Lime Fertilizer Interactions Affecting Vegetable Crop Production[1]

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ABSTRACT

Experiments at the North Willamette Experiment Station have evaluated response of vegetables to lime and other fertilizers since 1970. The soils are moderately acid (pH 5.4 to 5.6), high in P, and better drained than most soils used for vegetable crop production in western Oregon. Typical soil acidity problems such as Mn toxicity are probably less severe than for many soils with comparable pH values. Therefore, lime responses at this location might be less than would be expected for many Willamette Valley soils.

Increasing pH of this Willamette SiL from less than 5.7 to 6.0 or higher had positive effects on yield or quality of several vegetable crops. Liming to pH 6.0 or greater improved stand establishment of carrots, onions, lettuce, and cole crops and early crop growth was greater. Liming acid soils increases available P and Ca, and reduces possibly toxic levels of Mn and other heavy metals.

Table beet yields increased with increasing soil pH but B deficiency canker increased with increasing soil pH unless B was also applied. Carrots and bush beans also responded to lime application, but increasing soil pH beyond 6.0 did not consistently increase yield of these crops. Optimal pH for lettuce production was 6.4 or greater. At soil pH below 5.7, heavy N fertilization reduced lettuce growth. Sweet corn yields were increased by application of lime and/or banded P fertilizer. An application of lime to bring soil pH to 6.0 reduced the need for high rates of banded or broadcast P for maximum sweet corn yields. The major effect of lime on sweet corn production on this location is to increase availability of soil P, but tissue levels of Mn, Cu, Zn, and Ca are also affected. Sweet corn yields did not increase with application of Cu or B and high rates of P fertilizer did not induce a Cu deficiency.

The effects on plant growth of liming an acid soil are exceedingly complex. In addition to lowering H ion concentration (soil pH) and raising Ca concentration, lime reduces availability of Al and potentially phytotoxic heavy metals, and often increases availability of P, S, and Mo (7). Vegetable crop yield increases following application of lime to western Oregon soils are well documented (1, 2, 3, 4, 5). However, application of calcitic lime has reduced vegetable yields through reduced uptake of Mg or K (10).

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Availability of P is limited in cold soils (9). Most vegetable crops in western Oregon are seeded during periods of low soil temperatures and subsurface band placement of P fertilizers is recommended on several crops to increase available P in the root zone. One of the major effects of liming an acid soil is to increase P availability and uptake. The extent to which liming may reduce the need for P fertilization or increase availability of applied P has been poorly understood. The lime and P requirements of vegetable crops differ widely by species and even by cultivar, and the optimum soil pH for a crop can vary by as much as a unit depending on soil organic matter content, clay type, and levels of P and minor elements (7).

Predicting crop response to lime application solely on the basis of soil pH has been only partially successful and vegetable crops have responded to band application of P even in the presence of high soil P levels and large applications of broadcast P (8). Interaction of P and lime with other yield limiting nutrients such as N, B, and Cu must also be considered in vegetable fertility programs. The effects of lime and its interactions with P, N and other nutrients on vegetable crop yields and elemental concentration have been investigated at the North Willamette Experiment Station since 1973 (2, 3, 4, 5, 8). Crops included in these studies were table beets, spinach, carrots, bush beans, lettuce, sweet corn, cauliflower, and onions. This report is a brief summary of some of these experiments with major emphasis on important interactions of lime application with P and other fertilizer elements.

MATERIALS AND METHODS

All studies were conducted on Willamette silt loam (Pachic Ultic Argixeroll) soils at three different sites at the North Willamette Experiment Station, Aurora, Oregon. The pH of the unlimed soil was usually 5.5 to 5.7. Applications of elemental S at 1.0 T/A or lime at rates as high as 8 T/A in randomized complete block design have resulted in plots with a soil pH range of 5.0 to 6.6. Other fertilizer variables such as N rate, P rate, B, or Cu were applied as splits of the lime variable main plots. Details of the experimental procedures for each crop are published elsewhere (2, 3, 8).

In the 1974 table beet experiments, the main lime plots of pH 5.8, 6.3, and 6.6 were split by application of B at 0, 3, or 6 lb/A and again by N at 150 or 250 lb/A. In 1976, the main lime plots of pH 5.2, 5.7, 6.2, and 6.6 were split by B at 0 or 3 lb/A, again by N at 50, 150, or 250 lb/A, and again by banded P at 0 or 50 lb/A (88 lb P_2O_5/A). 'Detroit Dark Red' cultivar was used in each experiment.

In the bush bean, carrot, and lettuce experiments in 1977 and 1978, the main lime plots of pH 5.1, 5.7, 6.4, and 6.6 were split by N at 0, 50, 100, and 150 lb/A (1977) or N at 50 and 150 lb/A (1978). In 1979, the main plots of pH 5.3, 5.6, 5.9, and 6.1 were split by N at 30, 130, and 230 lb/A. Cultivars were 'Blue Lake 274' bush bean, 'Ithaca' lettuce, and 'Chantenay' carrot.

In the sweet corn experiments in 1980, main lime plots of pH 5.5, 5.9, 6.2, and 6.4 were split by broadcast application of Cu at 10 lb/A and B at 20 lb/A in 2x2 factorial and again by banded P at 30 or 70 lb/A. In 1981, the same set of main lime plots were split by broadcast of P at 0 or 70 lb/A and again by banded P at 30 or 70 lb/A. In 1982, main lime plots of pH 5.4 and 6.0 were split by application of banded P at 0, 30, or 70 lb/A or banded P at 70 lb/A plus 10 lb Cu/A broadcast. Details of the sweet corn field and laboratory procedures, including N and irrigation rates, have been published elsewhere (8).

RESULTS AND DISCUSSION

1. Lime effects on seedling stands.

Liming an acid soil increases yield primarily through its effects on the nutritional status of the established seedling. However, liming also exerts an earlier effect; seedling emergence is often increased by liming an acid soil. Whether this effect is caused by increased availability of P or Ca, reduced toxicity of Mn, Al, or H, or improved soil mechanical properties is poorly understood. Plant tissue analysis is difficult because of the small amount of plant material available in the seedling stage and problems with data interpretation. On Willamette soil, liming has consistently increased seedling stands (Table 1) in the presence of varying rates and methods of application of other fertilizers. Stand increases with liming have occurred most consistently with small-seeded crops such as carrots, cole crops, and lettuce, but have also been observed with bush beans and sweet corn on more acid soils (pH 5.5). The tendency for stands of small seeded crops to decrease at pH 6.4 and higher (Table 1) has been fairly consistent on Willamette soil. The data presented in Table 1 are representative of results obtained in several experiments between 1978 and 1982.

2. Table beets: Effects of lime, N, P, and B.

Total yield of beet roots increased with increasing soil pH in both 1974 and 1976 (Table 2). In 1974, liming to pH 6.6 did not increase yields over those obtained at pH 6.3. However, in 1976, yields were higher at pH 6.6 than at pH 6.2. Application of B and P did not affect yields and the highest yields were obtained at the highest rate of applied N. Responses to lime and N were approximately additive and there were no significant lime x N interactions. Only mean yields for each soil pH are shown in Table 2. Liming increased leaf P and decreased leaf Mn concentrations markedly. Most of the yield response to lime can be attributed to increased availability of P and reduction of Mn toxicity. Since these effects occur simultaneously, it is difficult to specifically identify a single cause and effect relationship. Application of B increased leaf B concentrations and reduced incidence of root canker (B deficiency). Liming decreased leaf B concentrations, but increased canker only in the absence of applied B. For maximum production of quality table beets in western Oregon, soil pH should be at least 6.0, N should be applied at 200 or more lb/A, and B should be applied to reduce canker incidence if soil B is low or marginal.

3. Bush beans, carrots, lettuce: Effects of lime and N.

Application of lime increased yields of carrots and lettuce in each of the three years and increased bean yields in 1977 and 1979 (Table 3). Nitrogen application also increased yields but data shown in Table 3 are averaged over N rates. Highest bean yields in 1977 were at pH 6.4 or 6.6, but were not significantly higher than at pH 5.7. In 1979, highest bean yields were at pH 6.1. Liming consistently increased bean leaf P concentration and reduced leaf Mn concentration (Table 3). The highest bean leaf Mn concentration in these experiments was 415 ppm (1977, pH 5.1, 100 lb N/A). This is above the normal range but below the level of 600 ppm where visible toxicity symptoms have been noted (6). Obvious Mn toxicity symptoms were not present but yield reduction can occur even in the absence of visible symptoms. Liming also significantly increased bean leaf Ca and decreased bean leaf Zn concentrations. The bean yield increases with lime are attributable to a combination of reduced Mn levels and increased P and Ca uptake.

Carrot yields at the highest lime rate were not significantly greater than at lower rates of lime and yield increases did not correlate strongly with leaf tissue nutrient levels. Increased yields with lime may have resulted as much from increased stands as from improved plant nutrition.

Lettuce yields increased markedly with liming (Table 3). At pH 5.1 plants remained stunted, chlorotic, and failed to head. Liming significantly increased leaf P and decreased leaf Mn concentrations several fold (Table 3). Lime and N interacted significantly in affecting lettuce yield (Table 4): increasing N applications decreased yields at pH 5.1 or 5.7 but increased yields at higher pH. A similar interaction occurred in 1979. Levels of lettuce leaf Mn as high as 760 ppm (1979, 230 lb N/A, pH 5.3) occurred in plants grown on unlimed soil. Symptoms of Mn toxicity including stunting, marginal and interveinal chlorosis, and necrotic spots, were present at soil pH below 5.6. Increased lettuce yields with liming can be attributed mainly to elimination of Mn toxicity. Levels of leaf Mn above 200 ppm appear to be toxic in young seedlings. However, reduction of Al or H toxicity or improved uptake of P with liming may also have increased lettuce yields.

4. Sweet corn: Effects of lime, broadcast and banded P, Cu, and B.

In 1980, both lime and banded P application significantly increased the yield of mature ears of an early June sweet corn planting for each of two harvest dates separated by three days (Table 5). Lime significantly increased yield at all three rates of banded P at the second harvest. The high P rate increased yields over the low rate at each lime treatment rate at both harvests. Application of Cu and B did not affect yields; however, leaf tissue Cu and B concentrations were increased with Cu and B applications, respectively (data not shown). Lime application increased leaf tissue P at tasselling (Table 6). Banded P application significantly increased leaf P concentration (Table 6) and decreased leaf Cu from 8.2 to 7.5 ppm and leaf Zn from 38 to 35 ppm. Yield of mature ears increased linearly with increasing leaf P concentration ($r=.60$, $P<0.05$). However, leaf tissue P levels explain only a portion of the yield response to P, since at pH 6.2 or greater, yields were still increased by added banded P without a corresponding increase in leaf P concentration (Tables 5 and 6). However, with increased yields with high P and lime, total P uptake would be greater even in the presence of the same leaf P concentration. Broadcast P also increased yields, particularly at low rates of banded P (Table 7).

Trade offs in lime, broadcast P, or banded P application may be made. At zero lime application, the higher rates of P are necessary to achieve maximum yields; however, at higher soil pH the added yield resulting from P application is smaller.

In 1981, separate plantings were made on May 11 and June 3. For the early planting date (Table 8), liming increased mature ear yield at each of two harvests spaced four days apart. The lime effect was more pronounced in the absence of banded P and at the early harvest. Banded P significantly interacted with lime; banded P increased mature ear yield at the first harvest in the absence of lime, but the high P rate tended to reduce mature ear yield at high soil pH. Banded P tended to reduce yields at all soil pH levels at the second harvest, but the effect was not statistically significant. In the late planting, lime significantly increased mature ear yield at each of two harvests, for all rates of banded P (Table 9). The lime response was most pronounced in the absence of banded P. The low rate of banded P increased yield at the first harvest for all but the highest rate of lime, with high P rate increasing yields further only in the absence of lime. At the second harvest the low rate of banded P increased mature ear yield only in the absence of lime. As in 1980, highest yields were obtained at low soil pH only with added banded P. Broadcast P added to banded P did not affect mature or total ear yield for the early planting but raised yield at both harvests for the late planting date (Table 10). The increase was greatest at lower soil pH. This response to broadcast P at the late but not the early planting may be attributed to higher soil temperatures and increased P availability at the later planting. Banded P tended to increase leaf P concentrations, but the increases were not as great as in 1980. Lime and broadcast P each increased leaf P, particularly with the late planting. Liming decreased leaf Cu, Mn, and Zn concentrations. Banded P decreased leaf Cu concentration slightly.

In 1982, liming to increase soil pH from 5.4 to 6.0 increased mature ear yield and cutoff yield only in the absence of banded P. Mature ear yields increased with each rate of banded P in the absence of lime, but banded P did not affect ear yield in the presence of lime. Banded P increased cutoff yield at either soil pH (Table 11). Application of banded P at the low rate increased leaf P with a further increase from the high rate of banded P. Lime increased leaf P only in the absence of banded P (Table 11). Addition of Cu to the high rate of banded P increased leaf Cu content (data not shown) but had no effect on yield (Table 11).

5. Summary.

Soil pH has a marked effect on yield of all vegetable crops tested. On Willamette SiL, a pH of 6.0 is adequate for all crops except leafy greens, which require a soil pH of at least 6.4 on this location. The major effects of increasing soil pH are to increase stand establishment, early growth, and ultimately yield. Reduced soil acidity increases availability of native or applied P and reduces plant tissue Mn content. Band placement of P fertilizer is more effective than broadcast applications on cold, wet soils. Higher rates of banded P are necessary to achieve maximum sweet corn yields at low soil pH.

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Table 1. Effect of Soil Acidity on Stand Establishment of Vegetables, 12 Days after Seeding, June, 1979.

Soil pH	Stand (seedlings/m) Carrot	Cauliflower	Lettuce	Spinach
5.0	12.0	13.4	4.4	25.0
5.6	18.5	14.8	7.7	27.5
6.2	21.0	20.4	14.0	35.0
6.4	19.1	18.2	9.3	34.0
LSD(0.05)	1.9	2.1	1.7	4.8

Table 2. Effects of Soil Acidity on Table Beet Yield and Leaf Elemental Concentrations, 1974 and 1976.

Year	S/lime rate	Soil pH	Size grade (in. diam.) <1	1-2	>2	Total	Leaf+ P	Leaf Mn
1974	tons/acre		- - - - tons/acre - - - - - -				%	ppm
	check	5.8	0.6	7.7	3.3	11.6	0.53	993
	lime, 4.0	6.3	0.5	8.5	8.7	17.9	0.63	374
	lime, 8.0	6.6	0.8	9.0	8.2	18.0	0.68	292
	LSD(0.05)		NS‡	0.8	1.1	1.8	0.07	71
1976	S, 1.0	5.2	1.0	6.0	0.6	7.7	0.21	788
	Check	5.7	2.1	12.2	1.1	15.4	0.22	372
	lime, 4.0	6.2	2.4	19.1	1.3	23.0	0.24	153
	lime, 8.0	6.6	2.7	21.3	1.6	25.6	0.24	109
	LSD(0.05)		0.3	1.5	0.4	1.8	NS	39

+Leaf samples taken at 1 inch root diameter in 1974 and 2 inch diameter in 1976.

‡NS: Not significant, 5% level.

Table 3. Effects of Soil Acidity on Fresh Yield+ and Elemental Concentrations of Bush Bean, Carrot, and Lettuce, 1977-1979.

Year	Soil pH	Bush bean Yield	Bush bean P	Bush bean Mn	Carrot Yield	Carrot P	Carrot Mn	Lettuce Yield	Lettuce P	Lettuce Mn
		T/A	%	ppm	T/A	%	ppm	T/A	%	ppm
1977	5.1	6.7	0.21	359	5.8	0.19	144	1.5	0.24	330
	5.7	8.9	0.25	151	9.3	0.21	68	12.0	0.30	134
	6.4	9.3	0.29	107	11.1	0.23	51	23.8	0.34	74
	6.6	9.3	0.32	97	11.6	0.23	61	24.4	0.36	76
LSD(0.05)		0.7	0.05	49	1.4	NS‡	33	5.8	0.08	45
1978	5.1	5.4	0.22	198	5.8	0.17	75	1.9	0.26	186
	5.7	6.7	0.22	141	9.3	0.16	42	13.8	0.32	64
	6.4	5.8	0.23	117	8.9	0.17	29	17.3	0.34	36
	6.6	6.2	0.34	103	9.7	0.18	27	16.4	0.36	37
LSD(0.05)		NS	0.04	41	1.1	NS	10	1.6	0.05	42
1979	5.3	4.0	0.22	137	12.0	0.18	132	3.3	0.27	610
	5.6	5.4	0.25	96	13.8	0.19	80	11.6	0.39	177
	5.9	5.8	0.26	87	13.8	0.19	58	15.6	0.39	152
	6.1	6.2	0.27	72	14.2	0.18	54	18.2	0.45	86
LSD(0.05)		0.5	0.03	17	0.6	NS	31	2.4	0.08	38

+Yields averaged over all rates of N.

‡NS: Not significant, 5% level.

Table 4. Interaction of Soil Acidity and N Rate on Yield of Lettuce, 1977.

N rate (lb/A)	Soil pH 5.1	5.7	6.4	6.6
	- - - - - - - -Yield (T/A)- - - - - - - -			
0	2.3	21.3	21.3	21.3
50	1.9	15.6	22.2	23.1
100	0.6	7.1	24.9	25.3
150	0.8	3.6	25.3	28.0

LSD(0.05), yield = 2.7 T/A.

Table 5. Effects of Lime and Banded P on Sweet Corn Mature Ear Yields+, 1980.

Soil pH	First harvest (9/22)			Second harvest (9/25)		
	Banded P, lb/A					
	0	30	70	0	30	70
	- - - - - - - - - - - tons/A - - - - - - - - - - - -					
5.5	1.1	7.0	7.6	2.9	9.4	10.1
5.9	2.9	7.5	7.9	6.7	9.8	10.0
6.2	3.2	7.6	8.4	4.9	9.2	10.2
6.4	3.3	7.6	8.1	5.9	10.1	10.6

LSD(0.05), within harvests = 0.5.

+Yields averaged over all rates of B and Cu.

Table 6. Effects of Lime and Banded P on Sweet Corn Leaf P Concentration, 1980.

Soil pH	Banded P, lb/A 0	30	70	Soil pH mean
	- - - - - - - - % - - - - - - - - - - - -			
5.5	.24	.30	.33	.29
5.9	.28	.32	.37	.32
6.2	.32	.29	.32	.31
6.4	.34	.33	.38	.35
Banded P mean:	.30	.31	.35	

LSD(0.05), banded P rate = 0.02; LSD(0.05), lime rate = 0.02.

Table 7. Effects of Broadcast P and Banded P on Sweet Corn Mature Ear Yields[+], 1980.

Broadcast P lb/A	First harvest (9/22)			Second harvest (9/25)		
	Banded P, lb/A					
	0	30	70	0	30	70
	tons/A					
0	3.8	4.9	7.7	10.1	10.9	11.5
70	5.1	8.3	8.1	11.2	11.1	11.6

[+]Yields averaged over all rates of lime, B, and Cu.

Table 8. Effects of Lime and Banded P on Sweet Corn Mature Ear Yield[+], Early Planting, May 11, 1981.

Soil pH	First harvest (8/31)			Second harvest (9/3)		
	Banded P, lb/A					
	0	30	70	0	30	70
	tons/A					
5.6	7.8	8.9	9.4	11.0	10.8	10.5
6.0	9.9	9.8	10.4	11.7	11.2	11.5
6.2	10.4	10.5	10.0	12.3	11.5	11.1
6.6	11.2	10.7	10.4	11.4	11.2	10.7

[+]Yields averaged over all rates of broadcast P.

Table 9. Effects of Lime and Banded P on Sweet Corn Mature Ear Yield[+], Late Planting, June 3, 1981.

Soil pH	First harvest (9/14)			Second harvest (9/17)		
	Banded P, lb/A					
	0	30	70	0	30	70
	tons/A-					
5.6	2.7	4.7	5.8	4.9	6.4	7.2
6.0	5.7	7.2	6.8	7.6	8.0	7.7
6.2	6.4	7.6	7.4	8.9	8.6	8.8
6.6	7.2	7.4	7.5	8.8	8.8	8.6

[+]Yields averaged over all rates of broadcast P.

Table 10. Effects of Lime and Broadcast P on Sweet Corn Mature Ear Yield[+], Late Planting, June 3, 1981.

Soil pH	First harvest (9/14)		Second harvest (9/17)	
	Broadcast P, lb/A			
	0	70	0	70
	- - - - - - - - - - tons/A - - - - - - - - - -			
5.6	4.3	6.2	5.7	7.8
6.0	6.1	7.9	7.1	8.6
6.2	7.5	7.5	8.5	8.9
6.6	6.7	8.1	8.4	9.0

LSD(0.05), first harvest = 0.9; LSD(0.05), second harvest = 0.6.

[+]Yields averaged over all rates of banded P.

Table 11. Effects of Lime and Banded P on Sweet Corn Mature Ear Yield and Cutoff, and Leaf P Concentration, 1982.

Banded		Soil pH					
		5.4	6.0	5.4	6.0	5.4	6.0
P	Cu	Mature Ear Yield		Cutoff ratio		Leaf P Concentration	
-lb/A-		- - tons/A - - -				- - - - % - - - - - - -	
0	0	9.5	10.7	0.42	0.45	0.33	0.38
30	0	10.8	10.1	0.50	0.49	0.42	0.41
70	0	11.6	11.0	0.46	0.49	0.46	0.45
70	10	11.3	10.3	0.47	0.51	0.46	0.47