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LIME EFFECTS ON P AVAILABILITY¹D. T. Westermann²

INTRODUCTION

Nutrient uptake can be predicted by assuming that plant roots absorb nutrients from the soil solution and that the rate of absorption is dependent upon the nutrient concentration in the soil solution (2). The root growth rate also affects P uptake since uptake is directly proportional to active root surface area, particularly new root hairs. The three main soil characteristics that describe the P supply to the plant root are: (a) P concentration in the soil solution before growth, (b) the ability of the soil to replenish the P in the soil solution, the buffer power, and (c) the P diffusion rate through the soil. The diffusion process is the main supply mechanism for P reaching the root surface.

There are several factors that directly or indirectly influence soil and fertilizer P availability. These include soil, fertilizer, management, and environmental characteristics. Additional details of the complex reactions and interactions are beyond the scope of this paper, but can be found in recent reviews (4, 7).

A nutrient survey showed that 25 out of 123 potato fields in Idaho had soil test P concentrations (STPC) more than adequate, but petiole $\text{PO}_4\text{-P}$ concentrations considered to be deficient (11). The significance of the petiole $\text{PO}_4\text{-P}$ concentration in relation to plant growth needs have been better defined (12) since that report. This paper presents data showing the effects of lime on soil solution P concentrations and P uptake by plants.

METHODS AND MATERIALS

The data in this paper were obtained from a number of different experiments. In 1983, 13 experimental sites (PG83) were established in potato fields across southern Idaho. A preplant soil sample (1 ft) was obtained from each site before any fertilizer was applied. Petiole $\text{PO}_4\text{-P}$ concentrations, P uptake, and dry matter and tuber yields were monitored in each experiment during the growing season. The three P fertilization treatments established at each site were dependent upon preplant STPC. The cultural practices at each site were controlled by the individual potato grower.

Two field experiments were conducted at Kimberly on a site that contained plots where the soil was mixed to 5 ft in 1974 (3). Russet Burbank potatoes and Stephens' winter wheat were grown in 1983 and 1984, respectively. This experiment had a comparison of high and low lime concentrations across three different residual-P concentrations. Representative soil samples (1 ft) were obtained from each plot in April of the respective cropping year. Each experiment was monitored for P uptake, plant tissue P concentrations, and dry matter yields. Standard cultural practices were followed in each experiment.

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Data were also obtained from a P incubation study containing eleven soils. These included Shano fine sandy loam, Greenleaf silt loam, Declo silt loam, Millville silt loam, and a native Portneuf silt loam surface soil. Four Portneuf surface soil (1 ft) and 2 subsoil samples from irrigated fields near Kimberly were also included. Their lime concentrations (9) ranged from less than 0.5% to over 47%, and the initial STPC from 3 to 31 mg P kg⁻¹. Finely ground MCP, < 200 mesh, was added at P rates of 0, 10, 20, 40, 80, 160, and 320 mg P kg⁻¹, and incubated (70°F) at 25% moisture by weight for 2 months with 3 wetting-drying cycles before sampling and analysis.

Potato petiole samples (30-50, fourth leaf down from growing tip) were obtained at early tuber set. Total P uptake was estimated from whole plants in a 5 ft row section at early tuber set, and at selected intervals during tuber growth. The tubers and roots were washed. Total P uptake in the wheat experiment was estimated from stand counts and 10-20 aboveground plants from each plot. All plant samples were dried at 140°F and ground through a 40 mesh screen in preparation for chemical analyses (1, 5, 6).

All soil samples were air-dried (~95°F) and crushed with a soil-pulverizer (flail type) before analysis. The samples were analyzed for NaHCO₃ extractable P (10), acid equivalent lime (9), and solution-P. The 0.01 M CaCl₂ procedure used to estimate solution-P was as follows: 3 g air-dried soil added to 30 ml 0.01 M CaCl₂, and 200 µl toluene, continuous shaking for 24 hr at 70°F, centrifuging, filtering, and P determination on filtrate (8). Phosphorous concentrations were also determined on solutions obtained by centrifuging soil samples after 6 days incubation at field capacity moisture condition. The solution-P (0.01 M CaCl₂) was related to the P concentration in the soil solution obtained by centrifugation: solution-P (0.01 M CaCl₂) = 0.931 (soil solution-P) - 0.014, r² = 0.99.

RESULTS AND DISCUSSION

Initial data analysis for the PG83 sites showed a poor relationship between the STPC and the P uptake or petiole PO₄-P concentration at early tuber set (Table 1). Correlation coefficients improved when the lime equivalent was added to the regression equation, usually after a logarithmic or square root transformation. The regression coefficient for lime was always negative. Correlations with only solution-P were slightly lower for initial P uptake, but improved for petiole PO₄-P concentration. Final P uptake in mid-September was poorly correlated with solution-P, better with STPC, and by also considering soil lime. Final P uptakes were confounded from P additions during tuber growth on some sites.

Table 1. Correlation coefficients between selected variables in the 1983 potato growers data set.

Dependent variable	Independent Variables		
	STPC	STPC, Lime	Solution-P
			r
Petiole P - 1st	0.66	0.82	0.93
Initial P uptake	0.68	0.86	0.80
Final P uptake†	0.77	0.86	0.69

†P sometimes added by grower during growing season.

Winter wheat yields were curvilinearly related to both initial STPC and solution-P (Fig. 1). Significant yield differences occurred between treatments with similar STPC's (7-9 and 22.5-24), while similar yields occurred in treatments with STPC's of 9 or 22.5 ppm. These differences appear to be related to the lime equivalent concentrations. The apparent yield-STPC incongruities disappeared when solution-P concentrations were related to yields instead of STPC (Fig. 1).

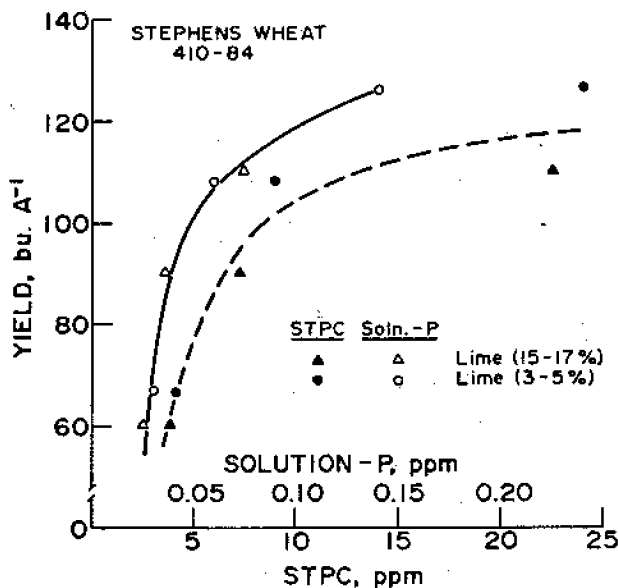


Fig. 1. The relationship of STPC and solution-P to winter wheat yields.

Phosphorous uptake by the winter wheat was related to STPC and solution-P (Fig. 2). Incongruities also existed in the STPC relationships, except for the last sampling at the soft dough growth stage. Phosphorous uptake was smaller at the earlier samplings in the treatments with 15 - 17% lime, even though their STPC's were similar. A good relationship between P uptake and solution-P existed at all sampling dates.

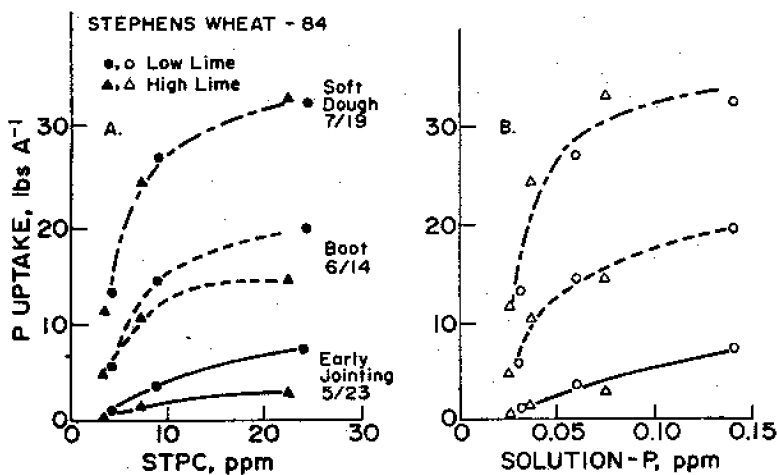


Fig. 2. The relationship of STPC (A) and solution-P (B) to P uptake by winter wheat at different sampling dates.

The final P uptake by potatoes grown on these plots in 1983 was related to both solution-P and STPC (Fig. 3). Approximately 0.1 ppm solution-P and 15 ppm STPC were necessary for maximum P uptake. Tuber yield relationship was similar and approached 550 cwt A⁻¹, with 80% #1 tubers. The two highest STPC on the low lime equivalent plots (3-5%) had solution-P concentrations greater than 0.1 ppm, while a 31 ppm STPC and 15 - 17% lime equivalent plot had less than 0.1 ppm solution-P.

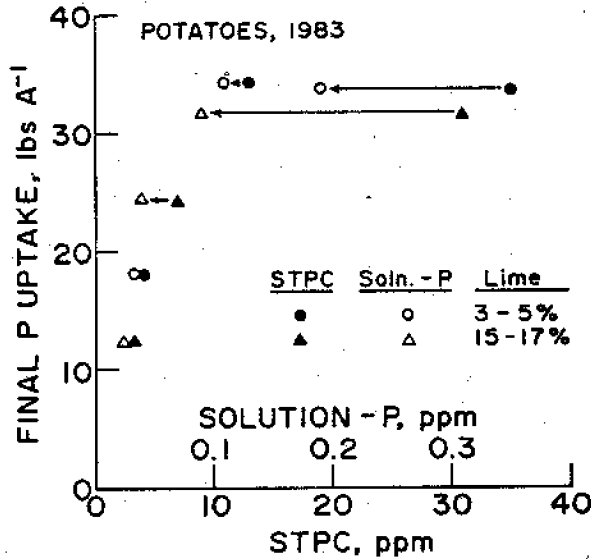


Fig. 3. The relationship of STPC and solution-P to P uptake by potatoes in mid-September.

The solution-P concentration in the 1984 winter wheat experiment was dependent upon the STPC and the lime equivalent (Fig. 4). On this series of plots there were two separate populations, the 3-5% and 15-17% lime equivalent plots, respectively. The slope for the 3-5% lime equivalent plots was approximately two times that for the 15-17% plots. Similar relationships were found in the 1983 potato plots (data not shown).

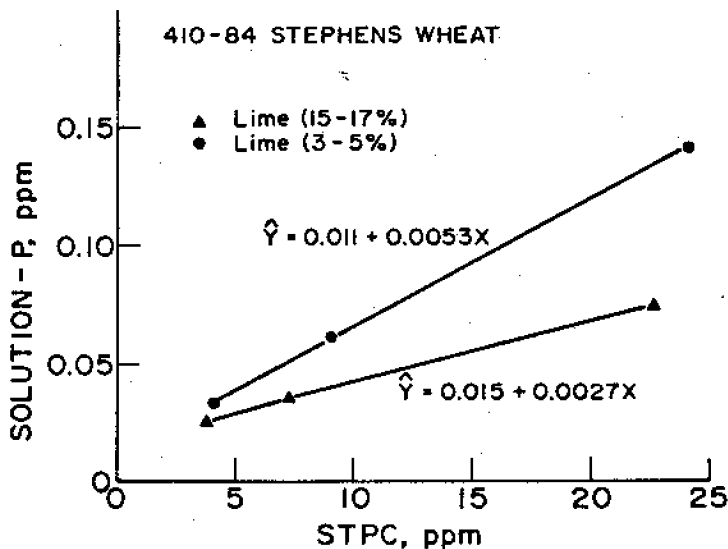


Fig. 4. The relationship between STPC and solution-P for two different lime equivalents in the 1984 winter wheat study.

The relationships between STPC and solution-P for 7 of the 11 soils in the P incubation study are shown in Fig. 5. Some relationships appear to be nearly linear while others are curvilinear. The relationships for the other four soils were similar to those shown. These relationships appear to be dependent upon soil type (series), lime equivalent, and the physical and chemical characteristics of the lime.

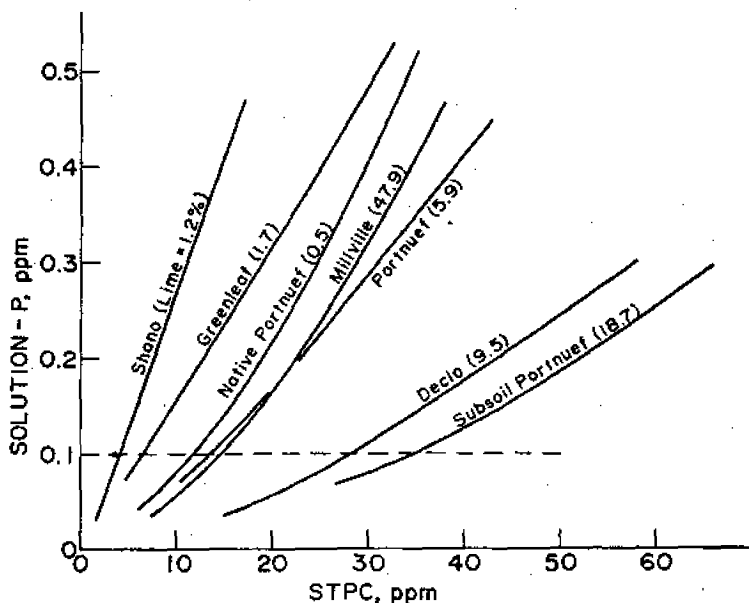


Fig. 5. The relationships between STPC and solution-P for six different soils from the P-incubation study. Lime equivalent in parenthesis.

The STPC needed to provide 0.1 ppm solution-P for all 11 incubation soils was estimated from the STPC, solution-P relationship. This STPC was then plotted against the lime equivalent of that soil (Fig. 6). The linear relationship indicates that the STPC should increase 1.4 ppm for each percentage point the lime equivalent increases to have sufficient P available to provide a solution-P concentration of 0.1 ppm. Data from the PG83 sites showed a similar relationship, except for one site where the subsoil was recently exposed with a 19.5% lime equivalent that required an STPC of 50 ppm (Fig. 6). Another anomaly in this study was with the Millville soil. The 1.4 slope was also obtained from greenhouse and growth chamber studies where P and lime were variables (Unpublished data, D. T. Westermann).

CONCLUSIONS

These data indicate that the soil solution-P concentration is sometimes dependent upon the lime content and its characteristics, as well as the STPC. Higher STPC's were needed to provide the same P concentration in the soil solution as the lime equivalent increased. Attempts to further characterize the *in situ* lime have not fully identified the mechanisms involved. Recently exposed calcareous subsoils appear to be more reactive than irrigated soils farmed for a number of years. Soils containing other forms of carbonate minerals (e.g., dolomite [in Millville soil]), carbonate minerals coated with non-reactive materials, or limed acidic soils may not necessarily follow the relationships shown in this paper. Adjustments of P soil tests for this lime effect may also not be necessary for all crops. This consideration would be much more important for annual crops in which continuous P uptake is

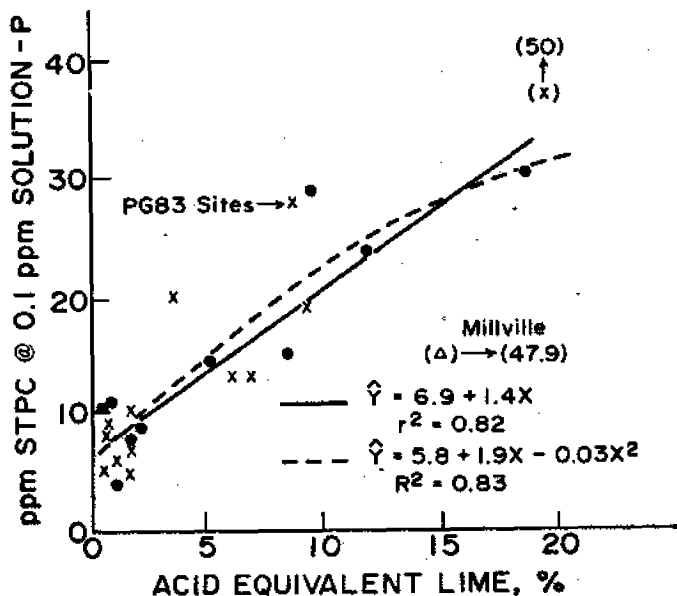


Fig. 6. The relationship of lime equivalent and STPC needed to have a solution-P concentration of 0.1 ppm.

necessary for plant growth during all the growing season, e.g., potatoes. Crops that complete their life cycle before the end of the climatic growing season, e.g., small grains, may only show a delay in maturity rather than a yield loss.

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