Increasing Phosphate Rock availability using a Lupin Green Manure Crop

Roger D. McLenaghen, Parmjit S. Randhawa, Leo M. Condron and Hong J. Di

Agriculture and Life Sciences Division, PO Box 84, Lincoln University, Canterbury, 8150, New Zealand. Email mclenagh@lincoln.ac.nz, singhp1@lincoln.ac.nz, condronl@lincoln.ac.nz, dih@lincoln.ac.nz

Abstract

Legumes have been shown to increase the dissolution and utilisation of phosphate rock (PR) phosphorus (P) compared with non-legumes because of their acidifying effect on the rhizosphere. A promising agronomic approach for optimising nutrient availability in organic cropping systems appears to be the integration of legume green manures (GM) into the cropping rotation. A field experiment was conducted to study the combined effect of legume growth (in terms of improved P utilisation from PR) and subsequent organic matter additions (green manure incorporation) on crop growth compared with a corresponding winter fallow system. Three rates of PR (0, 60, 120 kg P/ha) were applied in autumn before sowing of lupin green manure and maize as the crop. A fourth PR treatment involving the application of 60 kg P/ha as PR in spring, before maize sowing was also employed. The objective of the study was to quantify the impact of preceding lupin (green manure), treated or not treated with PR, on a subsequent maize crop, and to evaluate winter fallow and green manure effects in terms of P availability. The observed improvements in maize yields following green manuring and PR application of approximately 1.5t/ha and the 3.1-5.3 kg/ha increase in P uptake by maize in the first season were due to a combination of P release into soil solution following the mineralisation of organic P additions via the lupin GM and increased solubilisation of residual P due to rhizosphere and possible mycorrhiza colonisation processes.

Key Words

Resin-P; mineralisation; Lupinus angustifolius; Zea mays

Introduction

Legumes have been shown to increase the dissolution and utilisation of phosphate rock (PR) P compared with non-legumes mainly due to rhizosphere processes (Horst *et al.* 2001; Kamh *et al.* 1999; Vanlauwe *et al.* 2000a). Accordingly, the incorporation of legumes as green manure in cropping systems may improve the utilisation of PR and therefore influence the dynamics and availability of P. The most promising agronomic approach in organic cropping systems appears to be the integration of legume green manures into the cropping rotation, which can mobilise P from sparingly soluble PR or fractions that are not available to the following crop (Horst *et al.* 2001). This not only positively affect soil properties and increases nitrogen (N) supply, but also increases P supply to the main crop (Kabir and Koide 2002; Polthanee *et al.* 2002). One suggestion is that a legume green manure can be used to enhance P cycling by modifying the distribution and availability of PR and that this might have beneficial consequences for the following crop.

A field experiment was conducted over 2 years to study the combined effect of legume growth (in terms of improved P utilisation from PR) and its subsequent incorporation as a green manure on the test crop in comparison to a corresponding winter fallow system. Lupin (*Lupinus angustifolius, cv.* Fest) was grown as a green manure and maize (*Zea mays, cv* Elita) as a test crop. The objective of the study was to quantify the impact of the preceding lupin green manure, treated or not treated with sparingly soluble (reactive) PR, on the subsequent maize crop, and to evaluate winter fallow and green manure effects in terms of P availability.

Materials and methods

Experimental design and treatments

The experimental site was located at Lincoln University, in the Canterbury region, South Island, New Zealand. The soil at the experimental site is a Templeton silt loam (Immature Pallic soil, (Hewitt 1998; Udic Haplustepts, Soil Survey Staff 1998). The Templeton soil had an initial slightly acidic pH of 5.7, low exchangeable calcium (3.9 cmol_c/kg), low levels of oxalate extractable iron and aluminium (0.2 g/kg for both) and a low P retention of 20%.

© 2004. SuperSoil 2004: 3rd Australian New Zealand Soils Conference, 5 – 9 December 2004, University of Sydney, Australia. Published on CDROM. Website www.regional.org.au/au/asssi/

Treatments were arranged in a split-plot randomised complete block design with winter fallow (F) and lupin green manure (GM) as the main treatments. Four sub-plot phosphate rock (PR) treatments were:
Control;
PR applied @ 60 kg P/ha in February ($PR60_{Feb}$) before sowing lupin;
PR applied @ 60 kg P/ha in September ($PR60_{Sept}$) before sowing maize;
PR applied @ 120 kg P/ha in February ($PR120_{Feb}$) before sowing lupin.

The PR was commercial grade Ben-Guria classified as sparingly soluble (reactive) with Total P content of 12% and 35% Citric acid solubility. The trial included four replicate plots (3 x 6 m) of each treatment (32 plots). The PR treatments, except $PR60_{Sept}$, were applied at the start of the trial on 5th February 2001 (before the commencement of first cycle) and on 9th March 2002 (before the commencement of second cycle). The $PR60_{Sept}$ was applied before lupin (GM) incorporation during both cycles. A hand operated rotary hoe was used to incorporate PR to 15 cm, after broadcasting.

In the first cycle one irrigation was applied to the lupin due to severe drought conditions in April, but in the second year no irrigation was required for March sown lupin. The lupin GM was incorporated at the flowering stage in early spring into the surface soil to about 15 cm depth.

Table 1: Dates of lupin and maize sowing, lupin green manure incorporation and maize harvest during first (2001/02) and second cycle (2002/03).

Operation	First cycle	Second cycle	Season
Lupin sowing	05 Feb 2001	09 Mar 2002	Summer
Lupin incorporation	09 Sept 2001	04 Sept 2002	Early spring
Maize sowing	26 Oct 2001	07 Nov 2002	Spring
Maize harvest	07 Feb 2002	17 Jan 2003	Summer

The maize crop was planted (seeding rate of 32 kg/ha at 20 cm inter-row and 60 cm row spacings) 6 to 9 weeks after GM incorporation (Table 1). Although the experiment outlines procedures that may be useful in organic farming practices the protocol for the experiment was not a strict organic system. Therefore, to limit other nutrient effects, potassium (K) and sulphur (S) were applied at a rate of 80 and 40 kg/ha as KCl and K_2SO_4, respectively, before sowing maize in the second cycle. During the trial recommended plant protection measures were also taken against stem borers and weeds. The maize was irrigated with sprinkler irrigation to bring the soil to field capacity when required, according to the distribution of summer rain. The maize was harvested at silking and flag leaf stage during the first and second cycles of rotation respectively.

Plant and soil sampling
Lupin fresh weight was determined before incorporation by using a square quadrant ($0.5m^2$) from two random positions in each plot. The above ground material was cut near the soil surface using hand clippers and weighed in the field. For maize fresh weight, a power-operated cutter was used to harvest two rows from the centre of each plot, avoiding the plot edges by 1.5 meters. Lupin and maize sub-samples for dry matter content and plant analysis were collected randomly from each bulk fresh sample. The samples were dried at 60 °C for 48 hours and grounded through a Cyclotec 1092 sample mill and stored in 50 mL vials before analysis.

Soil samples (0-15 cm depth) were collected for resin-P analysis in both years from the F and GM plots after lupin harvest (AL) and after maize harvest (AM). Soil samples were air-dried at 20 °C for 3 days, crushed, sieved through a 2 mm sieve and stored in plastic containers.

Plant and soil analysis
Plant material was analysed for total P using nitric-perchloric acid digest followed by vanadomolybdate colorimetry (Olsen and Sommers 1982). Total organic N in plant material was determined using a LECO CNS-2000 elemental analyser.

A simplified cation and anion exchange resin extraction technique described by Saggar *et al.* (1992) was used to determine resin P values.

Statistical analysis

Analysis of variance (ANOVA) on the different variables was performed using the Genstat 6.2 (Lawes Agricultural Trust, Rothamstead, UK) package in accordance with the split plot design. The significance of differences at different harvests between main-plot effects (lupin green manure and fallow plots), sub-plot effects (PR treatments) and their interactions were determined using standard error of the difference in means (SED) values at 5% ($P<0.05$). Single degree of freedom contrasts were analysed to compare PR addition with the control to the F and GM plots where appropriate.

Results and Discussion

Resin-P

At the start of the trial the soil at the experimental site was low in available P (Resin-P 19.6 mg P/kg; Olsen P 7 mg P/kg). In the control plots resin-P values remained low and varied from 17-21 mg P/kg (35-60 mg P/kg is predicted optimum for maize). Resin-P is a relatively new test in New Zealand, and there is only limited data available in New Zealand, but investigations have shown a good correlation with Olsen P values with an average resin-P to Olsen P ratio of 2.5 (Kay and Hill, 1998). The resin-P test is likely to have a better correlation with plant growth when slow release phosphorus fertiliser is used (Kay and Hill, 1998). A response to PR application in the soil can be expected due to favourable conditions for PR dissolution (low P, low calcium and adequate moisture) (Bolan *et al.* 1990; Khasawneh and Doll 1978; Rajan *et al.* 1996), and is shown by significant increases in resin-P values in PR treatments (Table 2).

Table 2: Effect of practice (F, GM) and PR on resin-P determined after lupin (AL) and after maize (AM) during the first and second cycle.

Treatment	Practice	2001-2002		2002-2003	
		Resin-P (mg P/kg)			
		AL	AM	AL	AM
Control	Fallow	20.5	19.3	19.2	17.2
	Lupin GM	19.8	20.6	17.7	19.3
$PR60_{Feb}$	Fallow	31.1	28.3	26.4	27.1
	Lupin GM	27.4	26.5	25.9	27.7
$PR60_{Sept}$	Fallow	21.8	22.4	21.3	22.8
	Lupin GM	20.3	20.9	21.3	23.0
$PR120_{Feb}$	Fallow	34.9	27.0	32.6	29.1
	Lupin GM	32.9	28.3	34.6	34.1
SED		1.69	2.37	2.44	2.06

In control treatments resin-P values were reduced in F plots after maize, compared with the lupin GM However the control-lupin GM treatment retained resin-P levels close to original values even though P is being taken up and lost via crop removal. This indicates that the lupin GM is extracting otherwise non-available native P sources (Table 2) and releasing this P to the following maize crop. In a rhizosphere experiment using isotope exchange kinetics on the same soil, Randhawa (2003) found that lupin rhizosphere was able to solubilise the less soluble P fractions for P uptake. In the first cycle, resin-P values increased significantly after PR application, but the application of PR before the start of second cycle did not show the magnitude of increase observed in the first cycle. Also, in the first cycle samples taken from PR plots after lupin harvest showed significantly lower resin-P values for lupin GM than F plots, indicating P uptake by the lupin plants. After the maize crop in both cycles, resin P values were similar or enhanced for lupin GM-PR treated plots, indicating some of the P in lupin material had become available to the following maize crop even though the maize crop itself had removed large amounts of P (Table 4). This again indicates that the lupin was able to extract P from sources that were otherwise unavailable to the maize crop.

Lupin dry matter yield and P Uptake

Lupin produced an overall average DMY of 4.6 t/ha and 7.5 t/ha in the first and second cycle, respectively. Similar (non-significant) lupin dry matter yields were observed in the control and PR treated plots during both the cropping cycles except for a significant increase for PR120 treatment in the first cycle (Table 3). The P uptake was significantly increased for PR60 and PR120 compared to the control during the first and second cycles.

The response to sparingly soluble (reactive) PR by legume in a P deficient, low Ca soil is consistent with other studies (Haynes 1992; Horst *et al.* 2001; Kamh *et al.* 1999). The significant increase in lupin P uptake, during both years, was due to increased P availability from PR dissolution and is possibly further enhanced by the legume due to higher Ca uptake and acidification of the rhizosphere (Randhawa 2003) or is again due to the lupin GM extracting native non-available P. The higher N uptake with PR application may be from atmospheric fixation or from soil in our study, indicating that PR application improved legume residue quality (Table 3). Phosphorus is known to have an important effect on legume N fixation especially during early growth in P deficient soils (Chien *et al.* 1993; Hill *et al.* 2001).

Table 3: Lupin dry matter yield (DMY) (t/ha) and N and P uptake (kg/ha) before incorporation in cycle 1 (2001) and cycle 2 (2002).

Treatment	**DMY (t/ha)**		**N uptake (kg/ha)**		**P uptake (kg/ha)**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
Control	3.96	7.05	88	120	6.67	9.91
$PR60_{Feb}$	4.19	7.88	112	179	7.88	15.49
$PR60_{Sept}$	4.60	7.67	79	158	8.26	12.25
$PR120_{Feb}$	5.51	7.34	120	165	10.38	14.66
$SED_{0.05}$	0.77	0.79	17.4	27	1.48	1.87

Maize yield and P uptake

Maize harvesting was done at silking stage in 2001, but at to flag leaf stage in 2002 and this was the reason for higher DMY and P uptake in 2001 compared with 2002. During both years of the experiment the results indicate that either lupin GM incorporation or PR application alone did not increase the maize DMY compared to the control-F (Table 4). The similar maize DMY in control-lupin GM and fallow-PR treatments clearly indicate that omitting either the lupin GM or PR application can lead to little effect on subsequent maize growth (Table 4). The lack of response in the control-lupin GM in increasing maize DMY compared with the F plots might be due to higher N fertility of the soil as the site was under pasture rotation earlier. However, P deficiency may also be a limiting factor as P was omitted at the experiment site for at least four years before the start of experiment. Breman et al. (2001) suggested that the introduction of a legume was not an adequate strategy where P was limiting.

The effect of GM-PR addition on DMY and P uptake were significant in both cycles, again indicating that P was a major growth limiting factor. Carsky *et al.* (2001) suggested that application of PR without legumes had little effect in improving yield, but the combination of PR with legumes markedly increased yields.

When PR was applied before the sowing of maize and without any lupin GM incorporation (F-$PR60_{Sept}$), there was no significant increase in maize DMY or P uptake compared to the control treatments. The fallow $PR60_{Sept}$ plots also showed significantly lower maize DMY and P uptake than when PR had been applied 8 months earlier (F-$PR60_{Feb}$) indicating that maize has limited ability to utilise insoluble forms of P. However, when lupin GM is incorporated with PR (GM-$PR60_{Sept}$) then both maize DMY and P uptake is significantly increased (Table 4). Calculations from Table 3 on lupin P content would indicate that the amount of extra P added from the lupin GM incorporation and mineralisation does not fully explain the extra P uptake in lupin GM-PR plots. Therefore in lupin GM plots, the enhanced effect of PR may also be attributed to lupin mediated dissolution as organic matter addition can favour PR solubilisation (Barea *et al.* 2002). This might also explain the increased resin-P values after the maize crop following lupin incorporation (Table 2). Legume GM and PR in combination may have influenced P uptake of maize in at least three ways.

Firstly, when the GM was incorporated, the P contained in the GM was made available to the maize through mineralisation (Nziguheba *et al.* 2000).

Table 4: Effect of practice (F, GM) and PR on maize DMY (t/ha) and P uptake (kg/ha) during 2001-20002 (silking stage) and 2002-2003 (flag leaf stage).

Treatment	**Practice**	**2001-2002**		**2002-2003**	
		DMY (t/ha)	P uptake (kg/ha)	DMY (t/ha)	P uptake (kg/ha)
Control	F	8.23	21.28	6.30	12.21
	GM	7.56	21.10	5.78	11.60
PR60$_{Feb}$	F	8.55	24.77	6.48	13.25
	GM	10.02	27.90	6.53	16.89
PR60$_{Sept}$	F	7.74	19.99	6.05	13.59
	GM	9.15	24.35	7.01	16.02
PR120$_{Feb}$	F	8.47	23.75	5.91	14.83
	GM	10.16	29.09	7.25	19.31
SED		**0.779**	**2.49**	**0.680**	**1.93**

Secondly, lupin GM can increase aggregate stability, influencing root growth, soil aeration, soil microbiological activity and thus nutrient uptake and yield (Kabir and Koide 2002). However, in this experiment, this effect is unlikely as the aggregate stability was already good, due to the fact that the area had been under pasture for a number of years.

Thirdly, the incorporation of organic matter as lupin GM might increase the availability of insoluble forms of P and thus the ability of the maize crop to absorb P from the soil solution. Recent studies have indicated earlier infection of cereal roots with native arbuscular mycorrhiza fungi (AMF) in plots sown to cereals after legumes, compared with continuous cereal plots, may be more important in explaining rotation effects for subsequent cereals than a legume induced increase in P availability (Bagayoko *et al.* 2000). Vanlauwe *et al.* (2000b) reported that the addition of PR increased AMF infection in legumes but did not change the AMF infection rate of maize roots. They suggested that increases in AMF in legume roots might be related to rhizosphere processes which develop a synergistic microbial interaction in the tripartite legume-rhizobium-mycorrhizal complexes which may also facilitate PR solubilisation (Barea *et al.* 2002). However, insufficient P supply can restrict mycorrhizal development (Bolan *et al.* 1984). The availability of P derived from the PR may be enhanced in the rhizosphere of the legumes thus stimulating the colonisation of the roots by AMF. These processes are reported to be mediated by the legume species rather than by indigenous microbial population as AMF infection was higher in legumes than non-legumes (Vanlauwe *et al.* 2000b). Mycorrhizal colonisation effects however, need to be verified by further studies.

Conclusions

Lupin as a green manure winter crop in combination with PR can enhance P nutrition of the subsequent maize crop due to the capacity of lupin to solubilise the sparingly soluble (reactive) PR. These increases in maize performance clearly reflected the earlier observed responses of the green manure lupins to PR addition. The enhanced P uptake by maize in GM-PR combinations compared with F-PR also indicate processes operating in the lupin rhizosphere that result in better utilisation of PR and the subsequent effect of lupin organic matter additions on the increased solubilisation of residual PR.

References

Bagayoko M, Buerkert A, Lung G, Bationo A, Romheld V (2000) Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: soil mineral nitrogen, mycorrhizae and nematodes. *Plant and Soil* **218**, 103-116.

Barea JM, Toro M, Orozco MO, Campos E, Azcon R (2002) The application of isotopic (P-32 and N-15) dilution techniques to evaluate the interactive effect of phosphate-solubilizing rhizobacteria, mycorrhizal fungi and Rhizobium to improve the agronomic efficiency of rock phosphate for legume crops. *Nutrient Cycling in Agroecosystems* **63,** 35-42.

Bolan NS, Robson AD, Barrow NJ (1984) Increasing phosphorus supply can increase the infection of plant roots by vesicular-arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry* **16,** 419-420.

Bolan NS, White RE, Hedley MJ (1990). A review of the use of phosphate rocks as fertilizers for direct application in Australia and New Zealand. *Australian Journal of Experimental Agriculture* **30,** 297-313.

Breman H, Reuler HV, van Reuler H, Vanlauwe B, Diels J, Sanginga N, Merckx R (2001) Legumes: when and where an option? (No panacea for poor tropical West African soils and expensive fertilizers) pp.285-298

Carsky RJ, Oyewole B, Tian G (2001) Effect of phosphorus application in legume cover crop rotation on subsequent maize in the savanna zone of West Africa. *Nutrient Cycling in Agroecosystems* **59,** 151-159.

Chien SH, Carmona G, Menon RG, Hellums DT (1993) Effect of phosphate rock sources on biological nitrogen fixation by soybean. *Fertilizer Research* **34,** 153-159.

Haynes RJ (1992) Relative ability of a range of crop species to use phosphate rock and monocalcium phosphate as P sources when grown in soil. *Journal of the Science of Food and Agriculture* **60,** 205-211.

Hewitt AE (1998). New Zealand Soil Classification. 2nd edition. Lincoln, Canterbury, New Zealand, Manaaki Whenua Press.

Hill GD, McKenzie BA, Ganeshan V, Andrews M, Andrews ME, Humphry DR (2001). The nodulation and yield response of narrow-leafed lupin and pea to different forms of phosphorus. Proceedings of plant microbial interactions: Positive interactions in relation to crop production and utilisation, University of Sunderland, UK 2-3 July 2001. Aspects of Applied Biology. pp.165-172.

Horst WJ, Kamh M, Jibrin JM, Chude VO (2001) Agronomic measures for increasing P availability to crops. *Plant and Soil* **237,** 211-223.

Kabir Z, Koide RT (2002). Effect of autumn and winter mycorrhizal cover crops on soil properties, nutrient uptake and yield of sweet corn in Pennsylvania, USA. *Plant and Soil* **238** 205-215.

Kamh M, Horst WJ, Amer F, Mostafa H, Maier P (1999) Mobilization of soil and fertilizer phosphate by cover crops. *Plant and Soil* **211,** 19-27.

Kay T, Hill R (1998) Field consultants guide to soil and plant analysis*: Field sampling, laboratory processing and interpretation,* Hamilton, New Zealand.

Khasawneh F, Doll E (1978) The use of phosphate rock for direct application in soils. *Advances in Agronomy* **30,** 159-206.

Nziguheba G, Merckx R, Palm CA, Rao MR (2000). Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. *Biology and Fertility of Soils* **32,** 328-339.

Olsen SR, Sommers LE (1982). Phosphorus, In ‘Methods of Soil Analysis. Second edition. Agronomy Series’. (Eds AL Page, RH Miller, DR Keeney) pp. 403-430. (Soil Science Society of America, Madison).

Polthanee A, Vidhaya T, Wason P (2002) Effect of fallow and mungbean residues on soil properties and yield of the succeeding corn crop in a mungbean-corn cropping systems. *Thai Journal of Agricultural Science* **35,** 137-146.

Rajan SSS, Watkinson JH, Sinclair AG (1996) Phosphate rocks for direct application to soils. *Advances in Agronomy*: **57,** 77-159.

Randhawa PS (2003) Influence of green manuring and phosphate rock inputs on soil phosphorus cycling and availability. PhD Thesis, pp 82-101. (Lincoln University).

Saggar S, Hedley MJ, White RE (1992) Development and evaluation of an improved soil test for phosphorus: 1. The influence of phosphorus fertiliser solubility and soil properties on the extractability of soil P. *Fertilizer Research* **33,** 81-91.

Soil Survey Staff (1998) Keys to soil taxonomy. 8th edition. Washington, DC, United States Department of Agriculture.

Vanlauwe B, Diels J, Sanginga N, Carsky RJ, Deckers J, Merckx R (2000a). Utilization of rock phosphate by crops on a representative toposequence in the Northern Guinea savanna zone of Nigeria: response by maize to previous herbaceous legume cropping and rock phosphate treatments. *Soil Biology and Biochemistry* **32,** 2079-2090.

Vanlauwe B, Nwoke OC, Diels J, Sanginga N, Carsky RJ, DeckersJ, Merckx R (2000b) Utilization of rock phosphate by crops on a representative toposequence in the Northern Guinea savanna zone of Nigeria: response by Mucuna pruriens, Lablab purpureus and maize. *Soil Biology and Biochemistry* **32,** 2063-2077.