Agronomic Use of Phosphate Rock for Direct Application

By S.H. (Norman) Chien, Luis I. Prochnow, and Robert Mikkelsen

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 CO3$^{2-}$ substitution for PO4$^{3-}$ 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).

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

Equation 2: RAE, % = 163.4 – 20.6 pH + 0.78 clay

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-

See Table 1 and Figure 1 for more details.

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

<table>
<thead>
<tr>
<th>PR source</th>
<th>NAC1, % P2O5 of rock</th>
<th>Empirical formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Carolina, USA</td>
<td>9.7</td>
<td>Ca_{9.51}Na_{0.32}Mg_{0.01}(PO_{4.77})(CO_{3.12})F_{2.49}</td>
</tr>
<tr>
<td>Gafsa, Tunisia</td>
<td>8.7</td>
<td>Ca_{9.45}Na_{0.33}Mg_{0.02}(PO_{4.46})(CO_{3.16})F_{2.46}</td>
</tr>
<tr>
<td>Bahia Inglesa, Chile</td>
<td>6.9</td>
<td>Ca_{9.59}Na_{0.30}Mg_{0.16}(PO_{4.99})(CO_{3.10})F</td>
</tr>
<tr>
<td>Central Florida, USA</td>
<td>5.3</td>
<td>Ca_{9.56}Na_{0.19}Mg_{0.07}(PO_{4.79})(CO_{3.01})F_{2.43}</td>
</tr>
<tr>
<td>Tennessee, USA</td>
<td>3.7</td>
<td>Ca_{9.85}Na_{0.11}Mg_{0.08}(PO_{4.54})(CO_{3.44})F_{1.81}</td>
</tr>
<tr>
<td>Patos de Minas, Brazil</td>
<td>2.5</td>
<td>Ca_{9.95}Na_{0.03}Mg_{0.02}(PO_{4.89})(CO_{3.15})F_{2.05}</td>
</tr>
</tbody>
</table>

1Neutral ammonium citrate (NAC)

Abbreviations: P = phosphorus; Al = aluminum; Ca = calcium.
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 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 38% as the 2% citric acid (CA) solubility of PR increased from 2.1% to 13.1% P\(_{2}\)O\(_5\) (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\(_{2}\)O\(_5\) content provided on the package label is irrelevant to PR reactivity in the soil. In fact, mostigneous PR sources are high in P\(_{2}\)O\(_5\) content (>34%), but very low in reactivity due to little CO\(_2\)/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...
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.

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**References**


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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<.