The form and fate of stubble phosphorus in cropping soils

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Abstract

Phosphorus (P) within stubble can be released directly to soil as soluble P or assimilated by microorganisms and subsequently released back into the soil through mineralisation. The chemical composition of P in crop stubble may play an important role in the rate of stubble P release. Crop stubble sampled after grain maturity in 2010/11 and 2011/12 contained 1-5 kg P/ha. Nuclear magnetic resonance (NMR) spectroscopy was used to determine the different forms of P present in the stubble. On average 50% of the total stubble P was orthophosphate which is water soluble and readily available to plants and microorganisms. The remaining P forms were identified as phospholipids, ribonucleic acid (RNA) and pyrophosphate. The majority (65-90%) of P in the major stubble component (stems) was water-soluble, and most of this was detected as orthophosphate. However, this includes organic P forms that may have been hydrolysed during the water extraction.

Results from a field leaching experiment show between 0 and 7.5% of stubble P was released from 52 mm (collected after 11 mm and 41.4 mm) of summer rainfall. That indicated crop stubbles in the field release some P into soil solution which could be readily accessed by plant roots. However, the slower release of stubble P in the field compared to the laboratory suggests that residues potentially play a more important role as a long term P supply to subsequent crops. Subsequent experimentation will measure the contribution of surface applied and incorporated stubble P to crop plant P nutrition using ^{33}P isotopic techniques.

Key words

Crop residues, speciation, nutrient cycling

Introduction

A key consideration for growers when planning fertiliser applications is how much phosphorus (P) stubbles can supply, and when this P will become available to crops during the growing season. Phosphorus within the stubble can be released directly to soil as soluble P (where it can be used immediately by the crop or chemically fixed onto the soil) or be assimilated by microorganisms and subsequently released back into the soil (McLaughlin et al. 1988). The chemical composition of crop stubble plays an important role in the rate of nutrient release. Green and senesced crop stubble have been shown to contain both inorganic and organic P forms (Jones and Bromfield 1969; McLaughlin et al. 1988). The presence of different chemical P forms in the stubble that vary in their susceptibility to immediate release is likely to influence the proportion of P that undergoes direct release to the soil solution or microbial uptake and decomposition.

The quality of crop stubble is usually assessed using the C: nitrogen (N): P ratio of the stubble. This approach assumes that the ratio of C:N:P influences the proportions of P that follow pathways of immediate release or incorporation by microorganisms and subsequent release back to the soil. The basis of this approach is that growth of the microbial population on a C source such as stubble requires critical concentrations of nutrients such as N and P. How crop stubble affects soil P availability will therefore depend on the balance between direct release of P (and C and N) from stubble and microbial uptake and release. Many previous studies suggest that the timing and quantities of P release vary and are not well explained by the total amount of P or the ratio of carbon (C): P in stubble (Fuller et al. 1956; Enwezor 1976). Stubble type, tillage, moisture supply and amount can significantly influence the timing and amount of P released from stubbles to the soil (Fuller et al. 1956; Zibilske et al. 2002). Our research aims to better identify P forms in crop stubble, understand how these forms influence P release and breakdown from stubble, thereby providing a better estimation of the contribution stubble P makes to subsequent crop P nutrition.

Methods

Sampling

Mature crop stubble was sampled from eight different crop species from two farming properties near Karoonda (Mallee region) and Truro (Mid-North region), of South Australia. The crop species were wheat (*Triticum aestivum),* barley (*Hordeum vulgare*), oat (*Avena sativa*), rye (*Secale cereale*), canola (*Brassica napus*), bean (*Phaseolus vulgaris*), lupin (*Lupinus angustifolius)* and pea (*Pisum sativum*). Crop stubbles were oven-dried at 60°C and separated into stem and leaf (referred to as stem throughout this paper), chaff (protective casing of cereal grains or the pod encasing the seed for canola and legume crop species) and seed. Crop parts were ground to <2 mm and triplicate stubble samples were digested using concentrated HNO_3 at 140°C. The total P concentration in the digest was determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Nuclear magnetic resonance (NMR) spectroscopy analysis

Ground stubble samples were extracted with NaOH-EDTA in triplicate based on the method of Cade-Menun and Preston (1996) originally developed for soil extraction. This involved shaking 2.0 g of dried stubble with 40 mL of 0.25 mol L^{-1} NaOH and 0.05 mol L^{-1} Na_2EDTA for 16 hours. Solution ^{31}P NMR spectra were acquired at 24°C on a Varian INOVA400 NMR spectrometer (Varian, Palo Alta, CA) at a ^{31}P frequency of 161.9 MHz.

Solubility of stubble P

Ground stem stubble was extracted in triplicate using deionised water (60:1 v/w). These samples were sonicated for 10 minutes to disrupt cell walls and release all soluble stubble P. Samples were centrifuged (1400 × g) and filtered using Whatman No. 42 filter paper. Orthophosphate in the water extracts was measured colorimetrically using the method of Murphy and Riley (1962) and total P concentration was measured using ICP-AES.

Field Leaching

In December 2011 a leaching experiment was established to assess the effect of summer rainfall on stubble P release under field conditions. Large pieces of pea and wheat stubble (5 cm) were placed in wire mesh bags at a rate equivalent to 2 t stubble/ha (3.5 g/container). These mesh bags were placed over funnels which were set in plastic containers to capture the stubble leachate. Containers containing no stubble were also placed in the field to account for any P contamination from windblown soil into the funnels. The leachates collected were analysed for total P concentrations as above. These samples were analysed for concentrations of water soluble C and N using a Formacs^{HT} series combustion TOC/TN analyser.

Results & Discussion

Forms of phosphorus in stubbles

Crop stubble samples contained 200-500 mg P/kg dry weight (equivalent to 1-5 kg P/ha). On average, 52% of stubble P was identified as orthophosphate, which has the potential to be returned directly to the soil in a form readily available for crop utilisation (Figure 1). Previous studies using water extracts to identify the molybdate reactive P (orthophosphate) in crop residues report similar values (Jones and Bromfield 1969). This source of P would be immediately available for uptake by plants (via root uptake), but also liable to assimilation by microorganisms, as well as sorption (chemical fixation) onto soil minerals. The remaining forms of P included P associated with phospholipids and ribonucleic acid (RNA) and pyrophosphate. These P forms are not directly available to plants, but are considered to be easily decomposed by microbes. Microbes that decompose the stubble temporarily tie up some of the P in their biomass but also release P through mineralisation which can potentially provide P to plant roots.

The increased concentration of orthophosphate in the crop stubble corresponded to higher concentrations of total P. The large variation in orthophosphate concentrations (56 to 326 mg/kg dry wt) amongst stubble appears to be related to differences in the total P concentration of stubble samples (Figure 1). Previous studies indicate that as plants absorb 'luxury' concentrations of P it is stored as orthophosphate (White and Ayoub 1983). Phosphorus deficiency has also been shown to alter the partitioning of this P between different plant organs. Most P is stored in the reproductive organs (seeds) at the expense of P accumulation in vegetative organs (stem and chaff) in P deficient plants. This results in reduced concentrations of P remaining in the stem residues after crop harvest. Crops with higher total P concentrations will consequently return both greater quantities of P to the soil but most of this P will be orthophosphate, which readily available for absorption by plants.

Our results show that stubble P can be present in both inorganic and organic forms. The commonly used C: P ratio does not distinguish between P present as inorganic P (orthophosphate) and organic P. This ratio assumes that all stubble P must be decomposed by microorganisms and released as orthophosphate through mineralisation to be plant available. However, we have demonstrated that on average half of the P in stubble is already in a form readily available to both plants and microorganisms. The use of a C: P ratio is therefore a poor predictor of potential mineralisation and immobilisation, due to the different pathways inorganic and organic P forms can take from stubble to soil.

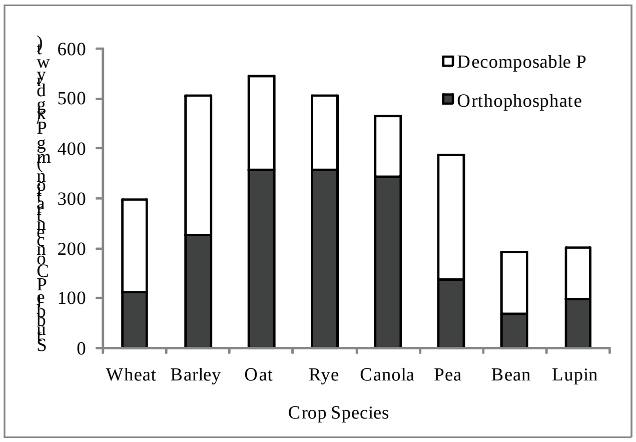

Figure 1. Total P concentration in eight crop types displaying the proportion of orthophosphate and easily decomposable P forms.

Relationship between P forms and solubility

Water soluble P in stem residues represented 65-95% of the total stubble P (Figure 2), of which an average of 93% was orthophosphate. It would appear that during the water extraction enzymes converted some of the non-orthophosphate P forms (pyrophosphate, phospholipid and RNA) to orthophosphate. At first glance, these results suggest that following the first significant summer rainfall event, the majority of stubble P would be released from the stubble in a form available for plant uptake. However, when this experiment was repeated in the field using conditions that better represented paddock conditions, very different results were obtained.

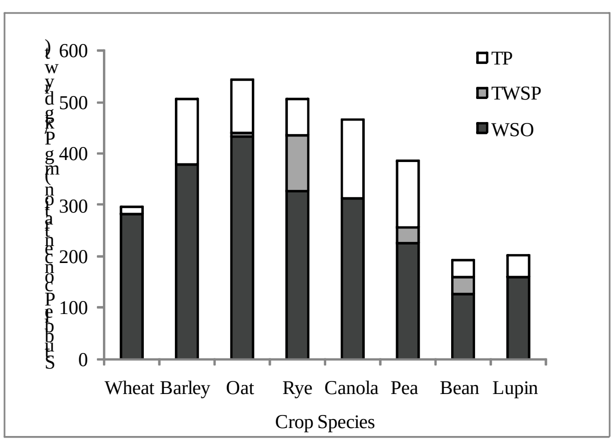

Figure 2. Concentration of total stubble P that was water soluble and the concentration of water soluble P detected as orthophosphate. TP = total stubble P, TWSP = total water soluble P and WSO = water soluble orthophosphate.

Field Leaching

Leachate was collected at two separate sampling events following 52 mm of rainfall since harvest 2011. None of the total P in the wheat stubble was released at either sampling time compared to a total of 7.5% for the pea stubble (Table 1). This is most likely due to the total P concentrations of the stubbles used. The P concentration of the pea stubble (1176 mg P/kg) was nearly five times that of the wheat stubble (250 mg P/kg). A similar trend between the stubble types was observed for both soluble C and N (Table 1).

Table 1. Stubble C, N and P (± standard deviation) lost from summer rainfall events (total 52.4 mm rainfall).

	Rainfall (mm)	Stubble type	Soluble C (mg/mm rainfall)	Soluble N (mg/mm rainfall)	Soluble P (mg/mm rainfall)	Stubble P leached (%)
Sampling time 1	11	Wheat	0.15 ±0.01	0.018 ±0.011	nd	0
		Pea	0.31 ±0.02	0.075 ±0.023	0.010 ±0.004	3.3
Sampling time 2	41	Wheat	0.24 ±0.05	0.004 ±0.002	nd	0
		Pea	0.35 ±0.05	0.032 ±0.006	0.005 ±0.002	4.2

nd = not detected

The slower rate of release of soluble P from stubble in the field compared to the laboratory highlights the effect of stubble size and sonication on P release. The use of realistically sized stubble P pieces is important for measuring P release as most studies which commonly use ground (<2 mm) stubbles may overestimate the rate of P release in the field. This experiment has shown summer rainfall events leached a small concentration of soluble stubble P into soil solution and is dependent on total stubble P concentration. The slower release of stubble P in the field compared to the laboratory suggests that stubble potentially plays a more important role as a longer term P supply.

Conclusions

A large percentage of P in above-ground stubble is in a form readily available to either plants or microorganisms. Much of this is orthophosphate, which is directly available for plant uptake, immobilisation by microorganisms or sorption onto soil minerals. Stubble P also includes organic P species, which can undergo mineralisation to inorganic P and stabilisation to form less available organic P forms. The majority of P forms in stubble are soluble during a simple lab based water extraction. However, when incubated under field conditions stubble P release is much slower, suggesting that it may potentially release P at a slower rate throughout the growing season.

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