PHOSPHORUS AVAILABILITY WITH ALKALINE/CALCAREOUS SOIL

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ABSTRACT

Phosphorus (P) is an essential nutrient required by plants for normal growth and development. The availability of P to plants for uptake and utilization is impaired in alkaline and calcareous soil due to the formation of poorly soluble calcium phosphate minerals. Adding fertilizer P at "normal" rates and with conventional methods may not result in optimal yield and crop quality in these soils common in arid and semi-arid regions. Several fertilizer P management strategies have been found to improve P nutrition for plants grown in alkaline and calcareous soil. Research results show that relatively high P fertilizer rates are required for crops grown in alkaline soil, with increasing rates needed as lime content in these soils increases. Concentrated P fertilizer bands improve P solubility with resulting yield increases, even when applied to crops grown in soil with relatively high soil test P concentrations. Applying organically complexed P in the form of biosolids or as a mixture of liquid P and humic substances can also enhance P nutrition and result in yield increases. Application of slow release and cation complexing specialty fertilizer P materials has also been shown to effectively increase yields in calcareous soil. In-season applied P through the irrigation water can deliver P to plant roots when deficiencies are observed, but the effectiveness and results are less than with P incorporated into the soil. Finally, it is important to maintain a proper balance of P with other nutrients for general plant health and to avoid excess nutrient induced deficiencies of other nutrients. In some cases, these methods are relatively new and need further refinement with regard to rates, timing, and technique; but all are potential methods for improving P supply to plants grown in alkaline and calcareous soil.

PHOSPHORUS NUTRITION

Phosphorus (P) is an essential macronutrient, being required by plants in relatively large quantities (~0.2 to 0.8%) (Mengel and Kirkby, 1987; Mills and Jones, 1996). Potassium and nitrogen are the only mineral nutrients required in larger quantities than P. Providing adequate P to plants can be difficult, especially in alkaline and calcareous soil.

Alkaline soil is defined as soil with pH greater than neutral, typically 7.5 to 8.5. Calcareous soil is defined as having the presence of significant quantities of free excess lime (calcium or magnesium carbonate). Lime dissolves in neutral to acid pH soil, but does not readily dissolve in alkaline soil and, instead, serves as a sink for surface adsorbed calcium phosphate precipitation.

The bioavailability of P is strongly tied to soil pH. The formation of iron and aluminum phosphate minerals results in the reduced solubility of P in strongly acidic soil, improving as pH approaches nearly neutral. This maximum solubility and plant availability of P at pH 6.5 declines again as the pH increases into the alkaline range. This effect of reduced P availability in alkaline soil is driven by the reaction of P with calcium, with the lowest solubility of these calcium phosphate minerals at about pH 8. The presence of lime in alkaline soil further exacerbates the P availability problem. The lime in calcareous soil reacts with soil solution P to form a strong calcium phosphate bond at the surface of the lime. These alkaline and calcareous soils are common in arid and semi-arid regions with little rainfall. Soil in regions with a long history of excess rainfall tends to have a low pH due to calcium and other bases being leached from the soil, being replaced by the hydrogen ion found in water.

The resulting effect of low P solubility in alkaline and calcareous soil is relatively poor fertilizer P efficiency. Plants grown in these conditions can be stunted with shortened internodes and poor root systems due to P deficiency. Deficiency symptoms are sometimes observed as a darkening of the leaf tissue, although it is more common to observe yield loss with no readily seen symptom.

Simply adding fertilizer P at “normal” rates and with conventional methods may not result in optimal yield and crop quality (Stark and Westermann, 2003). Several fertilizer P management strategies have been found to improve P nutrition for plants grown in alkaline and calcareous soil, namely: 1) relatively high P fertilizer rates, 2) concentrated P fertilizer bands, 3) complexed P fertilizer, 4) slow release fertilizer P, 5) cation complexing P fertilizer, 6) in-season P fertilizer application, and 7) balancing P with other nutrients. These methods may be used alone or in various combinations to effectively supply P to plants growing in alkaline and calcareous soil. In some cases, these methods are relatively new and need further refinement with regard to rates, timing, and technique.

HIGH P FERTILIZER RATES

When contrasting fertilizer calibration research performed on alkaline and calcareous soil with acid/neutral pH soil, it is apparent that relatively higher rates of broadcast/incorporated P fertilizer are required. For example, research trials conducted in North Dakota on sugarbeets suggest a critical level of about 10 ppm bicarbonate extractable P (Moraghan and Etchevers, 1980). In contrast, recent work in Idaho shows a critical level of about 20 to 25 ppm for sugarbeets grown in alkaline soil, with the amount of P fertilizer required increasing with increasing lime percentage (Jeff Stark, University of Idaho, personal communication, 2004).

Research work was also performed for potato grown in alkaline soil in Idaho and, similar to the sugarbeet findings, the amount of P required is relatively high (Stark and Westermann, 2003), as compared to rates used in regions without a predominance of alkaline/calcareous soil. This research also shows that the P rates for potato production need to be increased as the lime percentage in the soil increased. Cooperative trials with the University of Idaho, growers, and the fertilizer industry documented that these newly suggested rates work well under actual field conditions (Stark and Westermann, 2001).

CONCENTRATED FERTILIZER P BANDS

Although not always a replacement for necessary broadcast fertilizer P applications, adding P to soil in a concentrated band often results in further increases in yield and crop quality. The band application results in an overwhelming increase in soil solution P, effectively overcoming (temporarily) the reaction of calcium with soluble phosphate. This practice tends to provide a significant increase in P uptake, especially for early season growth when P availability is most limiting due to low soil temperatures and poorly developed root systems (Mengel and Kirkby, 1987).

There is an additive response when banded fertilizer P was applied in conjunction with broadcast/incorporated P for potatoes grown in calcareous soil (2 to 12% lime) with bicarbonate extractable P of 8 to 18 ppm (Figure 1). In some cases, it is recommended to apply banded P even when no broadcast P is necessary (Stark and Westermann, 2003), but banded P should not be seen as a replacement for broadcast P in medium to low testing soils (Figure 1).

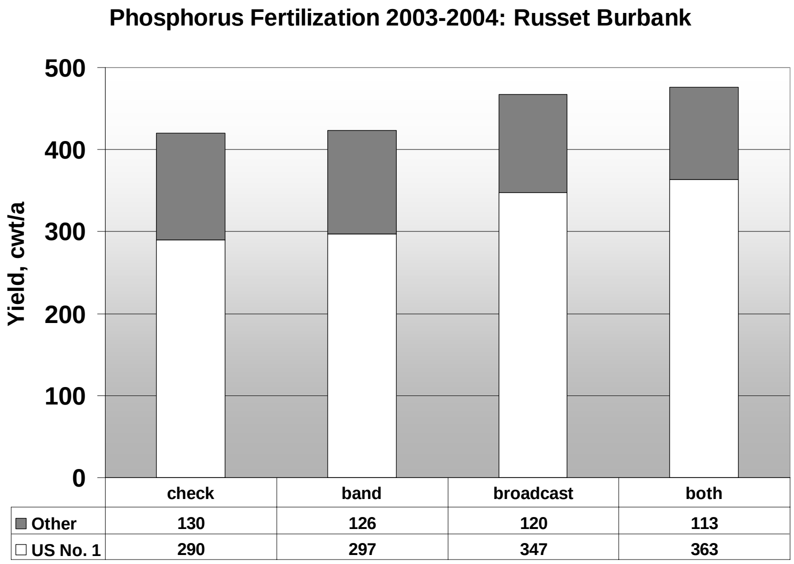

Figure 1. Combined yield results for potato trials in Eastern Idaho showing an additive increase with banded P fertilizer on calcareous soil with low to medium bicarbonate extractable P (8-18 ppm). Means greater than 15 cwt/acre are statistically significant for U.S. No. 1 (alpha = 0.10).

However, studies in soil with relatively low P in the north-central U.S. show that banded P alone performed as well as or better than broadcast P alone for sugarbeets. These studies show yield increases with the use of 12 to 20 lbs P_2O_5/acre of ammonium polyphosphate (10-34-0) starter in sugarbeets (Lamb, 1986; Moraghan and Etchevers, 1980; Sims and Smith, 2001). These researchers found increased yields when a starter band was placed: 1) in direct seed contact, 2) two inches below the seed, and 3) two inches below and two inches to the side of the seed. The magnitude of the response, however, was delayed and reduced as the distance between the seed and the starter fertilizer band increased. Sims and Smith (2001) concluded that direct seed contact was the best option due to the rapid, vigorous response and because much of the soil in which the sugarbeets are being grown in that region is high in clay and susceptible to implement-soil interface compaction, thus creating a poor seed bed. Unlike many other crops, little advantage was found by placing the starter band two inches to the side of the sugarbeet seed. Other research also supports the fact that optimum placement of phosphorous (P) for sugarbeets seems to be directly below the seed (Anderson and Peterson, 1978).

Results from a three-year sugarbeet trial in Idaho confirm this effect on calcareous soil, with the optimal placement for beets seeming to be relatively deep (6 inches) (Hopkins and Ellsworth, 2005). Deep banded application of P to sugarbeets grown on calcareous soil with high bicarbonate extractable soil test P (20 to 38 ppm) yielded better than plots receiving broadcast or no fertilizer P, although the effect was only observed in fields with relatively high yields. Interestingly, the shallow bands did not perform as well, due to the dominant tap root taking up much of its P deep and directly below the seed. Unlike most other crops, sugarbeets do not explore the top soil extensively until 7 to 9 weeks after emergence, instead focusing energy on development of the deep taproot, which is likely the reason for the contrast between sugarbeets and potatoes shown herein.

COMPLEXED P FERTILIZER

Phosphorus availability to plants for uptake can be improved by any means that results in an increase in solubility. Phosphorus bound to organic materials found in biosolid waste or commercially available fertilizer additives has been shown to improve P solubility and, thus, P nutrition in plants.

Phosphorus bound in organic materials (such as manure, compost, or industrial biosolids) serves as a slow release source of P for plants. Of course, not all of the P found in these materials is bound by organic materials and, as such, reacts similarly as other forms of inorganic phosphate with the soil. Biosolids can serve as a very good source of nutrients and humic substances, but there are many potential downsides of applying biosolid waste to soil, including: presence of weed seeds, nutrient imbalances, odor, presence of toxins, cost of transportation, compaction of soil due to heavy axle loads, etc.

Another alternative is to add concentrated commercially available humic substance amendments directly with P and other fertilizers to promote bioavailability without the drawbacks listed above. Humic substances are a mixture of naturally occurring organic materials that arise from the decay of plant and animal residues that are broken down by soil organisms. The remaining products serve as building blocks of humic substances. Humus is a generic term describing humic substances, which are comprised of three distinct groups, namely: humic acid, fulvic acid, and humin. Plant growth and health is favorably impacted as soil humus levels increase. Plants grown in soil with low humus levels can benefit from the addition of concentrated, “plant active” humic substances (Hopkins and Stark, 2003).

A recent three-year study at the University of Idaho evaluated the effect of three rates of P (0, 60, or 120 lbs P_2O_5/acre) applied in the mark-out (pre-plant starter) band with and without humic acid at a 10:1 v/v ratio. Petiole P concentrations during tuber bulking increased by an average of 0.03% with the addition of humic acid. Humic acid treatment increased yields of U.S. No. 1 tubers greater than 10 oz in 2 of 3 years of the study. Averaged across years and P rates, humic acid application increased total yield by 18 cwt/acre, U.S. No. 1 yield by 22 cwt/acre, and gross return by $152/acre (Hopkins and Stark, 2003). Fulvic acid and other organic binding agents also potentially have the ability to enhance P bioavailability.

It should be noted that the probability of P nutrition being improved to the point of increased yields when applied with concentrated humic substances is likely increased as the soil test P and organic matter decrease and the pH and lime concentration increase. It is reasonable to assume that the effect of humic substances applied at relatively low rates is more effective if applied in a concentrated band. Although positive results were found for banded application of humic acid with P on potatoes grown on low organic matter, calcareous soil; the potential benefits of humic substances with other soil types, crops, and fertilizer/amendment placements should be evaluated before expecting satisfactory results.

SLOW RELEASE FERTILIZER

Another strategy that can improve P availability to plants is slow release fertilizer materials. Adding highly soluble P fertilizer results in a temporary increase in soil solution P concentration at levels that exceed chemical equilibrium constants, forcing precipitation of phosphate minerals. In alkaline soils, calcium phosphate is rapidly formed following fertilizer dissolution. A slow release P fertilizer minimizes formation of calcium phosphate as the soil solution P concentration does not spike at high levels and the P is released in a more timely fashion.

Studies in Idaho showed that Polyon (Simplot Grower Solutions, Boise, Idaho) resulted in increased potato yield and tuber quality when compared with more traditional P fertilizer (Jeff Stark, University of Idaho, personal communication 2004).

CATION COMPLEXING P FERTILIZER

Avail (Simplot Grower Solutions, Boise, Idaho) is a relatively new product that is designed to bind calcium and magnesium in the micro site immediately around the fertilizer prill. This precipitation effectively minimizes the formation of the highly insoluble calcium phosphate minerals and leaves P in a more soluble state which is more likely to be taken up by plant roots. Limited research with this product used on potatoes shows significant increases in yields and tuber quality (data not shown).

IN-SEASON P FERTILIZER APPLICATION

Substantial research on nitrogen in potato production shows the value of split applying this nutrient, with a majority applied during the peak uptake rates during the season (Stark and Westermann, 2003). Nitrogen fertilizer quickly converts to the nitrate form, which is easily leached or volatilized under conditions with ample soil water. Furthermore, nitrate does not form poorly soluble minerals and, thus, is not subject to solubility problems. Alternatively, P is not typically subject to leaching loss and does not volatilize. And, as mentioned previously, P readily forms poorly soluble soil minerals. Therefore, the chemistry of P does not lend itself to movement in the soil and, as such, it is reasonable to assume that P should be incorporated into the soil zone where roots grow and take up nutrients.

At times, tissue analysis shows that a crop is potentially P deficient despite pre-season fertilization efforts. Can P be applied in-season to some benefit? Recent research in potatoes shows that, although not as efficient as pre-plant broadcast/incorporated fertilizer, P can be applied with some benefit during the season as an injection in the irrigation water (Hopkins and Ellsworth, 2003). However, it is recommended that every effort should be made to supply adequate P with other methods and use the in-season P application as a last resort if tissue analysis shows deficiency. Foliar applications of P may also be beneficial, but should not take the place of a good pre-plant fertilizer P program (data not shown).

BALANCING P WITH OTHER NUTRIENTS

Adding P in combination with ammonium tends to enhance availability of both nutrients. Ammonium and other acidifying fertilizer materials can enhance P solubility and uptake by roots. In general, it is also wise to have generally sufficient nutrient levels of other nutrients to promote overall good root development, which is so important for P interception and uptake.

Excessively high levels of certain nutrients can induce deficiencies of others. High rates of zinc, iron, manganese, and copper can induce deficiencies of P and visa-versa. This effect has been observed in many crops. Recent work in Idaho shows that excess P can result in potato yield and quality loss, which may be overcome with addition of zinc fertilizer (Hopkins and Ellsworth, 2003). Although this effect was observed by other researchers and in one year of this trial, no yield loss was observed at rates as high as 600 lbs P_2O_5/acre in two other years of the trial. There are also many claims with regard to optimum P-micronutrient ratios, but these purported ratios are not generally based on experimental data collected under field conditions. In fact, it is common to see a variety of soil P-micronutrient ratios in fields with exceptionally high yields, leaving the concept of optimal ratios in doubt. More work is needed to determine if optimum ratios exist and, if so, the width of this range.

SUMMARY

Phosphorus is an important and essential nutrient for all plants. Availability of P in high pH soils, especially those with excess lime, is relatively poor. Lowering pH is not an economical option for most crops and, as such, other strategies must be employed to enhance P uptake by roots, including: 1) relatively high P fertilizer rates, 2) concentrated P fertilizer bands, 3) complexed P fertilizer, 4) slow release fertilizer P, 5) cation complexing P fertilizer, 6) in-season P fertilizer application, and 7) balancing P with other nutrients.

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