelletized compost from pig slurry (CS-NPE); pelletized compost from pig slurry (CS-PE); non-pelletized compost from digestate (CD-NPE); and pelletized compost from digestate (CD-PE). Fertilization with P ranged between 82 and 113 mg P kg^{-1} soil. The results indicate that PE and NPE compost, increased the assimilable P (P Olsen) in the soil a week after being applied and the increase is maintained for at least 6 weeks. This increase was between 32.7 and 40.7 mg P kg^{-1} in the Regossol and between 31.6 and 41.8 mg P kg^{-1} in the Cambissol with respect to the control (12.9 y 11.9 mg P kg^{-1} respectively). The CD-PE shows a greater increase of P Olsen available per unit of P added for both soils, at 7 days and at 42 days. On the other hand, the CS-NPE presents the smallest increases in both soils. As preliminary conclusion the results suggest that pelletization did not affect assimilable P in the soil, moreover the pelletized composts from digestate showed higher increases in P with respect to other treatments.

Construction of general critical levels and an alternative proposal of phosphorus fertilizer equivalent

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The low level of phosphorus (P) currently present in the most intensively used soils of Uruguayan territory makes P one of the most limiting nutrients. Carrying out a diagnosis of phosphorus fertility based on the P available in the soil in the surface layer, should allow estimating the optimum amount of P needed to cover crop requirements. The correct dose should arise from the soil P level, the critical level and a fertilizer equivalent (FE). The present work was based on a review of all available national information on phosphorus fertilization, with the aim of studying the critical soil P levels and proposing an alternative method of estimating the EF, through the relationship between the optimum dose and the available soil P level. Overall, 257 experiments were identified, which allowed the assembly of a metadata base. A general critical level of 14.5 mg kg-1 was determined using a linear plateau model and critical levels according to soil textural class, resulting in 10.2 mg kg-1, 13.8 mg kg-1 and 15.5 mg kg-1 values for fine, medium- fine and medium-coarse textures, respectively. To analyze the relationship between the optimum dose (which ensures 90% of the maximum response to P), as the available P in the soil increases, only the medium-fine texture sites were selected because they represent 73% of the total sites, fitting an alternative function (frontier). The coefficient b of this equation, in addition to having a high R2 (88%), was 10.5 for each unit below the general critical level defined. It is proposed to use this coefficient as an EF value, which would allow covering phosphorus deficiencies as the value of P in the soil becomes less available.

Effect of phosphate fertilization on nitrogen use efficiency of forage pastures. 1. Tall fescue pastures

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Nutrients deficiencies - mainly phosphorus (P) and nitrogen (N) - often depress forage productivity (FP) in pasture-based systems in the Pampas region (Argentina). Fertilizations are often used to attenuate these deficiencies, but it is necessary to increase the use efficiency of the applied nutrients. The FP and the response to N fertilization (i.e. agronomical N use efficiency, NUE) of TF was studied with and without P supply in rainfed tall fescue pastures. The experiment was conducted from 29-07-21 to 26-11-21 (mean air temperature: 13.2ºC, precipitation: 197 mm, potential evapotranspiration: 330,7 mm) in a tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh) pasture on a typical Natracualf (pH 8.9, P-Bray 5.8 mg kg^{-1}; organic matter 3.4%). The P treatments (0 and 50 kg P ha^{-1}) and N treatments (0, 50, 100, 200, and 400 kg N ha^{-1}) were applied using a factorial design in randomized blocks with three replications (plots size: 1.5x4 m). Accumulated forage was harvested (0.1 m^2, 3 cm above ground level), was dried and weighted to establish the PF (kg DM ha^{-1}). The NUE was calculated as (FPN_x-FPN_0)/N_x (x is the N level of treatment and N_0 the control for each P rate). Potential models were fitted to explain the association between NUE and applied N. Applied N and P increased FP and NUE ($p<0.05$), no significant interactions observed. The N application increased FP from 3001 kg DM ha^{-1} (0N) to 6110 and 6632 kg DM ha^{-1} (200N and 400N, no difference between them), and with P application from 4843 kg DM ha^{-1} (0P) to 5482 kg DM ha^{-1} (50P). Greater NUE were obtained with 50P than with 0P and in both cases decreased with increasing the N dose. Potential models were adjusted for each P treatment (Figure 1). Additional research is needed to improve management of pasture nutrition in temperate-humid regions.

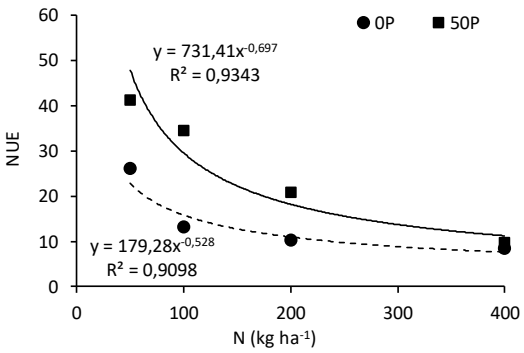

Figure 1. Nitrogen use efficiency in relation to N applied and potential models adjusted for each P treatments (0P: circles and discontinued line; 50P: squares and continued line).

Long term change in soil test P and farm gate P balance of grazing dairy farms of southern Uruguay

Emely D´Andrea[1], Santiago Fariña[2], Alejandro La Manna[2], Nicolás Baráibar[2], Carmen Fugazot[3], Andrés Quincke[2]

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Uruguayan dairy farms underwent an important intensification process during the last decades. Although pasture-based grazing systems are still dominant, one important component of such intensification is the increase of extra-farm feed inputs, along with an increased stocking rate and an increased supplementation rate per cow. Another component is the generally higher fertilizer rates used to increase forage productivity. In this study we compare soil P tests from a set of 25 dairy farms surveyed initially during 2005, 2006 or 2007 and surveyed for a second time in 2022. Composite soil samples were collected from two paddocks per farm at one georeferenced point per paddock. Sampling depths were 0-7.5 and 7.5-15cm on both surveys. In the 2022 survey we sampled additionally at the 0-2.5cm depth, as an environmental indicator for P runoff risk. Soil P tests were Bray-1 and citric acid 0,5%. Records of P inputs (fertilizer, imported feed) and outputs (milk production and liveweight gain) collected on a monthly basis ("Producción Competitiva" support platform of Conaprole cooperative) will be used to estimate a cumulative farm gate P balance. We will analyze and discuss soil P tests of two sampling times and explore empiric relationships between observed changes in soil P test and cumulated farm gate P balance.

Main factors defining the response to phosphorus fertilization in grain crops in Uruguay: a review

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Despite more than 50 years of soils fertilization, in grain crop production systems and due to the low level of phosphorus (P) in Uruguayan soils, P is one of the most limiting nutrients. The present work offers a review of all the available national information on phosphorus fertilization, which allows describing its evolution in time and space, and identifying the main factors that affect the patterns of response to P. Overall, 257 experiments were identified, allowing the assembly of a metadata base and, that had to be grouped into three categories according to the quantity and quality, given its variability. Temporally, the identified trials started in 1965 until 2014, 80% of them sowed between 1970 and 1990, almost all on wheat and soybean crops (75 %), and the remainder on corn, sorghum, sunflower and barley. Most of the experiments were located in the western coast of Uruguay (approximately 70%); on medium-fine texture soils (46%) and an average initial soil available P level around of 9 mg kg-1 (although variable, with values between 7 mg kg-1 at the beginning and 11 mg kg-1 in more recent years). Using the Decision Tree Report for Continuous Responses method, it was determined that the main variables determining the response to P addition (measured by the relative yield) were the initial soil P level and the textural class when soil P level was between 4 and 13 mg kg-1. The sites with the greatest response to P fertilization (with an average of 37%) were those with soil P less than 6 mg kg-1 for medium-coarse textures.

Theme 5 - Impact of phosphorus on environmental quality and on biodiversity
Keynote presentation

Phosphorus in agricultural riverscapes: impacts and processes

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Eutrophication, caused by excessive inputs of nitrogen and phosphorus, is a growing problem in fluvial systems. Diffuse inputs of nutrients to rivers and streams include agricultural fertilizers and increased soil leachate and erosion due to tillage. Phosphorus (P) is generally the limiting nutrient in aquatic environments and its excess produces many negative effects in fluvial systems, including increased growth of algae and aquatic weeds, lowering of oxygen levels due to higher decomposition, loss of species less adapted to eutrophic conditions, and blooms of cyanobacteria. All these impacts lead to the loss of aquatic biodiversity. Although several management actions have been proposed to reduce diffuse inputs of P to streams and rivers, the recovery from eutrophication (reoligotrophication) can be difficult due to the hysteric behavior of many aquatic systems.

The Pampas (central Argentina) is one of the most productive regions of the world for crop production. For many years, we have been studying the impact of agriculture on Pampean streams, and we can draw some conclusions about the cycle of P in these environments. Dissolved P levels are usually high in the streams when compared with streams from elsewhere, but this could not be clearly associated to agricultural activities. However, increasing P levels have been detected in the streams in the last years, possibly due to the intensification of agriculture. We also observed that superficial runoff is the main contributor of P to the streams. In spite of enriched conditions, P retention capacity in the streams is elevated, and it may be related to heterotrophic uptake and adsorption to channel sediments. However, we observed a net P release at reach scale, suggesting that in-stream generation surpass retention processes.

Overall, our results highlight the importance of implementing management practices, especially in riparian areas, to reduce the input of P to agricultural streams.

Theme 5 - Impact of phosphorus on environmental quality and on biodiversity
Oral presentation

Vertical transport of phosphorus in soils and rotations of the Pampean Region of Argentina

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Most studies addressing phosphorus (P) loss from soil to water courses concentrate on erosion and surface runoff. However, there is growing evidence that vertical and subsurface flow may also be important, particularly when preferential flow pathways connect P-enriched topsoil and deep horizons. Our objective was to evaluate the effect of soil type and inclusion of cover crops (CC) in the rotation on drainage and P leaching. We used six filled-in lysimeters (3.3 x 3.3 x 1.4 m deep) containing a Typic Argiudoll of silt loam texture (Pergamino series) and a Typic Hapludoll of sandy loam texture (Junín series), three each, cultivated with a maize-soybean rotation (M-S) with or without fall-winter cover crops (CC) between 2014 and 2022. Drainage was measured daily after each rainfall and soluble reactive phosphorus (SRP) concentration was determined to calculate P loss. The amount of drainage was similar between soils and higher in the M-S than in the M-CC-S rotation during the intercropping periods (161 vs 101 mm, $p<0.05$). The correlation between rainfall and drainage was higher for Pergamino than for Junín when considering same-day events ($r=0.44$ vs 0.26) and it decreased for Pergamino but not for Junín with a 1-day lag between series ($r=0.29$ vs 0.25). The amount of SRP lost was higher for Pergamino than for Junín (0.24 vs 0.15 kg P/ha, $p<0.01$) and in the M-CC-S than in the M-S rotation (0.22 vs. 0.17 kg P/ha, $p<0.05$). These results suggest that: 1) water flows through different channels in each soil, the rapid flow of Pergamino after rain probably occurs through preferential flow channels (macropores) while the slower flow of Junín is probably associated to matrix porosity, and 2) P leaching is related to the flow path (Pergamino>Junín) and to top soil P enrichment by CC residues (M-CC-S>M-S).

Agriculture exports substantially more P than other soil covers in simulated runoff

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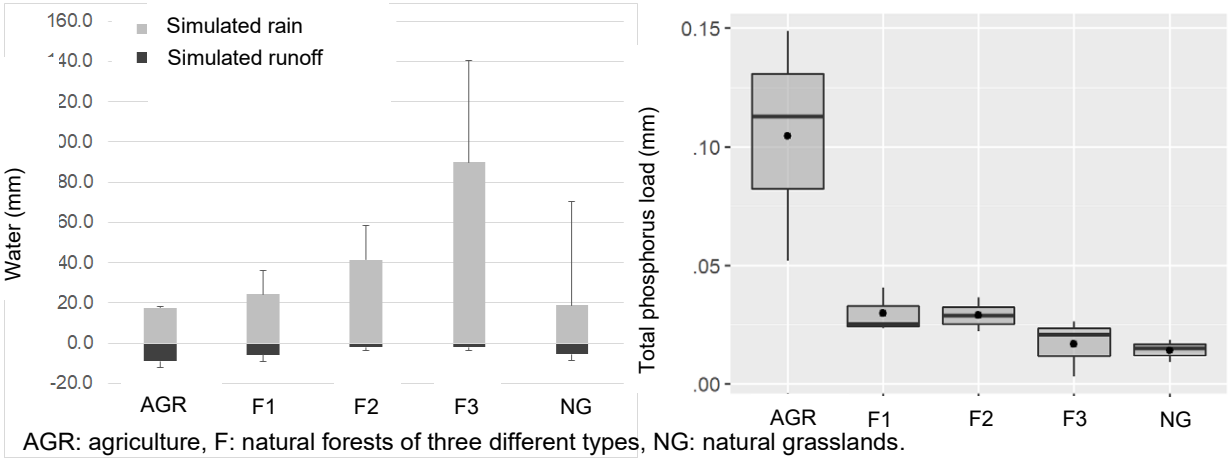
Centro Universitario Regional del Este, Universidad de la República.

Founds were provided by Uruguay REDD+ Project (Ministry of Environment - Ministry of Livestock, Agriculture and Fisheries) in agreement with INIA.

To determine the P export in runoff of different soil uses and covers a field survey was conducted in planted pastures, natural grasslands and different types of natural forests in the south of Uruguay, in sites with similar soils type. Runoff was generated artificially using a mini-rain simulator and water was collected to determine suspended solids, phosphorus, and nitrogen. Soil cover, apparent density and content of PhosphorusBray I, carbon and nitrogen were determined in soils at each sampling site. Naked soil and apparent density were notoriously larger in agriculture, nitrogen and carbon content were lower while PhosphorusBray I was lower in natural grasslands. The highest volume of artificial runoff was obtained in agriculture which also started faster than in the other soil covers. Natural forest showed the opposite result. Suspended solids, total and dissolved phosphorus and nitrogen loads were by far larger in agriculture runoff in comparison to the other soil covers. Results showed that agriculture behaved as an open system, with the largest exportation of water, particles and nutrients, in contrast with natural forests and natural grasslands that behaved in the opposite way, showing to be suitable for their use as buffers zones.



AGR: agriculture, F: natural forests of three different types, NG: natural grasslands.

Water quality impact from soils receiving dairy factory wastewater

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In New Zealand, land application is the most adopted treatment of agricultural, industrial and municipal wastewater. Long-term irrigation with dairy factory wastewater can lead to accumulation of phosphorus (P) in the soil, increasing the risk of P losses that can impair water quality. The aim of this study was to better understand P soil cycling in enriched soils that received dairy factory wastewater, and to evaluate mitigation strategies to minimize P losses. Soil samples (0-7.5, 7.5-15 and 15-30 cm depths) were collected from irrigated and non-irrigated soils at seven sites covering a range of New Zealand soils (Andisol, Entisoil, Inceptisol). Samples were analysed for soil pH, and different P analysis. Using existing data, only the concentration of soil P at one site (Andisoil), was analysed from deeper layers together with analysis of P in groundwater. Additionally, soils that covered a range of pH in water (5.3-6.9) were incubated with iron, aluminium or calcium amendments designed to reduce potential P loss**.** Wastewater irrigated soils from 0-7.5 cm layer had greater total P concentrations (range from 1200-7300 mg P kg^{-1}) than non-irrigated. Additionally, these soils showed an increase of P in all the inorganic forms (115-1853%) while few changes were found in organic forms. Furthermore, at one site, large amounts of P have leached through the profile, at least 4.5 m depth. Close to the sampling site, a groundwater well presented high concentrations of dissolved reactive P (3.6 mg L^{-1}). The incubation experiment indicated that most amendments are efficient on decreasing potential P losses. Globally, few studies have found P concentrations as high as those from this study. To avoid that these soils become a continuous source of P for downstream waterways, the adoption of mitigation strategies at farm level are recommended.

Spatial variation of the concentration of phosphorus and nitrogen in river systems of Uruguay

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Uruguay navigates multiple changes in land use, the use of goods and services provided by nature, as well as in the associated management and governance systems. Management seeks to overcome fragmentation in analysis and decision making, moving towards more comprehensive models, with greater capacity for learning and handling uncertainty.

Virtual basins are artificial systems that integrate a set of information with the purpose of knowing patterns of (dis) similarity of attributes in space and time, as well as their relationships. This theoretical-methodological framework has been used to understand the factors that explain the spatial patterns of phosphorus and nitrogen in river courses in Uruguay.

Statistical analysis (GAM, GLM, RF) of georeferenced databases available and/or built by the Cuencas Virtuales project (ANII) confirm that phosphorus and nitrogen concentrations can be predicted satisfactorily from a reduced set of basin attributes that comprise combinations of structural factors (topography, size, rainfall), types and uses of the land (natural field, agriculture, among others) and specific pressures (discharges). The importance of the indicated factors varies over time, a pattern expected by the significant differences in the flow regime between winter and summer, as well as by the associated production cycles. The watershed attributes that explain the spatial heterogeneity of nutrient levels at the national scale have known causal relationships. The predictor variables may involve multiple mechanisms operating, for example, basins with deep soils present higher levels of nitrogen and phosphorus in the watercourses naturally due to exchanges between terrestrial and aquatic systems. Simultaneously, on these soils, agriculture is developed that contributes to nutrient levels through fertilization. In this case, these two factors (type of soil and land use) act additively.

Finally, based on the evidence, the strengths and weaknesses of the water quality monitoring system on a national scale are analysed.

On the prediction of phosphorus fluxes in the santa lucía basin under different land use and management practices using swat model

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Several actions have been carried out in the Santa Lucia River basin (1.343.300 ha) in order to reduce the impact of anthropogenic pressure and improve water quality. Environmental models may be used as supportive tools when assessing the effect of local actions at a basin scale. To have a better understanding of which is the best combination of strategies and management guidelines that may result in an improvement of water quality, a SWAT model was built in the Santa Lucia River basin for the 1983-2019 period. In this context, the objective of this work is to present the progress made in the development of the model and to describe the scenarios in which phosphorus fluxes can be predicted with the implemented tool. Local data was collected and used as an input for the model: DEM, cartographic and physicochemical representative soil data and 2015 land use map, crop rotation sequences, fertilization dates and doses, point source discharges. Climatological forcing was built with 41 rainfall stations and one agro climatological station. Eight flow gauges were used to calibrate and validate the model using sequential uncertainty fitting algorithm (SUFI-2). The model performance was evaluated using Nash-Sutcliffe efficiency (NSE) and Kling-Grupta efficiency (KGE), obtaining values between 0.65 and 0.82 and between 0.68-0.87 respectively. This tool can predict phosphorus fluxes between soil and water for various scenarios such as subsuperficial phosphate fertilization, vegetative mining, buffer zones, land use changes, downstream dilution effects of reservoirs, which will support decision making in water and soil resources planning in Uruguay.

Theme 5 - Impact of phosphorus on environmental quality and on biodiversity
Poster Session

A study on the feasibility of applying ferric chloride to the soil to reduce phosphorus losses by runoff

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In Uruguay, most of the phosphorus (P) inputs to water bodies are assumed to be of agricultural origin, and largely associated with overland flow. The Santa Lucía river basin is one of the zones with larger losses, and it contains the water sources that supply 60 % of the country's population needs. To reduce these losses, one possibility would be the soil application of ferric chloride ($FeCl_3$), since the reactions that occur between Fe^{3+} and P form lesser labile compounds. In Uruguay, however, there are no reports about the degree of P reductions, both in labile soil forms and in runoff, which could be achieved by this application, especially in the heavy-textured soils that predominate in this basin. Thus, the objective was to evaluate this application as a way to effectively reduce P exports from soil to water in agricultural areas of this basin. For this, different doses of $FeCl_3$ were evaluated, both under laboratory (0 to 686 kg Fe ha^{-1}) and in greenhouse conditions (0 to 116 kg Fe ha^{-1}). These doses, mixed with soil, caused strong and rapid reductions in labile P with the first doses, but the additional effect of the following ones was diminishing. Subsequently, in field conditions and under simulated rain, the application of $FeCl_3$ (0 to 46.5 kg Fe ha^{-1}) to the soil surface was evaluated in two sites. The results indicated that P soluble decreases averaged 37 and 60 %, while P total decreases were 43 % and 67% for the minimum and maximum doses, respectively. Again, the highest rates of decline were achieved with the lowest doses. Therefore, the $FeCl_3$ application of relatively small doses would have the potential to reduce P losses, but to recommend its use, information is required about the permanence of this effect and the environmental risk associated with this application.

Phosphorus concentrations in the queguay river basin: a reference system for low impact watersheds in the pampa biome

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Phosphorus levels in fluvial ecosystems are indictors of land-use intensification and nutrient loading in many agricultural landscapes, including the Rio de la Plata grasslands of South America. We evaluated Total Phosphorous (TP) and Soluble Reactive Phosphorus (SRP) in rivers, streams and lakes associated with a protected river-floodplain in the Queguay River basin in Uruguay. From 2019-2021, we measured phosphorus (P) and nitrogen (N) forms, basin-scale land-use via Sentinel satellite imagery; and trophic status based on nutrient concentrations and Principal Components Analysis. Results highlighted low TP and SRP concentrations in the Queguay rivers, indicating this watershed as a national reference for evaluating Phosphorous concentrations in Uruguay's watersheds. Levels of total phosphorus (TP) in rivers averaged 44-51 µg/L, classifying them as oligotrophic-mesotrophic systems. Streams ranged in TP from 51-97 µg/L, suggesting meso- to eutrophic states according to TP levels, and potential anthropogenic eutrophication in smaller basins with crop cover >25%. Floodplain lakes are a conservation target within the protected area and had TP averaging 74-109 µg/L, suggesting eutrophic-hypereutrophic states based on TP and potential external nutrient inputs. The positive correlation between basin-scale crop cover and mean TP and soluble reactive phosphorus (SRP) concentrations suggested that land-cover plays a role in nutrient levels of fluvial and lotic systems. This study establishes a baseline for Phosphorous concentrations in lakes and fluvial ecosystems in the Queguay River basin within the La Plata River Grasslands. We also fill a major geographical gap regarding P levels in freshwater ecosystems of Littoral Uruguay. Results highlight the value of the Queguay basin as a reference system, but also its potential vulnerability to P inputs from external sources.

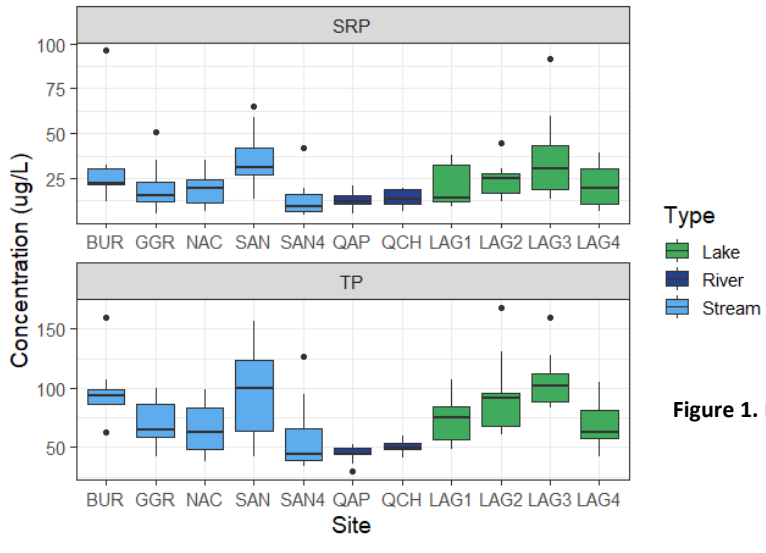

Figure 1. Phosphorus concentrations (Soluble Reactive Phosphorus and Total Phosphorus) in lakes, rivers and streams in the Queguay River Basin in Uruguay.

Phosphorus everywhere: diagnosis of eutrophication intensity in lotic systems of Canelones (southern Uruguay)

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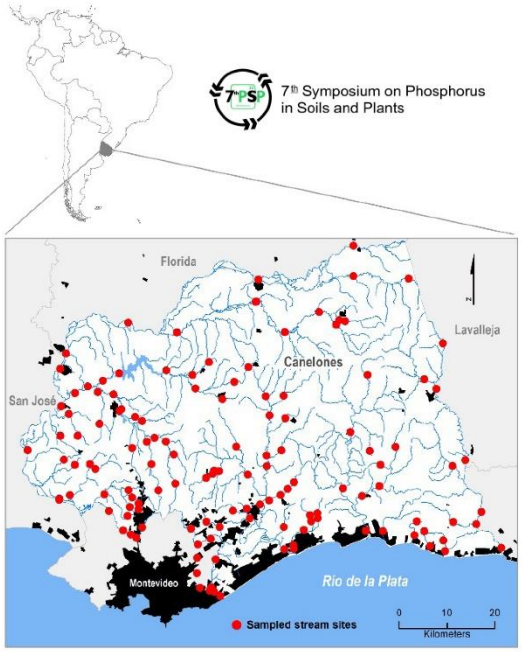
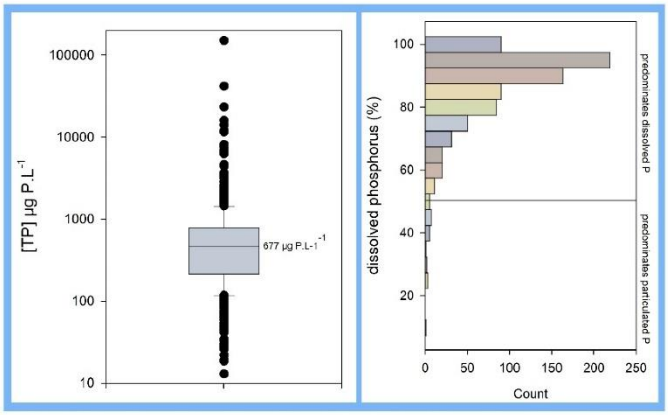
Due to its proximity to the country's capital, urbanization and intensive agriculture occurred early in the Department of Canelones (Uruguay, South America). The application of unsustainable practices for decades has left a deep environmental footprint. Currently, the territory of Canelones presents a mosaic matrix with highly modified patches and high population density. Livestock land use predominates, while intensive agriculture increases eastward, dairy farming increases northward, and forestry and rainfed agriculture increases to the southeast. Furthermore, the drinking water supply for most of the country's population comes from surface water sources in this same territory. This study presents the state of the diagnosis regarding the level of eutrophication of Canelones's fluvial systems, based on the most complete existing data set that integrates basins and micro-basins throughout the departmental territory (1138 data corresponding to 134 sampling points between 2014 and 2021; Strategic Plan for Water Quality, Intendencia de Canelones). Quantitative analysis was performed in a facility considered as Laboratory of Excellence in international proficiency tests. The total phosphorus concentration of Canelones's fluvial systems adequately fits a Log-normal distribution, with Q1 = 289 µg $P.L^{-1}$, median = 677 µg $P.L^{-1}$, and Q3 = 1300 µg $P.L^{-1}$. Only 0.4% of the samples comply with the current regulations for total phosphorus (25 µg $P.L^{-1}$; Decree 253/79 and amendments), while 94,3% of samples exceed 100 µg $P.L^{-1}$. Most of the phosphorus flowing through the river systems of Canelones does it in dissolved form (97.6% of the samples). This characterization is in agreement with all present-day studies available for the area and establishes the superlative magnitude of the eutrophic problem in the region.





Goyenola, G.; Acevedo, S.; Cabrera, S.; Fosalba, C.; Fleitas, V.; Urtado, L.; Díaz, I.; Recoba, C. (2022) Phosphorus everywhere: diagnosis of eutrophication intensity in lotic systems of Canelones (southern Uruguay)

Phosphorus inputs from rural landscapes with low productive intensity and risks in shallow aquatic systems

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Eutrophication is the main problem of water quality at a global and national level, its main causes are mainly linked to the absence and/or deficiencies in wastewater treatments or inadequate management of fertilization of production systems in rural landscapes. The evaluation of punctual and diffuse nutrient inputs is a key aspect to evaluate the risk of eutrophication, as well as the definition of strategies to control the causes of the environmental problem. This contribution evaluates the phosphorus inputs from two sub-basins (Sauce and Pan de Azúcar streams) associated with the main drinking water reservoir, Laguna del Sauce, in Maldonado-Uruguay.

From August 2018 to May 2022, water samples were collected on a weekly basis for the analysis of nutrient concentration (total, total dissolved and inorganic dissolved fractions) at the intersection of the streams with route 9. These sampling sites have hydrometric stations and flow records. Both sub-basins have low-intensity production systems, dominated by pastoral livestock on natural and artificial grasslands and Eucalyptus forestry. The coverage of natural grasslands (campo natural) and forest (monte serrano y bosques fluviales) are important, conditioned by the topography of the land and the predominance of superficial soils. The estimated loads in g m-2 day-1 or year-1 are lower compared to watersheds with agriculture or intensive systems productions. However, it can promote and maintain eutrophication processes in Laguna del Sauce due to its shallow depth and considerable retention time (hydraulic load of the system), a risk evaluated using the Fast and Lee (1978) model.

Based on the results, the main implications in: the management of the Laguna del Sauce basin, eutrophic ecosystem rehabilitation, and finally, risk assessment systems of the diffuse supply of nutrients in lentic systems of Uruguay, are analysed.

Phosphorus losses by surface runoff in two rice rotation systems

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Sustainability of water quality and quantity in Merín Lagoon (ML) basin has become an issue of concern, recognizing nutrient runoff from agricultural environment as one of the major sources influencing water impairment. The main area of rice cultivation in Uruguay is located in this watershed. We implemented a daily water balance method to evaluate the effect of land use intensity on surface runoff and phosphorus losses in two rice-based rotation systems that belong to a long-term experiment located in the ML basin. The experiment was carried out in 2020-2021 during the rice flooded period (125 days). Treatments were (a) rice-pasture (RP, rice-cover crop-rice followed by 3.5 yr of a perennial pasture, and (b) continuous rice (RR, rice-cover crop). Although both treatments required a similar irrigation volume (752 ± 96 mm), the estimated surface runoff for RR (237 ± 6 mm) was a little higher than for RP (205 ± 14 mm). The average total phosphorus (TP) concentration of the inflow water was 147 ± 59 µg L. TP contents of standing water in the paddy field peaked in the first six days of flooding and decreased over time. Concentrations were always higher for RR (350 - 6,500 µg L) than for RP (190 - 2,990 µg L). Results showed that the intensified rotation (RR) increased TP losses by 2.3 times compared with RP (1.4 and 0.6 kg ha^{-1}). A single event (pre-harvest drainage) accounted for 48% of the total export of TP due to high outflow volume. We concluded that the conversion of rice-pasture rotation to a more intensive rice production system increases the risk of P losses to surface waters. However, avoiding surface runoff at the beginning of the flood period and at pre-harvest drainage may reduce significantly P losses and their impacts on water quality from rice paddies.

Phosphorus losses from Soil in Uruguay

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In Uruguay a high concentration values of P in water was been attributed to the phosphorus fertilization management and the erosion process. Three fundamental mechanisms of total P loss from the soil (PLS) ware considered and estimated: direct from fertilizations or feces; P in surface runoff; P in sediment by erosion process. Loss mitigation strategies were analyzed: soil inversion tillage of different proportions of the land; erosion reduction; and control of amount of phosphorus extractable by Bray 1 in first 15 cm of topsoil. The PLS values were higher in the regions associated with agriculture and dairy (average of 3.66 kg.(ha.year)-1 P), but have decreased (0.99 kg .(ha.year)-1 P) since the regulation of erosion mitigation. At the national level, losses due to runoff would represent 71% of the PLS and erosion 27%. The land with natural prairie represents 68% of the national PLS, the land with agriculture 15% and the forested land 8%. None of the three simulated strategies to mitigation of PLS would succeed in decrease the values for agriculture or dairy in a significant way; the P Bray 1 values should be limited below 10 mg.kg-1 to be useful, but would be limiting for most cultivated species. The expansion of agriculture and forestry have not caused considerable increases in the national total PPT values, but agriculture (in replacing of natural prairie) could be contributing 27% of the losses of phosphorus on high-intensity agricultural basins such as the San Salvador river. Eliminating agricultural and dairy use would reduce the total national PPT value by 11% only.

State of the art on the Uruguayan phosphorus transfer continuum: from fields to water eutrophication

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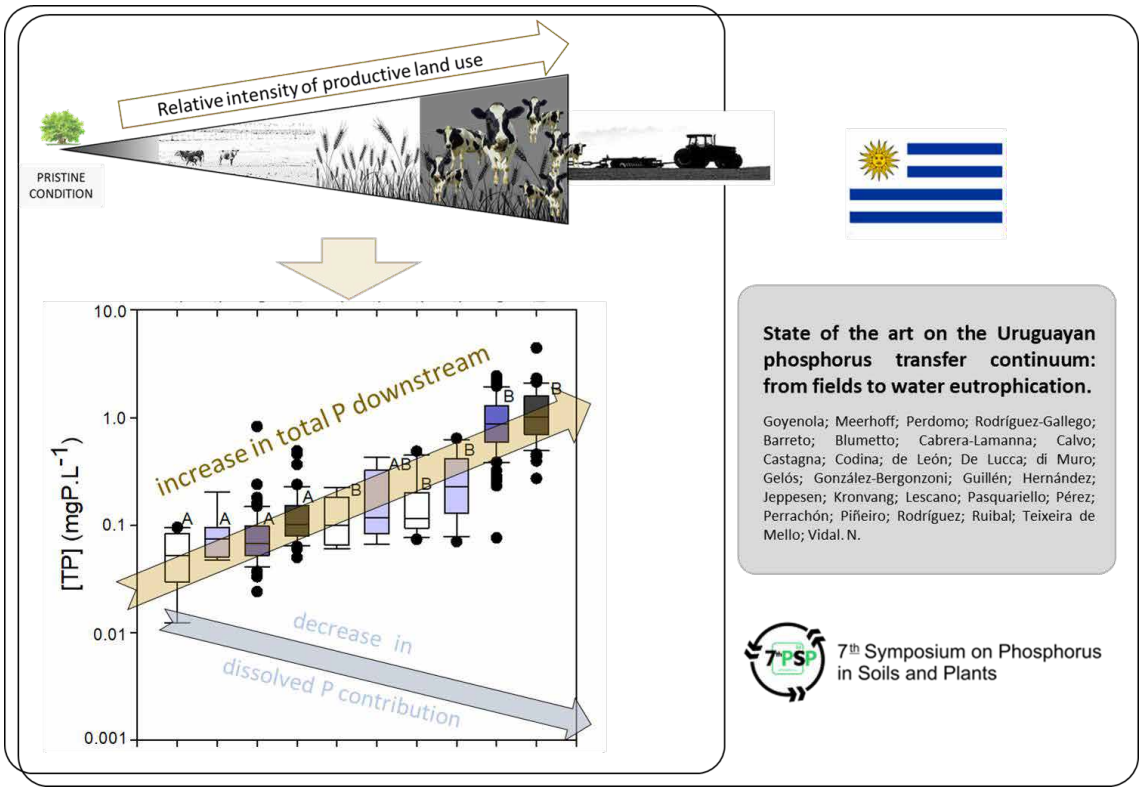
Land use is intensifying worldwide, particularly in many developing countries that experience a process of agricultural expansion and intensification. According to overwhelming scientific evidence, this activity is the main driver of freshwater eutrophication. Technological changes in agricultural production over the last two decades have promoted alterations in the biogeochemistry of phosphorus (P) in catchments, modifying nutrient sources, types and location, as well as the processes and magnitude of mobilisation, delivery, and resulting impacts on freshwaters. The actual ensemble of industrial agriculture practices focuses on increasing productivity and soil conservation by reducing erosion, but unintentionally it has enhanced the losses of dissolved P in riverine ecosystems. Nevertheless, at least in South America, the traditional agronomic paradigm that soils act as a sink of P with no significant exportation as long as there is no erosion, has been shown to be hard to break. This work compiles complementary evidence about the P transfer continuum from fields to water in Uruguay, generated by three independent research groups working for more than a decade. Synthesis derived from a multidisciplinary approach allow us to conclude that: 1) P is exported from fields largely in dissolved forms, 2) particulate P exportation is associated with low frequency extreme rain events and is favoured by a low field vegetal cover, 3) the increase of P export rate correlates positively with an increase in soil compaction, vertical P stratification, and increase in the intensity of agricultural use of soil, 4) most of the P that flows in Uruguayan lotic systems does it in dissolved forms. We argue that updating the theoretical framework on P biogeochemistry and losses by acknowledging empirical evidence from recent years is imperative to support evidence-based management and address serious environmental, economic and health issues caused by eutrophication.



State of the art on the Uruguayan phosphorus transfer continuum: from fields to water eutrophication.

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7th Symposium on Phosphorus in Soils and Plants

SWAT model for Phosphorous mobilization from intensive irrigated agricultural catchment in northern Uruguay

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Water quality at the catchment scale is affected by agriculture, wastewater plants, and landfills, among other factors. One of the most important nutrients affecting water quality is Phosphorous (P), as it causes eutrophication of water bodies. In agriculture catchments, P can come from animal wastes or fertilizers, and good management practices can help reduce negative impacts on water quality. However, these undesirable impacts of agriculture on water quality at the catchment scale are difficult to quantify due to limited data. In this context, this work aims to quantify the impacts of agricultural intensification at the catchment scale using the SWAT model with a very limited data set. A case study is presented for an intensive irrigated agricultural catchment in northern Uruguay, where the main land uses are rice, soybeans and livestock. A moving window cross-calibration method was proposed to address the problem of limited data, and preliminary relationships between water discharge and phosphorus were established to verify water quality predictions. The results suggest that the main source of phosphorus in the watershed is grazing, which increases the availability of P through animal waste and increases erosion and sediment transport through animal trampling. A direct benefit of this work is a catchment-scale nutrient prediction that is flexible enough to be used in multi-scenario and good practices analyses.

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