Agronomic Use of Phosphate Rock for Direct Application

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Phosphorus is critically needed to improve soil fertility and crop production in many areas of the world. Direct application of phosphate rock (PR) has been shown to be a valuable source of nutrients in some conditions. This article reviews the relative agronomic effectiveness of PR with respect to water-soluble phosphate fertilizer.

In many acid soils in the world, especially in the tropics, soil fertility limitations constrain successful crop production. These soils usually are low in plant-available P and often have a high P-fixing capacity that results in low efficiency of water-soluble P (WSP) fertilizers such as triple superphosphate (TSP) or diammonium phosphate (DAP) by crops. Application of unprocessed PR to soil can be an attractive alternative to WSP fertilizers in such cases.

Source of Phosphate Rock

The best predictor of the agronomic performance of PR is solubility, which is normally measured in the laboratory with neutral ammonium citrate (NAC), 2% citric acid (CA), or 2% formic acid. The solubility of PR reflects the chemical and mineralogical characteristics of the specific P minerals. The principal mineral in most PR sources is apatite, but it varies widely in physical, chemical, and crystallographic properties.

The chemical formula of apatite in some representative PR is shown in **Table 1**. In general, the NAC solubility increases as CO_3^{2-} substitution for PO_4^{3-} in the apatite structure increases. The solubility of PR is known to correlate well with crop response. **Figure 1** shows that crop response to finely ground PR depends on the source and the solubility.

The solubility of PR generally increases with smaller particle size. However, the agronomic effectiveness of ground and unground highly reactive PR sources does not strictly follow the solubility pattern. For example, the solubility of unground reactive PR (-35 mesh; 0.5 mm) is less than that of the same but ground PR (-100 mesh; 0.15 mm), but their agronomic effectiveness is similar under field conditions (Chien and Friesen, 1992) and greenhouse conditions. (See photos on next page). It is not sufficient to compare the solubility and the agronomic effectiveness of various PR sources based only on particle-size distribution. A solubility database of many PR sources around the world has been compiled by Smalberger et al. (2006).

Table 1. The solubility and empirical formula of apatites in some sedimentary phosphate rocks.

PR source	NAC[1], % P_2O_5 of rock	Empirical formula
North Carolina, USA	9.7	$Ca_{9.53}Na_{0.34}Mg_{0.13}(PO_4)_{4.77}(CO_3)_{1.23}F_{2.49}$
Gafsa, Tunisia	8.7	$Ca_{9.54}Na_{0.32}Mg_{0.12}(PO_4)_{4.84}(CO_3)_{1.16}F_{2.46}$
Bahia Inglesa, Chile	6.9	$Ca_{9.59}Na_{0.30}Mg_{0.12}(PO_4)_{4.90}(CO_3)_{1.10}F_{2.44}$
Central Florida, USA	5.3	$Ca_{9.74}Na_{0.19}Mg_{0.07}(PO_4)_{5.26}(CO_3)_{0.74}F_{2.30}$
Tennessee, USA	3.7	$Ca_{9.85}Na_{0.11}Mg_{0.04}(PO_4)_{5.54}(CO_3)_{0.46}F_{2.18}$
Patos de Minas, Brazil	2.5	$Ca_{9.96}Na_{0.03}Mg_{0.01}(PO_4)_{5.88}(CO_3)_{0.12}F_{2.05}$

[1]Neutral ammonium citrate (NAC)

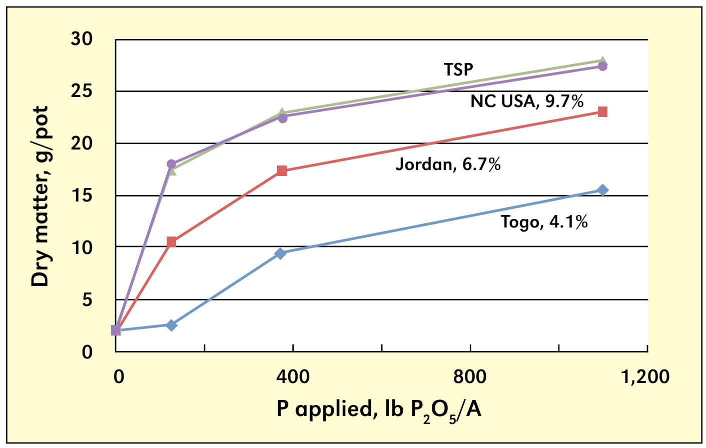


Figure 1. Dry-matter yield of maize fertilized with ground phosphate rock varying in neutral ammonium citrate solubility, compared with a soluble P source (TSP) in an acid soil (pH 4.8) (Chien and Friesen, 1992). The citrate solubility of each PR source is shown as percent P_2O_5.

Soil Properties

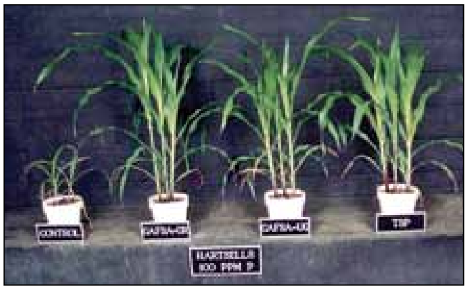
pH Among the soil properties, pH has the greatest influence on the agronomic effectiveness of PR. Chien (2003) reported that the relative agronomic effectiveness (RAE) of a highly reactive Gafsa PR (Tunisia) compared to TSP (RAE = 100%) increases as soil pH dropped in 15 soils with widely varying properties. However, soil pH alone was able to explain only 56% of variability of RAE in this study (Equation 1). By also considering the clay content (related to soil pH buffering capacity and cation ion exchange capacity), it is possible to explain 74% of variability of RAE (Equation 2). Since pH is a logarithmic scale of acidity, the agronomic effectiveness of PR sharply decreases as soil pH increases above 5.5. Therefore, the agronomic value of PR diminishes above this pH unless with an effective crop species.

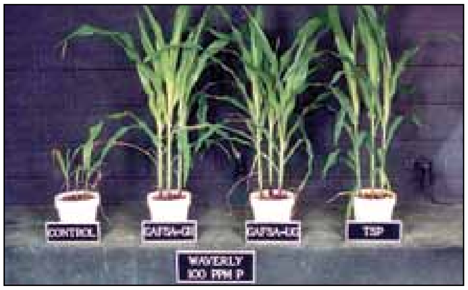
Equation 1: $RAE, \% = 181.4 - 21.1\,pH \quad (R^2 = 0.56)$

Equation 2: $RAE, \% = 163.4 - 20.6\,pH + 0.78\,clay \quad (R^2 = 0.74)$

Soil P-fixing capacity The release of P from PR generally increases with a greater P-fixing capacity of the soil. Adsorption and precipitation of soluble P provide a sink that favors PR dissolution. However, as the soil P-fixing capacity increases, the concentration of soluble P released from PR may initially decrease more rapidly than that from WSP sources, despite the fact that the dissolution of PR increases with an increase of soil P-fixing capacity. The negative effect of soil P-

Abbreviations: P = phosphorus; Al = aluminum; Ca = calcium.





These photos compare the effect of ground (GR) and unground (UG) PR on corn growth in two soils (Hartsells, pH = 4.8; Waverly, pH = 5.3). The Gafsa (Tunisia) PR is compared with TSP and an unfertilized control in the greenhouse.

fixing capacity on RAE of PR may be most significant for short-term crops, such as some vegetables. For long-term crops or residual short-term crops, RAE of PR compared to WSP tends to increase with increasing soil P-fixing capacity. **Figure 2** shows that the RAE of multiple PR sources varying in reactivity increases from the first bean crop to the third crop grown on soil with a high P-fixing capacity (Chien, 2003). This is due to (1) the residual effect of TSP decreases rapidly in soils with high P-fixing capacity, and (2) slow dissolution of PR in the soil with time.

Presence of Ca and organic matter Since dissolution of PR also releases Ca, soils with high initial Ca content typically have slower PR dissolution, according to the mass action law. For many tropical acid soils, exchangeable Ca is low and thus provides favorable conditions for PR dissolution. The positive influence of soil organic matter on increasing the agronomic effectiveness of PR has also been reported (Chien, 2003). Enhanced dissolution of PR due to formation of a chemical complex between soil organic matter and Ca^{2+} ions is proposed to be the mechanism.

Management Practices

The most effective way to apply PR is to broadcast it onto the soil, followed by incorporation with tillage. This technique maximizes the reaction of PR with the soil and minimizes interaction between PR particles. Band application of PR is not recommended because it limits the contact of PR particles with the soil, resulting in reduced dissolution. The effectiveness of PR is also reduced by granulation of fine particles (Chien, 2003).

Management of PR application for flooded rice requires special attention because soil pH generally increases upon flooding. The agronomic effectiveness of reactive PR can be drastically reduced when it is applied at or after flooding, whereas the PR can perform well when applied to the soil at least 2 weeks before flooding (Chien, 2003).

Adding limestone to acid soils is a common practice to raise soil pH and decrease Al toxicity. However, the increased pH and additional Ca from the lime are both detrimental to PR dissolution. Therefore, liming practices should balance the need to alleviate the Al toxicity with reducing PR dissolution (Chien and Friesen, 1992). It is recommended that liming to increase soil pH be limited to a range of pH 5.2 to 5.5 in order

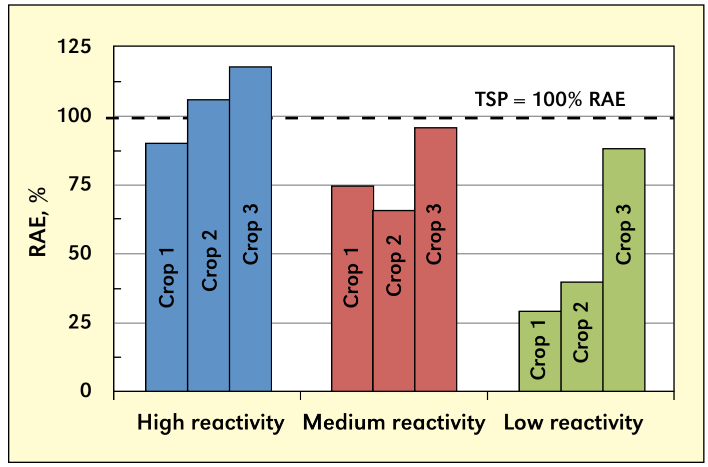


Figure 2. Relative agronomic effectiveness (RAE) of multiple PR sources (varying in solubility) on the seed yield of three successive bean crops grown on an Andosol in Colombia (Chien, 2003). RAE is calculated by comparison with TSP. All PR sources were applied one time at a rate of 410 lb P_2O_5/A.

to optimize the agronomic effectiveness of PR.

Crop Species

The usefulness of PR as a nutrient source varies with the crop species. In general, the effectiveness of PR is higher for long-term or perennial crops than for short-term or annual crops. PR has been used extensively for many tree crops in Asia, including rubber, oil palm, and tea. Use of PR for perennial pastures has been successful too.

Acidification in the plant rhizosphere accounts for some of the differences among crop species to utilize PR. In a study using six plant species, Van Ray and Van Diest (1979) found that Gafsa PR (Tunisia) was equivalent to TSP for buckwheat, which produced much lower rhizosphere pH than did other plant species.

Among the crop species, rape (canola) is known to be efficient in utilizing PR. Root exudation of organic acids is thought to contribute to PR dissolution. Habib et al. (1999) reported that rape was able to utilize a medium-reactive Ain Layloun PR (Syria), even in calcareous soils. Subsequently, Chien et al. (2003) found that the RAE of nine PR sources for rape grown on an alkaline soil (pH 7.8) increased from 0% to 88% as the 2% citric acid (CA) solubility of PR increased from 2.1% to 13.1% P_2O_5 **(Table 2)**.

Use of Phosphate Rock for Organic Farming

PR is sometimes used for direct soil application in organic farming systems. The success of PR for organic crop nutrition largely depends on its reactivity in the soil. The total P_2O_5 content provided on the package label is irrelevant to PR reactivity in the soil. In fact, most igneous PR sources are high in P_2O_5 content (>34%), but very low in reactivity due to little CO_3/PO_4 substitution in apatite mineral structure, and therefore not suitable for direct application in organic farming (Chien et al., 2009). However, details regarding the reactivity of PR are rarely provided for organic growers.

Factors affecting the effectiveness of PR for organic farming should be considered more or less the same way as for conventional farming. One exception is when PR is added

Table 2. Characteristics of different P sources and their relative agronomic effectiveness (RAE) for rape grown on an alkaline soil (pH 7.8) to maturity (Chien et al., 2003).

P source	Total P_2O_5 [1]	Solubility in 2% citric acid, %	Reactivity class[2]	RAE, %
TSP	46.2	100	-	100
Gafsa PR (Tunisia)	30.1	13.1	High	88
Ain Layloun PR (Syria)	28.1	12.2	Medium high	82
Chelesai (Kazakhastan)	17.0	10.0	Medium	74
Tilemsi PR (Mali)	26.2	10.3	Medium	72
El-Hassa (Jordan)	31.3	9.0	Medium	64
Kenegesepp (Russia)	29.9	7.8	Medium low	64
Kadjari (Burkina Faso)	25.3	6.0	Low	60
Kaiyang (China)	32.4	5.1	Low	42
Panda Hills (Tanzania)	24.8	2.1	Very low	0
Check	-	-	-	0

[1]As percent P_2O_5 of rock.
[2]Based on CO_3/PO_4 substitution in apatite structure.

during composting, where conditions may result in an alkaline rather than acidic environments (Chien et al., 2009) and the chelation of organic matter with Ca ions derived from apatite may be important to dissolve PR.

Phosphate Rock Decision Support System (PRDSS)

Many global agronomic trials with PR have been integrated into a single tool to predict its agronomic effectiveness in specific situations. IFDC (An International Center for Soil Fertility and Agricultural Development), in collaboration with FAO/IAEA (Food and Agriculture Organization/International Atomic Energy Agency), developed and published a PRDSS model for PR sources (Smalberger et al., 2006; >http://www-iswam.iaea.org/dapr/srv/en/dapr/home<). The PRDSS can be used in making decisions between use of WSP fertilizers and PR to meet crop nutrition needs. The PRDSS also provides assistance to determine conditions where the use of PR is more economical than WSP as a source of plant nutrients.

Conclusions

The agronomic and economic effectiveness of PR can be equivalent to or better than WSP fertilizers in some circumstances. Unlike WSP fertilizers, which can be widely used, there are specific factors – including the reactivity of PR sources, soil properties, management practices, and crop species – that must be taken into account in order to maximize the utilization of PR. Use of the PRDSS model is an effective means to predict the best use of this nutrient resource. BC

Response of soybeans to P source in Brazil.

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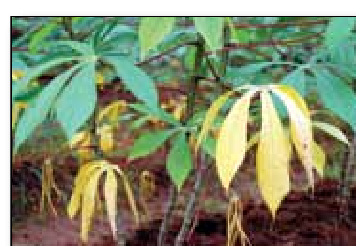
Crop Nutrient Deficiency Photo Contest Entries Due by December 15

December 15, 2010, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. There are four categories: Nitrogen (N), phosphorus (P), potassium (K), and Other (secondary nutrients and micronutrients).



Preference is given to original photos with supporting/verification data. Cash prizes are offered to First Place (USD 150) and Second Place (USD 75) in each of the four categories, plus a Grand Prize of USD 200 will be provided to best overall photo.

Entries can only be submitted electronically. For details and instructions, visit this website: >www.ipni.net/photocontest<.