Management of P Nutrition in Andisols, Oxisols Challenging

While fluids did not excel over granular here in plant growth, they did in calcareous soils.

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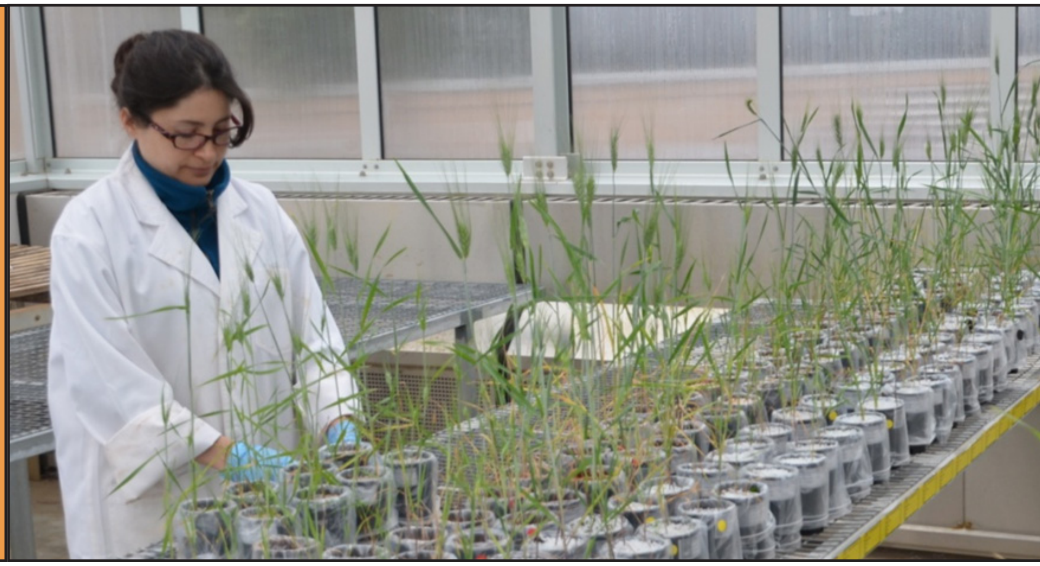
Summary: Our study demonstrated that in acidic and oxide-rich soils, where the availability of phosphorus (P) is restricted by strong adsorption reactions, P fluid fertilizers did not provide any additional advantage to plant growth over the granular sources. In contrast, fluid P fertilizer was highly effective in calcareous soil. Chemical properties of the soils need to be considered prior to the selection of P fertilizers as they play a vital role in the fate of P in soils.



Andisols and Oxisols are rich in P-sorbing minerals, such as Al/Fe oxyhydroxides or allophone. Management of P nutrition in these soils is often very challenging. To overcome P deficiency and to increase the bio-available P pool in soil, the application of fertilizer P is necessary. In these soils, a substantial quantity of fertilizer P is required to achieve economically acceptable yields; however, over-fertilization can result in environmental problems and accumulation of P in the soil. Phosphate fertilizers come from a finite resource and recently there has been speculation of exhaustion (in the next few centuries) of the more accessible sources, which may lead to an increase of the already high fertilizer prices.

Phosphorus fertilizers are commonly applied in the form of granules, but the use of fluid P is also a viable alterative. The selection of fertilizer type (granular vs. fluid) should be made, taking into consideration the chemical properties of the soils. It has been shown that there is more bio-available P in calcareous soils fertilized with fluid P than with granular P fertilizers. However, our previous work has indicated this is not the case for Andisols and Oxisols. A greater percentage (34%) of added P with granular fertilizer remained in a labile form (potentially plant available) than with fluid fertilizer (24% labile). These results indicated that when adsorption (not precipitation) reactions reduce the availability of fertilizer P, the use of fluid sources may not provide any agronomic advantage over the conventional granular formulations.

Objective

This study aimed to investigate the relative effectiveness of fluid and granular P fertilizers for wheat grown in acidic, strongly P-sorbing soils under glasshouse conditions. Also a calcareous soil was included for comparison.

Methodology

Materials. Surface soil samples (0 to 10 cm depth) of two Andisols from Chile and New Zealand (North), two Oxisols from Australia (Greenwood and Redvale), and a calcareous Inceptisol from Australia (Port Kenny) were used for this pot experiment.

Soils. All soils were characterized by low soil test P level and high capacity to fix P. Selected soil chemical properties are presented in Table 1.

Fertilizers. The P fertilizers evaluated were:

- Granular triple super-phosphate (TSP, 20% P)
- Mono-ammonium-phosphate (MAP, 22% P)
- Di-ammonium-phosphate (DAP 20% P)
- Fluid mono-ammonium-phosphate (flMAP, 26% P).

Rates. Fertilizer rates were 150 mg kg-1 for Chile, North, Greenwood, and Redvale soils, and 40 mg kg-1 for Port Kenny soil. Higher P rates were used for the Andisols and Oxisols because of their very high P sorption capacity. Also a control (no fertilizer) treatment was included for each soil. Each treatment was replicated four times.

Soils. A total of 260 cm3 of dried-air and 2-mm sieved soil (weight of soil calculated based on the soil bulk density) was used in each pot. The soils were placed in double plastic bags and –basal macro- (100 mg N, 33 mg K, 21 mg Mg, 28 mg S per kg) and micro- (0.83 mg Fe, Mn, Zn, Cu, 0.083 mg Co, Mo, B per kg) nutrients were added as a solution. Consequently, soils were uniformly labeled with 500 kBq kg-1 of carrier-free 33P-orthophosphate and watered to field capacity.

Application. Three days after soil labeling and basal nutrient application, the P fertilizer treatments (granular and fluid) were applied at equidistant points around the pot and at 3 cm depth. One day after the P fertilizer application, four pre-germinated wheat seeds (Triticum aestivum) with average weight of 40 mg ±0.05 mg were sown in each pot at an approximate depth of 1 cm. The seedlings were thinned to 2 plants per pot five days after planting. The pots were watered daily.

Harvesting. Six weeks after planting, the plants were harvested; shoots were cut about 1 cm above the soil surface, oven-dried at 70oC for 48 hours and the dry weight recorded. The dried plant material was ground and digested in hot HNO3 prior to elemental analysis by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The 33P activity in the digests was measured by fluid scintillation counting.

Calculating. In this experiment we used the isotopic dilution technique to calculate P fertilizer efficiency, the proportion of P in the shoots that derived from the applied fertilizer (Pdff%) Eq. 1:

$$\%Pdff = 100 \text{ X } \{1 - \left(\frac{33\ Pshoot_f}{SA_{Pdfsoil} \text{ x } _{Pshoot\,f}}\right) - \%Pdfseed_f$$

Where $^{33}Pshoot$ is the shoot P activity (kBq plant^{-1}) of the fertilized plants, $SA_{Pdfsoil}$ is the specific activity of the soil exchangeable P that was estimated from the plants grown in the control treatments (no fertilizer) (kBq mg^{-1}). $Pshoot_f$ is the shoot P concentration of the plant grown in the fertilized treatment (mg plant^{-1}). $\%Pdfeed_f$ is the % seed P contribution to the shoot in the fertilized plants.

The total wheat seed P content determined by acid digestion was of 3.3 mg g^{-1} ± 0.3 mg g^{-1}, average of 10 seeds, so that total seed P was 0.13 mg plant^{-1}. The amount of P from the seeds that translocated to the shoots needs to be accounted for since it can vary between fertilized and non-fertilized treatments. The seed contribution of the plants in the control treatments was estimated by assuming that L-values (isotopic exchangeable P determined from plants grown in labeled soil) equal E-values (isotopic exchangeable P in soil suspension) as discussed in the Results section.

Analysis. The analysis of variance (ANOVA) by soil was performed using GenStat statistical package 15th edition. Treatment differences were analyzed with Fisher protected least significant difference (LSD, P≤0.05).

Table 1. Selected soil properties of the soils used in the study.

Soil properties‡	Chile	North	Greenwood	Redvale	Port Kenny
Soil type	Andisol	Andisol	Oxisol	Oxisol	Calcareous Inceptisol
Country of origin	Chile	New Zealand	Australia	Australia	Australia
pH(1:5 in water)	5.3	5.72	5.87	6.4	8.44
Clay (%)	14	7	13	61	3
$CaCO_3$ (%)	b.d.l.§	b.d.l.	b.d.l.	b.d.l.	28
Al_{ox} (g kg^{-1})	42.8	42	17.3	2.34	0.241
Fe_{ox} (g kg^{-1})	16.7	8.19	4.14	2.22	0.098
Total P (mg kg^{-1})	1122	1549	157	128	375
Ca^{2+} (cmolc kg^{-1})	1.5	6.6	4	7.4	26.6
Mg^{2+} (cmolc kg^{-1})	0.3	1	2.7	2.5	9.5
K^+ (cmolc kg^{-1})	0.6	0.48	0.42	0.37	1.6
C_{DGT} (µg L^{-1})	4	11	6	2	33

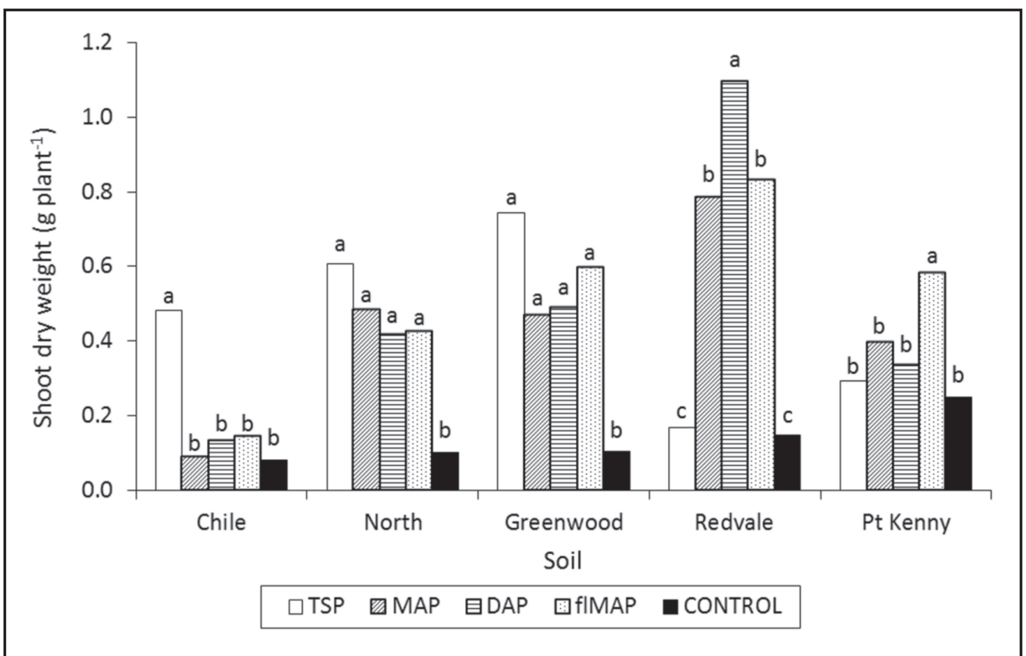


Fig. 1. Shoot dry matter yield (g plant^{-1}) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (flMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at P ≤ 0.05.

Results

Yield, P concentration. In the Andisols (Chile and North) and Oxisols (Greenwood and Redvale) there was no significant difference in dry matter growth between granular (MAP) and corresponding fluid MAP (flMAP) fertilizer (Figure 1). In contrast to the acidic soils, flMAP produced 31% more plant dry matter than its granular counterpart in the calcareous soil (Port Kenny). The results from this experiment sustain our initial hypothesis that no agronomic benefit is to be expected with fluid fertilizer in acidic and oxide-rich soils. The plausible explanation is that with fluid fertilizer, applied P is likely to be more diluted in a larger volume of soil, resulting in P being strongly adsorbed to the Al/Fe oxides of the soils. In the calcareous soil, precipitation of Ca-P minerals is the main P-fixation process. Thus, higher dilution with fluid P is beneficial because it likely results in less over-saturation and therefore less precipitation of these minerals.

Soils. In three of the five soils, there was no significant difference between the granular fertilizers.

In the Chile soil, wheat plants fertilized with the granular TSP grew better and produced significantly higher dry matter yields than the other fertilizers. The better performance of TSP in the Chile soil could be related to the addition of Ca with the fertilizer (TSP, 15% Ca). In this soil exchangeable Ca (1.5 cmolc kg^{-1}) was very close to the minimum level (1 cmolc, kg^{-1}) recommended for adequate plant growth. In this experiment, Ca was not added in the basal fertilization to avoid opportunities of Ca-P precipitation that could hinder the results.

In the Redvale soil, TSP performed much worse than the ammoniated sources. In our previous study, we found that significantly less P remained labile when calcium phosphate fertilizers were applied in the Redvale soil. We hypothesized that the lower P availability may be due to Ca-P precipitation at the relatively high pH of this soil.

P effect. In the Andisols and Oxisols the addition of P fertilizer significantly increased tissue P concentration with respect to the control (Figure 2). However, the concentration of P in the shoots was still deficient in many of the amended treatments where the measured shoot P concentrations were below the critical level of 3 mg g^{-1}. In the calcareous Port Kenny soil, P concentration did not statistically differ between the control and the fertilizer treatments.

The seed P contribution needs to be taken into account to distinguish between uptake from soil and fertilizer applied P. Several studies have used the assumption of 50 percent of total seed P translocation to the shoots. However, the uptake of P in the control treatments of the Oxisols and Andisols was very low and in some cases even less than 50 percent of total seed P. Hydroponic experiments were conducted with labeled P to determine the seed P contribution and showed that the translocation of seed P to the shoot increased with increasing P supply.

Most literature studies have shown good correspondence between E and L values, except for some species known to mobilize P (e.g. white lupin). Therefore, to estimate the seed contribution, we assumed the E values that were previously determined (data not shown) equaled the L values:

$$\text{L value} = \frac{R}{\dfrac{33P_{shoot}}{P_{shoot} - P_{dfseed}}}$$

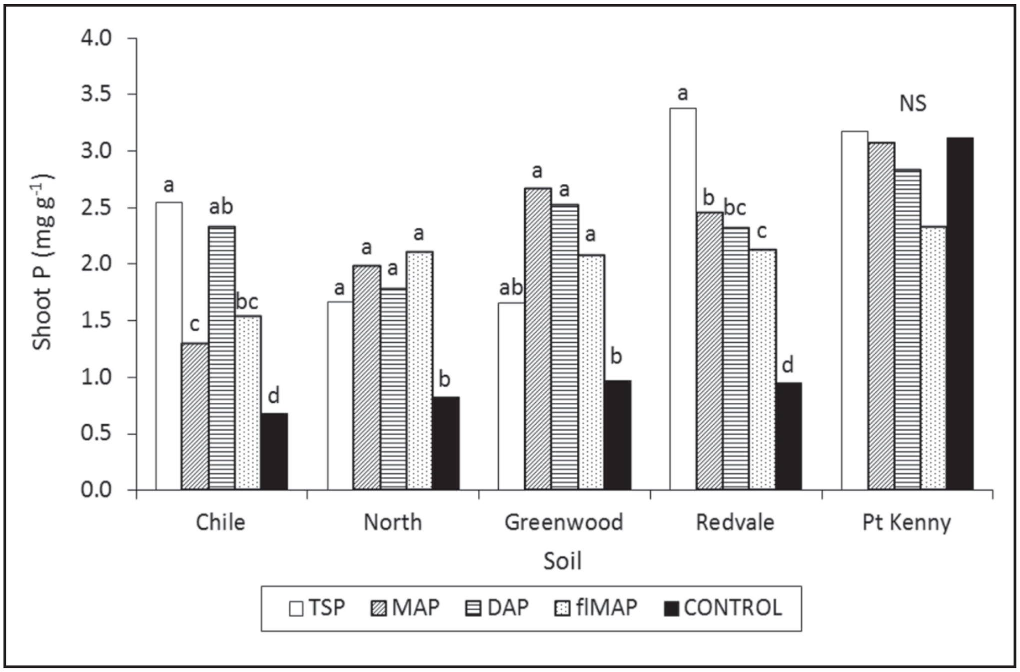


Fig. 2. Shoot P concentration (mg g^{-1}) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (flMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at $P \leq 0.05$.

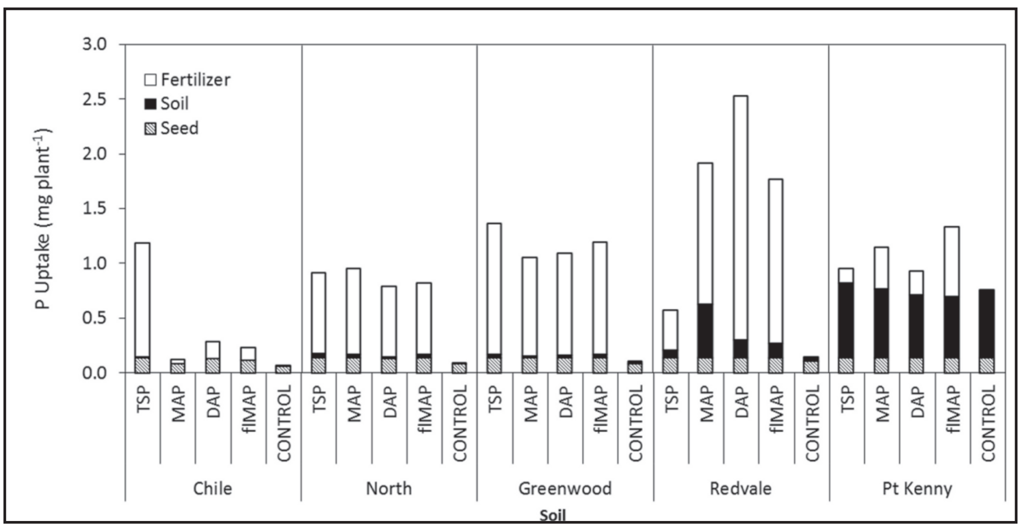


Fig. 3. Distribution of P in the plant shoots derived from fertilizer, soil, and seed. Granular fertilizers (TSP, MAP, and DAP), fluid fertilizer (flMAP), and control (nil P).

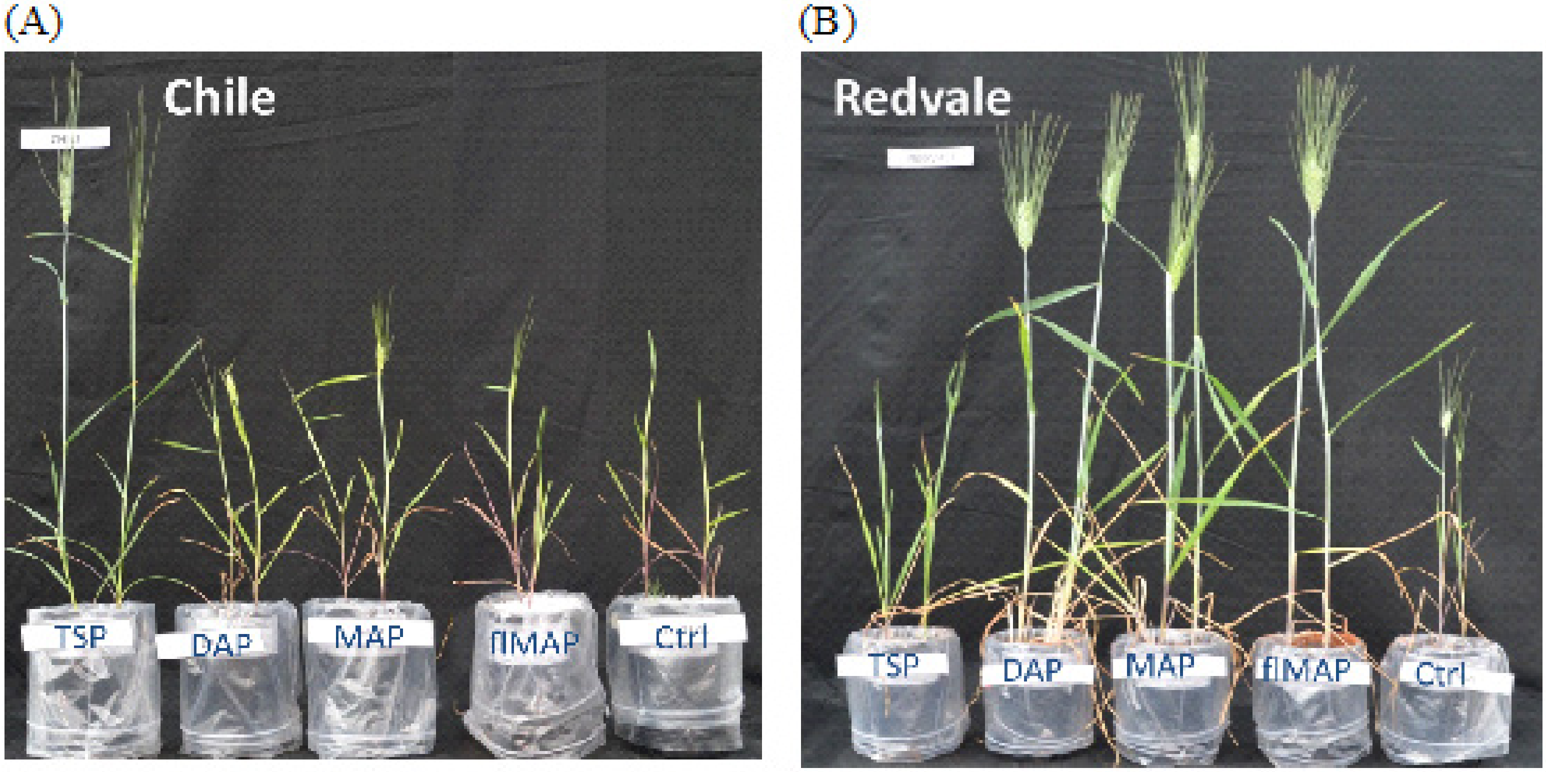
R (above) is the applied 33P dose. This allowed estimating the P seed contribution for all control treatment replicates. Translocation of seed P to shoot increased with increasing P uptake in the shoot and the relation could be well described with an exponential equation:

$$P_{dfseed} = A \times (1 - \exp(B \times P_{shoot}))$$

A and B are fitted parameters. This equation was used to estimate the seed P contribution in the fertilizer treatments. Note that the estimate of seed P contribution was less crucial for the fertilizer treatments, as the relative contribution of seed P to shoot P uptake was smaller.

The contribution of P from the fertilizer, soil, and seed to the total P uptake of the plants is shown in Figure 3. For the Andisols and Oxisols, the highest contribution to P uptake came from the fertilizers with an average value of 75 percent (average of all treatments). In

"Fluid P fertilizers were highly effective in calcareous soils."



Plant response to fertilizer sources: wheat plants grown for 6 weeks in Andisol, Chile (A) and Oxisol, Redvale (B).

these soils, the contribution of P from the soil was minimal due to the low P availability. For the calcareous soil, the contribution of P from the fertilizer ranged from 15 percent for TSP to 48 percent for flMAP. The greater TSP efficiency in the Chile soil may be due to an effect of Ca nutrition. In the Redvale soil the TSP appears to be the worst fertilizer option.

Summing up

This study demonstrates that in acidic and oxide-rich soils where the availability of P is restricted by strong adsorption reactions, fluid P fertilizer did not provide any additional advantage over granular sources to plant growth.

In contrast, the fluid P fertilizer was highly effective in the calcareous soil, in agreement with previous studies.

The chemical properties of the soils need to be considered prior to the selection of P fertilizers as they play a vital role in the fate of P in soils. The management of P nutrition in soils that strongly adsorb P is very challenging because a very high P rate is needed in order to obtain adequate yields, but care should be taken to minimize the negative impacts that over-fertilization can cause to the environment.

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