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Effect of Soil Acidity and Nitrogen on Yield and Elemental Concentration of Bush Bean, Carrot, and Lettuce[1]

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Abstract. **Bush beans (*Phaseolus vulgaris* L.), carrots (*Daucus carota* L.), and lettuce (*Lactuca sativa* L.) were grown for 3 years on soils amended with S or lime and N fertilizer. Yields of all crops increased with lime application but response to N varied among crops and years. Lettuce head weight tended to increase with N application at pH greater than 6.0, but it decreased with N application at lower pH levels. A soil pH of 5.6 to 6.4 was optimal for carrots and beans, and of 6.1 to 6.6 for lettuce. Plant tissue K and Mg concentrations were not affected by soil pH or N rate. Phosphorus and Ca concentration of plant tissue generally increased with lime application. Plant tissue Zn and Mn concentration usually decreased with increasing soil pH between pH 5.1 and 6.4. The reduction in bean and lettuce leaf Mn concentration between pH 5.1 and 5.7 ranged from 30 to 71%. Low bean yields at pH 5.1 were possibly caused by a combination of Mn toxicity and P deficiency. Failure of lettuce to head at low pH may have been caused by Mn toxicity.**

Soil acidity effects on plant growth are complex, and may be influenced by differences in sensitivity of species and cultivars, soil microorganisms, soil types, and nutrient availability. Hydrogen ion toxicity is seldom a factor in poor plant growth except at pH below 4.5 (3). Calcium (14), P (18), and Mo (2) deficiencies have been implicated in poor growth of plants on acid soils. Manganese (4, 6, 9) and Al (12, 18) toxicity have also been cited as being responsible for poor plant growth on acid soils. Some investigators (10, 11) have concluded that the primary benefit of liming acid soils is the reduced concentration of Mn and Al in the soil solution.

The use of soil pH alone as an indicator for predicting crop response to lime application on acid soils has been only partially successful. In addition to differences in species and cultivar response, the maximum pH at which a crop may respond to lime application can vary by as much as 1 unit depending on the organic matter content, type of clay, and P levels present in a soil (1).

The soils of western Oregon are moderately to strongly acidic and most crops respond favorably to application of lime. The following experiments were conducted to determine the response to lime and N fertilizer of 3 vegetable crops, and to identify soil pH levels and plant tissue elemental concentrations which would be useful in predicting crop response to lime application.

Materials and Methods

Elemental S at 2.25 Mt/ha and agricultural limestone flour (95% $CaCO_3$ equivalent, less than 0.7% $MgCO_3$) at 0, 9.0, and 18.0 MT/ha were applied to 188 m^2 plots of Willamette silt loam (Pachic Ultic Argixeroll, fine-silty, mixed, mesic) 2 years prior to planting the first crop. Resulting soil pH averaged 5.1, 5.7, 6.4, and 6.6, respectively, at planting time. These plots were used in 1977 and 1978.

Agricultural limestone flour at 0, 4.5, 9.0 and 13.5 MT/ha was applied to 213 m^2 plots of Willamette silt loam 6 months prior to planting in 1979. Resulting soil pH averaged 5.3, 5.6, 5.9, and 6.1, respectively. In both cases, lime treatments were in randomized block design with 4 replications.

In 1977, the pH level main plots were randomly split into 4 subplots with N rates of 0, 56, 112, and 168 kg N/ha, as NH_4NO_3.

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In 1978, the main plots were randomly split into 2 subplots with N rates of 56 and 168 kg N/ha. In 1979, the main plots were randomly split by application of 34, 146, and 258 kg N/ha. All N was broadcast immediately after planting.

Applications of P as concentrated superphosphate and K as KCl were broadcast and plowed down prior to planting at kg/ha rates of 108 and 112 in 1977, 98 and 187 in 1978, and of 67 and 34 in 1979.

Cultivars of bush bean grown were 'Blue Lake 274', 'Spartan Arrow', and 'Tendercrop', in 1977, 1978, and 1979, respectively. 'Ithaca' lettuce and 'Chantenay' carrot were grown in all 3 years. Row spacings were 0.5 m in 1977 and 0.75 m in 1978 and 1979. Planting dates were June 6, 1977, May 25, 1978, and May 31, 1979. Beans and carrots were planted to a stand of approx. 13/m and 48/m, respectively. Lettuce was thinned to in-row spacing of approx. 15 cm.

Herbicide applications were made in accord with standard commercial practice for each crop (13). No fungicides or insecticides were used. Overhead sprinkler irrigation was applied as needed.

In 1977 and 1978, plant tissue was collected for elemental analysis as follows: bean, 20 middle leaflets/subplot of youngest mature trifoliate just prior to bloom; carrot, 20 petioles/subplot at early taproot formation; lettuce, 20 outer leaves/subplot just prior to heading. In 1979, each crop was sampled 3 times: once at the above growth stages; about 2 weeks earlier and 2 weeks later than above for beans and lettuce; and 3 weeks earlier and later for carrots. Each crop was harvested at market maturity.

Plant samples were dried at 60°C and ground in a stainless steel Wiley mill to pass a 20-mesh sieve. Subsamples (1.0 g) were digested with HNO_3:$HClO_4$, heated to dryness, and the ash dissolved 1N HCl. Phosphorus was assayed by a colorimetric molybdate-vanadate method (7). Calcium, K, Mg, Mn, and Zn were analyzed by air-acetylene flame atomic absorption.

Results and Discussion

In 1977, bean pod yield increased significantly with an increase in soil pH from 5.1 to 5.7. Increasing soil pH to 6.4 or 6.6 did not further increase yield. Pod yield also increased with N application up to 112 kg N/ha (Table 1). Bean pod size distribution did not vary significantly with treatment (data not shown). In 1978, bean stands were significantly affected by birds and neither N nor soil pH significantly affected yield. In 1979, yield increased significantly with lime application, but the yield response to N was not significant. Greatest yield was obtained at pH 5.9 or 6.1 (Table 1).

Carrot yield increased with an increase in soil pH from 5.1 to 5.7 in 1977 and 1978 and from 5.3 to 5.6 in 1979. Increasing soil pH beyond 5.7 resulted in a further yield increase only in 1977 (Table 1). At the wide between-row spacings used in these experiments, the lowest N rate was adequate each year (Table 1). The high rate of N reduced carrot stands by 13% in 1978 and 9% in 1979 ($P \leq 0.05$), compared to the low N rate. The decreased stands may have contributed to decreased yields at higher N rates in 1978 and 1979 (Table 1). Stand counts were not made in 1977.

Lettuce head weight increased significantly with an increase in soil pH in all 3 years (Table 1). When soil pH was reduced by the addition of S, or on unlimed soil with high rates of N, plants were severely stunted, chlorotic, and failed to produce heads. Soil pH and N interacted significantly in affecting lettuce yield in 1977: increasing N applications resulted in decreased mean head weight at pH 5.7, but head weight increased with 112 or 168 kg N/ha at higher soil pH (Table 2). A similar interaction occurred in 1979 (Table 2). High N rates reduced lettuce seedling emergence; however, since plants were thinned to uniform stand, yield potential was not affected.

Yield results of the first 2 years demonstrated that the optimal pH for all crops was in the 5.7 to 6.6 range. A pH of 5.1 was definitely too low, and application of lime at 18 MT/ha (pH 6.6) did not increase yields over those obtained with 9 MT/ha (pH 6.4). In addition, lettuce and carrot stands tended to be reduced at the high lime rate (data not shown). In 1979, the experiments were designed with a narrower soil pH range to define more closely the optimal pH range for each crop. Only lettuce yield increased significantly with the highest rate of lime application

Table 1. Effects of N rate and soil pH on fresh yield of bush bean pods, carrot roots, and lettuce.

Year	N rate (kg/ha)	Yield (MT/ha) Bean	Carrot	Lettuce	Soil pH	Yield (MT/ha) Bean	Carrot	Lettuce
1977	0	15	20	37	5.1	15b[y]	13c	3.3c
	56	18	24	35	5.7	20a	21b	27b
	112	22	21	33	6.4	21a	25a	53a
	168	22	21	33	6.6	21a	26a	55a
Significant effects[z]		L**Q**	NS	L**		**	**	**
1978	56	13	21	28	5.1	12	13b	4.1c
	168	15	17	27	5.7	15	21a	31b
					6.4	13	20a	39a
					6.6	14	22a	37a
Significant effects		NS	NS	NS		NS	*	**
1979	34	12	64	31	5.3	9.0c	54b	7.2d
	156	12	60	27	5.6	12b	62a	26c
	268	11	58	25	5.9	13ab	62a	35b
					6.1	14a	64a	41a
Significant effects		NS	L**	L*		**	**	**

[z]Linear (L); quadratic (Q); not significant (NS); 5% level (*); 1% level (**).
[y]Mean separation within columns for each year by Duncan's multiple range test, 5% level.

Table 2. Interaction of N rate and soil pH on yield of lettuce.

Year	N rate (kg/ha)	Yield (MT/ha) Soil pH 5.1	5.7	6.4	6.6
1977	0	5.1fg[z]	48c	48c	48c
	56	4.2fg	35d	50c	52bc
	112	1.4g	16e	56b	57b
	168	1.9g	8.1f	57b	63a
		Soil pH 5.3	5.6	5.9	6.1
1979	34	9.8g[z]	38bc	35cd	39bc
	156	5.5g	24e	33d	44a
	268	5.7g	16f	36bcd	40ab

[z]Mean separation within each year by Duncan's multiple range test, 5% level.

(Table 1). All rates of lime application appeared equally effective for carrot production. Bean yields increased significantly with the first increment of lime, but higher rates of lime did not further increase yields (Table 1).

The application of lime and N did not significantly affect the K and Mg concentration of bean and lettuce leaves, or carrot petioles, in any of the 3 years (data not shown). K concentrations averaged 2.2%, 8.0%, and 5.7%, and Mg concentrations 0.33%, 0.24%, and 0.35%, for beans, carrots, and lettuce, respectively.

Increased soil pH was associated with increased P concentration of bean and lettuce leaves in 1977 and 1978 (Table 3). Lime application is known to increase availability of P in western Oregon soils that are high in content of hydrous oxides of Fe and Al (8, 9). In 1979, leaf or petiole samples were taken at intervals to determine effects of growth stage and nutrient availability on elemental conditions. Lettuce leaf P concentration increased with increasing soil pH at the first 2 growth stages but not at the third (Table 4). However, bean leaf P concentration increased with increasing soil pH at the second and third samplings but not at the first (Table 4). Leaf P concentration tended to increase with crop maturity in both lettuce and bean. Thus, growth stage is important in determining nutrient deficiencies or response to fertilizer applications. Bean leaf tissue was marginally P deficient at the early growth stage, whereas 4 weeks later leaf P concentration of plants grown on limed soil was above the deficiency level of 0.25% (5). Carrot petiole P concentration did not change as a function of soil pH in any year.

Bean leaf Ca concentration significantly increased with increasing soil pH in 1979 (Table 4) and tended to increase with pH in 1977 and 1978 (Table 3). Carrot petiole Ca concentrations also tended to increase with increasing soil pH, but the increase was statistically significant only in 1977 (Table 3).

Lettuce leaf Ca concentration decreased with an increase in soil pH from 5.1 to 5.7 in 1977 and 1978 (Table 3). Further increases in soil pH were associated with increased leaf Ca concentration in 1978. In 1979, lettuce Ca concentration decreased with increasing soil pH at the first 2 samplings, but increased with soil pH at the third sampling (Table 4). The reduction in lettuce leaf Ca concentration with the first increment of lime was associated with a large increase in yield, increased leaf P concentration, and decreased Mn concentration. Reduced Ca concentration associated with lime application may be interpreted as a dilution effect when plant Ca concentrations are not deficient and plant growth is greatly accelerated.

Bean leaf Zn concentration decreased with increasing soil pH up to pH 6.4 in 1977 and 1978 (Table 3), but was unaffected in 1979 (Table 4). Soil Zn availability is known to decrease after liming (17). Bean leaf Zn concentrations at high pH in 1977 and 1978 were somewhat below the normal range of 30–60 ppm (5) and possible foliar symptoms of Zn deficiency (chlorotic mottle, reduced leaf size) were noted. However, presence of foliar symptoms and low leaf Zn concentration were not associated with yield reduction.

Carrot petiole and lettuce leaf Zn concentration also decreased with an increase in soil pH from 5.1 to 6.4 in 1977 and 1978 (Table 3). In 1979, carrot and lettuce Zn concentration decreased with lime application, but the magnitude of the decrease lessened as the crop matured (Table 4).

Mn concentration in bean and lettuce leaves and carrot petioles decreased with increasing soil pH in each year, with most of the

Table 3. Main effect of soil pH on elemental concentration of bean and lettuce leaf and carrot petiole tissue, 1977 and 1978.

Crop	Soil pH	1977 P (%)	1977 Ca (%)	1977 Zn (ppm)	1977 Mn (ppm)	1978 P (%)	1978 Ca (%)	1978 Zn (ppm)	1978 Mn (ppm)
Bean	5.1	0.21c[z]	2.28	31a	359a	0.22b	2.40	33a	198a
	5.7	0.25bc	2.44	29ab	151b	0.22b	2.48	29ab	141b
	6.4	0.29ab	2.66	26b	107bc	0.23b	2.90	22b	117b
	6.6	0.32a	2.54	26b	97c	0.34a	2.75	23b	103b
Significant effects		*	NS	**	**	*	NS	*	**
Carrot	5.1	0.19	1.18b	26a	144a	0.17	1.01	30a	75a
	5.7	0.21	1.18b	21b	68b	0.16	1.01	21b	42b
	6.4	0.23	1.34a	18c	51b	0.17	1.09	15c	29c
	6.6	0.23	1.37a	18c	61b	0.18	1.16	14c	27c
Significant effects		NS	*	**	**	NS	NS	**	**
Lettuce	5.1	0.24b	1.23a	44a	330a	0.26b	1.04a	41a	186a
	5.7	0.30ab	0.95b	40a	134b	0.32a	0.77b	40a	64b
	6.4	0.34a	1.01b	31b	74c	0.34a	0.92ab	30b	36b
	6.6	0.36a	1.01b	29b	76c	0.36a	1.02a	29b	37b
Significant effects		*	*	**	**	**	*	**	**

[z]Mean separation within columns for each crop by Duncan's multiple range test, 5% level.
NS, *, **Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

Table 4. Main effect of soil pH on elemental concentration of bean and lettuce leaf and carrot petiole tissue, 1979.

		First sampling				Second sampling				Third sampling			
Crop	Soil pH	P (%)	Ca (%)	Zn (ppm)	Mn (ppm)	P (%)	Ca (%)	Zn (ppm)	Mn (ppm)	P (%)	Ca (%)	Zn (ppm)	Mn (ppm)
Bean	5.3	0.17	2.02c[z]	33	208a	0.19	1.73	37	147	0.22b	2.05b	27	137a
	5.6	0.17	2.35b	36	135b	---	---	---	---	0.25a	2.31a	26	96b
	5.9	0.17	2.51ab	34	109c	0.26	1.79	33	70	0.26a	2.48a	27	87bc
	6.1	0.17	2.59a	34	93c	---	---	---	---	0.27a	2.33a	29	72c
Significant effects		NS	**	NS	**	*	NS	NS	**	**	*	NS	**
Carrot	5.3	0.18	1.09	81a	132a	0.13	1.16	55	112	0.15	1.10	44	117a
	5.6	0.19	1.18	61b	80b	---	---	---	---	0.16	1.16	43	79b
	5.9	0.19	1.19	55b	58b	0.13	1.30	38	61	0.16	1.13	40	67b
	6.1	0.18	1.20	51b	54b	---	---	---	---	0.15	1.26	37	53b
Significant effects		NS	NS	*	**	NS	NS	*	**	NS	NS	NS	**
Lettuce	5.3	0.27b	1.42a	92a	610a	0.27	1.04	50	296	0.40	0.50b	56	148a
	5.6	0.39a	0.92b	70b	177b	---	---	---	---	0.40	0.54b	48	71b
	5.9	0.39a	0.85b	69b	152b	0.36	0.40	51	59	0.41	0.51b	50	65b
	6.1	0.45a	0.62b	68b	86c	---	---	---	---	0.39	0.68a	48	59b
Significant effects		**	**	*	**	*	*	NS	**	NS	*	NS	**

[z]Mean separation within columns for each crop by Duncan's multiple range test, 5% level.

NS, *, **Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

reduction occurring between pH 5.1 and 5.7 in 1977 and 1978, and between pH 5.3 and 5.6 in 1979 (Tables 3, 4). Bean leaf Mn concentration has been found to decrease with liming (9). The highest bean leaf Mn concentration in these experiments was 415 ppm (1977, pH 5.1, 112 kg N/ha), which is above the normal range of 30 to 300 ppm for bean leaves (5), but below levels where visible toxicity symptoms have been observed at 600 to 800 ppm (9) or 1000 ppm (4). Visible symptoms of Mn toxicity (interveinal chlorosis beginning at leaf margins) in plants from pH 5.1 plots were either absent or very mild; however, high Mn levels could reduce yields without producing visible toxicity symptoms. Bean yield increases associated with liming might be attributable to a combination of reduced Mn levels and increased P or Ca uptake.

Reduction in lettuce leaf Mn concentration with an increase in soil pH from 5.1 to 5.7 or from 5.3 to 5.6 was 52 to 71% (Tables 3, 4). Levels as high as 760 ppm (1979, first sampling, 258 kg N/ha) were obtained at the lowest pH. Symptoms of Mn toxicity including stunting, marginal and interveinal chlorosis, and necrotic brown spots were observed on plots with a soil pH less than 5.6. Symptoms were not present in plants grown on limed soil. The large magnitude of decrease in lettuce Mn concentration, and the disappearance of toxicity symptoms and yield increase associated with soil pH increase from 5.1 to 5.7 or from 5.3 to 5.6, indicate that more than 150–200 mg/kg Mn concentration at heading may be toxic to crisphead lettuce. The rapid reduction in lettuce Mn concentration with increasing plant age (Table 4) reaffirms the importance of determining the appropriate growth stage for diagnostic tissue analysis.

Table 5. Main effect of N fertilizer on elemental concentration of carrot petiole and lettuce leaf.

1977			1979[z]			
N applied (kg/ha)	Carrot Ca (%)	Lettuce Mn (ppm)	N applied (kg/ha)	Carrot Mn (ppm)	Carrot Zn (ppm)	Lettuce Mn (ppm)
0	1.37	142	34	69	57	199
56	1.25	173	156	86	62	253
112	1.27	149	258	86	67	316
168	1.18	151				
Significant effects[y] L**		Q**C**		L*	L**	L**

[z]First sampling.

[y]Linear (L), quadratic (Q), cubic (C); 5% level (*); 1% level (**).

N application did not affect Ca concentration of bean or lettuce leaves, but did reduce Ca concentration of carrot petioles in 1977 (Table 5). Carrot petiole Zn concentration increased with increasing rate of N application in 1979 (Table 5).

Mn concentration of all crops tended to increase with N application, but this increase was statistically significant only in lettuce and carrots (Table 5). The increased carrot Zn and Mn concentration and increased lettuce Mn concentration with increasing N may have been caused by increased soil acidity associated with use of ammonium-containing fertilizers (15, 16).

Soil pH remains the best indicator for predicting crop response to application of lime. Plant Mn concentration may be a valuable indicator, particularly for highly acid-sensitive crops such as beans, lettuce, and leafy greens. Plant tissue concentrations of Ca and P, which often respond to liming, may also prove to be valuable indicators of the need for liming.

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