# The Response of Wheat Grown in Andisols and Oxisols to Granular and Fluid Phosphorus Fertilizers

Daniela Montalvo[1], Fien Degryse[1], and Mike J. McLaughlin[1,2]

[1] Soil Science, Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, SA 5064, Australia.

[2] CSIRO Land and Water, Sustainable Agriculture Flagship, Waite Precinct, PMB 2, Glen Osmond, SA 5064, Australia

## INTRODUCTION

Andisols and Oxisols are rich in P-sorbing minerals, such as Al/Fe oxihydroxides or allophane. Management of P nutrition in these soils is often very challenging. To overcome P deficiency and to increase the bioavailable P pool in soil, the application of fertilizer P is necessary. In these soils, a substantial quantity of fertilizer P is required to achieve economical acceptable yields; however, overfertilization 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 into an increase of the already high fertilizer prices (Obersteiner et al., 2013).

Phosphorus fertilizers are commonly applied in the form of granules, but the use of fluid P is also a viable alternative. 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 bioavailable P in calcareous soils fertilized with fluid P than with granular P fertilizers (Lombi et al., 2005). 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) (Montalvo et al., 2014). These results indicated that when adsorption – and 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. The present 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.

## MATERIALS AND METHODS

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

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

| Soil properties‡ | Chile | North | Greenwood | Redvale | Pt Kenny |
|---|---|---|---|---|---|
| Soil type | Andisol | Andisol | Oxisol | Oxisol | Calcic Inceptisol |
| Country of origin | Chile | New Zealand | Australia | Australia | Australia |
| $pH_{(1:5 \text{ in water})}$ | 5.30 | 5.72 | 5.87 | 6.40 | 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 | 42.0 | 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 |
| $Ca^{2+}$ (cmol$_c$ kg$^{-1}$) | 1.5 | 6.6 | 4.0 | 7.4 | 26.6 |
| $Mg^{2+}$ (cmol$_c$ kg$^{-1}$) | 0.3 | 1.0 | 2.7 | 2.5 | 9.5 |
| $K^+$ (cmol$_c$ kg$^{-1}$) | 0.6 | 0.48 | 0.42 | 0.37 | 1.6 |
| $C_{DGT}$ (µg L$^{-1}$) | 4 | 11 | 6 | 2 | 33 |

‡U.S. soil taxonomy classification; particle size analysis by pipette method (McKenzie et al., 2002); $CaCO_3$ content (Martin and Reeve, 1955); ammonium oxalate extractable Al ($Al_{ox}$) and Fe ($Fe_{ox}$) (Rayment and Higginson, 1992); total P determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) after soil sample digestion with *aqua regia* (Zarcinas et al., 1996); exchangeable $Ca^{+2}$, $Mg^{2+}$, and $K^+$ measured with ammonium acetate at pH 7.0 (Rayment and Higginson, 1992); $C_{DGT:}$ diffusive gradient in thin-film P concentration, critical value 60 µg L$^{-1}$ (Mason et al., 2010).
§b.d.l.: below detection limit

The P fertilizers evaluated were granular triple superphosphate (TSP, 20% P), mono-ammoniumphosphate (MAP, 22% P), di-ammoniumphosphate (DAP 20% P), and liquid technical grade ammoniumphosphate (TGMAP, 26% P). Fertilizer rates were 150 mg kg$^{-1}$ for Chile, North, Greenwood, and Redvale soils; and 40 mg kg$^{-1}$ for Pt 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.

A total of 260 cm$^3$ of air-dried 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 uniformily labelled with 500 kBq kg$^{-1}$ of carrier-free $^{33}$P and watered to field capacity. Three days after soil labelling and basal nutrient application, the P fertilizer treatments (granular and liquid) 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 aproximate depth of 1 cm. The seedlings were thinned to 2 plants per pot five days after planting. The pots were watered daily. Six weeks after planting the plants were harvested; shoots were cut

about 1 cm above the soil surface, oven-dried at 70°C for 48 h and the dry weight recorded. The dried plant material was ground and digested in hot $HNO_3$ prior to elemental analysis by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The $^{33}P$ activity in the digests was measured by liquid scintillation counting.

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 fertilizers (Pdff % ) Eq. 1:

$$\%Pdff = 100 \times [1 - \left(\frac{^{33}Pshoot_f}{SA_{Pdfsoil} \times Pshoot_f}\right) - \%Pdfseed_f] \qquad \text{Eq. 1}$$

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 $plant^{-1}$), $\%Pdfseed_f$ 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 the 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 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 equals E values, as disscussed in the Results and Discussion section.

Statistical analysis:

The analysis of variance (ANOVA) by soil was performed using GenStat statistical package 15th ed. Treatment differences were analysed with Fisher protected least significant difference (LSD, $P \leq 0.05$).

# RESULTS AND DISCUSSION

## Dry matter yield and shoot P concentration

In the Andisols (Chile and North) and Oxisols (Greenwood and Redvale) there was no significant difference in dry matter growth between the granular (MAP) and corresponding fluid (TGMAP) fertilizer (Fig. 1). In contrast to the acidic soils, TGMAP produced 31% more plant dry matter than its granular counterpart in the calcareous soil (Pt 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 the 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. In this case, the higher dilution with fluid P is beneficial because likely results in less oversaturation and therefore less precipitation of these minerals.

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 the exchangeable Ca was of 1.5 $cmol_c$ $kg^{-1}$, a value that is very close to the miminum level of 1 $cmol_c$ $kg^{-1}$ recommended by Kamprath (1984) for adequate plant growth. We deliberately decided not to apply Ca in the basal nutrition to avoid opportunities of Ca-P precipitation that could interfere with the results of our experiment. In the Redvale soil, TSP performed much worse than the other fertilizers. In our previous study we found that significantly less P remained labile when calcium phosphate fertilizers were applied in the Redvale soil (Montalvo et al., 2014). We hypothesized the lower P availability may be due to Ca-P precipitation at the relatively high pH of this soil.
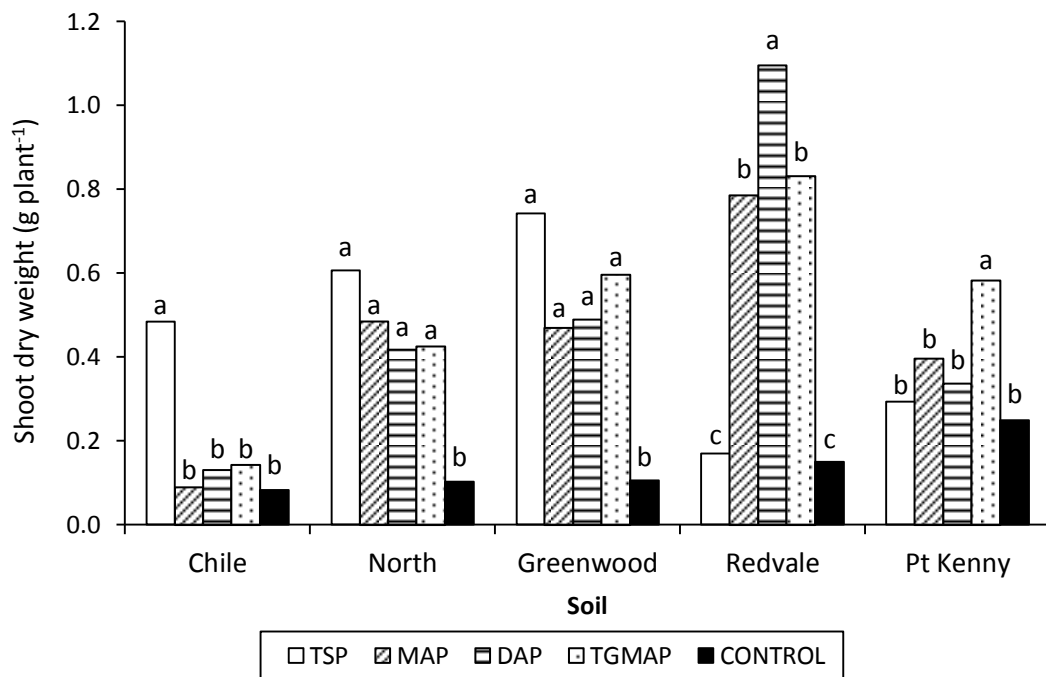


Fig. 1. Shoot dry matter yield (g plant[-1]) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (TGMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at P ≤ 0.05.


In the Andisols and Oxisols the addition of P fertilizer significantly increased the tissue P concentration (with respect to the control) (Fig. 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 2 to 3 mg $g^{-1}$ (Reuter and Robinson, 1997). In the calcareous Pt Kenny soil, P concentration did not statisticaly differ between the control and the fertilizer treatments.
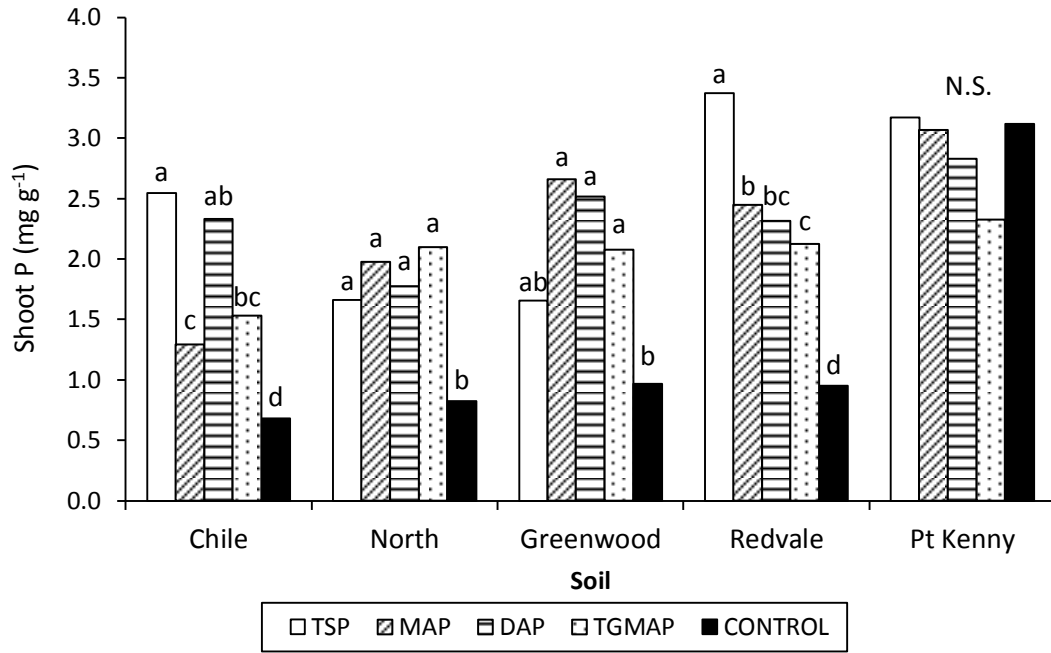
Fig. 2. Shoot P concentration (mg g$^{-1}$) for wheat grown in soils with granular (TSP, MAP, DAP) or fluid (TGMAP) fertilizer. A control treatment (nil P) was included for each soil. Bars appended with different letters are statistically different at P ≤ 0.05.

Fertilizer, soil, and seed P contributions to the total P uptake

The seed P contribution needs to be taken into account to distinguish between uptake from soil or fertilizer-applied P. Several studies have used the assumption of 50% of total seed P translocation to the shoots (Bertrand et al., 2006; Mason et al., 2013; McBeath et al., 2012). 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% of total seed P. Pypers et al. (2006) conducted hydroponic experiments with labeled phosphorus to determine seed P contribution, and showed that the translocation of seed P to the shoot increased with incrasing 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 estime the seed contribution, we assumed that the E values that were previously determined (data not shown) equalled the L values:

$$\text{L value} = R/(\frac{^{33}P_{shoot}}{P_{shoot} - P_{dfseed}}) \qquad \text{Eq. 3}$$

with R the applied $^{33}$P dose. This allowed estimating the P seed contribution for all control treatment replicates. The 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 as proposed by Pypers et al. (2006).

$$P_{dfseed} = A \times (1 - \exp(B \times P_{shoot})) \qquad \text{Eq. 4}$$

with A and B 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 Fig. 3. For the Andisols and Oxisols, the highest contribution to P uptake came from the fertilizers with an average value of 75% (average of all treatments). In 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% for TSP to 48% for TGMAP. The greater TSP efficiency in the Chile soil may be due to and effect of Ca nutrition. In the Redvale soil the TSP appears to be the worst fertilizer option.
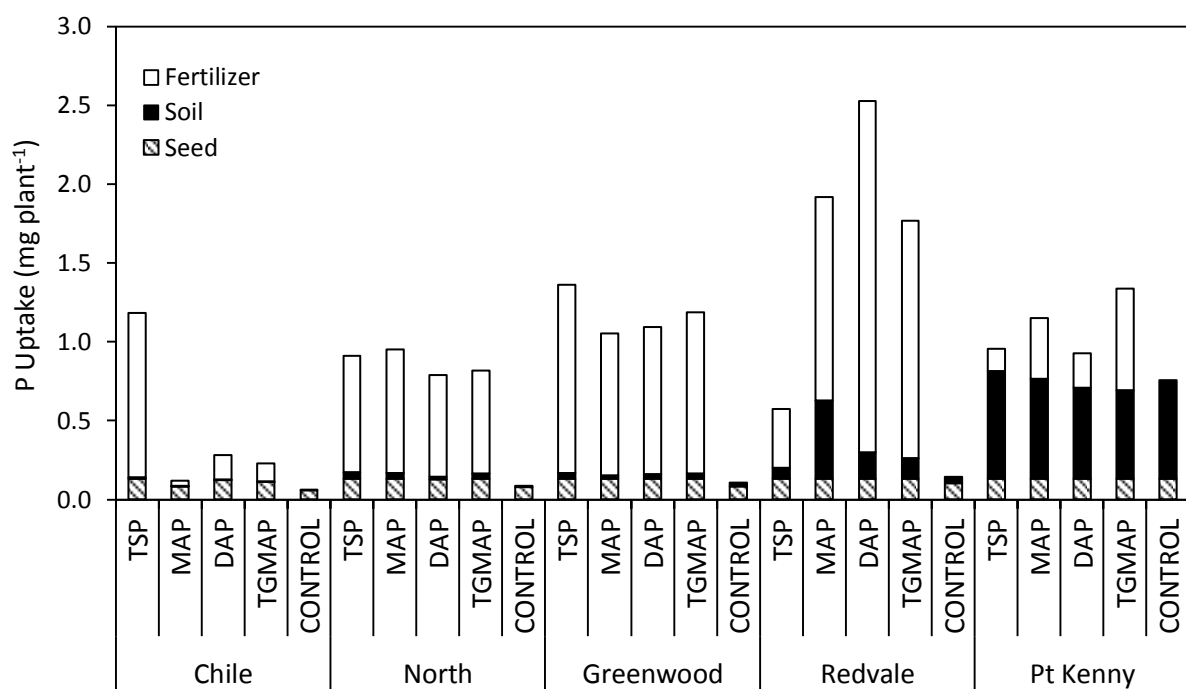


Fig. 3. Distribution of P in the plant shoots derived from fertilizer, soil, and seed. Granular fertilizers (TSP, MAP, and DAP), fluid fertilizer (TGMAP), and control (nil P).

**CONCLUSIONS**

This study demonstrates that in acidic and oxide-rich soils where the availability of P is restricted by strong adsorption reactions, fluid P fertilizers did not provide any additional advantage over the 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 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 overfertilization can cause to the environment.

## ACKNOWLEDGMENTS

## REFERENCES

Bertrand, I., M.J. McLaughlin, R.E. Holloway, R.D. Armstrong, and T. McBeath. 2006. Changes in P availability induced by the application of liquid and powder sources of P, N, and Zn fertilizers in alkaline soils. Nutr. Cycl. Agroecosyst. 74:27-40.

Kamprath, E.J. 1984. Crop response to lime on soils in the tropics. In: F. Adams, editor. Soil acidity and liming. American Society of Agronomy Madison. p. 349-368.

Lombi, E., M.J. McLaughlin, C. Johnston, R.D. Armstrong, and R.E. Holloway. 2005. Mobility, solubility and lability of fluid and granular forms of P fertiliser in calcareous and non-calcareous soils under laboratory conditions. Plant Soil. 269:25-34.

Martin, A.E., and R. Reeve. 1955. A rapid manometric method for determining soil carbonate. Soil Sci. 79:187-198.

Mason, S., A. McNeill, M.J. McLaughlin, and H. Zhang. 2010. Prediction of wheat response to an application of phosphorus under field conditions using diffusive gradients in thin-films (DGT) and extraction methods. Plant Soil. 337:243-258.

Mason, S., M. McLaughlin, C. Johnston, and A. McNeill. 2013. Soil test measures of available P (Colwell, resin and DGT) compared with plant P uptake using isotope dilution. Plant Soil. 373:711-722.

McBeath, T.M., M.J. McLaughlin, J.K. Kirby, and R.D. Armstrong. 2012. Dry soil reduces fertilizer phosphorus and zinc diffusion but not bioavailability. Soil Sci. Soc. Am. J. 76:1301-1310.

McKenzie, N.J., K.J. Coughlan, and H.P. Cresswell. 2002. Soil physical measurements and interpretation for land evaluation. CSIRO Publishing, Collingwood, Vic.

Montalvo, D., F. Degryse, and M.J. McLaughlin. 2014. Fluid Fertilizers Improve Phosphorus Diffusion but not Lability in Andisols and Oxisols. Soil Sci. Soc. Am. J. 78:214-224.

Obersteiner, M., J. Penuelas, P. Ciais, M. van der Velde, and I.A. Janssens. 2013. The phosphorus trilemma. Nature Geosci. 6:897-898.

Pypers, P., L. Loon, J. Diels, R. Abaidoo, E. Smolders, and R. Merckx. 2006. Plant-available P for maize and cowpea in P-deficient soils from the Nigerian Northern Guinea Savanna – Comparison of E- and L-values. Plant Soil. 283:251-264.

Rayment, G.E., and F.R. Higginson. 1992. Australian laboratory handbook of soil and water chemical methods Inkata Press, Melbourne, Vic.

Reuter, D.J., and J.B. Robinson. 1997. Plant analysis: an interpretation manual. 2nd ed. CSIRO Publishing, Collingwood, VIC.

Zarcinas, B.A., M.J. McLaughlin, and M.K. Smart. 1996. The effect of acid digestion technique on the performance of nebulization systems used in inductively coupled plasma spectrometry. Commun. Soil Sci. Plant Anal. 27:1331-1354.