PHOSPHORUS NUTRITION IN POTATO PRODUCTION

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ABSTRACT

Idaho soils tend to be high in pH and calcium carbonate (free lime), both of which reduce phosphorus solubility and availability to plants. Considerable research has occurred in Idaho during the recent past to elucidate optimum phosphorus rates for potatoes (*Solanum tuberosum*). The question remains, does method and/or timing of phosphorus applications impact yield and quality of potatoes. Research shows that excess phosphorus rates decrease yield and quality. Research in other crops shows that excessive phosphorus does not create phosphorus toxicity; rather excessive phosphorus induces zinc or other micronutrient deficiencies. No research has been conducted to determine the reason why excess phosphorus rates reduce yield and quality in Idaho potato production. Due to soil variability and relatively high phosphorus application rates to potatoes, many fields in Idaho have at least some portion that is substantially over-fertilized. The severity and nature of this problem needs to be elucidated. Two studies were conducted in Aberdeen, ID, with Russet Burbank potato to start answering these questions. The first study was conducted to evaluate the effect of phosphorus application method and timing to a potato crop. Three rates of phosphorus (0, ½, and full rate based on soil test) were applied in three timing scenarios: 100% pre-plant, 100% in-season, and 50% pre-plant/50% in-season. Phosphorus application resulted in significantly improved total and U.S. No.1 yields at the full rate, but not at the half rate. The 100% pre-plant phosphorus application resulted in more total yield and U.S. No.1's than either of the in-season applications. The second study was conducted to evaluate the possibility of phosphorous-zinc interaction and determine its impact on potato yield and quality. Four rates of phosphorus (0, 200, 400, and 600 lb P_2O_5/acre) were applied with and without added zinc (0 and 20 lb zinc/acre). Phosphorus application at the recommended rate (200 lb P_2O_5/acre) resulted in significant yield and quality increases. Over-application of phosphorus resulted in decreased yield and quality. Adding zinc when phosphorus was over-applied resulted in yields equivalent or greater than those observed when phosphorus was applied at the optimum rate. Further research is needed to confirm these single-year observations.

INTRODUCTION

Phosphorus Application Method and Timing - "An ounce of prevention is worth a pound of cure - Benjamin Franklin, 1706-1790.". Nutrition is crucial in determining potato yield and quality, as well as influencing the potato plant's ability to withstand negative effects from pests, water, temperature, and other stresses. Phosphorus is one of the 17 essential elements required for plant growth and reproduction (Marschner, 1986). Phosphorus (P) is used in the plant for energy storage and transfer, maintenance and transfer of genetic code, and is structural component of cells and many biochemicals

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(Marschner, 1986). Phosphorus deficiencies result in poor root growth, stunted top growth, reduced yield and crop quality, and delayed maturity.

Phosphorus, along with nitrogen and potassium, is classified as primary macronutrient. Primary macronutrients are needed in relatively large quantities and are often deficient in crops not receiving fertilizer application.

Additional work with nitrogen has successfully shown that timing of nitrogen fertilizer application also impacts yield and quality. Potato plants take up 50-60% of their nitrogen after tuber bulking is initiated (Stark and Westermann, 2003). Split applying the nitrogen results in a more uniform availability and uptake of the nitrogen throughout the season. Although "spoon-feeding" nitrogen has proven to be a good management practice, this may not be true for phosphorus. Nitrogen and phosphorus chemistry are vastly different. Plant available nitrogen exists primarily as nitrate in the soil. Nitrate is a very soluble and, therefore, mobile compound. Nitrate is readily leached downward or moved laterally with water movement, which is especially a problem for shallow rooted crops such as potatoes. In addition, nitrate can be lost to the atmosphere under saturated conditions. For these reasons, "spoon-feeding" nitrogen has proven to be a good management practice in potato production (Stark and Westermann, 2003).

In contrast, phosphorus is neither mobile nor subject to gaseous losses. In fact, the potential problem with phosphorus is related to the reasons why it is not mobile (Hopkins, 1995; Loneragan and Webb, 1993; MacLean, 1974; Marschner, 1986; Moraghan and Mascagni, 1991). Phosphorus fertilizer dissolves and results in an increase in phosphorus that is in soil solution. Due to equilibrium chemistry, the soil solution will not tolerate high levels of phosphorus. As a result, most of the phosphate (term for the phosphorus ion, PO_4^{3-}) in soil solution quickly precipitates (forms a mineral deposit) as it reacts with calcium and other positively charged ions in the soil. As plants absorb phosphorus out of soil solution, these phosphate minerals will slowly dissolve in order to maintain equilibrium of phosphate in soil solution. The amount and type of phosphate minerals, as well as the pH and the amount of carbonate minerals present, control the rate of phosphorus being re-supplied into the soil solution where it is available for plant utilization. Idaho soils tend to be high in pH and free lime; both of which reduce phosphorus solubility and availability to plants (Marschner, 1986; Moraghan and Mascagni, 1991; Stark and Westermann, 2003). Considerable research has occurred in Idaho during the recent past to elucidate optimum phosphorus rates for potato production.

The question remains as to whether or not method and/or timing of phosphorus application impact the in-season availability of phosphorus to the plant and, as a result, the yield and quality of potatoes. There are obvious advantages to pre-plant application of phosphorus. This method allows for the phosphorus to be mixed with soil, where it is more likely to come into contact with roots. However, in-season application of phosphorus via the irrigation system has been shown to effectively increase petiole phosphorus concentrations. The question remains as to which method or combination thereof is superior.

Phosphorus-Micronutrient Interactions - Producers have increasingly realized the importance of fertilizing crops with phosphorus over the last half century, especially as yields and production intensity have increased. This is particularly true for growers in eastern Idaho, due to the predominance of potatoes grown in alkaline and/or calcareous soil. Potatoes have a relatively high phosphorus requirement and availability of phosphorus to plants is reduced as pH and/or calcium carbonate concentrations increase causing a reduction of phosphorus solubility (Marschner, 1986; Moraghan and Mascagni, 1991; Stark and Westermann, 2003). Through experience and research, growers and agronomists have learned the importance of applying fertilizer phosphorus to potatoes grown in alkaline and/or calcareous soil.

Unfortunately, it seems to be human nature to fall into the trap of "if some is good, more is better." As a result, many fields in eastern Idaho have received so much phosphorus from fertilizer and animal wastes that soil test levels for this nutrient are high (Potash and Phosphate Institute, 2001). Despite high residual soil phosphorus, many growers continue to apply substantial amounts of phosphorus fertilizer. Over-fertilization not only impacts the grower's earnings, but is also an environmental risk. High residual phosphorus levels in soil susceptible to runoff and erosion increase the risk of surface water contamination and diminished water quality due to eutrophication (oxygen depletion due to algae blooms).

The apparent answer to the problem is to only apply the amount of phosphorus required. However, even if a grower sensibly applies phosphorus (based on soil analysis, realistic yield goal, and research based fertilizer guidelines), spatial variability of soil phosphorus will likely result in over-application of fertilizer in areas with phosphorus levels higher than the rest of the field. It is common for fields to have considerable spatial variability of plant available soil phosphorus. This spatial variability is due to naturally occurring differences in soil properties and long-term differences in nutrient removal rates across a field.

For example, an area of a field with shallow, poor soil does not yield as well as the rest of the field. As a result, less phosphorus and other nutrients are removed by crops from this "poor" area, and phosphorus tends to build up in the soil. Continued phosphorus application, based on the field average, will result in an excessive build up of phosphorus in this poor area, despite the best efforts of the grower to follow reasonable fertilizer practices.

In addition to reduced revenue and environmental risks, excessive phosphorus fertilizer application to potatoes can reduce zinc (Zn) uptake (Christensen, 1972; Christensen and Jackson, 1981; Soltanpour, 1969) and yield and tuber size (Idaho Potato Commission, 1997). Additionally, excessive soil and/or fertilizer phosphorus may also negatively affect crops grown in rotation with potatoes (Moraghan and Mascagni, 1991). This is of particular concern in eastern Idaho, where soil phosphorus concentrations and fertilizer phosphorus applications tend to be high. The crops typically grown in rotation with potatoes in eastern Idaho have a relatively lower phosphorus requirement. The effects of high available phosphorus on crops grown after potatoes have not been adequately studied.

The causes of the reduction in crop yield and quality due to excess phosphorus have not been fully elucidated. However, it is likely that the primary reason is due to an antagonistic interaction with other nutrients (Table 1). Although phosphorus interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with zinc. Zinc is taken up by plants as a cation (Zn^{2+}) and phosphorus is taken up by plants as a species of the phosphate (PO_4^{3-}) anion. Positively and negatively charged ions have an electrical attraction to one another, facilitating the formation of a chemical bond that can form in either the soil or the plant tissue. The relative strength of the phosphorus-zinc bond is strong and does not readily break without dramatic changes in the physical or chemical environment. If excess phosphorus binds a large amount of the zinc normally used by the plant, the result can be a phosphorus-induced zinc deficiency.

The phosphorus induced zinc deficiency has been well documented in corn. Although not as widely studied, there is also evidence that this phosphorus-zinc interaction occurs in many other plant species (Table 2). In addition to the phosphorus-zinc interaction, there is also evidence that there is a phosphorus-interaction with other cationic micronutrients: manganese (Mn), iron (Fe), and copper (Cu) (Table 1). Although substantial evidence exists linking yield loss caused by excess phosphorus inducing a deficiency of one or more micronutrients, very little work has been performed confirming and quantifying the effect in soil, crop, and environmental conditions in eastern Idaho. In addition, no guidelines are available for predicting this malady and only circumstantial management guidelines are available.

MATERIALS AND METHODS

Phosphorus Application Method and Timing - The first year of a phosphorus fertilizer timing study was completed at a UI Aberdeen Research & Extension Station field with 17 ppm P (Bicarbonate extraction) and 5% excess lime. Plot size was 40 ft. X 40 ft. as defined by the location of the sprinkler system (sprinkler heads located at each corner of each plot). The study consisted of five replications in a randomized complete block design of the following treatments:

Treatment ID	Phosphorus Rate, lb P_2O_5/a	Application
Check	0	NA
½ - PP	90	100% pre-plant
½ - WR	90	100% water-run
½ - PP/WR	90	50% pre-plant & 50% water-run
PP	180	100% pre-plant
WR	180	100% water-run
PP/WR	180	50% pre-plant & 50% water-run

The University of Idaho phosphorus recommendation for a 400 cwt./acre yield goal on this soil is 100 lbs P_2O_5/acre broadcast plus 40 lb P_2O_5/acre starter. No starter was applied for treatment consistency reasons. In an effort to compensate, slightly more broadcast phosphorus was added for a full rate level of 180 lb P_2O_5/acre. The pre-plant phosphorus was applied using 11-52-0 broadcast and then mixed with soil. The in-season phosphorus was applied as 10-34-0 injected into the irrigation system three times during the growing season (June 13, July 2, and July 16). Sprinkler nozzles were plugged during the fertigation period for plots not receiving in-season phosphorus. Nitrogen was balanced in all plots to insure that no differences between treatments existed.

Nutritional levels were monitored through weekly petiole sampling. The petioles were sampled in each plot on June 26 and July 10 to establish differences in phosphorus uptake (analysis not yet complete – data not presented here).

Normal grower practices were followed throughout the season in an effort to maximize tuber yield and quality. Two rows - 30 feet in length were harvested out of the center of each plot. Tuber yields and quality were determined by separating tubers based on size, shape, and skin characteristics. Differences across treatments were determined by analysis of variance and means separated by LSD.

Phosphorus-Zinc Interaction - The first year of a phosphorus fertilizer timing study was completed at a UI Aberdeen Research & Extension Station field with 15 ppm bicarb P, 5% excess lime, and 1.0 ppm DTPA Zn. Plot size was 4 rows (12 ft.) X 30 feet. The study consisted of five replications in a randomized complete block design of the following treatments:

Treatment	Phosphorus Rate, lbs.-P_2O_5/a	Zinc Rate, lbs.-Zn/a
Check	0	0
1X-P	200	0
2X-P	400	0
3X-P	600	0
1X-P + Zn	200	20
2X-P + Zn	400	20
3X-P + Zn	600	20

The University of Idaho phosphorus recommendation for a 400 cwt./acre yield goal on this soil is 130 lbs.-P_2O_5/acre broadcast plus 40 lbs.- P_2O_5/acre starter. No starter was applied for treatment consistency reasons. In an effort to compensate, slightly more broadcast phosphorus was added for a full rate level of 200 lbs.- P_2O_5/acre. The phosphorus fertilizer was applied as triple super phosphate (0-46-0). The zinc fertilizer was applied as zinc sulfate ($ZnSO4$). Both phosphorus and zinc fertilizer was applied pre-plant broadcast, followed by mixing with the soil. Sulfur was balanced in all plots to insure that no differences between treatments existed.

Nutritional levels were monitored through weekly petiole sampling. The petioles were sampled in each plot on June 26 and July 10 to establish differences in phosphorus uptake (analysis not yet complete – data not presented here).

Normal grower practices were followed throughout the season in an effort to maximize tuber yield and quality. Two rows - 20 feet in length were harvested out of the center of each plot. Tuber yields and quality were determined by separating tubers based on size, shape, and skin characteristics. Differences across treatments were determined by analysis of variance and means separated by LSD.

RESULTS AND DISCUSSION

Phosphorus Timing - Significant responses were observed for rate and application method. A 33 cwt./acre yield response to phosphorus application was observed when the full recommended rate was combined across application methods. No difference was observed between the check and the ½ rate of phosphorus. Significant differences were also observed when application methods were combined across phosphorus rates. Both the 100% pre-plant (372 cwt./acre) and water-run (376 cwt./a) were significantly higher than the check (352 cwt./a) and the split application (359 cwt./a) methods.

When evaluating individual treatments, all application methods receiving the full rate resulted in significantly increased yields over the check (Fig. 1). Although not statistically different from one another, the highest yield was achieved at the 100% pre-plant treatment, followed by the 100% water-run.

Tuber quality was also significantly impacted by rate and application method. The percentage of malformed tubers was reduced (data not shown) and the percentage of U.S. No. 1 grade tubers was increased at the full rate of phosphorus, especially when applied 100% pre-plant (Fig. 1).

These results of this single year of data show that no advantage was gained by "spoon feeding" phosphorus during the season or a split 50/50 treatment. Although this data is compelling, further research is needed to confirm this effect under different soil and environmental circumstances.

Phosphorus-Zinc Interaction - Significant responses were observed both for phosphorus and zinc fertilization, as well as a significant interaction between the two (Fig. 2). Applying phosphorus at the recommended rate (200 lbs. P_2O_5/acre) resulted in a significant yield increase; however, excessive application [2 times the recommended rate (2x) or 3 times (3x)] decreased yields relative to the recommended rate. Applying zinc apparently alleviated the negative effect of excess phosphorus, although only at the high rates of phosphorus.

Tuber quality was also significantly impacted in this study (Fig. 2). The best treatments for U.S. No. 1 were at the recommended rate of phosphorus and at the 2x rate when zinc was added with it.

CONCLUSIONS

This data suggests that split applying phosphorus or applying it all in-season may not be beneficial for potatoes, unlike the findings that support this practice for nitrogen fertilizer application. Additionally, the results of the phosphorus-zinc interaction trial, coupled with the data from other studies cited herein, indicate that high rates of phosphorus are likely inducing zinc deficiency in commercial potato production fields in Idaho. Further research is needed to confirm these effects and to work out details for best management options.

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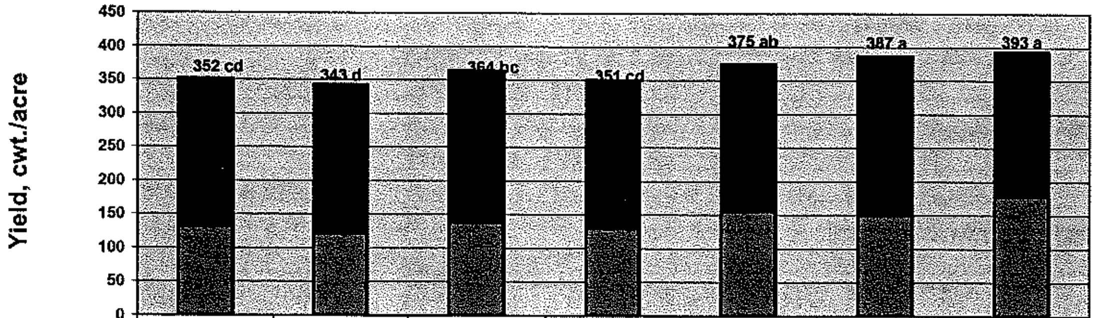
Table 1. Cationic micronutrients potentially susceptible to a phosphorus induced deficiency when phosphorus is present in significant excess.

Micronutrient	**References**
Copper (Cu)	Rhoades et. al., 1992; Safaya, 1976; Timmer and Leyden, 1980
Iron (Fe)	Brown and Tiffin, 1962; Haleem et. al., 1992; Singh et. al., 1996
Manganese (Mn)	Beer et. al., 1972; Fageria and Baligar, 1989; Hellin and Alcaraz, 1980; Safaya, 1976
Zinc (Zn)	Brown and Tiffin, 1962; Cakmak and Marschner, 1987; Christensen, 1972; Christensen and Jackson, 1981; Fageria and Baligar, 1989; Hopkins, 1995; Loneragan and Webb, 1993; Loneragan et. al., 1979; Loneragan et. al., 1982; MacLean, 1974; Marschner, 1986; Moraghan, 1984; Moraghan and Mascagni, 1991; Safaya, 1976; Safaya and Singh, 1977; Singh et. al., 1986; Soltanpour, 1969; Torun et. al. 2001

Table 2. Plant species known to exhibit the phosphorus-micronutrient interaction with zinc, manganese, iron, or copper.

Species	**References**
Potato (*Solanum tuberosum* L.)	Beer et. al., 1972; Buniak and Dziezycowa, 1976; Christensen, 1972; Christensen and Jackson, 1981; Soltanpour, 1969
Corn (*Zea mays* L.)	Brown and Tiffin, 1962; Christensen, 1972; MacLean, 1974; Moraghan, 1984; Safaya, 1976
Wheat (*Triticum aestivum* L.)	Beer et. al., 1972; Brown and Tiffin, 1962; Fageria and Baligar, 1989; Moraghan, 1984; Singh et. al., 1986; Torun et. al., 2001
Barley (*Hordeum vulgare* L.)	Beer et. al., 1972; Brown and Tiffin, 1962
Oats (*Avena sativa* L.)	Beer et. al., 1972; Rhoades et. al., 1992
Rice (*Oriza sativa* L.)	Fageria and Baligar, 1989; Singh et. al., 1996
Sorghum (*Sorghum bicolor* (L.) Moench)	Hopkins, 1995
German millet (*Setaria italica*)	Brown and Tiffin, 1962
Flax (*Linum usitassitimum* L.)	Moraghan, 1984
Alfalfa (*Medicago sativa* L.)	Fageria and Baligar, 1989; MacLean, 1974
Clover (*Trifolium pratense* L. and *subterranium* L.)	Beer et. al., 1972; Fageria and Baligar, 1989
Bean (*Phaseolus vulgaris* L.)	Brown and Tiffin, 1962; Christensen, 1972; Fageria and Baligar, 1989; Moraghan, 1984
Soybean (*Glycine max* (L.) Merr.)	Brown and Tiffin, 1962; Moraghan, 1984
Lupin (*Lupinus albus* L.)	Pin and FuSuo, 1995
Cowpea (*Vigna unguiculata* (L.) Walp)	Safaya and Singh, 1977
Cotton (*Gossypium hirsutum*)	Brown and Tiffin, 1962; Cakmak and Marschner, 1987
Okra (*Hibiscus esculentus*)	Brown and Tiffin, 1962; Loneragan et. al., 1982
Cabbage (*Brassica oleracia* L.)	Buniak and Dziezycowa, 1976
Tomato (*Solanum hycopersicum*)	Brown and Tiffin, 1962
Sugarbeet (*Beta vulgaris* L.)	Beer et. al., 1972; Buniak and Dziezycowa, 1976
Dill (*Pencedanum graveolus*)	Brown and Tiffin, 1962
Cocklebur (*Zanthium spinosum*)	Brown and Tiffin, 1962
Sour orange (*Citrus aurantium*)	Timmer and Leyden, 1980
Lemon (Cit*rus limon*)	Hellin and Alcaraz, 1980

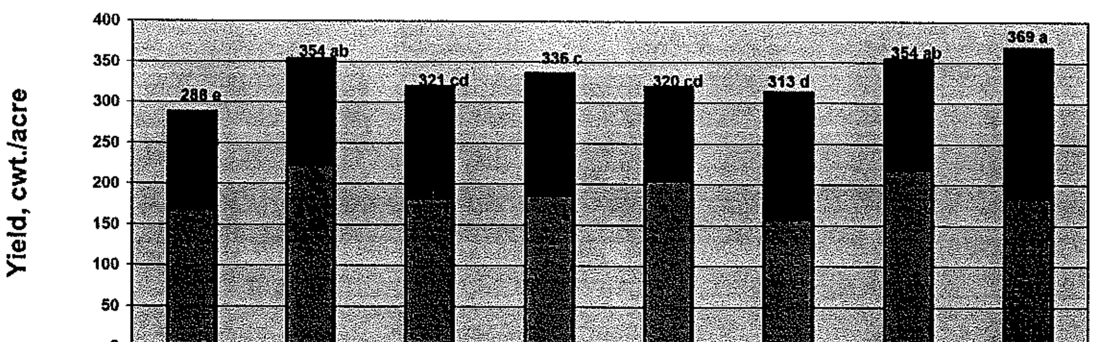
P Placement Effects on Yield and Quality



	check	1/2 rate 50/50	1/2 rate water-run	1/2 rate preplant	full rate 50/50	full rate water-run	full rate preplant
Other	220	222	226	220	219	236	214
US no. 1	132 c	122 c	138 bc	130 c	156 b	151 b	179 a

Figure 1. *Russet Burbank* potato yield response to phosphorus rate and placement. Rates were 0 (check), 90 (½ rate), and 180 lb P_2O_5/a (full rate). Three placement methods were used, namely: 100% pre-plant, 100% water-run applied four times during the season, and 50% pre-plant + 50% water-run. Phosphorus applied at the full-recommended rate resulted in the greatest yield. No advantage was realized by "spoon feeding" the phosphorus during the season. Means followed by the same letter are not significantly different from one another at P=0.05.

Zinc Fertilizer Effects on Excess Phosphorus



	check	1x P	2x P	3x P	Zn	1xP +Zn	2xP +Zn	3xP +Zn
Other	119	130	137	149	115	155	135	184
US no.1	169 c	224 a	183 bc	187 bc	205 ab	159 c	219 a	185 bc

Figure 2. *Russet Burbank* potato yield response to phosphorus and zinc fertilization. Rates were 0, 200, 400, and 600 lb P_2O_5/a and 0 and 20 lb Zn/a. Application of both phosphorus and zinc resulted in significantly increased yields. Excessive application of phosphorus resulted in yield decrease as compared to the 1x (recommended rate). Application of zinc with phosphorus ameliorated the negative impact of excess phosphorus. Means followed by the same letter are not significantly different from one another at p =0.10. (Yield LSD = 17; U.S. No. 1 LSD = 31; Other LSD = Not Significant).