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Phosphorus Solution Concentrations for Production of Tomato, Pepper, and Eggplant in Minesoils[1]

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Abstract. **Phosphate-sorption isotherms were used to predict the rates of P fertilizer required to establish 6 concentrations of solution P in reclaimed minesoils. Tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum annuum* L.), and eggplant (*Solanum melongena* L.) were grown during 2 successive years on the same minesoil plots, fertilized each year with sufficient P to establish the desired solution P levels. At every solution P level, the rate of fertilizer P required the second year was less than the initial year, with the relative amount needed to re-establish the solution P levels considerably reduced at the higher solution P concentrations. Optimum solution P was reached at 0.2 ppm for tomato and pepper, while eggplant required 1.6 ppm P in solution for optimum yield. Regression analysis estimated optimum levels of solution P at 1.56 ppm for eggplant and 0.28 ppm for tomato and pepper. The optimum minesoil solution P levels for each species was similar to that reported for these same crops on other soils, indicating the broad applicability of these data and the sorption isotherm method for assessing P-fertilizer requirements. Marginal leaf necrosis and yield reductions of 73–75% occurred with tomato and pepper when solution P concentrations were increased to 2.4 ppm. Yield response at suboptimal solution P levels was greater for tomato and pepper than eggplant, suggesting that the P nutrition of the latter crop is less efficient than the former species.**

The phosphate sorption approach to P nutrition combines both soil and plant factors in estimating the P requirements for specific soil-crop combinations. P-sorption isotherms have been used to define the relationship between sorbed P and P in the soil solution (2, 13, 21, 26). During plant growth, sufficient P must desorb from the soil to maintain solution concentrations. Soil chemistry, mineralogy, and management affect the rate of fertilizer P required for a given soil to achieve and maintain a desired level of P in solution. For each plant species, an optimal solution P concentration can be identified from yield-solution P curves (8, 9, 10, 11, 12, 20). In turn, the corresponding rate of fertilizer P required for maximum yields can be predicted for a given soil from a phosphate sorption isotherm.

A solution concentration of 0.2 ppm P was originally proposed as a standard level at which most plants would make adequate growth (4). Optimum P concentrations, however, vary among plants, ranging from 0.03 ppm for some pasture species (1) to 0.13 ppm for sweet corn (12) to 0.3 ppm or greater for lettuce and eggplant (20). Fertilization practices for wheat have been based on a solution P concentration of 0.3 ppm (21). For each plant species, the optimum P concentration has been shown to remain relatively constant on soils of widely differing sorption capacities (10, 11). However, crops can vary tremendously in their yield response under suboptimal solution P levels (20).

There are about 1 million ha of land disturbed by surface mining of coal and more than 4 million ha of land are underlain by strippable coal reserves (19). The potential of disturbed lands for use in crop production can be equal to or greater after proper reclamation than before mining or excavation began (19). However, the available P of disturbed land is often critically low and must be improved to attain acceptable crop productivity (5).

The objectives of this study were to determine the optimum solution P concentrations and respective fertilizer rates for production of tomato, pepper, and eggplant on a reclaimed minesoil. Phosphate-sorption isotherms were used to estimate the initial and second-year P requirements for vegetables in the minesoils. The information obtained from this study is particularly illustrative of the P fertility of Appalachian minesoils (5), and is possibly applicable in evaluating the response of vegetables to solution P concentrations in other soil types (16, 20).

Materials and Methods

The minesoil material used in this study consisted of 6-year-old strip mine spoil (minesoil) which had not received any special treatment in addition to the normal reclamation procedure of fertilizing with 16–12–12 (N, P, K) at the rate of 392 kg/ha and seeding with a mixture of sericea lespedeza (*Lespedeza cuneata* G. Don.) and Kentucky-31 fescue (*Festuca arundinacea* L.). The minesoil material was highly variable with exposed, localized bands of gray, brown, and black material frequently encountered. The minesoil originated from parent material above the Lyons and Dorchester coal seams and consisted mainly of shales, siltstones, and sandstones in various stages of decomposition.

Three vegetable crops were grown on the same plots for 2 successive years. At the start of this study in 1978, the minesoil pH was adjusted to about 6.2 by disking in CaO at the rate of 2 MT/ha. K as KCl was applied according to soil test analysis and N as NH_4NO_3 was added based on standard recommendations for producing vegetables in Virginia. Dolomitic limestone was not added because the minesoil tested high in Mg. P was applied as triple superphosphate at 5 rates to adjust the soil solution P to 0.05, 0.10, 0.20, 0.40, and 1.60 ppm. Fertilizer rates needed to attain each desired solution P concentration were calculated, based on a predetermined minesoil bulk density of 1.64 g/cc, by converting μg P sorbed per g from a sorption isotherm curve to kg P/ha-furrow slice.

P-sorption curves were constructed following commonly used procedures (9) with some minor modifications. Duplicate 4-g

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samples of minesoil, screened through a 2-mm sieve, were equilibrated for 6 days at constant temperature in 40 ml of 0.01 M $CaCl_2$ containing various amounts of $Ca(H_2PO_4)_2 \cdot H_2O$ ranging from 0.01 to 100 ppm P. Two drops of toluene were added to minimize biological activity. Samples were shaken for 30 min twice daily. After 6 days, the samples were centrifuged at 2500 rpm for 10 min and filtered. P in the supernatant solution was determined colorimetrically (18, 27). The amount of P sorbed by the minesoil was calculated by the difference between the P content in the initial and final supernatant solutions. Sorption isotherms were constructed by plotting P sorbed vs. log P remaining in solution.

Sorption isotherms were again used in the spring of 1979 to determine the residual P levels from the previous year and to serve as a basis for applying additional fertilizer to re-establish the solution P levels for 1979 crop production. Isotherms were determined for each treatment plot originally established in 1978. In addition, a solution P level of 2.4 ppm was established for the first time in 1979. Cultural practices were similar both years, except K was not applied in 1979. All P and K and one-half of the N were broadcast prior to planting and disked to a depth of 15 cm with a power rototiller. The remaining one-half of the N was sidedressed at first cultivation for all crops.

Vegetable transplants were started in the greenhouse 8 weeks prior to field setting. Cultivars used were 'Red Pak' tomato, 'Cal Wonder' pepper, and 'Dusty' eggplant. The experimental design was a split-plot replicated 4 times, with vegetable species as main plots and fertilizer P rates as subplots. Each experimental unit was 12 m^2 (3×4 m), containing 18 plants, 6 of which were sampled for yield analysis. Fruit production is reported as marketable yield and percentage of relative yield. Relative yield was calculated at the yield at each specific level of solution P divided by the highest yield for each vegetable crop.

Tissue sampling and preparation were done as reported by Donohue and Hawkins (6). Leaf samples were taken at early fruiting and dried in a forced-air oven at 70°C for 24 hrs. Dried tissue was ground to pass through a 20-mesh sieve, ashed in a muffle furnace at 500° for 4 hrs, and P determined colorimetrically. Tissue P was plotted against solution P.

Results and Discussion

Initial and second-year soil P requirements. The initial P-sorption isotherm (Fig. 1) for the previously uncultivated minesoil showed a low to moderate capacity to sorb P. Addition of 110 μg P/g was required to establish a concentration of 0.2 ppm P in soil solution. This value is considerably lower than the P sorption reported in some agricultural soils (12, 16, 20). However, the initial P-fertilizer requirements (Table 1) were dispro-

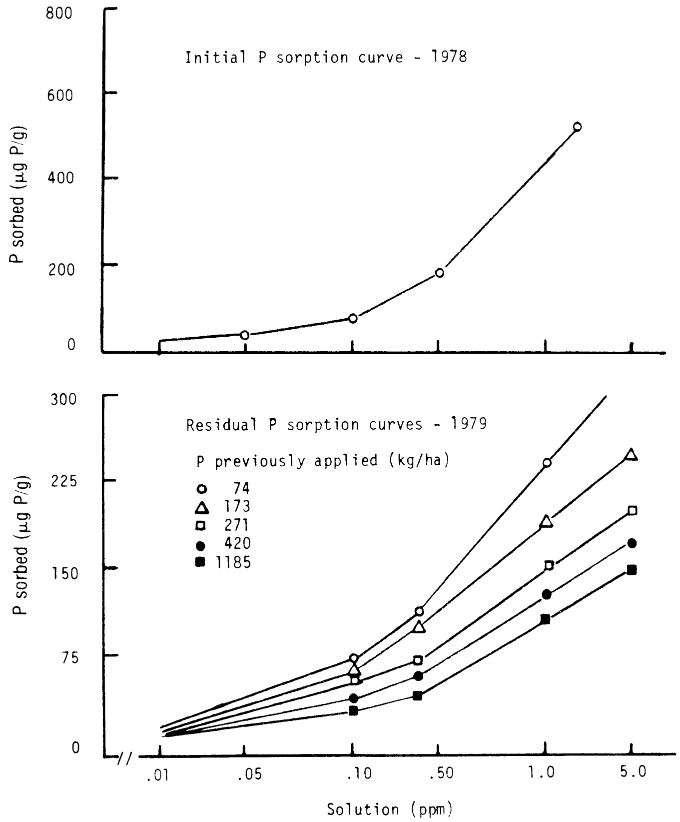

Fig. 1. Initial and residual P-sorption curves for minesoil in 1978 and 1979.

portionately high when compared to the levels of P sorbed. This was primarily the result of the compacted condition of the minesoil, as evidenced by a bulk density of 1.64 g/cc of soil. Since conversion of sorption values to P fertilizer is according to bulk density, soil compaction inflated the initial P-fertilizer requirements.

Fertilizer rates to re-establish solution P levels in 1979 were reduced compared to 1978. In every case P was required, even when rates as high as 1185 kg/ha were applied a year previous. Sorption isotherms (Fig. 1) determined from each of the 1978 treatments were displaced to the right and showed reduction in slopes, indicating a decreased sorption capacity. The concentration of residual P was apparent as the downward shift in each of the sorption curves in 1979 was in direct relation to the amount of P originally applied. These results clearly show the residual effect of high rates of fertilizer P. Consequently, the P requirements (Table 1) to re-establish solution P levels decreased by

Table 1. Initial and second-year fertilizer P required to establish desired solution P concentrations in minesoils.

	Initial P required, 1978		Second-year P required, 1979		Percentage of 1979 to 1978	
P in solution (ppm)	Sorbed (μ P/g soil)	Applied (kg/ha)	Sorbed (μ P/g soil)	Applied (kg/ha)	Sorbed (%)	Applied (%)
.05	30	74	25	60	83	81
.10	70	173	60	144	86	83
.20	110	271	55	131	50	48
.40	170	420	60	144	35	34
1.60	480	1185	104	248	22	21
2.40[z]	---	---	530	1309	---	--

[z]Initial establishment of 2.40 ppm P was in 1979.

19% at 0.05 ppm P in solution to 79% for 1.60 ppm P in solution. Soil compaction was reduced in 1979 as minesoil bulk density decreased to 1.59 g/cc of soil. This improvement was only slight and its effect on P fertility was probably minimal.

Plant growth and yield. Vegetable yield response to solution P levels was relatively consistent for both years of the study (Table 2). However, eggplant response was uniquely different than tomato and pepper. Highest yields of pepper and eggplant were one-half of national averages, while those of tomato were comparable (15).

An optimum P level in solution could not be identified for eggplant in 1978. Eggplant yields increased with each P increment in solution and at no point did yields level off or start to decrease. Regression analysis (Table 2) for 1978 showed highly significant linear relationships for the effects of minesoil solution P concentrations on eggplant yield. When the range of solution P was expanded in 1979, a yield plateau was established between 1.6 and 2.4 ppm solution P. This resulted in highly significant linear ($R^2 = 0.48$) and quadratic ($R^2 = 0.68$) relationships between solution P and eggplant yield. Estimated optimum solution P requirements from regression equations (Table 3) predicted maximum eggplant yields at 1.13 and 1.56 ppm solution P in 1978 and 1979, respectively. The predicted value of 1.56 ppm is considered to be a reliable estimate of the optimum solution P requirements since it is based on the establishment of a definite yield plateau. The relatively high solution P requirement of 1.56 ppm for eggplant may suggest a poor adaptation to minesoil, although similar results have been reported on other soils (20).

Table 2. Effect of minesoil solution P concentrations on marketable yield of 3 vegetable crops, 1978 and 1979.

Solution P (ppm)	Marketable vegetable yield (MT/ha)					
	1978			1979		
	Tomato	Pepper	Eggplant	Tomato	Pepper	Eggplant
.05	7.7	1.2	2.5	7.5	1.1	2.0
.10	13.9	2.5	3.4	12.6	3.6	3.6
.20	18.3	4.3	4.3	20.3	5.1	4.9
.40	15.9	3.7	5.2	18.2	4.8	6.4
1.60	13.6	3.4	6.3	12.4	4.1	7.2
2.40	---	---	---	5.5	1.3	6.9
Significance						
Linear[z]	NS	NS	**	*	NS	**
Quadratic[z]	**	**	*	**	**	**
Cubic[z]	**	**	NS	**	**	NS

[z]Significant at 5% (*), 1% (**), or nonsignificant (NS).

Tomato and pepper yields were depressed at high concentrations of solution P. This resulted in highly significant quadratic and cubic relationships between yield and solution P concentrations in these crops (Table 2). Optimum solution P requirements estimated from regression analysis (Table 3) for both species in 1978 were identical at 0.26 ppm and closely correlated with the field data. Estimated optimum solution P levels in 1979 increased to 0.72 ppm for tomato and 0.78 ppm for pepper. This appeared to contradict the field results which showed optimum solution P levels in the proximity of 0.2 to 0.4 ppm. When the 1979 yield data were analyzed without the observations at 2.4 ppm P, in an attempt to explain the discrepancy between observed and predicted data, the estimated optimum solution P concentrations decreased to 0.28 ppm in both tomato and pepper and R^2 values increased to about 0.95 (Table 3). It appears that the extreme yield reductions at 2.4 ppm solution P in combination with unequal spacings between solution P levels in the regression analysis caused disproportionate increases in the estimated optimum P requirements.

The sharp decrease in tomato and pepper yields between 0.2 and 2.4 ppm solution P indicated a possible P toxicity. Relative yields (Table 4) decreased 73% in tomato and 75% in pepper. Visual damage to both crops became apparent at 2.4 ppm solution P as a marginal necrosis on the older leaves, starting at the tip and progressing toward the base. Affected pepper plants also contained mild symptoms of interveinal chlorosis. Leaf P concentrations (Table 5) at which visual damage occurred were 0.72% in tomato and 0.46% in pepper. These values, while high, are not considered excessive for these vegetable species. In necrotic leaf tissue attributed to P toxicity, P concentrations have ranged from 0.9% in some pasture species (1, 14) to 1.2% in soybeans (7) and 4.5% in clover and oats (24). The lower leaf P concentrations found in this study may be the result of

Table 4. Relative yield response of 3 vegetable crops to minesoil solution P concentrations.[z]

Solution P (ppm)	Relative yield (%)					
	1978			1979		
	Tomato	Pepper	Eggplant	Tomato	Pepper	Eggplant
.05	42	28	40	37	22	28
.10	76	58	54	62	71	50
.20	100	100	68	100	100	68
.40	87	86	83	90	94	89
1.60	74	79	100	61	80	100
2.40	---	---	---	27	25	96

[z]Relative yield values are based on yield data contained in Table 2.

Table 3. Regression equations of minesoil solution P concentrations on vegetable yields for 1978 and 1979.

Season	Vegetable	Equation	Estimated optimum P (ppm)	R^2
1978	Tomato	$Y = 1.51 + 149.64x - 349.47x^2 + 162.91x^3$	0.26	.94
	Pepper	$Y = -0.66 + 41.56x - 94.12x^2 + 43.59x^3$	0.26	.88
	Eggplant	$Y = 2.33 + 9.20x - 4.19x^2$	1.13	.63
1979	Tomato	$Y = 7.69 + 49.22x - 45.30x^2 + 10.18x^3$	0.72	.78
	Pepper	$Y = 1.57 + 14.38x - 11.97x^2 + 2.47x^3$	0.78	.74
	Eggplant	$Y = 2.89 + 6.67x - 2.14x^2$	1.56	.68
1979[z]	Tomato	$Y = -0.51 + 173.26x - 386.86x^2 + 177.25x^3$	0.28	.96
	Pepper	$Y = -1.06 + 54.15x - 121.49x^2 + 56.04x^3$	0.28	.95

[z]Data are for the 1979 season without yield observations at 2.4 ppm solution P.

Table 5. Observed and estimated leaf P concentrations for 3 vegetable crops, 1979.[z]

Vegetable	Leaf P concn (%)						
	Solution P levels						
	0.5 ppm	0.1 ppm	0.2 ppm	0.4 ppm	1.6 ppm	2.4 ppm	Optimum leaf P
Tomato							
Observed	.27	.32	.41	.50	.59	.72	.41
Estimated	.35	.36	.37	.41	.60	.73	.37
	$Y = .342 + .161x$				$R^2 = .87$		
Pepper							
Observed	.23	.26	.28	.30	.36	.46	.28
Estimated	.26	.26	.27	.29	.39	.45	.27
	$Y = .251 + .084x$				$R^2 = .95$		
Eggplant							
Observed	.24	.26	.30	.33	.39	.50	.39
Estimated	.26	.27	.28	.30	.41	.49	.41
	$Y = .260 + .096x$				$R^2 = .94$		

[z]Based on observed solution P values of 0.2, 0.2, and 1.6 and estimated solution P values of 0.28, 0.28, and 1.56 for tomato, pepper, and eggplant, respectively (Table 3).

the adverse effects of the strip mine environment on plant growth. P uptake in eggplant increased to a maximum of 0.50% and showed no visible deleterious effects or significant yield reductions. For all vegetable species, plant P uptake was linear with increasing solution P levels as plants accumulated P in excess of their maximum yield requirements.

The severe yield reductions in tomato and pepper could not be attributed to a "P-induced" zinc (Zn) deficiency. Zn uptake (data not shown) decreased with increasing solution P concentrations in all vegetable crops. However, Zn leaf concentrations averaged 121 ppm in tomato and 103 ppm in pepper for the highest level of solution P. This compares favorably to the Zn levels (65–198 ppm) commonly found in tomato tissues at early fruiting (3). A leaf P concentration of 2.4% has been associated with "P-induced" Zn deficiency in tomato (22). This value is considerably above the P concentrations found in this study. In addition, "rosetting" and "little leaf," which are general symptoms of Zn deficiency, failed to develop in any of the plants. P-Zn interactions are complex and not thoroughly understood. Some researchers (17) have suggested that, as the P level in the plant tissue increases, the physiological requirement for Zn increases independent of the Zn tissue concentration.

Vegetable response to suboptimal solution P levels varied among species. Yields for each crop increased linearly until optimum P was reached. The rapid rise in the relative yield response for tomato and pepper suggests that these plants were highly sensitive to inadequate P. Based on relative yields, it appeared that tomato produced the best yields and eggplant the poorest at suboptimal P levels. This was not unexpected, since tomato possesses an expanded fibrous root system and is able to utilize a larger volume of soil and consequently a larger P reservoir. Eggplant, in contrast, has somewhat restricted root system, reducing its usable soil volume. The effect of this difference evidently becomes more apparent when solution P is limiting and, therefore, may account for the high solution P requirement (1.6 ppm) for maximum yield in eggplant.

Mycorrhizal associations can increase P uptake of crop species, especially at suboptimal soil P levels (25, 29). Normal microbial activity is generally disrupted in minesoils (23, 28). Yield response to suboptimal solution P levels in our experiments (Tables 2 and 4) was less than that reported for vegetable crops in agricultural soil (20). Reduced mycorrhizal associations might have been responsible for this difference.

The data demonstrate the specificity in the optimal P solution concentrations for vegetable crops in minesoil. Solution P levels (0.2 ppm) that produce maximum yields in tomato and pepper were deficient for eggplant. Conversely, the high solution P requirement (1.6 to 2.4 ppm) of eggplant caused significant yield reductions in tomato and pepper and resulted in visual symptoms associated with P toxicity in other species.

Optimal solution P concentrations for tomato and pepper were found to be quite exacting as slight deviations, either suboptimal or surplus, resulted in significant yield reductions. Some vegetables, such as cabbage, have shown a relatively flat yield response curve (20), indicating a good ability to utilize low levels of solution P.

Data from this study showed that optimal solution P concentrations remained relatively constant over a 2-year period, even though soil P-fertilizer requirements were considerably reduced by the effects of residual P. There appears to be little, if any, soil-type plant species interactions in terms of the optimum solution P concentration for crops grown in this study. The widely different optimum minesoil solution P levels for tomato and eggplant are similar to that reported for these 2 crops grown on other soil types (16, 20).

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Response of Blueberry Seedlings to a Range of Soil Types[1]

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Abstract. **The growth and elemental composition of a range of blueberry (*Vaccinium* sp.) progenies was greenhouse-tested on 5 unmulched soils. Three of the soils, low in pH and fertility, represented the physiographic regions of the eastern United States; Coastal Plain, Piedmont, and Appalachian Highlands; also included were a high-pH, high-fertility Piedmont soil and a commercial blueberry Coastal Plain soil. Two studies, 10 and 20 weeks in duration, were made with seedlings of crosses of blueberry clones of hybrid origin. Growth was significantly higher for seedlings grown on the commercial blueberry soil in both studies. *V. ashei* (rabbiteye) seedlings grew significantly larger than all others when measured over all soil types in one experiment but not the other. There were no significant differences in growth among the 4 progenies when averaged over all soil types. Percent sand was positively correlated with growth while both percent silt and clay were negatively correlated with growth. Plant composition was generally within acceptable levels for Ca, Mg, K, Fe, and Zn. Plant Mn and Al, although variable, tended to be higher than reported values. Soil Mn was significantly and negatively correlated with growth. It was possible to select individual seedlings which grew well on each of the mineral soils represented in the study.**

The production and cultivation of the highbush blueberry, which covers a broad climatic range from Maine to Florida, has been steadily increasing (10). Blueberries grow best in acidic, well-aerated, sandy soils which are indigenously high in organic matter or have been heavily mulched (1, 6, 8). The increased demand for the fruit, coupled with growing interest in pick-your-own operations, necessitates expansion of production onto less favorable soils which usually require heavy mulching or soil amending.

This study was initiated to examine factors, edaphic and/or genetic, which must be modified in order to grow blueberries on unmulched mineral soils. This report concerns a preliminary greenhouse study over a 2-year period using a range of soil types and blueberry germplasm. The specific objectives were: 1) to observe blueberry growth on different soils, as measured by short-term dry weight production, and 2) to examine tissue elemental composition in relation to soil nutrient levels.

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