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Improving green manure quality with phosphate rocks in Ontario Canada

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Summary

Phosphate rock (PR) was applied to one conventional and two organic dairy fields and planted with buckwheat (*Fagopyrum esculentum*) as a green manure crop. In total, five types of PR were applied at three application rates in order to determine the yield, concentration of P in the aboveground tissue and the P uptake of buckwheat. It was found that PR of relatively high carbonate substitution and small particle diameter could increase buckwheat tissue concentrations to a quality such that mineralization of the buckwheat mulch could occur. Buckwheat mulch and residual PR increased soil P flux as determined by anion exchange membranes *in situ* in the following spring. This provides evidence that buckwheat of high P quality has the potential to supply P to a subsequent crop.

Keywords: Phosphate rock, *Fagopyrum esculentum*, green manure, soil phosphorus

Introduction

Agricultural soils under long-term organic management can become deficient in plant-available phosphorus (P) over time (Entz *et al*., 2001). P fertilisation on organic farms depends primarily on the on-farm recycling of organic materials, such as compost, green manures (GM), mulches and farmyard manures with minimal farm P inputs (Loes & Ogaard, 2001). In an attempt to avoid P deficiencies in growing crops, application of phosphate rock (PR) has been proposed; however evidence of their effectiveness in calcareous soils is required before PR use can be widely recommended in Canada. Certain plant species exhibit mechanisms localized in the rhizosphere that allow for the efficient use of P through the dissolution of PR. Buckwheat (*Fagopyrum esculentum*), a common cover crop in organic agriculture, has been shown to utilize P from PR even in calcareous soils (Zhu *et al*., 2002). Additionally, it has been found that the P concentration of buckwheat tissue can reach luxury levels (beyond 0.5% P) (Bekele *et al*., 1983). When grown as a green manure crop, buckwheat has the potential for supplying P to subsequent crops if the concentration of P in the tissue is high enough for mineralization to occur or to decrease P adsorption (Nziguheba *et al*., 1998). This field study had two primary objectives: to evaluate the effects of five PR of varying mineralogy and origin on yield and aboveground tissue P of a buckwheat crop; and to determine if mulching and incorporating the residues from buckwheat grown with PR influenced soil P availability the following spring.

Materials and Methods

Phosphate rock characterization and field application

The experiment was conducted on one conventional (CON) and two organic (ORG1 and ORG2) dairy farms in Southwestern Ontario, Canada. The field sites were on loam soils of the Podzol order and annual rainfall was 960 mm. In order to maximize the potential for PR treatment effects on plant growth, fields were selected based on low to medium (< 10.0 ppm P) available P ($NaHCO_3$-extractable) levels. Soil pH was 7.5, 7.6 and 6.9 for ORG1, ORG2, and CON, respectively. Additionally, fields previously cropped in alfalfa were chosen to ensure an adequate supply of N for the buckwheat crop. The PRs used in the experiment vary in geological and geographical origin and as a result will vary chemically and mineralogically. Table 1 highlights PR characteristics relevant to solubility and plant uptake. PR solubility increases with decreased particle size and length of the unit-cell a-axis, which indicates an increase in carbonate substitution of the apatite mineral.

Table 1. *Selected characteristics of the phosphate rocks*

PR	Deposit location	Total P (%)	Available P (mg P kg rock$^{-1)}$	*a*-axis (Å)	Particle size (% passing 0.125 mm)
SRPR	Ontario, Can.	1.4	0	no data	no data
VPR	Ontario, Can.	16.8	80	9.3712	8.3
CPR	Florida, USA	8.7	100	9.3520	93.0
TPR	Tennessee, USA	12.7	118	9.3396	10.3
PPR	N. Carolina, USA	10.1	24	9.3234	1.1

At each site, the experiment was arranged as a two factor (P treatment and P application rate) randomized complete block design with four replicates. Three PR were applied on the organic field sites, while five PR and two soluble fertilizers (MAP and TSP) were applied on the conventional field site for comparison. All of the P treatments were applied on ploughed soils at rates of 100, 400 and 800 kg total P ha^{-1} in June 2004 and immediately incorporated by rototilling to 10 cm. A control treatment with no addition of P was included.

Buckwheat planting, harvesting and mulching

Buckwheat was sown at 67 kg ha^{-1}, with no additional tillage, within one week following the incorporation of the P fertility treatments. Buckwheat biomass yield was determined at approximately seven weeks of growth (just prior to seed set) by cutting a 1.10 m × 5 m swath. The fresh biomass weight was taken in the field and a subsample (1 kg) was retained, dried (60°C for 48 h) and ground (< 1 mm). The tissue P as a percentage of total plant biomass was determined by high temperature dry oxidation of the organic matter and dissolution of the ash with 1 M HCl. Total P in the digests was determined using atomic absorption. At the time of buckwheat harvest in August, all the aboveground buckwheat material (2.7 to 3.0 t DM ha^{-1}) from each plot was returned to half of the plot (subplot). This gave subtreatments of unmulched and double rate mulching. The buckwheat mulch remained on the soil surface over the winter and was rototilled in spring of 2005. An annual ryegrass (*Lolium multiflorum*) crop was planted after rototilling with no additional tillage; however the ryegrass yield and nutrient data will not be presented here.

Soil sampling and analysis

In spring 2005, the flux of soil P (µg 10 cm^{-2}) was determined using anion exchange membranes encased in plastic PRS^{TM} probes (Plant Root Simulators^{TM}, Western Ag Innovations, Saskatoon, SK, Canada). Three probes per subplot were inserted in the soil (0-10 cm depth) prior to tillage, removed and immediately replaced following rototilling of the buckwheat mulch. For time management reasons, only organic plots applied with CPR at the 400 and 800 kg P ha^{-1} rate and VPR at the 800 kg P ha^{-1} rate were analysed as well as the control plots. The flux of P was also monitored on the control and TSP (800 kg P ha^{-1} rate) main plots on the conventional site. The probes were removed and replaced with clean probes every two weeks for a total of 8 weeks. The P accumulated in the probes was eluted with 0.5 M HCl and analysed using the Murphy-Riley method. Tukey-Kramer multiple comparisons test was used to determine differences ($P < 0.05$) between treatment means.

Results

Concentration of P in buckwheat tissue and P uptake due to PR application

P fertility treatments significantly affected buckwheat biomass yield on the conventional site only. Mean yields for each farm site were 3.13, 2.79, and 2.81 t DM ha^{-1} for ORG1, ORG2, and CON, respectively. Fig. 1 highlights the response of the P concentration in buckwheat to P treatment and rates. VPR and the SRPR were ineffective at increasing buckwheat tissue P concentrations compared to the control on any of the farm sites. CPR improved the concentration of P in buckwheat tissue by as much as 103% on the ORG2 site compared to the control. Application rate did not significantly affect yield on this site (data not shown). ORG2 had the lowest initial available P (4.8 mg P kg soil^{-1}), and it was expected that the response to P addition would be the most pronounced. The effectiveness of CPR was consistent across both organic farms. On the CON field site, TPR and PPR at 800 kg P ha^{-1} produced similar gains in tissue P concentration as TSP and MAP at 100 and 400 kg P ha^{-1}. The maximum concentration of P in the buckwheat tissue attained by any PR was 0.399% with application of 800 kg P ha^{-1} of CPR on the CON site. Among organic sites, the same treatment (CPR800) also produced the highest buckwheat tissue concentration, 0.347% on

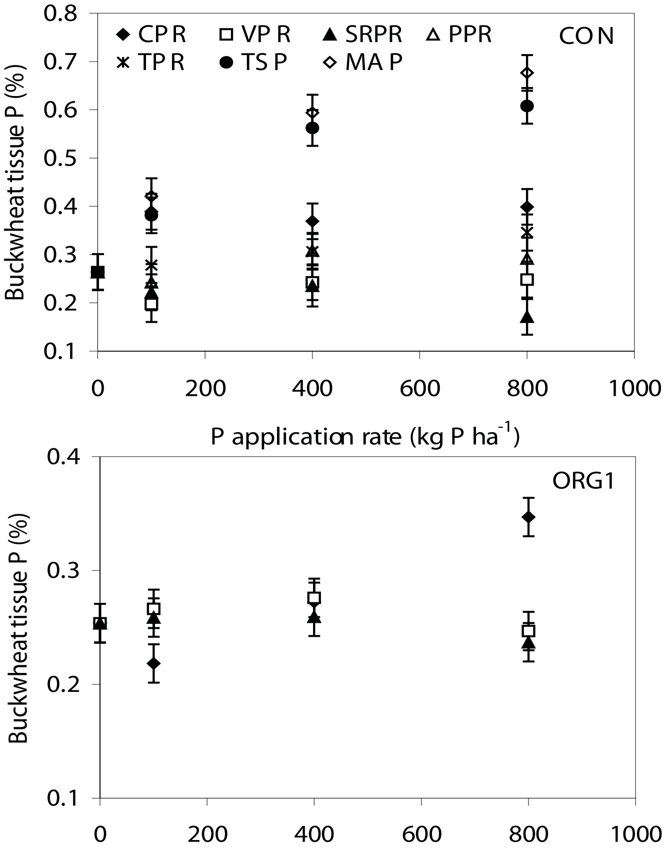

Fig 1. The concentration of P % in the aboveground buckwheat tissue for CON and ORG1 sites. Bars indicate standard errors (n=4 df=18).

site ORG1.

Effect of buckwheat mulch and residual PR on spring soil P flux

In spring 2005, cumulative soil P flux (µg P 10 cm^{-2}), on mulched subplots for treatments CPR and TSP applied at 800 kg P ha^{-1} was significantly greater (8.5 and 95.2, respectively) than the control (5.21 µg P 10 cm^{-2}) over 8 weeks. The initial two weeks in May resulted in the largest flush of P (2.02 µg 10 cm^{-2}), likely due to drought conditions in late May and early June which would limit P movement. Both rates of CPR application produced P fluxes greater than the control in the first two weeks of measurement in early May 2005 (Fig. 2). There were no significant differences in P flux due to PR in subsequent dates apart from CPR at the highest rate in the final two weeks (end of June 2005). There was no mulching and PR interaction; however mulching increased the average two week soil P flux over unmulched plots by 38%. Available P in the soils was significantly increased due to buckwheat mulching in April and June. CPR applied at 800 kg P ha^{-1} increased available P of soils sampled in June by 36% (data not shown).

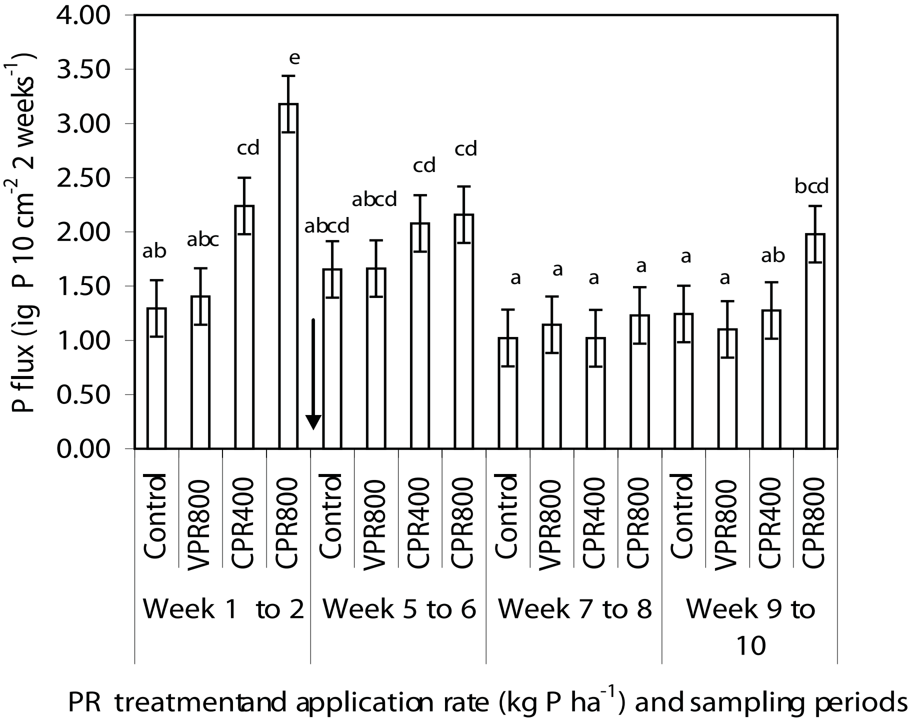

Fig. 2. Soil P flux (µg P 10cm^{-2}) over each two week period on site ORG 1 as sampled by PRS™ probes. There was a significant sampling date, P treatment, and application rate interaction. Similar letters indicate no significant difference between treatment means by Tukey-Kramer. Bars indicate standard errors (n=8 df=87). The arrow indicates the two week period where rototilling and ryegrass planting occurred.

Discussion

Buckwheat utilised P from CPR even in soils with high pH, suggesting that the limiting factor for the use of the PR is not necessarily due to soil or crop factors, but due to the characteristics of the rock. The very large grain size limits the use of PPR and TPR in supplying P to plants despite the high degree of carbonate substitution in these rocks. Grinding can improve the agronomic effectiveness of PR; however the cost to grind the material and the lack of appropriate machinery to spread such fine material would limit its adoption (Bolland & Gilkes, 1989). Buckwheat was able to utilize CPR most effectively due to the combination of the small grain size and relatively high carbonate substitution of the apatite mineral in the PR. Additionally, the large volume of all PR applied to the soil likely increased PR contact with the buckwheat roots, increasing the likelihood of dissolution by H^+ released by the plant.

The high P concentration of buckwheat tissue resulted in increased flux of P in soil of plots receiving CPR at the highest rate of application in the year following initial application. The concentration of P in the buckwheat was 0.35%, which is above the concentration that Nziguheba *et al*. (1998) found was necessary to decrease P adsorption in high P sorbing soils. In the present study, the initial concentration of P in the buckwheat residue explained 74% of the variation in cumulative soil P flux, while the total amount of P applied in the buckwheat residue could only explain 39% of the variation. Pypers *et al*. (2005) also found that when plant residues of varying P contents were added to soil at 45 kg P ha^{-1}, the P concentration of the residue had more effect on P availability than the total amount of P added to the soil in the residue. Thus the quality rather than the quantity of the residue determines the availability of P from these organic materials. Based on the present soil P flux data, buckwheat grown with CPR at high rates of application has the potential for supplying P to a subsequent crop. Further study is currently being conducted on the response of annual ryegrass to buckwheat mulching and residual PR.

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