The Nature of Phosphorus in Calcareous Soils

By A.B. Leytem and R.L. Mikkelsen

Calcareous soils (containing free lime) are common in many arid and semi-arid regions of North America and occur as inclusions in more humid regions. Phosphorus (P) is very reactive with lime. Following fertilizer application, P undergoes a series of reactions that gradually reduce its solubility. In most calcareous soils, there does not appear to be a strong agronomic advantage of any particular P source when managed properly. Organic matter can inhibit P fixation reactions to some extent. Some fertilizer recommendations call for additional P to be added when the soil contains high amounts of free lime.

Calcareous soils are common in arid and semi-arid climates and occur as inclusions in more humid regions, affecting over 1.5 billion acres of soil worldwide and comprising more than 17% of the soils in the U.S. Calcareous soils are identified by the presence of the mineral calcium carbonate ($CaCO_3$ or lime) in the parent material and an accumulation of lime. This is most easily recognized by the effervescence (fizzing) that occurs when these soils are treated with dilute acid. The pH of these soils is usually above 7 and may be as high as 8.5. When these soils contain sodium carbonate, the pH may exceed 9. In some soils, $CaCO_3$ can concentrate into very hard layers, termed caliche, that are impermeable to water and plant roots.

Calcareous soils can be extremely productive for agricultural use when they are managed properly. Since they are most frequently found in semi-arid and arid regions, supplemental irrigation water is often the first barrier for crop production. Limited availability of P is often the next most limiting factor for plant growth.

When P fertilizer is added to calcareous soils, a series of fixation reactions occur that gradually decrease its solubility and eventually its availability to plants. Phosphorus "fixation" is a combination of surface adsorption on both clay and lime surfaces, and precipitation of various calcium phosphate minerals. While the total lime content of a soil is important for predicting P reactions, the lime particle size (and its effect on reactive surface area) is often a better predictor of P behavior. Although a calcareous soil may be dominated by free lime, it may also contain significant amounts of iron (Fe), aluminum (Al), and manganese (Mn)...either as discrete minerals, as coatings on soil particles, or complexed with soil organic matter. These metals provide strong sorption sites for P and are frequently more significant in controlling P solubility in calcareous soils than lime itself. Their importance should not be ignored.

Effervescence (fizzing) occurs when calcareous soils are treated with dilute acid. Regular soil testing is important to monitor availability of P in calcareous soils.

As fertilizer P reacts in calcareous soils, it is converted to less soluble compounds such as dicalcium phosphate dihydrate or

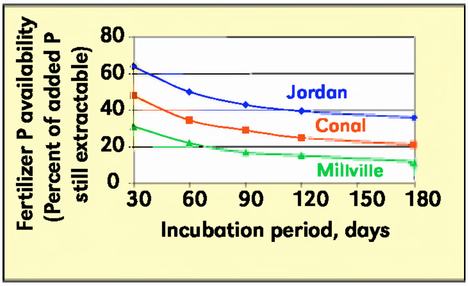

Figure 1. Fertilizer P undergoes a reduction in solubility following addition to three calcareous soils (Sharpley et al., 1989).

octacalcium phosphate. In some cases it may eventually convert to hydroxyapatite. A variety of management practices can be used to slow these natural fixation processes and increase the efficiency of applied fertilizer for crop growth. A number of the factors controlling P availability will be briefly covered.

Time—Insoluble rock P is treated after mining from geologic deposits to enhance its solubility and usefulness for plants. Fertilizer P is most soluble immediately after addition to soil, then it undergoes many chemical reactions that result in gradually diminished solubility (**Figure 1**).

Residual fertilizer P continues to be available for plant uptake for many years, but freshly applied P is generally most soluble and available for plant uptake. The common practice of building soil P concentrations to appropriate agronomic ranges provides a long-term source of this nutrient to crops.

Phosphorus Fertilizer Source—Many studies have demonstrated that there are no consistent agronomic differences in most commercially available P fertilizers added to calcareous soils. The selection of a specific P source should be based on other factors such as application equipment, suitability of fluids or granules, and price.

However, considerable work is currently underway to improve P availability with new P products and fertilizer additives. This topic will be explored in greater detail in future articles. For example, recent work from Australia in extremely calcareous soils has suggested that fluid P sources may have somewhat greater solubility and enhanced plant availability than granular fertilizers. It has been hypothesized that granule dissolution may be suppressed in these soil conditions. Additional work is underway in the U.S. to see if these results hold for soil conditions more typical of North America.

There is large variability in the solubility and availability of P from various materials added to calcareous soil (**Figure 2**). These large differences are largely due to the unique properties of the materials, rather than any unique character associated with a specific soil. For example, the polymer-coated, slow release P source has very low apparent solubility, but is able to support high levels of plant P accumulation. The soluble P sources and liquid manures have very high solubility and also are able to maintain high P recovery by barley.

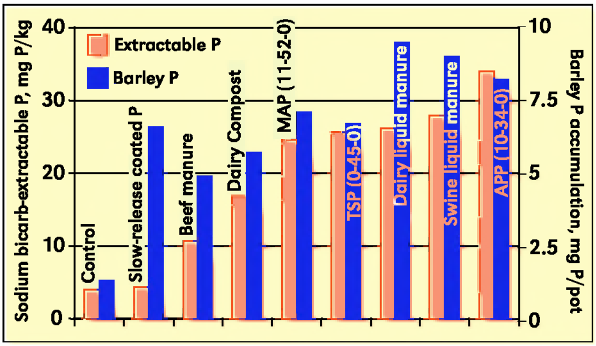

Figure 2. Extractability and P uptake by barley from various sources following incubation in a 12% lime soil. Sources initially added at a rate of 60 mg P/kg; extractions are average of 2- and 6-weeks sampling dates. (Leytem and Westerman, 2005).

Organic Matter—In the soil solution, there are several chemical components that will delay or prevent the reaction of P with lime. Organic matter has been found to interfere in the fixation reactions of P with lime. This inhibition of P

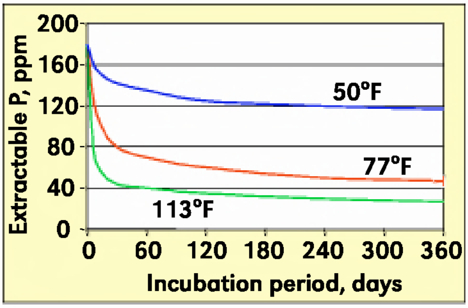

Figure 3. The effect of soil temperature on fertilizer P extractability in a calcareous soil (Javid and Rowell, 2003).

fixation may account for the observation that P availability is frequently greater in manured soils and with the addition of humic substances in lime-rich soil. Higher levels of soluble Fe, Al, and Mn are also related to increased P fixation in calcareous soils.

Temperature—Soil temperature has two opposing effects on soil P availability. When fertilizer P is added to soil, it continually reacts and forms increasingly stable compounds for many months after application. The kinetics of the conversion of P to less soluble forms is more rapid under warmer conditions than in cooler soil (**Figure 3**).

An opposite effect occurs as increased soil temperature raises the solubility of soil P forms (both adsorbed or precipitated P). This well-known phenomenon accounts for frequent crop responses from added P in cool soils in the spring. In addition to improved solubility, higher soil temperature increases P diffusion to plant roots and enhances overall root activity and proliferation. When planting early in the season, or in high-residue conditions, cold soil temperatures can induce an early-stage P deficiency in many types of soil. A starter P fertilizer application may help overcome these limitations.

Adjusting for Calcareous Soils—Since the presence of lime in soils can reduce P availability to crops, fertilizer recommendations are frequently adjusted to account for this condition. For example, the University of Idaho recommendations for potato fertilization state that an additional 10 lb P_2O_5/A needs to be applied for every 1% increase in soil lime (**Figure 4**).

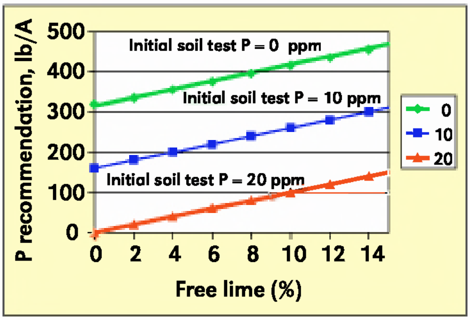

Figure 4. University of Idaho P fertilizer recommendations for potatoes grown in calcareous soil take into account the free lime content of the soil (Tindall and Stark, 1997).

Calcareous soils can be extremely productive when managed properly. Maintaining an adequate supply of plant-available P is essential to profitable and sustainable crop production. Since a variety of soil reactions tend to decrease the plant-availability of added fertilizer P in calcareous soil, regular soil testing should be conducted to avoid crop loss due to plant nutrient deficiency.

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Figure References

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