



Management of crop residues affects the transfer of phosphorus to plant and soil pools: Results from a dual-labelling experiment



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ABSTRACT

Release of nutrients, including phosphorus (P), from crop residues remaining post-harvest is an important potential source of nutrients for subsequent crops. A glasshouse experiment examined the effect of size (ground <2 mm and large 50 mm) and placement (fully incorporated and no-till) of field-collected pea residue on subsequent P uptake by wheat and that found in soil hexanol-released P and resin-extractable P. The experiment used a dual-labelling approach (³³P and ³²P) to measure the contribution of soil, fertiliser and residue P to the growing plants, hexanol-released and resin-extractable soil P fractions. Soil and plant samples were taken 60 and 80 days after application of residues to soil. Residue treatment had no effect on plant dry matter, but the application of large residue pieces increased plant P uptake whether incorporated or surface-placed. The percentage of P contained in wheat derived from the residue ranged from 9 to 44% across the four residue treatments. The remaining P was derived from fertiliser (19–24%) and soil (33–76%) pools. On average, >60% of the added residue P was detected in plant, microbial and resin P pools when incorporated in soil compared to ~25% for the two surface-placed residue treatments. When considering residue management strategies based on the potential for influencing 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 show that even though residue P takes longer to break down when retained on the soil surface (e.g. under no-till management), this system was still able to provide small but agronomically significant amounts (0.6–0.7 kg P ha⁻¹) of P to subsequent crops.

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1. Introduction

Release of nutrients, including phosphorus (P) from residues remaining after harvest is an important potential source of nutrients for subsequent crops. Crop residues contain both inorganic and organic forms of P (Jones and Bromfield, 1969; McLaughlin et al., 1988a; Noack et al., 2012) resulting in different pathways into soil P pools. Residue P can be released directly to soil as soluble orthophosphate (where it can be used immediately by the crop or incorporated into labile and non-labile soil P pools) or be assimilated by microorganisms and subsequently released back into the soil. How much of the P in residues contributes to subsequent

crops, and when this P will be available to plants during the growing season are important considerations for growers when planning their fertiliser management.

The contribution of crop residues to the P nutrition of subsequent crops has been studied in the laboratory (Blair and Boland, 1978; Dalal, 1979; Fuller et al., 1956), in glasshouse/growth chambers (McLaughlin and Alston, 1986; Nachimuthu et al., 2009; Till and Blair, 1978) and in the field (McLaughlin et al., 1988a). Comparisons between studies are often difficult due to the use of different residue loads (both in terms of mass and P content), residue size, duration of the experiment, residue type, fertiliser addition and soil moisture. Generally studies using residues with or without fertiliser have found that 0–15% of the shoot P uptake comes from residues (Blair and Boland, 1978; Hassan et al., 2012; McLaughlin and Alston, 1986; McLaughlin et al., 1988a; Nachimuthu et al., 2009; Till and Blair, 1978). The majority of

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these studies have used ground (<1 mm) residues and incorporated them into the top 10 cm of soil (representing full tillage). Although these studies are not representative of current residue management in dryland agriculture, where there has been widespread adoption of reduced or no-till (Derpsch et al., 2010; Kassam et al., 2009; Llewellyn et al., 2012), they demonstrate that P derived from crop residues has the potential to supply a proportion of a crop plant's total P requirement.

The increasing adoption of no-till has implications for the transfer of residue P into the soil compared with full tillage systems (Buchanan and King, 1993; Deubel et al., 2011; Shear and Moschler, 1969). One of the main differences between these systems is that surface residues are subject to more frequent and extreme wetting and drying events than incorporated residues. Jones and Bromfield (1969) found that orthophosphate was readily leached from residues if microbial activity was inhibited. Surface-placed residues have increased physical separation from soil and microbial attack, therefore wetting events may be the dominant mechanism contributing to residue P loss in these systems. Although residue P has been shown to be more readily leached in no-till compared with full tillage systems (Sharpley and Smith, 1989), the ability of a subsequent crop to access this residue P in no-till systems has not been well researched.

The aim of this study was to examine the effect of residue size and placement on the amount of residue P cycled to the wheat plant, and soil pools. The contribution of fertiliser P to the wheat plant under these different management treatments was also measured.

2. Methods

2.1. Soil properties

Surface soil (0–10 cm depth) was collected in the grain producing region of southern Australia near Black Point (S34°36.776', E137°48.599'), and was classified as a Calcarosol according to the Australian Soil Classification (Isbell, 1997). The soil was oven-dried at 40 °C and sieved to less than 2 mm prior to characterisation and use in the glasshouse experiment. Soil pH (H₂O) and electrical conductivity (EC) were measured in a 1:5 soil:water suspension (Rayment and Higginson, 1992). Calcium carbonate content was measured according to Martin and Reeve (1955). Field capacity was measured according to Klute (1986), and total organic carbon according to the method of Matejovic (1997). Cation exchange capacity was measured using the compulsive exchange method utilising NH₄Cl/BaCl₂ (method 15E1, Rayment and Higginson, 1992). Phosphorus buffering index (PBI) was measured according to Moody (2007), and diffuse gradient thin film P (DGT-P) was measured using the method outlined by Mason et al. (2010).

Black Point surface soil was an alkaline (pH 8.5) loam with no surface salinity issues or detectable calcium carbonate in the A horizon (calcareous throughout the solum below 0.2 m), an organic carbon content of 16 g kg⁻¹, and cation exchange capacity of 17.9 cmol(+) kg⁻¹. The soil had a low PBI of 75 and plants grown in this soil were predicted to respond to additional P fertiliser according to the DGT-P critical concentration (measured 4 vs. critical concentration of 60 µg L⁻¹ (Mason et al., 2010)). The water content of the soil at field capacity was 22.2% w/w.

2.2. Residue properties

Mature pea (*Pisum sativum* L.) residue was collected from a farming property near Truro (139°7'46"E, 34°24'42"S), South Australia. Mature plants (sampled one day before harvest) were cut 1 cm above the soil surface. Plant samples were oven-dried at 60 °C

for one week and stem and leaf material was separated for use in this experiment. Triplicate residue samples were digested using concentrated HNO₃ at 140 °C (Zarcinas et al., 1987). The total P concentration in the digest was determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Total carbon (C) and nitrogen (N) contents were measured using a CNS-2000 high temperature combustion analyser (Leco Corporation Michigan, USA) and are expressed as g C kg⁻¹ and g N kg⁻¹ on an oven-dried basis. Residue P speciation was determined using solution ³¹P nuclear magnetic resonance spectroscopy. Briefly, crop residue was extracted with NaOH-EDTA and spectra were obtained on a Varian INOVA400NMR spectrometer (Varian, Palo Alto, CA). Detailed methods for extraction and analysis have previously been described in Noack et al. (2012). Total water soluble P and water soluble orthophosphate-P were determined as per the method of Noack et al. (2012). In brief, ground residue samples were extracted using deionised water and sonicated (Virtis Virsonic Sonicator[®], USA) for 10 min. Total P in the supernatant was measured using ICP-AES and orthophosphate was measured colourimetrically using the method of Murphy and Riley (1962).

Mature pea residue contained a total P concentration of 750 mg kg⁻¹ in the following forms: 37% orthophosphate, 31% phospholipid, 25% RNA and 7% pyrophosphate, as determined by NMR analysis (Noack et al., 2012). Water soluble P was 497 mg kg⁻¹ (66%) of the total residue P and 86% of this water-soluble P was detected as orthophosphate. The concentrations of C and N in the pea residue were 440 g kg⁻¹ and 12 g kg⁻¹, respectively.

2.3. Glasshouse experiment

The experimental design comprised one soil, four residue treatments and a control (no residue), replicated 8 times. The residue treatments included two different residue sizes: ground (<2 mm) and large (50 mm) pieces; and two residue placements: incorporated into the top 10 cm of each pot (full tillage) or distributed evenly over the soil surface (no-till). Residue treatments were designed to represent 'full tillage' (large residue incorporated into the soil), no-till (large residue left on the surface), as well as treatments simulating the use of the Harrington Seed Destructor[™] (Walsh et al., 2012) in which residues are ground before addition to the soil surface (ground residue on the soil surface). Note that we selected treatments in this study to represent the conditions residues experience in systems rather than selecting soils under conventional or no-till management. A treatment using ground incorporated residues was also included. Although this last treatment does not simulate current field practice, many previous experiments have applied residues in this manner (Fuller et al., 1956; McLaughlin and Alston, 1986; Nachimuthu et al., 2009; Sharpley and Smith, 1989; White and Ayoub, 1983). The residue treatments are referred to as ground incorporated (GI), large incorporated (LI), ground surface (GS) and large surface (LS) throughout this study. Residues were added at a rate of 20 g pot⁻¹ (15 mg P pot⁻¹), equivalent to 10 t dry matter ha⁻¹, which is equivalent to that produced by a 4 t ha⁻¹ grain crop with a harvest index of 0.29.

Batches of 30 kg of dry soil tumbling in a cement mixer were sprayed with carrier-free ³³P to ensure even distribution of ³³P throughout the soil volume. Each 30 kg batch of soil was sprayed with 1.5 L water, adding 5% water w/w (equivalent to 23% of field capacity) and adding 27.9 MBq ³³P (0.93 MBq kg⁻¹ soil). Soil was stored in large plastic bags for a two week equilibration period. After two weeks, a total of 3 kg of air-dried equivalent of soil was weighed into each pot. The pots were 15 cm diameter polyvinyl chloride drainage pipe cut in 17 cm lengths and fitted with end-caps (i.e. not free-draining). For incorporated residue treatments, 2.2 kg of soil was added to a 4 L plastic container and shaken with

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