Phosphorus turnover between rice crops in the rainfed lowlands from residual P fertiliser, rice straw and volunteer pastures

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Abstract

The fate of residual P fertiliser and P in crop residues in sandy rainfed lowland soils is poorly understood. Field experiments were undertaken to determine the effects of rice straw incorporation, and of residual fertiliser P on biomass of volunteer pastures and to quantify the fate of P recycled from them on subsequent rice growth. Returning rice straw with P fertilisation had additive effects on growth and yields of rice during the main wet season. Straw addition alone increased grain and straw yields on the nil-P and applied-P soils by about 10 and 5 %, respectively. Subsequently, in the early following wet season, the biomass of volunteer pastures responded significantly to the residual P and the straw incorporation. All soil P fractions significantly increased at 2 weeks after rice straw incorporation. The minor resin-P fraction fluctuated more over time compared to major soil P fractions (NaOH-Pi and NaOH-Po). Phosphate added with straw increased microbial biomass C but had only small effects on microbial biomass P. Microbial biomass P declined dramatically in the active growth stage of rice, suggesting strong competition for available P from crop uptake, whereas, microbial C increased progressively for up to 40 weeks after straw incorporation. In conclusion, the application of crop residues alone marginally increased rice productivity, soil P fractions and microbial biomass C and P, whilst greater increases were obtained with the combined application of P fertiliser with crop residues. There remains to be investigated the long-term impact of residual P fertiliser and organic inputs on crop yields, soil P forms and P turnover processes.

Media summary

The combined application of P fertiliser, its residual and crop residues resulted in greater increases in rice productivity, soil P pools and microbial biomass C and P.

Keywords

Phosphorus, phosphorus turnover, rainfed lowlands, residual phosphorus, rice straw, volunteer pasture

Introduction

Typically rainfed lowland soils in south-east Asia remain dry for 4-5 months after harvesting main wet season rice and then experience intermittent wetting and drying in the late-dry and early wet season fallow when volunteer pasture growth occurs (Pheav 2002). The proportion of legumes in the fallow pastures may increase after a long period of adding P fertiliser. Processes behind expected increases in crop production and soil fertility due to the improved fallow are not known. Indeed, the implications of the early wet season weedy fallow for P cycling and its interaction with rice straw decomposition are not well understood. As plant growth on the sandy lowland rice soils is strongly limited by P availability (Ragland and Boonpuckdee 1987; White et al. 1997), understanding the mechanisms of P transformations in the soil under a rice-fallow-rice cropping system will provide important information for farmers' adaptation of technologies to local resources available, and also to fill gaps in knowledge about P cycling in the rainfed lowland rice ecosystems. Our present studies aimed to assess the effects of applied P fertiliser plus rice straw, and its residual values on biomass production of volunteer pastures in the dry season and early wet season, and to quantify the fate of P recycled from plant materials when returned to the soil and its effects on the subsequent rice growth.

Materials and Methods

The field experiments which lasted for 5 consecutive rice crops over three years on sandy soils (Plinthustalf: Soil Survey Staff 1994; Prateah Lang soil: White et al. 1997), was described in detail by Pheav (2002). Briefly the present investigation concerning crop 5 and events in the main wet season, dry season and early wet season that followed (Figure 1). This experiment was established by split the plot into two equal parts. One half was treated with only P fertilisation, whereas, the other half was treated with P fertiliser and the return of straw. The effects of the residual P fertiliser and straw incorporation on biomass of volunteer pastures, soil microbial biomass and soil-P pools in the fallow period were also determined from the dry season till the early wet season. Soils and plant materials were sampled at the times as shown in Figure 1.

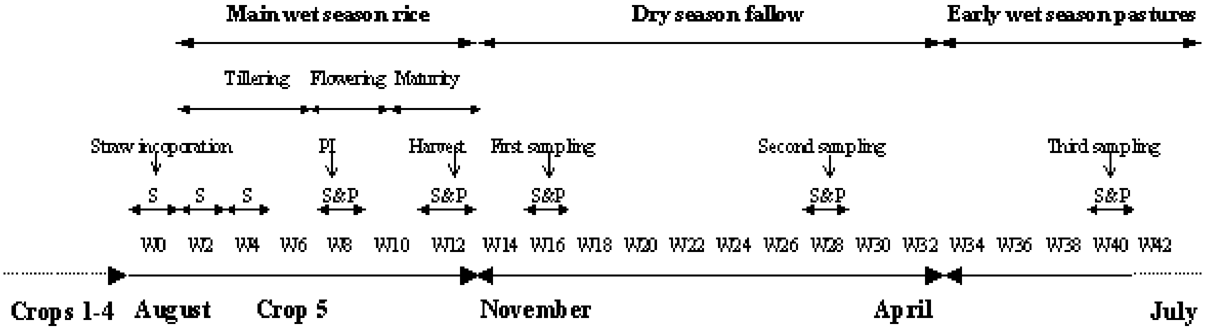

Figure 1. Schedule of soil (S) and plant (P) sampling undertaken in the field experiment on a sandy rice soil in the main wet season, dry season and in the early wet season.

Soil samples were analysed using the following methods: for soil P fractions using the sequential P fractionation method as described in Pheav et al. (2003); microbial biomass C and P were determined by the chloroform fumigation-extraction (Amato and Ladd 1988; Brookes et al. 1982; McLaughlin et al. 1986); details of these references were found in Pheav (2002).

Results and Discussion

Returning rice straw with P fertiliser application had additive effects on shoot dry matter (DM), grain and straw yields of rice during the main wet season (Table 1). Straw addition increased both grain and straw yields on the nil-P and applied-P soils by about 10 and 5 %, respectively.

Table 1. Dry matter (DM) of shoots at PI, and grain, straw, roots of rice harvested at maturity in response to P fertiliser and to straw application when rice was grown in the field during the main wet season on lowland sandy soils. Values are means of four replicates.

Treatment	Shoot DM	Grain yield	Straw yield	Root DM

Residue	P (kg/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)
Straw (-)	0.00	0.6	1.6	2.2	1.6
	16.5	1.0	3.5	4.7	2.2
	33.0	1.1	3.5	4.8	2.2
Straw (+)	0.00	0.7	1.7	2.3	1.7
	16.5	1.1	3.6	4.8	2.5
	33.0	1.2	3.8	5.3	2.6
LSD (P)		0.1**	0.2**	0.3**	0.3**
LSD (S)		0.1*	0.2*	0.2*	0.2*
LSD (P x S)		ns	ns	ns	ns

Statistical significances: ns: non-significance * $p \leq 0.05$; ** $p < 0.01$; LSD: the least significance at $p \leq 0.05$.

In the early wet season, shoot and root biomass of both legume (2 t/ha) and non-legume pastures (8 t/ha) responded significantly to the residual P plus rice straw incorporation (Figure 2). Volunteer pastures are likely to contain 3 to 10 kg P/ha (Pheav 2002), return of which to the soil will significantly benefit a following wet-season rice. The total biomass was significantly greater in non-legume compared with legume species, suggests that non-legume pastures contribute much more to P turnover. However, increased proportion of legumes in the fallow system through P fertilisation could be beneficial for nutrient cycling, especially for N because of symbiotic N_2 fixation and for P because of its high concentration in legumes relative to non-legumes (Pheav 2002). In addition, the low C:N ratio of the legume residues would accelerate P release by decomposition (Tang et al. 1999).

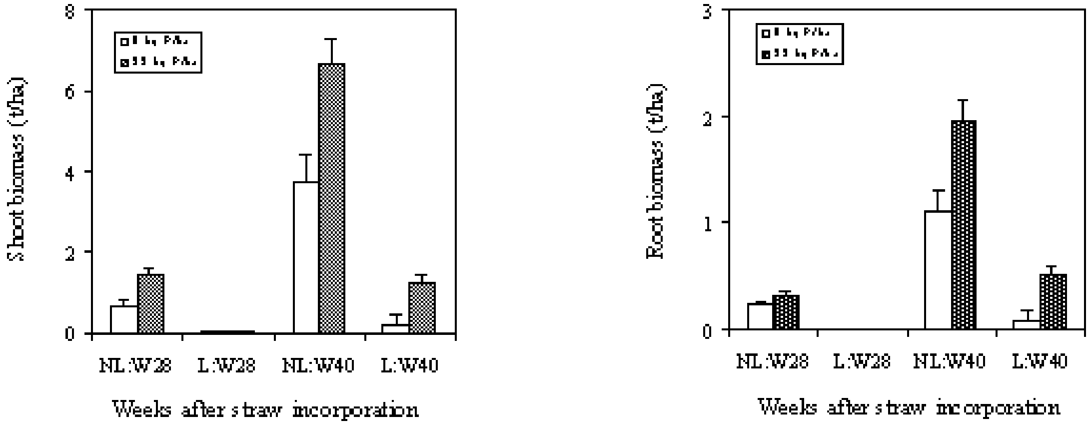

Figure 2. Shoot and root biomass of legumes (L) and non-legume (NL) pastures in the fallow in response to residual P fertiliser plus straw incorporation when grown in the late-dry season and in the early wet season (refer to Fig. 1) in the field condition. Plotted values are means of four replicates.

Available resin-P was a minor fraction of extractable soil-P, whereas, labile NaOH-Pi and NaOH-Po were larger soil P fractions at all growth stages (Figure 3). All soil P fractions significantly increased at 2 weeks after rice straw incorporation, and NaOH-Po was the fraction that increased the most. The resin-P fraction fluctuated more during crop growth compared to other major soil P fractions. The resin-P and NaOH-Pi fractions responded dynamically over time to changes in soil water regimes in the dry season and early wet seasons: these changes were linked apparently to intermittent dry and wet cycles in the field during the fallow period.

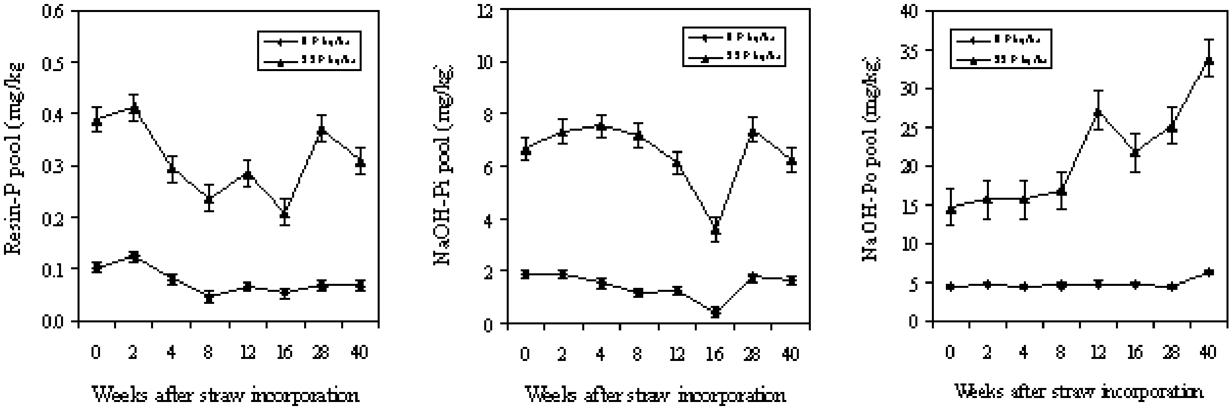

Figure 3. Changes in soil-P fraction from the main wet season to the dry and early wet season (refer to Fig. 1) on the plots that received different levels of residual P fertiliser plus straw incorporation in the field conditions. Plotted values are means of four replicates. Note the change in scale of Y-axes.

The lowest value of resin-P and NaOH-Pi fractions were found in the early dry season, increased significantly at the late dry season and then fell slightly at the early wet season. By contrast, the labile NaOH-Po fraction steadily increased till the early wet season. It is suggested that soil drying during the dry season causes decreased mineralisation of organic P; it also leads to increased immobilisation of P in the soil organic matter (Sah and Mikkelsen 1989a,b; Huguenin-Elie et al. 2003). The increase in resin-P and NaOH-Pi fractions at the early wet season can be attributed to the resumption of rainfall, which may accelerate mineralisation of organically-bound P in moist soil conditions or alternatively increase the solubility of Fe-P and Al-P minerals as anaerobic conditions develop (Sah and Mikkelsen 1989a,b). The decrease in resin-P and NaOH-Pi fractions at the early wet season could be due to depletion by the P uptake by volunteer pastures that increased four-fold in biomass in early wet season (Figure 2). These results suggest that in the rainfed lowlands with their variable soil water regimes during the dry, early wet and main wet seasons, the soil P pools are very dynamic and responsive in both aerobic and anaerobic conditions.

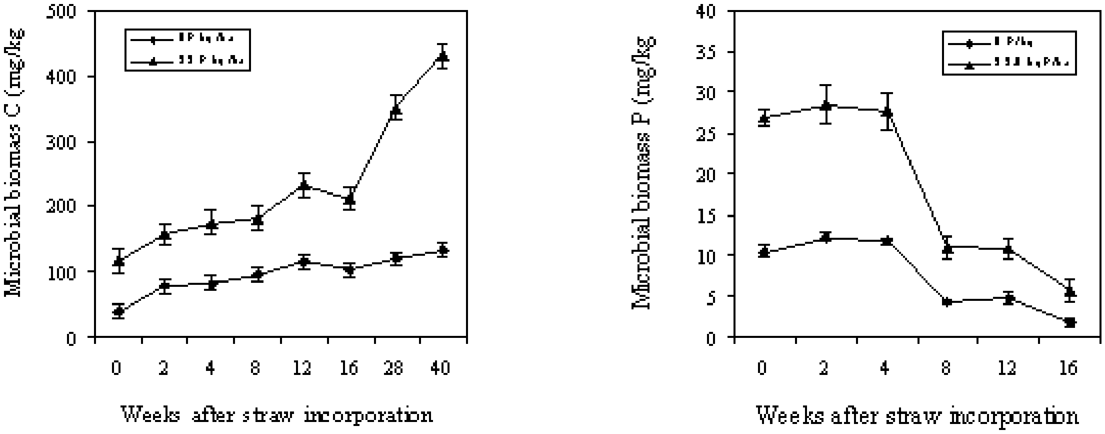

Figure 4. Changing patterns of microbial biomass C and P in the main wet season, the dry and early wet season (refer to Fig. 1), observed on plots receiving different levels of residual P fertiliser plus straw incorporation under field conditions. Plotted values are means of four replicates.

Phosphate fertiliser added with rice straw increased microbial biomass C but had only small effects on microbial biomass P (Figure 4). Microbial biomass C increased progressively for up to 40 weeks after straw incorporation, whereas, microbial biomass P peaked in weeks 2-4; this supports the finding of Maroko et al. (1999) that significant increase in microbial biomass P was detectable soon after incorporation of fallow residues. The increased microbial P could be attributed to rapid uptake of inorganic P from both native soil P and fertiliser P by microbial cells and conversion into the other forms of P (polyphosphates and metaphosphates) that serve as cellular storage products (Kouno et al., 2002). However, the decline in microbial P during the active growth stages of rice (maximum tillering and early flowering: weeks 4-8) suggests strong competition for available P from crop uptake, and one among other possible mechanisms is that with progressing crop growth, the high initial microbial biomass declined, and its pools of sequestered P diminished with time due to rapid turnover of microbial biomass P (Kouno et al., 2002).

Conclusion

For rice-based cropping systems the application of crop residues either as rice straw or as volunteer pastures marginally increased crop productivity and total P uptake of rice, whilst greater yields were obtained with the combined application of P fertiliser with crop residues. The return of organic residues alone resulted in marginal increases in rice yields and soil parameters such as P pools and microbial biomass C and P, but greater increases of these parameters were obtained with a combined use of inorganic P fertilizer plus crop residue additions. The long-term impact of these residual P and organic matter inputs on crop production, soil P forms and P turnover need to be explored.

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