# Crop residue phosphorus: Speciation and release in cropping soils

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SARAH RUTH NOACK

School of Agriculture, Food and Wine
University of Adelaide

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ABSTRACT

Crop residues remaining after grain harvest are an important potential source of nutrients, including phosphorus (P), to the cropping system. Crop residues contain both inorganic and organic forms of P and these forms may take different pathways into soil P pools. The rate and quantity of residue P released depends partly on the specific P compounds in the residues. The most commonly used measure of P in crop residues is total P, followed by separate measurement of inorganic P and organic P. These measures do not speciate residue P into specific compounds and consequently, residue P dynamics in soils remains poorly understood.

This thesis characterises P contained in crop residues using solution $^{31}$P nuclear magnetic resonance (NMR) spectroscopy and compares this technique with conventional chemical fractionation methods. These initial analytical studies provided the basis for subsequent investigations of the effect of plant P status and residue management on release of residue P in a soil-plant system, leading to a better understanding of the potential bioavailability of residue P in soil.

Inorganic and organic P forms were quantified using $^{31}$P NMR spectroscopy in different plant components (stem, chaff and seed) collected from field grown cereal and legume crops. The main forms of P detected in stem and chaff were orthophosphate (35-75%) and the easily degradable organic P forms, phospholipids (10-40%) and RNA (5-30%). The majority (65-90%) of P in stems was water-extractable, and most of this was detected as orthophosphate. This indicated that the majority of residue P in aboveground plant residues has the potential to be delivered to soil in a form readily available to plants and soil microorganisms.

An integrated approach combining spectroscopic techniques with chemical extraction assisted with verifying assumptions made when using chemical fractionation methods. The main assumptions investigated were; the selectivity of chemical extractants for a single P species, the ability of the extractant to bring all of the P form into solution, and to examine if other P species were released into solution or if the P speciation was changed with extraction. The results showed that the orthophosphate concentration in water/acid extracts was increased due to the hydrolysis of pyrophosphate and organic P species, but decreased due to incomplete recovery of orthophosphate from the crop residues. These effects largely cancelled each other out. Treatments widely used to extract phospholipid (extraction with ethanol:ether and ethanol:ether:chloroform), were found to be selective for phospholipid P, but were quite ineffective, with only ~10% of the phospholipid P determined by solution $^{31}$P NMR extracted in each case. These results strongly suggest that speciation of crop residue P using chemical fractionation can be compromised by the incomplete recovery of a given P species and the transformation of other P species during extraction.

As plants approach maturity and start to senesce, the primary sink for phosphorus is the seed but it is unclear how plant P status affects the resulting P concentration and speciation in the seed and remaining plant parts, i.e. the residues. Wheat and canola grown in the glasshouse were supplied three different P rates (5, 30 and 60 kg P ha$^{-1}$ equivalent) designed to represent deficient, adequate and luxury levels of P. The speciation of P in roots, stem, leaves, chaff/pod and grain was examined. Stems and leaves, which contribute the bulk of post-harvest residue P, were dominated by orthophosphate, regardless of plant P status. Minor differences were observed in P speciation across the three P application rates and plant parts. The effect of this on P cycling is likely to be relatively minor in comparison to the overall contribution of these residues to soil P pools.

Release of nutrients, including P from crop residues remaining post-harvest is an important potential source of nutrients for subsequent crops. The effect of residue size and placement of field-collected pea residue on subsequent P uptake by wheat, soil hexanol-released P and resin-extractable P was measured in a glasshouse experiment. On average, > 50% of residue P was detected in plant, microbial and resin P pools when incorporated in soil compared to 20% for the two surface-placed residue treatments. When considering how residue management strategies may influence P supply to crops, incorporating residues will increase the rate of release and decomposition and therefore the potential for plant roots (if present) to access this P. The results also indicate that even though residue P takes longer to break down under no-till management, this system will still provide small but agronomically significant amounts of P to subsequent crops.

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**Sarah Noack** **Date**

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Noack, S.R., McLaughlin, M.J., Smernik, R.J., McBeath, T.M., Armstrong, R.D., 2012. Crop residue phosphorus: speciation and potential bio-availability. *Plant and Soil* **359**, 375-385.

Noack, S.R., McBeath, T.M., McLaughlin, M.J., Smernik, R.J., Armstrong, R.D., 2014. Management of crop residues affects the transfer of phosphorus to plant and soil pools: Results from a dual-labelling experiment. *Soil Biology & Biochemistry* (in press) **71**, 31-39.

Noack, S.R., McLaughlin, M.J., Smernik, R.J., McBeath, T.M., Armstrong, R.D., 2014. Phosphorus speciation in mature wheat and canola plants as affected by phosphorus supply. *Plant and Soil* **online first**.

Components of the research described in this thesis have been published or have been submitted for publication (as listed below). The contribution of each author to these works is described below.

Chapter 2: Plant and soil; 2012, **359**, 375-385.
Chapter 3: Talanta; submitted
Chapter 4: Plant and soil; accepted for publication
Chapter 5: Soil Biology and Biochemistry; accepted for publication

NOACK, S.R. (Candidate)
Experimental development, performed analysis on all samples, data analysis and critical interpretation, wrote manuscript.

I hereby certify that the statement of contribution is accurate.

Signed Date

McLAUGHLIN, M.J.
Supervised development of work, data analysis and interpretation, reviewed manuscript.

I hereby certify that the statement of contribution is accurate.

Signed Date

SMERNIK, R.J.
Supervised development of work, data analysis and interpretation, reviewed manuscript.

I hereby certify that the statement of contribution is accurate.

Signed Date

McBEATH, T.M.

Supervised development of work, data analysis and interpretation, reviewed manuscript.

I hereby certify that the statement of contribution is accurate.

Signed Date

ARMSTRONG, R.D.

Supervised development of work, data analysis and interpretation, reviewed manuscript.

I hereby certify that the statement of contribution is accurate.

Signed Date 04/04/2014

This thesis is presented as a combination of papers that have been published, accepted or submitted for publication.

Chapter 1 provides an overview of the literature on residue P chemistry, fate in cropping soils and methods for the determination of residue P. This chapter also includes the proposed objectives of the research presented in this thesis.

Chapter 2 comprises a paper published in *Plant and Soil*. It describes the application of solution $^{31}$P NMR spectroscopy to speciate P forms in various field-collected crop residues.

Chapter 3 describes an experiment to compare and combine chemical fractionation methods with solution $^{31}$P NMR spectroscopy for the speciation of P in crop residues. This work has been prepared as a manuscript and submitted to *Talanta*.

Chapter 4 comprises a paper that has been accepted for publication in *Plant and Soil*. It describes a glasshouse experiment used to determine the effect of plant P status on resulting P speciation in mature wheat and canola plant parts.

Chapter 5 comprises a paper that has been accepted for publication in *Soil Biology and Biochemistry*. The experiment used a dual labelling approach ($^{33}$P and $^{32}$P) to measure the effect of size and placement of field-collected pea residue on plant and soil P pools.

Chapter 6 provides a synthesis of the findings contained in this thesis and includes recommendations for future work.