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Differential capacity of wheat, lupin and subterranean clover to acquire P from different sources

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Abstract

Most soils in Western Australia are P deficient, whereas water-soluble P fertilizers are expensive and have only about 10% efficiency. A low-cost alternative is phosphate rocks that can mitigate P deficiency. A pot experiment was conducted to evaluate the effectiveness of three plant species; white lupin, wheat and sub clover grown in a mildly acidic soil to acquire P from different phosphorus sources (rock phosphate, composted rock phosphate and potassium phosphate) and a control treatment (without P). The experimental study was set up as a completely randomized block design arranged with three replications in a factorial arrangements. Three P sources [potassium phosphate (KP), rock phosphate=RP and composted rock phosphate (ERAPHOS) =ER] at 60 mg P/kg soil + control (no P application). The three plant species were white lupin (*Lupinus albus* cv. Kiev), wheat (*Triticum aestivum* cv. Wyalkatchem) and sub clover (*Trifolium subterranean* L. cv. Dalkeith) + control (without plant). shoot and root dry matter of three species were the highest when P was supplied as potassium phosphate, while there was no significant differences between two other rock phosphate in associate with dry matter accumulation. Wheat had the highest root and shoot dry matter amongst crop species. Sub clover and wheat had a higher root/shoot biomass ratio than lupin. This indicates that sub clover and wheat have the morphological advantage of an extensive root system which can explore a larger volume of soil to access relatively immobile nutrients like P. Potassium phosphate treatment produced plants with the highest shoot micro- and macronutrient accumulation, except Ca element. Results also showed that composted rock phosphate does not offer significant value over standard rock phosphate and soluble chemical fertilizers like potassium phosphate.

Keywords: Lupin, potassium phosphate, rock phosphate, subterranean clover, wheat.
Abbrevation: KP- potassium phosphate; RP- rock phosphate; ER- ERAPHOS composted rock phosphate.

Introduction

After nitrogen, phosphorus (P) is the most influential mineral fertilizer for plant growth and development and is the world's second largest agricultural chemical. Phosphorus concentration in soil solution is very low (e.g. in the range of 100-400 g P/ha; Wild, 1988). Hence, soluble P is often the limiting mineral nutrient for biomass production, leading to yield losses of 5% to 15% and even substantially more (up to 100%) in highly weathered soils of tropics and subtropics as well as calcareous/alkaline soils of the Mediterranean basin (Hinsinger, 2001). Plants utilize relatively small amounts of applied phosphate fertilizers and the rest is rapidly converted into insoluble complexes in soil (Bolland *et al*., 1999); the efficiency of the added P fertilizer is only about 10% (Shenoy and Kalagudi., 2005). This leads to the need for frequent application of phosphate fertilizers, but their use on a regular basis is becoming increasingly costly and also environmentally undesirable (Reddy et al., 2002). This has led to a search for more environment-friendly and economically feasible strategies for improving crop production in low P soils (Shenoy and Kalagudi., 2005). Natural phosphate rocks can be a valuable alternative for P fertilizers in some soils. However, rock phosphate is not plant available in soils with pH greater than 5.5-6.0, but even under optimal conditions, plant yields are as a rule lower than those obtained with soluble phosphate (Khasawneh and Doll, 1978). Phosphate rock studies on pastures in Australia and New Zealand have produced contrasting results. Field studies in New Zealand have shown that phosphate rocks can be as effective as soluble P fertilizers, but similar studies in Western Australia have shown phosphate rocks to be ineffective because of limited dissolution (Bolland and Gilkes, 1990; Nuruzzaman et al., 2005). Grain legumes crops exhibited higher P-acquisition efficiency than wheat (Bolland *et al*., 1999), making them a valuable component in cropping systems on P-fixing soils. Kamh et al. (1999) demonstrated that growth and P uptake of a subsequent maize crop were enhanced due to mobilization of soil P by P-efficient legume crops. In a field trial, Horst et al. (2001) observed a positive rotational effect of P-efficient leguminous crops on the less P- efficient cereal crops. Development of cluster roots,

Table 1. F values for analysis of variance of growth parameters of shoots and roots of the crop species under three p-sources plus control treatment.

P sources	Plant height (cm)	Shoot dry weight (g/pot)	Root dry weight (g/pot)	Total dry weight (g/pot)	Root/S hoot ratio	Root length (m)	Root surface Area (cm^2)	Root diameter (mm/10)	Root volume (cm^3)
Control	15.2 c	0.77c	0.44 c	1.2 c	0.77 a	32.8 c	444 c	4.7 a	5.2 c
Potassium phosphate	26.8 a	7.92 a	2.37 a	10.3 a	0.32 b	199.3 a	2751 a	5.2 a	32 a
Rock phosphate	19.8 b	2.36 b	0.73 b	3.07 b	0.3 b	71.6 b	902 b	5.2 a	9.8 b
Eraphos	19 b	1.94 b	0.61 bc	2.6 b	0.29 b	56.1 bc	669 bc	4.9 a	7.2 bc

Treatment means marked with the same letter are not different ($p<0.05$, Duncan test).

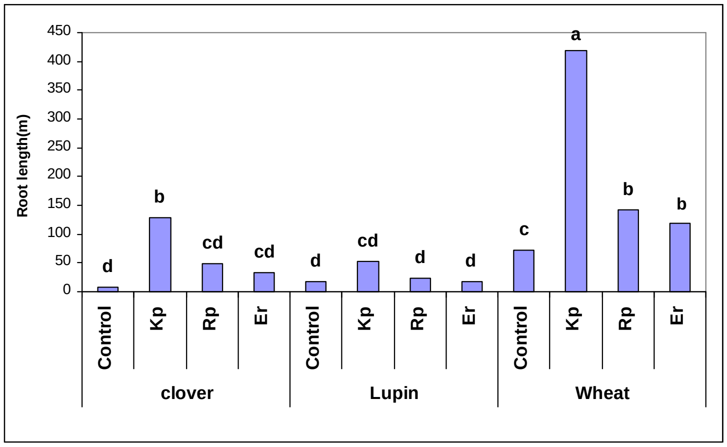

Fig 1. The effect of interaction between crop species and P supplies on Crop root length

coupled with the release of carboxylates into the rhizosphere, allows a plant to effectively obtain P from sparingly soluble forms (Jones, 1998a; Ryan *et al*., 2001; Neumann & Martinoia, 2002). The cluster-root morphology and physiology (carboxylate release) allow white lupin *(Lupinus albus*) (Gardner *et al*., 1983; Dinkelaker *et al*., 1989; Jones, 1998; Neumann *et al*., 2000; Shane *et al*., 2003) to access soil P that is unavailable to plant species such as wheat *(Triticum aestivum*) that does not have cluster roots and releases relatively small quantities of carboxylates (Hocking *et al.*, 1998; Veneklaas et al., 2003; Nuruzzaman et al., 2005; Pearse et al., 2006). While white lupin has been well studied, and grain legumes to a fair degree, there is little information about mechanisms of P acquisition from various P sources for pasture legumes. Present study was aimed to characterize root growth, development and P uptake of sub clover (as a widely grown pasture species), white lupin and wheat, supplied with different P sources.

Results and discussion

Plant growth

Analyze of variance revealed highly significant ($P<0.01$) differences among crop species, P supply and their interaction on plant height, shoot, root and total dry matter and root/shoot ratio (Table not shown). Wheat with potassium phosphate treatment had the highest shoot dry weight of 12.5 g and clover had the lowest shoot dry weight in control treatment (without P). With increasing soluble P, shoot dry weight increased by 6.9, 3 and 15 times (Tables 1&2). This result showed that Wheat and Clover had better response to addition of soluble P sources like potassium phosphate than Lupine (Table 1). There was no significant difference between Eraphos and Rock phosphate for shoot and root dry weight (Table 1). Wheat had the greatest root shoot and total dry matter among crop species (Table 1 & 2). Sub clover produced the lowest root dry matter (Table 2). There was no significant difference between shoot and total dry matter of sub clover and Lupine. These results showed that the dry matter of whole plants of each three species was greatest when P was supplied as Potassium phosphate (Table 1 & 2). There was no significant difference for Root/Shoot ratio between crop species. But control treatment (without P) had highest Root/Shoot ratio than other three P-supplies (Table 1). This result could be explained by the low P content of Lancelin soil which forced the plants to allocate more dry matter to roots than shoots in order to find P sources in soil profile. There have been a number of published studies on the availability of different P sources in soil. Tarafdar and Claasen (1988) demonstrated that glycerophosphate, lecithin and phytin (inositol) added to soil were at least equal to inorganic P sources in their availability to clover, barley, oats and wheat. In the present study, P supply led to a significant decrease in biomass of both shoots and roots, but the shoot growth appeared to be more sensitive to P supply than root growth (especially in Potassium phosphate treatment). Previous field studies have shown that freshly-applied rock phosphates are equally or more effective than freshly-applied single superphosphate (Fitzpatrick, 1961). Nuruzzaman et al, (2005) showed that wheat had remarkably low root P concentrations; approximately four times lower than that of *Faba bean*. The P economy of wheat seems strongly dominated by allocation to the shoots.

Table 2. Root and shoot growth parameters in crop species grown with three P sources for 56 days.

P supply	Plant species	Plant growth characteristics				
		Shoot dry weight (g/pot)	Root dry weight (g/pot)	Total dry weight (g/pot)	Root/Shoot ratio	Plant height (cm)
Control (no P applied)	Sub clover	0.11 h	0.11g	0.22 g	1.09 a	4.5 f
	Lupin	1.4 efg	0.51 f	1.9 ef	0.15 d	25.6 abc
	Wheat	0.82 gh	0.7 def	1.52 fg	0.23 cd	15.4 de
Potassium phosphate	Sub clover	7 b	1.06 cd	8.06 b	0.3 cd	22.6 de
	Lupin	4.4 c	1.6 b	6.02 c	0.37 cd	27.8 ab
	Wheat	12.5 a	4.47 a	16.9 a	0.36 cd	31.1 a
Rock phosphate	Sub clover	2.2 def	0.53 ef	2.7 def	0.33 cd	14.6 de
	Lupin	1.7 efg	0.56 ef	2.3 ef	0.24 cd	25.6 abc
	Wheat	3 d	1.12 c	4.2 d	0.86 b	20.1 cd
Eraphos	Sub clover	1.2 fgh	0.35 fg	1.54 fg	0.35 cd	12.17 e
	Lupin	2.5 de	0.57 ef	3.1 de	0.36 cd	24.4 bc
	Wheat	2.1 def	0.9 cde	3.05 de	0.43 c	20.4 cd

Treatment means marked with the same letter are not different ($p<0.05$, Duncan test).

Wheat shoots contained more than 90% of acquired P. Greater P availability led to a large increase in growth, but a much smaller increase in P concentrations. Among P supplies, potassium phosphate provided with the greatest Plant height while there was no significant difference between Eraphos and Rock phosphate (Figure 1).

Shoot nutrient contents

Analysis of variance showed highly significant ($P<0.01$) differences among crop species, P supply and their interaction on shoot micro and macro nutrients. Shoot P content was highest by Eraphos treatment for sub clover while control treatment provided with the lowest P content for all crop species (Table 3). However, the results showed that potassium phosphate caused the highest mean P content in all crops. It seems that this result is achieved due to the more availability of P by this treatment for plants. Therefore potassium phosphate treatment produced the greatest shoot and root dry matter (Table 1). Eraphos had greatest effect on shoot P uptake by wheat and sub clover. In contrast, in Lupine, potassium phosphate had greatest effect on P shoot uptake (Table 3). Chien (1979) showed that production of organic acids like citric, oxalic, tartaric, etc. during composting of organic matter could in turn, enhance the dissolution of P from RP. Further, lots of CO2 evolved during the process of decomposition of organic manures result in the formation of weak carbonic acid, which in turn dissolve RP and render the availability of P, thus these processes increase the efficiency of RP (Chien, 1979). The results were in close conformity of the work done by others (Mathur et al., 1980; Bangar et al., 1989). Sub clover had the most P uptake compared to other crop species (Table 3). Other reports showed that legumes had high potential to have root exudates for use of sparingly soluble P recourses in the soil (Bolland et al 1990, Rengel, 1999). In the potassium phosphate treatment, wheat produced the highest root, shoot and total dry matter but sub clover had greater shoot dry matter and lower root dry matter compared to Lupine (Table 3). Wheat has been reported as a species with slow root exudation rates (Neumann and Martinoia, 2002; Veneklaas et al., 2003, Nuruzzaman et al, 2005). The observed species differences in plant P content and growth may be due to a number of factors. The species studied differ in percentage biomass allocation to roots, root morphology, rhizosphere chemistry and tissue P concentrations. Sub clover and wheat had a higher root mass ratio than lupine, i.e., greater biomass allocation to the roots, than that of the other species (Table 3). This indicates that Sub clover and wheat have the morphological advantage of an extensive root system that can explore a larger volume of soil to access relatively immobile nutrients like phosphorus. Accumulation of biomass to roots by sub clover decreased in response to addition of P compared to control (Table 3). Eraphos and Rock phosphate treatment for wheat, showed thesimilar trends (Table3). It seems unlikely that sub clover due to producing organic acids and wheat for having larger root dry matter, length and volume, had any effect on Shoot P uptake on Eraphos treatment(Djordjevic et al, 1987) . Previous field studies have shown that white lupine plants have a great ability of mobilizing the sparingly soluble P through changing rhizosphere processes, particularly bycitrate exudation (Hinsinger, 1998; Marschner, 1995; Veneklaas et al., 2003). But in present study it seems that Sub clover uses this mechanism for uptaking phosphorus in the soil. Bolland and Gilks (1990) compared the responses of wheat, chickpea, white lupine and *Faba bean* to P application in glasshouse and field experiments, and found that chickpea, white lupine and faba bean had higher yields with no P application and lower yield responses to added P than wheat. potassium phosphate treatments had the highest micro and macro nutrients uptake by shoot except for Ca that Eraphos treatment in sub clover plant contented the highest amount of Ca (Table 3). The result could be explained by the higher content of Ca element in Eraphos structure (26%). The positive effect of phosphate amendments on plant growth may be attributed to either the effect of P on decreasing metal toxicity, or improvement of P nutrition, or a combination of both mechanisms. In present study we have found 2-fold more P, 1.5 fold more Ca, 1.4 fold Magnesium, 5-fold more Cobalt in Sub clover than Wheat (Data not shown). Also 2-fold more P, 3-fold Magnesium, 2-fold potassium, 3-fold Calcium and 3-fold Zinc than Lupine (Data not shown) was observed. Suong et al., 2005 observed that the lupine shoots accumulated approximately 10-fold more calcium, 5-fold more magnesium and 8-fold more sulphur than the wheat shoots regardless of whether they were grown in monoculture or mixed culture. Hettiarachchi et al. (2001) reported that PR

Table 3. Root and shoot growth parameters in crop species grown with three P sources for 56 days.

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Sub clover	Control	0.11 h	0.11g	0.22 g	1.09 a	4.5 f
	Potassium phosphate	7 b	1.06 cd	8.06 b	0.3 cd	22.6 de
	Rock phosphate	2.2 def	0.53 ef	2.7 def	0.33 cd	14.6 de
	Eraphos	1.2 fgh	0.35 fg	1.54 fg	0.35 cd	12.17 e
Lupin	Control	1.4 efg	0.51 f	1.9 ef	0.15 d	25.6 abc
	Potassium phosphate	4.4 c	1.6 b	6.02 c	0.37 cd	27.8 ab
	Rock phosphate	1.7 efg	0.56 ef	2.3 ef	0.24 cd	25.6 abc
	Eraphos	2.5 de	0.57 ef	3.1 de	0.36 cd	24.4 bc
Wheat	Control	0.82 gh	0.7 def	1.52 fg	0.23 cd	15.4 de
	Potassium phosphate	12.5 a	4.47 a	16.9 a	0.36 cd	31.1 a
	Rock phosphate	3 d	1.12 c	4.2 d	0.86 b	20.1 cd
	Eraphos	2.1 def	0.9 cde	3.05 de	0.43 c	20.4 cd

Treatment means marked with the same letter are not different ($p<0.05$, Duncan test).

was more effective than triple super phosphate or phosphoric acid in reducing Pb bioavailability for Zn–Pb contaminated soils. It is well known that white lupines growing in low P soils exude large quantities of citrate and protons from their roots which improves their P nutrition (Dinkelaker et al., 1989; Gardner et al., 1983; Gerke et al., 1994; Hocking and Pandall., 2001; Keerthisinghe et al., 1998). But in present experiment we couldn't confirm this fact. It seems that the lowest Root/Shoot ratio in lupine (Data not shown) is probably because of less root exudates along with the lower volume of root produced which lead to less P uptake by that plant.

Materials and methods

Experimental design

A pot experiment was conducted in a phytotron at 20/12 ºC (day/night) temperatures. The experiment was based on completely randomized block design arranged with factorial treatments (species × P sources) in three replications. We tested three P sources [potassium phosphate (KP), rock phosphate=RP and composted rock phosphate (ERAPHOS) =ER] at 60 mg P/kg + control (no P application). The three plant species were white lupin (*Lupinus albus* cv. Kiev), wheat (*Triticum aestivum* cv. Wyalkatchem) and sub clover (*Trifolium subterranean* L. cv. Dalkeith) + control (without plant). A sandy soil was collected from Lancelin(pH_{water} 6.2, organic carbon 8.3 g kg^{-1}, and available nutrients in mg kg^{-1} Colwell-P 2, K 20, Fe 28, Mn 2, Zn 0.06 and Cu 0.06), Western Australia, air-dried, sieved through a 2-mm sieve and thoroughly mixed. Three kg of soil was weighed into pots with 60 cm height. Basal nutrients were applied at the following rates (mg per 3 kg soil): NH_4NO_3 295, KCl 150, K_2SO_4 420, $CaCl_2.2H_2O$ 450, $MgSO_4.7H_2O$ 120, $MnSO_4.H_2O$ 30, $ZnSO_4.7H_2O$ 27, $CuSO_4.5H_2O$ 6, H_3BO_3 2.1, $CoSO_4.7H_2O$ 1.5 and $Na_2MoO_4.2H_2O$ 0.6. Basal nutrients were added to soil in solution. After drying, thee P fertilizer treatments were applied in bands at 4-cm depth from the soil surface.

Measurements

Lupin and sub clover seeds were inoculated with 1 mL suspension of root nodule bacteria before sowing. The bacterial suspensions were made in water from commercial peat inocula [*Bradyrhizobium* sp. (*Lupinus*) WU425] for lupins and (*Rhizobium trifolii* WU95) for clover at a rate of 5 g/L. Twelve days after sowing, plants were thinned to 8, 6 and 2 per pot for wheat, sub clover and lupin, respectively. Soil was watered to field capacity (15% w/w). Plants were harvested 56 days after sowing. Soil was separated from roots by sieving through a 4-mm sieve. Shoots and roots were dried at 70 °C for 48 h and weighed. Roots were kept in 50% v/v ethanol until scanning. Concentrations of K, Ca, Mg, Na, P and S in plant tissues were determined using inductively-coupled plasma emission spectrometry (ICPAES) after plant materials were digested in concentrated nitric acid.

Statistical Analysis

The data were analyzed by ANOVA using SAS-9 software (SAS Institute Inc., 1989). Duncan ($P\leq0.05$) test was employed for mean separation when F-values were significant.

Conclusions

The result showed that different crop plants showed similar responses to all three different P supplies. However, Potassium phosphate was the more effective treatment than others. There were no significant differences between Eraphos and Rock phosphate for growth parameters and some mineral elements uptake. Regarding to both low Western Australian soil P content and its sandy soil, we will not expect any increases in growth parameters and nutrient uptake in short time by Eraphos and Rock phosphate application. But probably for long time we can utilize these materials as supplements to potassium phosphate. It seems that the P in Eraphos and Rock phosphate can not be easily uptake by plants; so, the utilization of phosphate solubilizing microorganisms seems to be a good idea in combination with Eraphos and Rock phosphate. Finaly there can be no economic advantage in substituting Rock phosphate for Super phosphate.

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