



Book of abstracts

Part 1

Impacts of reducing "legacy phosphorus" in agricultural soils

ESPP webinar Wednesday, 2nd February 2022, 14h – 17h CET

14h00 – 14h30 (4 x 5 min + 10 mins discussion)

Opening: What do we mean by "legacy P"?

Chair: Christiana Staudinger, Jakob Santner, University of Natural Resources and Life Sciences, Austria

- Phil Haygarth, Lancaster University, UK European perspective
- Andrew Sharpley, University of Arkansas, US Phosphorus Legacies: Redefining the scientific, economic, and policy nexus to mitigate future water resource impairment
- Achim Dobermann, IFA (International Fertilizer Association) Industry perspective
- **Rich McDowell**, AgResearch: New Zealand perspective: predicting soil P changes if fertiliser use is stopped, agronomic and environmental targets

What is legacy phosphorus and what does this mean?

Philip M. HAYGARTH, Lancaster Environment Centre, Lancaster University, LA1 4YQ, United Kingdom, p.haygarth@lancaster.ac.uk

The term 'legacy phosphorus' has emerged in recent years to become a now well-established term used by the cognoscenti involved in the study of phosphorus in agricultural soil and catchments. It is a term related to the age of the soil phosphorus, with the legacy pool being conceptually much younger in age than indigenous soil phosphorus, but older than freshly added forms. It therefore provides a useful conceptual basis to describe and account for phosphorus stored in soils and catchments that persists as (a 'legacy' of) historic fertilizer (or recycled) inputs. The term can also be applied catchment wide too.

Historically, pre-agricultural intensification, phosphorus levels in soils were generally lower and more variable than agricultural soils of today, reflecting natural variations in indigenous soil phosphorus (mostly due to mineral apatite), or because of concentrated areas (mostly due to the P in returns of manure and urine). In Earth system timescales, the relatively recent production of rock phosphate fertilizer has resulted in the distribution of fertilizer phosphorus across many of the world's agricultural soils. In the latter decades of the 1900s phosphorus fertilizer was introduced and added to meet or exceed of crop requirements. The result was a raising of soil phosphorus levels that perturbed the biochemical make-up of the overall soil phosphorus and thus changed the way in which the established thinking about soil phosphorus pools were understood and conceptualised. This led to the emergence of the term 'legacy' phosphorus in the early 2000s.

Soils have certainly demonstrated a tendency to accumulate, store and lock-away surplus added phosphorus, rendering it not-so-easily available for crop uptake as it was intended. In chemical or biological terms, it is a point of debate about what this legacy phosphorus is (or becomes) and I am hopeful that this conference may shine some light on this complexity. Legacy phosphorus also has the added effect of contributing to phosphorus forms leaking to water. Sharpley *et al* and Jarvie *et al* (both 2013) raised the alarm about this and Haygarth et al (2014) wrote:

"In many high-profile cases, intended reductions in catchment P fluxes have not occurred as quickly as expected or desired by catchment managers; this is increasingly recognized to result from the legacy effect, associated with the build-up of P in the topsoil, and the complex release patterns in catchments and their rivers"

There is no doubt that the store of legacy phosphorus provides both a threat to water quality but also has medium- and long-term opportunities for use in food production. I look forward to seeing how we debate these issues in the upcoming conference.

References

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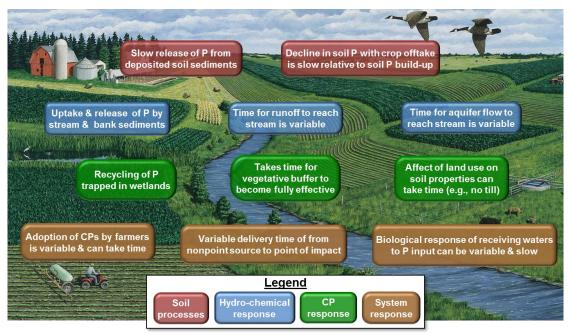
Phosphorus Legacies: Redefining the Scientific, Economic, and Policy Nexus to Mitigate Future Water Resource Impairment

Andrew SHARPLEY

Past and current management of phosphorus (P) in agricultural systems can lead to long-lasting legacies of water quality impairment. Legacy P refers to that stored in surface soils, ditches, riparian zones, wetlands, stream, and lake sediments from prior land and nutrient management. The stored P can be re-released as a soil's P sorption capacity becomes saturated for example, or after slight changes in catchment management and hydrologic response. Lag times associated with release of P from legacy stores may help explain difficulties in detecting water quality improvements at a catchment scale, even when remedial measures have been put in place on agricultural lands. The following processes are at play (and see Figure 1 below);

- a. *Soil processes*: without adequate soil P testing and a 4R nutrient management approach, P levels can quickly exceed crop sufficiency (less than a decade), it can take much longer (two or more decades) to decrease soil P to levels where P runoff is substantially reduced.
- b. *Hydrochemical processes*: P-spiraling between flowing water and bank and bed sediments and highly variable flow times influence response times.
- c. *Conservation practice* (CPs) *responses*: CPs such as vegetative or riparian buffers, designed as a sink for sediment and P, can transition to a source of P when their finite P saturation capacity is reached, masking downstream benefits of CPs.
- d. System and fluvial responses: the release of legacy P from deposited sediments can be influenced by the oxygen status of overlying waters, where reducing conditions favors the release of sediment-bound P. Also, variable distances from source to point of impact is highly variable and can result in further modification of P during transit and influence the time and extent of impact.

A better understanding of the spatial and temporal aspects of catchment response to P-load reductions in both flowing and standing water bodies is needed, which addresses overall physical and social complexity of individual systems, as well as mitigation of non-agricultural sources of P. Even so, scientifically-valid remedial strategies are often not adopted by farmers, due to logistical, practical, and cost limitations. Future legacy P stocks and stores can be limited by adotopn of P applications (as mineral fertilizer and manures) based on recently calibrated soil testing, 4R nutrient soruce management, and adaptaivley managing implemented CPs. These measures are well research and established but often lack socioeconomic and policy actions. Thus, research, economic, and policy communities needs to work closely with the farming community to generate innovative land stewardship and reward programs, which will decrease P runoff and which will empower farmers.



Conceptual representation of processes influencing system response to P legacies.

The ability to reduce soil legacy phosphorus at a country scale

Rich. McDOWELL, Ros DODD, Peter PLETNYAKOV, Alasdair NOBLE

The build-up of soil phosphorus (P) beyond plant requirements can lead to a long-term legacy of P losses that could impair surface water quality. Using a database of ~450,000 samples collected from 2001-2015 in New Zealand we report the level of soil P enrichment by soil type, land use and region and the time it would take for Olsen P to decline to agronomic targets (20-40 mg L⁻¹) if P fertiliser was stopped. We also modelled the time it would take for water extractable P, an indicator of P losses in surface runoff, to decline to an environmental target (0.02 mg L⁻¹). Some 63% of the samples were enriched beyond agronomic targets. The area-weighted median time to reach the agronomic target was predicted to occur within a year for 75% of samples but varied up to 11.8 years in some land uses. The area-weighted time to reach an environmental target can be easily met, additional strategies other than stopping P fertiliser inputs are required to meet an environmental target.

Paper available at: https://www.frontiersin.org/articles/10.3389/fenvs.2020.00006/full

14h30 – 15h00 (5 x 4 min + 10 mins discussion)

Europe: impacts of drawing down legacy P on crop yields (long-term trials)

Chair: Jakob Santner, University of Natural Resources and Life Sciences, Austria

- Inge Regelink, Wageningen University Research, Netherlands: 17 years trials on grassland in The Netherlands
- **Debby Van Rotterdam**, Nutrient Management Institute, Netherlands Legacy soil P: a mass balance approach in a 10- year mining experiment
- Agnieszka Rutkowska, State Research Institute for Soil Science and Plant Cultivation, Poland Long term effect of unbalanced fertilization with phosphorus and nitrogen a case study for Poland
- Sabina Braun, Swedish University for Agricultural Sciences, Sweden Grain yields and soil P changes from >50 years of soil fertility field experiments
- **Vladimir Nosov**, PhosAgro, Russia Sustainable crop production: decreasing phosphorus rates or splitting phosphorus application?

P mining on grassland soils: Long-term effects on nutrient uptake, soil P status and P leaching

Inge REGELINK^{a*}, Jantine VAN MIDDELKOOP^b, Phillip EHLERT

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Excessive P fertilisation has led to accumulation of P in grassland soils in the Netherlands
which, in turn, enhanced risks for leaching and surface runoff of P to surface waters. Here,
the effectiveness of P mining in terms of reducing levels of soil fertility P indicators and levels
of ortho-P in soil porewater as an indicator for P leaching as well as its consequences for
grass yield are assessed based on monitoring data from a long-term field trial on permanent
grassland (Middelkoop et al., 2016, Regelink et al., 2021, Van der Salm et al., 2017).

The field trial includes four grassland locations covering three soil types: Marine calcareous clay, peat and non-calcareous sandy soil. Grass was mowed and the mining plots received sufficient N fertiliser but no P fertiliser. Other plots received P fertilisation at a level equal to P uptake. At the start the P profiles in the soil differed between the soil types. On clay and peat, P contents were high in the 0-5 cm soil layer but strongly decreased with increasing depth whereas P was uniformly distributed over the upper 0-30 cm in the sandy soils. This difference is due to the far higher historical P inputs on sandy soils and ploughing of sandy soils as part of grassland renewal in the decades before field trial started.

Mining of P led to a decrease in P-Al-values in the 0-5 and 5-10 cm whereas these indicators remained unchanged in the lower soil layers. On sand, mining led to a reversal of the soil P profiles meaning that, after ten years of mining, P-Al-values were lower in the 0-5 cm as compared to the deeper soil layers. Mining also reduced levels of ortho-P in soil porewater but this effect was restricted to the upper soil layers 0-5 and 5-10 cm where also the decline in soil P indicators was observed. Hence, on the sandy soil, leaching of ortho-P from the root zone i.e. deeper than 10 cm still continued during the ten-year monitoring period.

Though soil P status in 0-10 cm soil samples declined on all sites, response of grass yield differed between the locations. Yield losses, expressed as the difference in P uptake as compared to P fertilised plots, were smaller on the on the sandy soils (17-30%) as compared to the clay and peat soil (48 and 56%, respectively) averaged over the period of 5 to 10 years after the start of the experiment. The smaller yield losses on sand are attributed to the high soil P status in the soil layers below 10 cm. To conclude, the overall P stock in the rooting zone has to be taken into account when assessing effectiveness of mining as a large part of the P stock may be overlooked when only the upper five or ten cm soil samples are being assessed.

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fertilisation sustain high herbage yields and phosphorus contents in alternately grazed and mown pastures? Nutr. Cycl. Agroecosystems 106, 93–111. https://doi.org/10.1007/s10705-016-9791-0

Regelink, I.C., Van Middelkoop, J., Geel, W. van, Ehlert, P.A.I., 2021. De enkelvoudige versus de gecombineerde indicator voor bepaling van de fosfaattoestand van de bodem. Wageningen. https://doi.org/10.18174/557176

Legacy soil P: a mass balance approach in a 10 year mining experiment

To better understand the availability of legacy soil P a unique 10 year mining experiment was conducted on former agricultural grassland in a stream valley using a mass balance approach. In this stream valley a decrease in the soil P status is desired to facilitate the transformation from production grassland to natural grassland with high biodiversity. Changes in different soil P fractions to 60cm depth (0-10, 10-30 and 30-60cm), yield, P-uptake, vegetation composition and soil water table were consistently monitored on 12 experimental plots during 10 years.

Over 10 years yields within experimental plots were hardly affected by continuous mining while P-content of the grass did decrease. The directly available soil P rapidly decreased under mining conditions to below detection levels. P-removal by the grass was closely related to the available soil P (P-AL) in the top 10 centimeters of the soil. P-removal was however a factor 2,5 to 7 higher than the decrease in available P in the top 10 centimeters of the soil over 10 years due to buffering. Buffering occurred from soil P reserves in the topsoil, translocation of P from deeper soil layers and P mobilization or P input from seepage water depending on the hydrological situation. A distinct difference was observed between dry sandy soils with P enrichment mainly in the top soil layer and soils with high water table.

On the dry sandy soils the rate at which the available soil P (P-AL) decreased depended on the prevailing P-AL concentration. Mining led to an initial fast decline at high soil P levels. This decline became slower and slower as soil P levels dropped. The level at which equilibrium was obtained depended on the net soil P balance and total P reserves. The change in total P reserves up to 60cm depth was approximately equal to the total P-removal by the grass vegetation over 10 years.

For soils with higher water tables (up to ground level in the winter) P in the soil profile was found to be highly variable over depth and time. There was no relationship between the change in soil P and P-removal rates by the grass vegetation. The results imply that legacy P must be removed before (re-)wetting when transforming grassland from production to a natural grassland with high biodiversity to prevent (high) losses to the water system. This gives opportunity for nature conservation organizations to work together with farmers in this transition phase and enables optimal use of legacy P in the soil.

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Report (in Dutch)

Van Rotterdam D., R. Postma, M. van Doorn 2021, Natuurontwikkeling Roeghoorn; Resultaten van 10 jaar uitmijnen en verschralen in het beekdal van het Oostervoortschediep, Nutriënten Management Instituut BV, Wageningen, Rapport 1802.N.21, pp 45.

Long term effect of unbalanced fertilization with phosphorus and nitrogen – a case study for Poland

RUTKOWSKA Agnieszka

The sixteen years field experiments were carried out between 2003-2018 in the Experimental Stations in Eastern and Western Poland. In Grabów, soil under the experiment was heterogeneous - sandy loam (World Reference Base WRB: Stagnic Luvisols. In Baborówko the experiment was localized partly on the sandy loam (WRB: Albic Luvisol) and partly on the black earth (WRB: Gleyic Phaeozem). The initial value of phosphorus (P) in Grabów soil was 69.8 mg P·kg⁻¹ soil and in Baborówko soil it was 111. mg P·kg⁻¹ soil (Egner-Riehm DL). Four crops were grown in the rotation: winter oilseed rape - winter wheat - maize - spring barley. In the split-plot layout, the first variable was P fertilizer in the P-plus and P-minus (control) treatments. P fertilizer was added annually at 39 kg P·kg⁻¹ under winter oilseed rape, 35 kg P·kg⁻¹ under maize and 31 kg P·kg⁻¹under wheat and barley using superphosphate. In the control, no P fertilizer has been added since 2003. The second variable was six levels of N fertilizer. Spring barley was fertilized with 0, 30, 60, 90, 120, 150 kg N·ha⁻¹·y⁻¹, winter wheat with 0, 40, 80, 120, 160, 200 kg N·ha⁻¹·y⁻¹, and winter oilseed rape and maize with 0, 50, 100, 150, 200 and 250 kg N·ha⁻¹·y⁻¹.

The results of the experiments revealed the presence of significant soil P mining causing a reduction in the content of available forms of P. In Grabów, where the initial value of available P was classified as high according to the polish classification, 69.8 mg P·kg⁻¹ soil, the sixteen years of P soil mining led to a decrease in available topsoil P to an average of 63.2 mg P·kg⁻¹ soil (medium P content class). There was a close relations between the intensity of soil P depletion and the range of applied N fertilizer rates. The smaller N doses of 30–50 kg N·ha⁻¹ did not change the soil P levels over the long term but the highest rates, 150–250 kg N·ha⁻¹, reduced available soil P by about 35%. In contrast, in the Baborówko region, where soil P content was very high (111.2 mg P·kg⁻¹ soil), the added N fertilizer did not affect the changes in soil P over the long term. Moreover, the year-to-year addition of P fertilizer resulted in an unnecessary accumulation of available P in the soil.

The results of the experiments indicate that several years without P fertilizer addition did not exhaust the available soil P to levels that limit crop productivity. Over the sixteen years (four crop rotations), the balance of phosphorus was -328 in Grabów and -272 kg P·ha⁻¹ in Baborówko. Nevertheless, such a negative balance has not affected the crop productivity in Baborówko, even at the highest rates of applied N fertilizer. In Grabów, a tendency for grain yield reduction together with N rates was found, in particular for maize, however, the interaction between the two experimental factors has not been statistically proven.

Grain yields and soil P changes from >50 years of soil fertility field experiments

Sabina BRAUN

In the Swedish long-term soil fertility experiments data on yields, crop nutrient content, and soil nutrient content (P extracted with ammonium acetate lactate, P-AL) has been recorded since the 1960's, at nine different locations in south and central Sweden. This has led to an impressing dataset on the effect of long-term fertilization on crops and soil. The experimental design consists of two crop rotations (one with manure added), four levels of nitrogen (N) addition, and four levels of phosphorus (P) and potassium (K) addition. The levels of P addition are no P, replacement of P removed by harvest, replacement P plus 15 kg P ha⁻¹ yr⁻¹, and replacement P plus 30 kg P ha⁻¹ yr⁻¹.

All nine experimental locations was used for crop production before the start of the field experiments, and has been historically fertilized. The soil P content at start was therefore typically quite high. Regardless of that, the grain yields for winter wheat, spring barley, and oats quickly became significantly lower in the treatments receiving no P addition. However, yields in the no P treatments has in most cases stayed constant over the duration of the experiments, showing that the soils ability to deliver P to plants has not been diminished over time even thou the P-AL values has decreased drastically.

In the treatments receiving the same amount of P as is removed by harvest, P-AL has been slowly declining over time. However, there is no significant difference in grain yield between this treatment and the treatments receiving surplus P fertilizer. We can therefore conclude that a P fertilization "in balance" can be a useful long-term strategy to reduce Swedish soil P levels without grain yield loss.

Homepage for the long-term field experiments in plant nutrients at the Swedish University for Agricultural Sciences (SLU):

https://www.slu.se/en/departments/soil-environment/research/soil-nutrient-cycling/slu-field-research-plant-nutrition/

Sustainable crop production: decreasing phosphorus rates or splitting phosphorus application?

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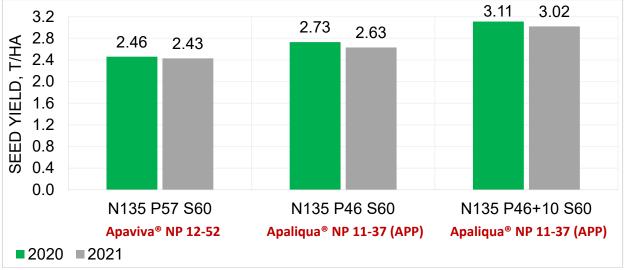
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Field experiments are conducted at Voke Branch, Lithuanian Agriculture and Forestry Research Center, in cooperation with PhosAgro and two-year results may be presented to the moment. Soddy-podzolic soil (Umbric Albeluvisols Abruptic according to World Reference Database for Soil Resources, 2014) had a loamy sand texture, low content of organic matter and close to neutral soil pH. Available P level in the soil before field experiment initiation was good in both seasons (225 mg P_2O_5 kg⁻¹ in 2019 and 210 mg P_2O_5 kg⁻¹ in 2020). Egner-Riem-Domingo method (AL-method) is a routine procedure for measuring soil P in the country. Such a good soil P level was formed due to the long-term P fertilizer application at the experimental location.

Three experimental treatments are studies: 1) $N_{135}P_{56}S_{60}$ using Apaviva NP 12:52 before sowing, and Ammonium Sulfate (AS) plus Ammonium Nitrate (AN) topdressing at BBCH 20 (T1); 2) $N_{135}P_{46}S_{60}$ using Apaliqua APP NP 11:37 before sowing, and AS and AN topdressing at BBCH 20 (T2); 3) $N_{135}P_{56}S_{60}$ using Apaliqua APP NP 11:37 before sowing and at BBCH 20 (foliar application at 10 kg P_2O_5 ha⁻¹), and AS and AN topdressing at BBCH 20 (T3). The recommended rate of P_2O_5 for the area is close to 56 kg P_2O_5 ha⁻¹.

Decreasing P rate by 18% when using liquid Ammonium Polyphosphate fertilizer resulted to yield increase by 8-10% compared to a higher P rate coming from a dry fertilizer (**Fig. 1**). Maintaining P rate when using liquid Ammonium Polyphosphate fertilizer and splitting P between broadcasting before planting and foliar application in the 3rd decade of May (P₄₆₊₁₀) resulted to yield increase by 24-26% compared to dry P fertilizer.





Note: $LSD_{0.05} = 0.11$ (both seasons)

Liquid Ammonium Polyphosphate fertilizer probably helped to decrease P fixation by the soil having a close to neutral pH thus increasing soil P availability to rapeseed plants. Liming was periodically done in the past to optimize soil pH of the experimental area.

Soil P uptake by plant roots decreases under low temperatures in spring that may be a case for Northern Europe, especially on podzolic soils. In 2020, May was noticeably cooler compared to the long-term average temperatures.

Split P application (soil + foliar) seems to be a reasonable approach for sustainable crop production. With split P application, soil P broadcasted rate may be decreased by 18 % according to two-season results. The study is being continuing during the 3rd season 2021-2022.

Source:Trial Results 2021 (PhosAgro agronomic trials. Technologies of successful agriculture). Edited by A.A. Zavalin and S.I. Voronov. ISBN 978-5-98020-258-3. Lika, Moscow, Russia, 2021. 184 p. (In Russian) https://www.phosagro.ru/upload/products/experimental-results-2021 ru.pdf

15h00 – 15h40 (7 x 3 min + 15 mins discussion)

Worldwide: legacy P, draw down, soil phosphorus

Chair: Steve Hallam, International Fertiliser Society

- Yu Gu, Wageningen University Research, Netherlands Potential of soil phosphorus saturation index for evaluating crop yield and runoff risks
- **Amy Shober**, University of Delaware, US Corn and soybean yield across continuum of soil test phosphorus concentrations under long-term drawdown
- Emileigh Lucas University of Maryland, US Lessons from manure-applied "legacy-P" drawdown in the mid-Atlantic coastal plain, USA
- Andrew Margenot, University of Illinois, US Legacy phosphorus drawdown at decadal to centennial scales in the U.S. Maize Belt
- Tiequan Zhang, Harrow R&D Centre Agi-Food Canada Legacy phosphorus in soils sustained crop yields with reduced soil phosphorus loss for 14 years
- **Barbara Cade-Menun**, Agriculture and Agri-Food Canada Soil phosphorus concentrations and wheat yields in a long-term fertilization study in Saskatchewan
- **Paulo Pavinato**, University of Sao Paulo, Brazil Legacy P availability in Brazilian tropical soils for sustainable crop production

Potential of soil phosphorus saturation index for evaluating crop yield and runoff risks

GU yu, ROS gerardus hendrik, ZHU qichao, CAI zejiang, XU minggang, DE VRIES wim

Exploiting and utilizing soil legacy P has great potential to decrease P fertilizer demand. This legacy P can be described in terms of variable P pools that accumulate in soil due adsorption on aluminum and iron oxides, occlusion to soil minerals and organic matter, and diffusion/precipitation in less available forms. Reducing P fertilizer input is relevant when the soil P status exceeds a level above which crop yield does not respond anymore and/or where the risk for P runoff to surface water is enhanced. We assessed the impact of long-term P addition, with varying P fertilizer and manure types, on changes in different P pools in soil, and evaluated how crop yield and environmental risk respond to legacy P in wheat-maize rotation systems in China. The concentrations of soluble, fast reactive, slow reactive and total P pools (extracted with CaCl₂, NaHCO₃, oxalate and acid, respectively) under nine fertilization treatments were monitored over 30 years, together with crop yield and P uptake. Long-term surplus P inputs significantly increased the concentrations of the four P pools, with relative changes decreasing from more than 20 fold for CaCl₂, 10 fold for NaHCO₃, 5 fold for oxalate and 2.5 fold for total P at a P accumulation near 6000 kgP ha⁻¹. The redistribution of P inputs over the pools varied with the degree of P legacy, with Olsen P and oxalate P levels coming at a maximum (saturation) at a P accumulation near 3000 kgP ha⁻¹. Above a critical P-CaCl₂ level near 2 mg/kg, crop yield did not respond anymore. We found a strong relationship between the P-CaCl₂ concentration and the P saturation index, being the ratio Poxalate/(AI+Fe)oxalate. A tipping point of enhanced P-CaCl₂ levels was observed near a PSI of 0.2, known as an upper critical value for enhanced P runoff risk to surface water. The critical P-CaCl₂ level near 2 mg/kg was also reached near a PSI of 0.2. This implies that the target agronomic P level equals an upper critical value for enhanced P runoff risk.

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Corn and soybean yield across continuum of soil test phosphorus concentrations under long-term drawdown

FIORELLINO, Nicole; SHOBER, Amy; KRATOCHVIL, Robert; and COALE, Frank

In agricultural fields receiving a history of high rates of animal manure as fertilizer, soil test phosphorus (P) concentrations can become elevated beyond what is necessary for crop production. These soils are at elevated risk for P loss, especially if pathways exist to transport P to nearby sensitive surface water. As P enters surface waters, it causes eutrophication which decreases water quality. Areas with elevated soil P concentrations exist in Maryland (MD), USA, with a potential risk of P loss to the Chesapeake Bay. Minimal solutions exist for producers who manage these soils beyond continuous cropping without additional P application to decrease soil P concentrations.

A long-term study was initiated in MD in 1994, where small, replicated plots were created at three locations across the state by annual application of manure to increase soil P concentrations. After four manure applications, each location had plots with five different soil P concentrations, including control plots where no manure was applied. Since 1998, all plots have managed under a grain crop or forage rotation with no additional P applications; other nutrients and lime were applied based on soil test recommendations generated from biennial soil sampling. From 2001 through 2015, an initial comparison of forage versus grain rotations was executed on these plots. The plots under the grain rotation continued through 2021, with corn and soybean yield collected for most years through this time period. Soil samples were analyzed using Mehlich-3 extraction. Previous publications have reported on the rate of Mehlich-3 soil P drawdown in these plots (Kratochvil et al. 2006; Fiorellino et al. 2017). By 2021, the plots receiving the lowest manure rate had soil P concentrations that were not significantly different that soils in the no manure control plots.

Historical manure treatment effects on grain crop (corn or soybean) yield varied across location, with manure treatment effects on yield observed in 22 of 45 site-years. Treatment effects on crop yield became more apparent as the study continued without additional P applications regardless of apparent convergence of soil P concentrations across treatments. Generally, there was annual fluctuation in corn and soybean yield at each location, likely due to annual growing conditions. However, yields across treatments at each location remained statistically similar one another until the 2021 growing season, when the crop yield in the control plots where soil test levels approached the agronomic critical level diverged from crop yields in plots receiving the other treatments. Despite a trend for declining soil test P since 2001, we hypothesize that it could be years or decades before soil test P declines in the manure-amended soils to the point at which yield is impacted if no supplemental P applications are made.

Key References:

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ESPP webinar: Perspectives for reducing "legacy phosphorus" in agricultural soils Section: Practical examples and lessons from drawing down "Legacy P" in different regions

Lessons from manure-applied "legacy-P" drawdown in the mid-Atlantic coastal plain, USA

The mid-Atlantic coastal plain, USA, has a history of intensive animal agriculture but limited land for manure application. Various P pools ranging from agronomic, such as Mehlich 3-P, and environmental, such as water-extractable P and P saturation ratio, were investigated over a 15year drawdown period. The three field sites located in the State of Maryland received dairy and poultry manures for the first four years at four rates (0, 100, 200, 300, and 400 kg total P ha⁻¹ year⁻¹) followed by no P applications. Water-extractable P declined (0.7–2.5 mg kg⁻¹ year⁻¹) for the first 9 years after P applications ceased but did not significantly decline (0.2–0.4 mg kg⁻¹ year⁻¹) in the last 6 years. At the same time, Mehlich 3-P declined (7.7–15.3 mg kg⁻¹ year⁻¹ or 5.4–6.3% year⁻¹) over 15 years. Yet, the highest manure treatments had Mehlich 3-P values above the regional agronomic threshold (92 mg kg⁻¹) and environmental thresholds of water-extractable P (8.6 mg kg⁻¹) and P saturation ratio (>0.15). The abundance of P present in agronomic and environmental P pools in these agricultural soils indicates that a drawdown period of decades is needed after P applications cease to reduce the excessive P build-up and mitigate P losses to receiving waters.

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Legacy phosphorus drawdown at decadal to centennial scales in the U.S. Maize Belt

Andrew MARGENOT, Maia ROTHMAN

The U.S. state of Illinois is situated in the heart of the nation's Maize Belt, which has undergone drastic acceleration phosphorus (P) fluxes driven by agricultural intensification in less than two centuries. Estimates of legacy P magnitude and potential for drawdown are lacking, and likely vary at (sub)field scales due to input and management history. We utilize two field experiments in Illinois spanning 36 years (Monmouth RDC) and 145 years (Morrow Plots) to demonstrate plotlevel accumulation and drawdown of legacy P under crop rotation and P fertilization practices. By combining soil P stock quantification, agronomic P balances, soil test P (Mehlich-3) trends, and P speciation (fractionation, XANES), we demonstrate diverse magnitudes and rates of legacy P drawdown. Drawdown in legacy P occurred at much slower rates than accrual, but this did not necessarily manifest in Mehlich-3 P values, which are used by Maize Belt farmers to decide on drawdown vs fertilization. Soil P speciation assessed by XANES and sequential fractionation is consistent with hypothesized transformations of historical P inputs, which could partly explain why legacy P may not be fully available for drawdown. At Monmouth RDC, legacy P from manure application was sufficiently to enable P deficits of -328 to -945 kg/ha to be incurred over 36 years without negatively impacting crop yields. At Morrow Plots, +150% increases in total soil P encumbered in < 20 years via high rock phosphate application enabled drawdown for +100 years to present day and may continue for another century. Even with high crop yields, decadal and centennial field experiments demonstrate that (i) agronomically 'safe' drawdown of total soil P stocks can occur over timespans an order of magnitude greater than the period of net accumulation, and (ii) legacy P magnitudes and drawdown rates (kg/ha·yr) may not necessarily be reflected in agronomic soil tests.

Legacy Phosphorus in Soils Sustained Crop Yields with Reduced Soil Phosphorus Loss for 14 Years

Tiequan ZHANG, Yutao WANG, Chin S. TAN and Tom WELACKY

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Legacy phosphorus (P) in agricultural soils has become a predominate source contributing to P loadings to Lake Erie since the mid-90s. Utilization of legacy P in soils can be an effective and ultimate measure to mitigate the risk of agricultural P loss and to circumvent potential P rock reserve shortage, while sustaining crop production. A field experiment was conducted to assess the impacts of P draw-down (PDD) (i.e., use of legacy P in soils) on crop yields, farming profitability, soil test P change, and complete soil P loss under corn-soybean rotation in a clay loam soil of the Lake Erie Basin, ON, Canada, from 2008 to 2021. Soil P loss in both surface runoff and tile drainage water was monitored continuously year-round each year for 14 years. Corn and soybean grain yields with PDD were identical to those with continuous P addition (CPA), averaged at 7.7 Mg ha⁻¹ for corn and 3.9 Mg ha⁻¹ for soybean, over 14 years. Compared to CPA, PDD increased net farming income by Canadian dollar (CAD) 104–125 ha⁻¹ year⁻¹ (i.e., USD 78.5– 94.4 ha⁻¹ year⁻¹), with savings on P fertilizer materials and associated application costs. Soil test P (Olsen P) in the top soil layer (0-15 cm) with PDD decreased linearly with crop production year at 3.27 mg P kg⁻¹ year⁻¹ or 16.2 mg P kg⁻¹ per 100 kg crop P removal per hectare, while in the lower soil layers, 15–90 cm, it remained unchanged. In comparison, CPA of 50 kg P ha⁻¹ sustained soil test P in the entire soil profile, 0-90 cm, over the 14-year period. Complete soil P loss with PDD reduced by an average of 38%, relative to CPA. PDD can be a beneficial management practice utilizing legacy P in soils to achieve both agronomic and economic goals in an environmentally sustainable manner.

Soil Phosphorus Concentrations And Wheat Yields in a Long-Term Fertilization Study in Saskatchewan, Canada

Barbara CADE-MENUN

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Many crops require phosphorus (P) fertilization for optimum yield, but most crops do not use all the fertilizer P added each year, leaving residual soil P that could potentially be used by subsequent crops. At the AAFC Research and Development Centre in Swift Current, Saskatchewan, a long-term study was initiated in 1967 with various wheat-based rotations, including continuous wheat (CW), fallow-wheat-wheat (FWW) and fallow-wheat (FW). A lentilwheat (LW) rotation was added in 1982. When established, plots were fertilized with 10 kg P ha ¹ yr⁻¹ (monoammonium phosphate) and either a) no N fertilizer (the -N+P treatment); or b) 32-50 kg N ha⁻¹ yr⁻¹ (ammonium nitrate from 1967-2007, urea from 2008; the +N+P treatment). No fertilizer was applied during the fallow phase of FW and FWW rotations, and no N fertilizer was applied to the lentil phase of the LW plots. Crop residues remain on the plots and are incorporated with tillage. All phases and fertilizer treatments are present each year, with three replicate plots. The soil is classified as Orthic Brown Chernozem in Canada (Aridic Haploboroll, USDA; Haplic Kastanozem, FAO), the climate is semi-arid, and the plots are not irrigated (rainfed only). In 1995 for CW and FWW rotations and in 2008 for LW and FW rotations, P fertilization ceased on subplots in each of these plots, adding +N-P and -N-P treatments. Crop yields plus straw and grain N and P concentrations are determined annually for each plot, and soil samples are collected annually post-harvest (0-7.5 and 7.5-15 cm depths).

Total P and soil test (Olsen) P concentrations (0-15 cm depth) and data for wheat yield and grain P concentrations were compared separately for each crop rotation, For FWW and CW, data from 1995-2015 were used, and were averaged by three-year periods to capture all phases of the FWW rotation. For FW and LW, data from 2009-2016 were used, averaged over two-year periods to capture both phases. For all rotations, stopping P fertilization in subplots significantly reduced total P and Olsen P compared to the main plots still fertilized with P. For FWW and CW, yields were always higher in treatments receiving N, regardless of P fertilization. For FWW, yields and grain P were reduced only in plots with no P since 1967. In CW rotations, yields and grain P were reduced by stopping P fertilizer only for the +N+P versus +N-P treatment. There were no significant differences in yield or grain P for the FW and LW rotations. For all rotations, annual yields were affected more by precipitation N fertilization than by P fertilization.

In addition to directly affecting yields, detailed studies indicate that N fertilization has significantly decreased pH in these plots, from ~7 in plots receiving no N from 1967 to ~5.5 in CW+N+P and LW+N+P treatments. This has altered the soil microbial community in these plots (e.g. Li et al. 2020. Environ. Microbiol. 22:1066-1088.), and has altered P biogeochemistry (e.g., Liu et al., 2015 Environ. Sci. Technol. 49:168-176.; Chen et al., 2021, Geoderma 404:115274), which have significant implications for long-term P cycling in these soils.

Legacy P availability in Brazilian tropical soils for sustainable crop production

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Accessing the crop availability of legacy phosphorus (P) reserves in the soil represents a central theme in cultivated areas to promote more sustainable crop production and improve P use efficiency of this finite resource. This study estimated how much of the legacy P accumulated in Brazilian soils after many years of fertilizer usage is plant available/profitable for crop production, in order to estimate the amount and fertilizer replacement value of the legacy P reserve. Soils were collected from the topsoil (0-20 cm) at ten locations covering the main agricultural production areas around Brazil, with known histories of cultivation/fertilization (i.e. different levels of residual/legacy P). An experiment was carried out in a climate-controlled greenhouse using Brachiaria (Urochloa ruziziensis) as a test crop to ascertain how much legacy P could be extracted from the soil over 12 consecutive crop cycles (each lasting for 1 month). We evaluated dry matter (DM) yield and P uptake at the end of every cycle and soil chemical P fractionation at 6 and 12 months. Crop response in DM yield and P uptake was directly influenced by the amount of labile P present in the soil, with better results in more clay-textured soils with higher capacity to buffer the labile P in solution compared to sandy soils. Brachiaria was able to deplete labile inorganic P fractions, with up to 78% of the resin extractable fraction and up to 50 and 54% of the bicarbonate inorganic and organic fractions exploited, respectively. Moreover, brachiaria was able to mobilize P from moderately- and non-labile fractions and transfer these to more labile plant available fractions, with a final mean P depletion of 29% of the total P pool across the 10 soils. This research presented here is important for better understanding P dynamics in soils, proving that plants are able to access less labile P fractions even under nutrient limiting conditions. As a traditional cover crop, we show that brachiaria has the capacity to effectively recycle legacy P into organic forms which should be more available to the next cash crop and thus make the production system more sustainable.

15h40 - 15h50 - break

15h50 – 16h20 (3 x 5 min, 10 min questions)

How does legacy P or draw-down impact losses to surface waters? Chair: tbc

- Victoria Barcala, Deltares, The Netherlands: Processes controlling the flux of legacy phosphorus to surface waters at the farm scale
- Juliane Hirte, Agroscope, Switzerland Reducing legacy soil phosphorus to tolerable levels for surface waters: A case study from Switzerland
- **Sarah Stackpoole**, US Geological Survey Legacy and contemporary phosphorus contributions influence river water quality trends in the conterminous United States

Processes controlling the flux of legacy phosphorus to surface waters at the farm scale

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Phosphorus (P) leaching from agriculture is a major driver of water eutrophication in downstream rivers and lakes. In NW Europe, agriculture intensified in the decades after the second world war and in recent years P surplus is close to zero (Bol et al. 2018; McDonald et al. 2019)(Figure 1). In drained lowland areas with intensive agriculture, a reduction in the fertilizer applications may be insufficient to improve the water quality in the short term (Melland et al. 2018), as the P accumulated in the soil during decades of high fertilization may continue leaching for many years. A complementary approach to reduce P exports from agriculture is to implement edge-of-field mitigation measures at the farm scale. The selection of effective measures requires a detailed insight into the chemical and hydrological transport mechanisms. Here, we determined the main P sources, processes, and transport routes at the farm scale to support the selection of appropriate mitigation measures. We quantified the legacy P, the different P pools stored in the upper soil, and related it to the yearly P export downstream. To do this, we combined high-resolution monitoring data from the soil, groundwater, surface water, and ditch sediments. Figure 2 shows a mass and water balance in the farm. The legacy P in the topsoil was high, about 2,500 kg/ha. The predominant subsurface flow and the subsoils' P sorption capacity retained the P mobilized from the topsoil and explained the relative moderate flux of P to surface waters (0.04 kg/ha during the 2018-2019 drainage season). The dissolved P entering the drainage ditch via groundwater discharge was bound to iron-containing particles formed due to the oxidation of dissolved ferrous iron. Once leached from the soil to the drainage ditch, resuspension of P-rich sediment particles during flow peaks were the most important P transport mechanism (78%). Therefore, hydraulic constructions that reduce flow velocities and promote sedimentation of P-containing particles could reduce the export of P further downstream.

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Reducing legacy soil phosphorus to tolerable levels for surface waters: A case study from Switzerland

Juliane HIRTE, Cäcilia VON ARB, Sebastian STOLL, Emmanuel FROSSARD, Christian STAMM, Volker PRASUHN

Diffuse phosphorus (P) loss from agricultural land to water bodies is still one of the main environmental concerns in Swiss agriculture. Although several measures have been in place since more than 30 years to reduce P inputs, water quality of some lakes is still unsatisfactory. A main P source is legacy soil P accumulated during decades of intense grassland management. While this soil P reservoir can be a major P source for grassland nutrition, the time scales of concurrent soil P decline by phytoextraction and satisfactory reductions of dissolved reactive P (DRP) in surface waters are for the most part unclear. It is therefore a predominant goal to identify concepts that best predict transfer of soil P to water bodies and to estimate the time it takes to reduce legacy soil P to tolerable levels for surface waters.

Here, we present a novel approach to link information of readily available soil P and catchment hydrology and to evaluate the time efficiency of P phytoextraction strategies for P decline. This case study is set in the Lake Baldegg catchment in Central Switzerland, which is characterised by a high percentage of intensely managed grassland and high soil test P (STP) values (CO₂-saturated water extraction). Spatial information on the hydrological risk of the catchment was generated by an adapted rainfall-runoff model (Hahn et al., 2013) and combined with an STP map based on 3723 measurements to identify a target STP value for satisfactory reductions of DRP in Lake Baldegg. Results from a P mining pot experiment with soils from the catchment area (Frossard *et al.*, 2014) fitted to a nonlinear mixed effects model facilitated the estimation of the phytoextraction kinetics representative of the studied catchment. We calculated the time span necessary to decrease current to target STP values for different cropping scenarios and initial STP levels.

Average STP in the catchment was 2.5 mg P kg⁻¹ soil and target STP for satisfactory reductions of DRP in Lake Baldegg was 1.6 mg P kg⁻¹ soil, which is still sufficient for grassland production according to official fertilization recommendations. Depending on initial STP levels, the predicted time necessary to reach this target STP was 2–9 years after cessation of P but not N and K fertilization (intensive management), 8–32 years after complete cessation of fertilization (extensive management), and 11–47 years when P fertilization was maintained at 80% of official fertilization recommendations (corresponding to current guidelines in the catchment area). This study highlights the efficiency of P phytoextraction as a mitigation strategy for catchments with high legacy soil P but also demonstrates the considerable time scales necessary to reach acceptable P levels (von Arb *et al.*, 2021).

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Hahn, C., Prasuhn, V., Stamm, C., Lazzarotto, P., Evangelou, M.W.H., Schulin, R., 2013. Prediction of dissolved reactive phosphorus losses from small agricultural catchments: calibration and validation of a parsimonious model. Hydrol. Earth Syst. Sci. 17, 3679-3693.

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Abstract for the European Sustainable Phosphorus Platform Webinar: Perspectives for reducing "legacy" phosphorus in agricultural soils.

Abstract related to webinar section: "How does legacy P or draw-down impact losses to surface waters"? Comprised of 3, 5-minute presentations with 5 minutes for questions.

Title: Legacy and contemporary phosphorus contributions influence river water quality trends in the conterminous United States

Authors: Sarah Stackpoole, Edward Stets, Lori Sprague

Abstract: The expected consequence in reductions of phosphorus (P) balances, which we define as P inputs (fertilizer and manure) minus outputs (crop uptake and harvest removal) is improved water quality through a reduction in river P loads. However, remobilization of legacy (historical) P can contribute to increased river loads, offset improvements in the contemporary (current year) water quality, and cause a "disconnect" between the P balance and river load trends, meaning the river load trend does not follow the nutrient balance trend. In this study, we examined how contemporary river P trends (between 1992 and 2012) responded to estimated changes in contemporary agricultural P balances for 143 watersheds in the conterminous United States, and whether that response was potentially affected by legacy P contributions. We found that legacy sources likely contributed to increasing river export in some watersheds, despite long-term decreases in the P balance. However, we found evidence of other types of "disconnections" in that reductions in P balances through time, even into deficiencies (outputs > inputs), were associated with stable or sometimes increasing river loads. Furthermore, even in watersheds where legacy P were likely sources and P balances increased, no consistent increases in river P loads was documented. We hypothesized that these results may result from the implementation of best management practices (BMPs), or the effect of changes in watershed P storage capacity.

16h20 – 17h00 (7 x 2 minutes, 20 mins discussion)

Conclusions from panel of experts

Chair: Steve Hallam, International Fertiliser Society Panellists are invited to draw conclusions (and future perspectives), 2 min each, and also to monitor and animate the discussion in the Chat and in the above questions/discussion sessions.

- Jim Elser, Arizona State University, USA
- Luke Gatiboni, NC State University, USA
- Marzena Smol, Polish Academy of Sciences
- Antonio Delgado, University of Sevilla, Spain
- Kari Ylivainio, Luke Natural Resources Institute Finland
- Leonardus Vergutz, UM6P Mohammed VI Polytechnic University, Morocco





Book of abstracts

Part 2

Impacts of reducing "legacy phosphorus" in agricultural soils

Other received abstracts

Incorporating Model Uncertainty into Predictions of Soil Test P

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Abstract

In this study we conducted an uncertainty analysis using the Annual P Loss Estimator (APLE) model on predictions of STP. Using Monte Carlo simulations, we predicted P drawdown at multiple sites in Maryland, USA under two cropping systems with different histories of P application over a 14-yr period. To incorporate model input error into prediction uncertainties, we assumed a triangular distribution of errors in all model inputs with a range of \pm 20%. We then evaluated whether measured and assumed uncertainties in model factors resulted in model-prediction uncertainties that were similar in magnitude to measured variability in STP between replicates. While model prediction uncertainties were generally greater than the variability observed for measured STP, the mean measured STP for nearly all site years fell within the 95% confidence intervals of the STP predictions. Results from this study show the importance of accounting for model uncertainties when predicting long-term drawdown of STP.

Impact of green manures on legacy soil phosphorus mobilisation and crop performance

Leo CONDRON

Lincoln University, New Zealand

In many agroecosystems, significant quantities of applied phosphorus have accumulated in the soil as "legacy phosphorus" which represents a potentially valuable resource that could contribute to ongoing and future plant phosphorus requirements. The inclusion of appropriate green manure crops in arable rotations may enhance the overall utilization and bioavailability of phosphorus, including legacy soil phosphorus. In the absence of a suitable field trial, an extended controlled-environment experiment was conducted to investigate and quantify the impact of three green manures crop species (blue lupin (Lupinus angustifolius), pea (Pisum sativum), barley (Hordeum vulgare) on mobilisation of legacy soil phosphorus and cereal crop yield and phosphorus uptake over two rotations. Results clearly demonstrated that the inclusion of blue lupin or pea as a green manure significantly increased cereal crop yield and phosphorus uptake by 27 - 35% and 15 - 29%, respectively, compared with fallow. This was due to a combination of enhanced mobilisation and acquisition of moderately labile forms of legacy soil phosphorus, together with increased biological cycling of phosphorus in soil. On the other hand, inclusion of a non-legume green manure significantly decreased cereal crop yield and phosphorus uptake compared with fallow, which was mainly attributed to enhanced net immobilisation of phosphorus during plant matter decomposition. The findings of this study clearly demonstrated that legume green manures have the potential to increase mobilisation of soil legacy phosphorus and thus improve phosphorus use efficiency in temperate crop systems, which in turn can reduce phosphorus inputs required to maintain production.

Watershed Response to Legacy Phosphorus and Best Management

Practices in a Lake Okeechobee sub-watershed, USA

Yogesh P. KHARE, Rajendra PAUDEL, Ruscena WIEDERHOLT, Thomas VAN LENT, Stephen

DAVIS, Young Gu HER

Abstract:

Soil phosphorus (P) built up due to past management practices, legacy P; in the Lake Okeechobee Watershed (LOW) in south-central Florida, USA, is often discussed as the root cause of lake eutrophication. The efficient improvement of the lake water quality requires the identification of critical P sources. However, it is still not clear how the water quality issues are attributed to different sources. This study apportioned the contribution of legacy P and inorganic fertilization to the P loading to the lake. We performed a global sensitivity analysis of the Watershed Assessment Model (WAM), which has been applied as a critical decision-making tool in environmental planning for LOW, using the Morris method. A previously calibrated WAM setup (Baseline) of LOW sub-watershed - Taylor Creek Nubbin Slough (TCNS), was used as a test case. Additionally, eight scenarios were newly formulated to estimate the contributions of various P sources. The Morris analysis indicated that total phosphorus (TP) loads are highly sensitive to the legacy P of the improved pasture legacy P, the major land use covering 46.2% of the TCNS watershed's drainage areas. The scenario analysis experiment revealed that legacy P, inorganic fertilizers, and other sources contribute 63%, 10%, and 32%, respectively, to the Baseline TP load of 111.3 mt/y. Improved pastures, dairies, citrus, and field crops are the top legacy P and/or inorganic P fertilizer TP load contributors. These results suggest that developing and implementing suitable conservation practices that can mine legacy P at the source level may meaningfully improve TP loads from entering Lake Okeechobee. Future efforts should include the evaluation of impacts of climate change on legacy P dynamics in this region. Also, our findings highlight the need for the accurate spatial mapping of legacy P, model refinement, and monitoring plans to track changes in legacy P for assessing restoration success.

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Trends in Soil Test Phosphorus Following Long-term Application of Poultry Litter

MOSESSO, Lauren; SHOBER, Amy; and FIORELLINO, Nicole

Many agricultural soils on the Delmarva Peninsula, USA (which includes Delaware and the Eastern Shore of Maryland and Virginia) have soil test phosphorus (P) concentrations that exceed the agronomic critical level due to the historical application of poultry manure at N-based rates. Current regulations have greatly restricted application of manure to soils with excessive soil test P concentrations, which requires many Delmarva Peninsula farmers to eliminate manure use due to water quality concerns related to elevated risk of P loss. Even if manure applications cease, drawdown of soil test P concentrations where P fertilizers would be recommended is estimated to take decades (Fiorellino et al. 2017, Kratochvil et al. 2006). A long-term study was established in 1995 at three locations across the Lower Eastern Shore of Maryland. Soils received applications of dairy manure or poultry litter at five rates (including a no manure control) designed to increase soil test P concentrations. Following manure applications. Mehlich-3 soil test P concentrations ranged from 57 to 450 mg kg⁴. Changes in P dynamics were then monitored under grain and forage cropping systems with no additional P applications to evaluate long-term changes in soil P dynamics. We present trends in soil test P and dominant P species in Donlonton fine sandy loam soils (Fine-loamy, glauconitic, mesic Aquic Hapludults) collected from the Central Maryland Research and Education Center location (CMREC) between 2003 to 2015; this site received dairy manure applications.

The CMREC soils from 2003, 2005, 2010, and 2015 were analyzed for Mehlich-3 P (North Eastern Coordinating Committee, 2011) and were subjected to a modified Hedley extraction (Sui et al., 1999) to determine the operational "forms" of P in the soil and the P-extractable rate of change. We determined the elemental composition of the soils using x-ray fluorescence (XRF) data. In addition, X-ray Absorption Near Edge Structure Spectroscopy (XANES) spectra on selected soils were conducted at the bending magnet beamline 9-BM at Advanced Photon Source (APS), Argonne National Laboratory. We used XRF data and modified Hedley extraction data to guide P standard inputs for linear combination fitting (LCF) in the XAS data analysis tool Athena (Ravel and Newville, 2005) to estimate the dominant P species represented in the XANES spectra for the soil samples.

Mehlich-3 and Hedley fractionation data show a significant decrease in P concentration (drawdown) of CMREC soils across all five soil P treatments between 2003 to 2015. The rate of change of operational (Heldley) soil P "forms" CMREC declined at a similar rate for all fractions except NaHCO₃-P regardless of the amount of manure applied. The rate of change was greater for the weaker extractants (water and NaHCO₃) and smaller for the stronger extractants (NaOH and HCI). Mehlich-3 P concentrations were nearly equivalent to the sum of H₂O- and NaHCO₃- extractable P. Preliminary XANES LCF results suggest the presence of P bound to Al oxides, Al phosphates of varying crystallinity, Fe phosphates, and Ca phosphates in these manure amended soils. These results support the hypothesis that more labile P pools are preferentially used by crops grown in "high P" soils, but that these labile pools tend to be replenished from more recalcitrant soil P pools. This transformation among soil P pools as more labile P is removed must be considered as we recommend usage of P fertilizers after a period of P drawdown, as there may be large amounts of more recalcitrant P still present in soils.

Key References:

Fiorellino, N., R. Kratochvil, and F. Coale. 2017. Long-term agronomic drawdown of soil phosphorus in Mid-Atlantic coastal plain soils. Agron. J. 109:455-461. doi:10.2134/agronj2016.07.0409

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On-site Prediction of Available Legacy Soil Phosphorus to Maintain Crop Productivity

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Legacy phosphorus (P) accumulated during historical land uses include both stable and releasable P with the point of P release indicated by the threshold P saturation ratio (PSR). The threshold PSR, calculated as the molar ratio of P to (Fe + Al), is ~0.1 for most soils reported in literature (Alfisols, Entisols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols and Vertisols). Phosphorus, Fe and Al can be obtained in an oxalate or a soil test solution such as Mehlich 3. The soil P storage capacity (SPSC), calculated from the threshold PSR, offers a means for distinguishing between loosely and tightly bound P in acid mineral soils for which P is primarily controlled by secondary Fe and Al species. SPSC (mg kg⁻¹) = (Threshold PSR – Soil PSR) * (Fe+AI) * 31. When SPSC is positive (Soil PSR < 0.1), the soil is a P sink and P fertilizer application is needed. When SPSC is negative (Soil PSR > 0.1), the soil is a P source and P may be "mined" from the soil with minimal risk of crop nutrient deficiency. The SPSC is, therefore, a quantitative means for describing recovery of legacy P and for estimating the extent of legacy P loss from agricultural soils in absolute terms (e.g., mmol kg⁻¹, mg kg⁻¹, or kg ha⁻¹). Results from a field study on three soil types illustrating mining of soil legacy phosphorus without jeopardizing crop yield are available at:

Nair, V.D., Sollenberger, L.E., Harris, W.G., Sharpley, A.N., Freitas, A.M., Dubeux Jr. J.C.B. and Rodriguez, A.N. (2020). *Mining of soil legacy phosphorus without jeopardizing crop yield.* Agrosystems, Geosciences & Environment 3(1), e20056 https://doi.org/10.1002/agg2.20056

References

- Dari, B., Nair, V.D., Sharpley, A.N, Kleinman, P, Franklin, D., and Harris, W.G. 2018. Consistency of the threshold phosphorus saturation ratio across a wide geographic range of acid soils. Agrosystems, Geosciences & Environment. doi:10.2134/age2018.08.0028
- 2. Nair, V.D. 2014. Soil phosphorus saturation ratio for risk assessment in land use systems. Frontiers in Environmental Science. 2:6. doi:10.3389/fenvs.2014.00006

Demonstration videos on P Mining

- Year 1: <u>https://youtu.be/-ScyoWhqHlg</u>
- Year 2: <u>https://youtu.be/z--yIPbvIqU</u>

New concepts for reducing legacy phosphorus in Germany

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In Germany, instead of the soil surface budget which was abandoned in 2020, a farm budget was set in place in 2018 to control surpluses on nitrogen and phosphorus. Budgeting at present is only compulsory for larger animal keeping farms, farm importing manure or farms running a biogas plant. For phosphorous, no target values have been defined. However, the scope of the application of the new ordinance shall be broadened by 2023 after it has been evaluated. In addition, measures to reduce legacy phosphorus shall be implemented.

Evaluation was undertaken by a working group and could recently be accomplished (report will be submitted to the German Parliament by end of December 2021 and published).

For phosphorus concentration in soils, in Germany three methods are legally accepted: extraction by CAL, by DL and Electro-Ultra-Filtration (DüV, VDLUFA). For the purpose of farm advice, concentration in soil is classified in 5 classes A to E. In the past the class limits had been set differently from the Federal States. For legal requirements, uniform target values for concentration of plant-available P are defined.

The presented two concepts will reset and unify the above classification, introducing 3 respectively 5 phosphorus-classes. The concepts aim at the limitation of phosphorus-surplus in relation to the soil phosphorus-concentration of a farm. Both concepts relate soil P concentration of a farm to maximum tolerable (also negative) phosphorus surplus. However, as one approach sets limits to a further increase of soil phosphorus-concentrations, the other proposes even a decrease of soil phosphorus-concentration in relation to future applications of organic fertilizers.

In order to assess the impact of the two concepts on adaptation needs such as P-reduced feeding and manure export, the effect of implementing both concepts on the amount of total phosphorus surplus is calculated, using regionally disaggregated data on German agricultural structure. Further, the timespan to reach moderate phosphorus levels in soils is estimated.

ESPP webinar: Perspectives for reducing "legacy phosphorus" in agricultural soils Section: How does legacy P or draw-down impact losses to surface waters?

Development of a New Method to Determine Water-Extractable P Pool in Legacy P Soils

A critical component of mitigating P losses from legacy P soils lies in accurately predicting dissolved P loss. This prediction often includes estimating the amount of soluble P extracted with a laboratory-based extraction, such as water-extractable P. Standard extraction methods to quantify the water-extractable P pool in soils were developed before the recognition of legacy P soils, and therefore may not accurately quantify this soluble P pool. We quantified the water-extractable P pool using different extraction ratios in soils from eight legacy fields with >10-fold higher plant-available P. We discovered that the narrow soil to water ratios (1:10 and 1:20) used in the current standard methods severely underestimate the pool of water-extractable P in legacy P soils due to the equilibrium constraints that limit further P release from solid to solution phase. We developed a revised method that includes using a 1:100 soil to water ratio to determine water-extractable P in legacy P soils. This new method will improve the quantification and risk assessment of soluble P losses in legacy P soils and will lead to developing strategies to reduce P losses to water bodies.

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Comparing grassland soil phosphorus index systems for the crossborder region of Ireland

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Soil phosphorus (P) tests and index systems are used as a guide to agronomic requirements and to estimate levels of risk for P loss to watercourses. While a multiplicity of soil tests exist, certain methods are mandated in specific regions. For example, in the Republic of Ireland (ROI) the statutory method is Morgan's extraction, while in Northern Ireland (NI) Olsen's extraction is statutory. Further differences in approach are sampling depth (ROI = 10 cm and NI = 7.5 cm) and the index systems built upon these tests. In ROI a four index system is used, with 1 signifying deficient soils with a definite response to fertiliser and 4 signifying high P soils with no likely fertiliser response. In contrast, NI operates a 6 index system, where 0 represents deficient soils with large fertiliser response and 4 indicates soils with excessive P and no response (2 is split into two sub-indices). These discrepancies in approach make it difficult to translate between systems and obscures catchment modelling in cross-border regions. Such cross-border catchments represent 17% of land area on the island of Ireland and it is estimated that international river basins encompass c. 47% of the Earth's surface. The objective of this study was to compare classification of P availability and to examine the implications of both index systems in the Irish border region (Vero et al., 2021).

Three datasets were incorporated in this study, including new soil samples and archived/previously analysed samples. All three sites are grassland catchments in the border region. A total of 1,116 samples were analysed, with 580 samples taken from 7.5 cm depth, and 411 samples from 10 cm depth. Each sample was analysed using Morgan's, Olsen's and water extractable P (WEP) methods. Results were categorised in to each index system and statistically compared using STATA.

There is a positive relationship between the two statutory tests for each sample, with variability increasing at higher P values. While there is a correlation between each statutory test and WEP, the strength of the relationship is relatively low (Morgan's; R²=0.60 and Olsen's; R²=0,45 (including site and pH interactions). As ROI and NI index systems have a different number of indices they were clustered into deficient, optimal, and excessive categories. The ROI system was biased towards lower estimates of P availability (or greater estimates of P requirement) compared to the NI system. The ROI system suggested 37% more soils were deficient in P compared to the NI system, which suggested 30% more soils had excessive P. Using the NI system, 57% of soils were placed in a higher category compared to the ROI system. Within that group, 26% of soils diverged by two index categories. Conversion equations were determined by which Olsen's and Morgan's P can be exchanged.

The implications of these differences in approach are that plant P supply may be over- or under-estimated, depending on index system, even in small, geographically identical regions, depending on political jurisdiction. Similarly, the perceived success of environmental measures to reduce legacy P may be skewed, depending on the statutory method of analysis.

Vero et al., 2021. Comparison of soil phosphorus index systems for grassland in the crossborder region of Ireland. *Journal of Plant Nutrition and Soil Science*. DOI: 10.1002/jpln.202100194