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# Lime and Phosphorus Effects on American Ginseng: I. Growth, Soil Fertility, and Root Tissue Nutrient Status Response

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**Abstract.** Soil applications of dolomitic limestone and P fertilizer before seeding American ginseng (*Panax quinquefolium* L.) affected root weight (RW) gain during the first 4 years of growth. At the end of each growing season, root size was greatest with the intermediate liming rate and with the high P rate. Lime resulted in positive linear responses in soil pH, K, Ca, and Mg and in root N, P, Ca, and Mg and curvilinear responses in soil Mn and Zn and in root K, Mn, and Zn. Applied P had a positive linear effect on soil Na and on root N, Ca, and Fe and a curvilinear effect on soil P and on root P and Ca. Terminal RW was positively correlated with soil pH, K, Ca, Mg, and Na and with root P, K, Ca, and Mg; RW was negatively correlated with root Mn and Zn. Regression analyses implicated only soil Ca and Na and root Mg and Zn as significant terms in prediction equations,

American ginseng is native to the hardwood-forested regions of eastern North America. It ranges from southeastern Canada southward to the Carolinas and Georgia and westward to states bordering the Mississippi River (Nash, 1898). Soils within this region vary in acidity and fertility. Roberts and Richardson (1981) sampled soil in sixty-four 0.4-ha sites in 12 Kentucky counties surveyed for native ginseng. Of 60 sites where ginseng was found, soil pH ranged from 4.5 to 7.4, P varied from 4.5 to 135 kg-ha<sup>-1</sup>, and K ranged from 118 to 411 kg-ha<sup>-1</sup>. Woodland soils from sites in North Carolina associated with native ginseng were acid (pH 4.4 to 5.1), low in P content (4.5 to 20.2 kg-ha<sup>-1</sup>),

and moderately high in K (65 to 267 kg-ha<sup>-1</sup>) (unpublished data). Hartman (1979) reported that the pH range of native soils in Marathon County, Wis., the center of commercial ginseng production in the United States, was 5.0 to 5.5, but that growers often grew ginseng immediately following alfalfa, which normally was limed to a pH of 6.5 to 6.9. Khwaja et al. (1984) analyzed soil samples and root and leaf tissue from commercial ginseng plantings in Wisconsin of different age, level of productivity, and apparent nutritional status. Soil pH ranged from 6.7 to 8.1 and soil P varied from 98 to 191 kg-ha<sup>-1</sup>.

Ginseng has been cultivated in North America since the late 19th Century (Nash, 1898); however, the scientific study of its nutritional needs and other cultural requirements has been largely neglected. Stolz (1981, 1982a) obtained smaller RW increases in 2nd-year plants by withholding N, P, Ca, or Mg from nutrient solutions in sand culture. Absence of Ca was more restrictive of root growth and resulted in earlier foliar deficiency symptoms than the absence of other elements.

Root growth and foliar color were positively related to N rate

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Abbreviations: RN, root nutrient; RW, root weight; SF, soil fertility.

in sand culture where N was derived from  $\text{NH}_4$  and  $\text{NO}_3$  in the proportion 1:14 (w/w) (Stolz, 1982b). Changing the proportion of N from those respective sources to 3:12 or to 0:15 caused no visual symptoms but reduced root growth. Root growth was positively correlated with P content of the solution. Elimination of Ca resulted in an increased incidence of root rot and earlier foliar senescence. Root growth increased with Ca to a  $1 \times$  rate in the solution and was less at a  $1.5 \times$  level, indicating a curvilinear response.

A 4-year experiment was initiated in 1978 to measure ginseng root growth and tissue nutrient element response to lime and P additions to a low pH/low P soil. Nitrogen also was a variable in the experiment; however, growth response to N was minor and will not be considered in this report.

### Materials and Methods

Topsoil from a wooded site on the Mountain Horticultural Crops Research Station, Fletcher, N.C., was used for this study. The soil was a Hayesville loam (clayey, oxidic, mesic Typic Hapludults) with the following nutritional status as determined by the Mehlich III extraction process (Agronomic Division, N.C. Dept. of Agr., Raleigh): pH = 4.3, P = 17 mg-dm<sup>-3</sup>, K = 0.25 meq/100 cm<sup>3</sup>, Ca = 0.80 meq/100 cm<sup>3</sup>, Mg = 0.24 meq/100 cm<sup>3</sup>, Mn = 10.4 mg-dm<sup>-3</sup>, Na = 0.06 meq/100 cm<sup>3</sup>. The soil was steam sterilized, screened, and batches were amended with three rates each of dolomitic limestone [ $\text{Ca-Mg}(\text{CO}_3)_2$ ] (0, 4.42, and 8.84 kg-m<sup>-3</sup>) and super-phosphate fertilizer (0N-8.7P-0K) (0, 0.16, and 0.32 kg P/m<sup>3</sup>) in factorial combination. (Note: The terms, "lime" and "phosphorus" will be used interchangeably with dolomitic limestone and superphosphate fertilizer, respectively.) Four-liter nursery pots with 2 cm of stone drainage were filled with each soil mix. Each plot consisted of one pot. Treatments were arranged in a RCB design and replicated 10 times.

Ten stratified seeds were planted equidistant around the periphery of each pot in Apr. 1978. Pots were placed outdoors on the ground from April to November each year under 75% wood lath shade supported 2 m above the soil surface and overwintered on the concrete floor of an enclosed, unheated building. Pots were watered with overhead irrigation as needed to maintain desired soil moisture. Pest control included weekly applications of mancozeb 80W (manganous ethylenebisdithiocarbamate + zinc ion) at 0.24 kg/100 liter from May through August each year for control of ginseng blight (*Alternaria panax* Whet.) and distribution of bait pellets [3.25% metaldehyde and 4.25% carbaryl (1-naphthyl methylcarbamate)] around the pots for control of slugs.

Roots were dug in October or November each year, washed free of soil, weighed, dipped in a suspension of captan 50W fungicide (3.6 g-liter<sup>-1</sup>) and replanted in the soil of their respective pots. The population was adjusted to three representative roots per pot at the end of the first growing season and to two at the end of the second. Each year, one or two replicates were used for tissue and soil testing. Final growth results were based on five replications. At termination of the experiment, roots from three replicates were analyzed for nutrient status (Agronomic Division, N.C. Dept. of Agr., Raleigh). Standard statistical procedures (Steel and Torrie, 1960) were used to analyze root growth response to treatment and to calculate correlations among soil fertility factors, root growth measurements, and ginseng root nutrient levels. Correlations and regression analyses involving tissue nutrients were based on the three rep-

licates analyzed for nutrient status. All root size data are fresh weights unless specified otherwise.

### Results and Discussion

First- and second-year responses to lime and P treatments were reported earlier (Konsler, 1979, 1980; Konsler and Shelton 1980). After one growing season, lime and P treatments resulted in average soil pH levels of 4.4, 5.5, and 6.5 and P concentration of 38, 196, and 464 kg-ha<sup>-1</sup>, respectively (Konsler, 1979). At 1 and 2 years of age, roots grown in soil at pH 5.5 were about double the weight of those grown at 4.4 (0.58 g vs. 0.27 g and 4.06 g vs. 1.98 g for years 1 and 2, respectively); at pH 6.5, roots were 59% and 29% larger at ages 1 and 2 years, respectively, than those grown in nonlimed soil (Konsler, 1979, 1980). Soil P level and RW were positively correlated; with the highest P level, roots were 33% and 47% larger at 1 and 2 years of age, respectively, than roots with no added P. Seedling roots were more regularly "spindle-shaped" with the intermediate rate of lime (Konsler, 1979; Konsler and Shelton, 1980).

At termination of the experiment, soil pH and P status had changed only slightly relative to the initial year. Lime treatments resulted in average terminal pH levels of 4.6, 5.5, and 6.4, while P differentials resulted in average P levels of 56, 200, and 377 kg-ha<sup>-1</sup>.

*Root growth.* The annual rate of RW gain for all treatments

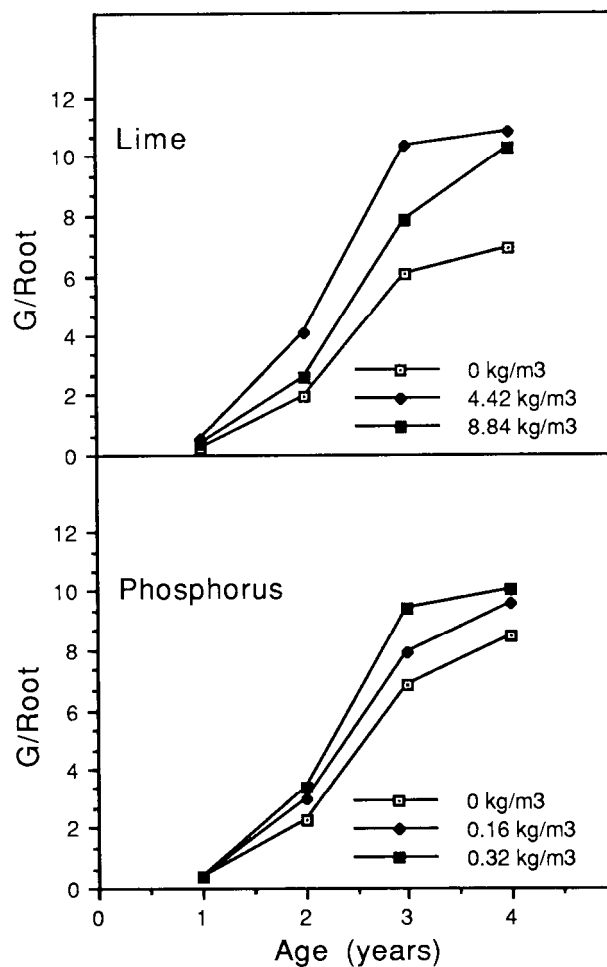


Fig. 1. Ginseng RW (g/root) response through 4 years to additions of dolomitic limestone and P (from 0N-8.7P-0K superphosphate fertilizer) to the potting medium. LSD (0.05) for year 1 = 0.03, 2 = 0.22, 3 = 0.67, 4 = 0.94.

increased with age through the third growing season and was reduced during the 4th year, resulting in a sigmoid (S-shaped) growth curve for each lime or P treatment (Fig. 1). A sigmoid growth curve is typical of many biological systems (Bakhuyzen, 1926; von Bertalanffy, 1957). Reduced growth rate during the 4th year (Fig. 1) may have been partially due to limitation in pot size. However, the shape of the growth curves was not atypical for high plant populations of ginseng, including populations typical of commercial production. Hartman (1979) reported seeding rates of 78 to 157 kg·ha<sup>-1</sup> among commercial growers in Wisconsin, or up to 275 seeds/m<sup>2</sup>. In a plant population study in ground beds, 4th-year growth rates were reduced relative to the 3rd-year rate for plant populations of 258, 86, or 43 plants/m<sup>2</sup> but not for 29 plants/m<sup>2</sup> (Konsler, 1982).

Fourth-year RW was affected by both lime and P treatments. RW increased linearly with P and was curvilinear with lime (Table 1). Maximum RW was associated with the median lime and high P levels. RW response to lime and P was qualitatively the same each year (Fig. 1).

*Soil fertility response to treatment.* Addition of dolomitic limestone and P fertilizer to soil affected not only the soil acidity

(pH) and P levels, but also caused changes in other SF factors (Table 2). Dolomitic limestone contributed Ca and Mg directly to the soil. Soil Ca and Mg were linearly related to liming rate, as was soil K. Manganese and zinc were curvilinear in their response to lime, and neither P nor Na was affected by liming rate (Table 2). Phosphorus applications resulted in a linear increase in soil P with a significant quadratic component (Table 2). Phosphorus also affected soil Na. Such interactions between lime or fertilizer additions to soil and nutrient status of other factors in the soil are not unusual (Bear, 1964; Pearson and Adams, 1967).

*Root weight vs. soil fertility.* Ginseng root growth was affected by lime and P treatments (Table 1); however, it is reasonable to assume that nutrition and growth were more directly related to the overall SF status resulting from the fertilizer applications.

Simple correlations between RW and each SF factor were computed to identify factors related to root growth. RW was positively correlated with soil pH, K, Ca, Mg, and Na (Table 3). Soil P, Mn, and Zn were not significantly correlated with terminal RW. A multiple regression analysis was performed with RW on the five factors with which it was correlated. Non-significant terms in the equation were deleted in sequence (Regress II: A Multiple Regression Program for Apple II/II E; Human Systems Dynamics) until only significant ( $P \leq 0.05$ ) ones remained. The resulting equation:

$$RW = 1.783 \text{ Ca} - 0.128 \text{ Ca}^2 + 97.619 \text{ Na} - 1.295 \quad [1]$$

with an  $R^2$  of 0.56 ( $P = 0.001$ ), suggests that Ca and Na were important SF factors in affecting terminal RW. For any fixed level of Na, the equation predicts an increase in RW with increasing Ca to 7.0 meq/100 cm<sup>3</sup>, then a decrease in root size with any further Ca increase. Thus, predicted response to Ca was in agreement with response to lime (Table 1) and the sand culture findings of Stoltz (1981, 1982a) who concluded that Ca was important to root growth and whose results showed a curvilinear response (1982b).

We found no studies investigating the role of Na in ginseng root growth.

*Tissue nutrient response to treatment.* Crop fertility recommendations often are based on tissue nutrient levels—generally

Table 1. RW response of 4-year-old ginseng to soil dolomitic limestone (lime) and P additions.

Addition (kg·m <sup>-3</sup> )	Wt/root (g)
Lime <sup>z</sup>	
0.0	7.53
4.42	10.9
8.84	10.3
P <sup>z</sup>	
0.0	8.67
0.16	9.54
0.32	10.8
Significance <sup>y</sup>	
Lime	L <sup>a</sup> Q <sup>a</sup>
P	L <sup>a</sup>
Interaction	NS

<sup>z</sup>Rates applied to potting medium at initiation of the experiment.

<sup>y</sup>L = linear; Q = quadratic.

<sup>NS, a</sup>Non-significant or significant at  $P = 0.001$ , respectively.

Table 2. Terminal SF status associated with three rates each of dolomitic limestone (lime) and P in a pot experiment with American ginseng.

Addition (kg·m <sup>-3</sup> )	pH	Nutrient element						
		P	Mn	Zn	K	Ca	Mg	Na
		mg·dm <sup>-3</sup>			meq/100 cm <sup>3</sup>			
Lime <sup>z</sup>								
0.0	4.6	91	12.0	3.3	0.23	2.2	0.44	0.056
4.42	5.5	94	8.5	3.4	0.25	5.2	0.51	0.061
8.84	6.4	97	12.0	2.2	0.29	9.0	0.57	0.068
P <sup>z</sup>								
0.0	5.5	25	10.1	2.7	0.27	5.1	0.52	0.058
0.16	5.5	89	11.0	3.0	0.25	5.4	0.47	0.061
0.32	5.5	168	11.4	3.2	0.26	5.9	0.52	0.064
Significance <sup>y</sup>								
Lime	L <sup>a</sup>	NS	L <sup>b</sup> Q <sup>a</sup>	L <sup>c</sup> Q <sup>a</sup>	L <sup>a</sup>	L <sup>a</sup>	L <sup>a</sup>	NS
P	NS	L <sup>a</sup> Q <sup>c</sup>	NS	NS	NS	NS	NS	L <sup>c</sup>
R (lime)	0.89 <sup>a</sup>	NS	0.47 <sup>b</sup>	0.78 <sup>a</sup>	0.63 <sup>a</sup>	0.97 <sup>a</sup>	0.49 <sup>a</sup>	NS
R (P)	NS	0.98 <sup>a</sup>	NS	NS	NS	NS	NS	0.30 <sup>c</sup>

<sup>z</sup>Rates applied to potting medium at initiation of the 4-year experiment.

<sup>y</sup>L = linear; Q = quadratic; R = multiple correlation coefficient.

<sup>NS, a, b, c</sup>Non-significant or significant at  $P = 0.001$ , 0.01, or 0.05, respectively.

Table 3. Correlation (r) between SF factors or RN elements and RW of 4-year-old American ginseng.

	Fertility factors and nutrient elements										
	pH	N	P	K	Ca	Mg	Mn	Zn	Cu	Na	Fe
r <sub>SF</sub>	0.58 <sup>a</sup>	---	NS	0.55 <sup>a</sup>	0.59 <sup>a</sup>	0.50 <sup>a</sup>	NS	NS	---	0.69 <sup>a</sup>	---
r <sub>RN</sub>	---	NS	0.66 <sup>a</sup>	0.66 <sup>a</sup>	0.66 <sup>a</sup>	0.67 <sup>a</sup>	-0.70 <sup>a</sup>	-0.68 <sup>a</sup>	NS	---	NS

NS,<sup>a</sup>Nonsignificant ( $P > 0.05$ ) or significant at  $P = 0.01$ , respectively.

from leaf tissue samples (Ulrich, 1976). In the present study, expendable, treated ginseng plants were not available nor was foliage on record plants adequate for tissue sampling during the growing season. Therefore, leaf tissue was not analyzed for nutrient content. However, root tissue from record plants was not restricted in quantity and samples were analyzed for content of N, P, K, Ca, Mg, Mn, Zn, Cu, and Fe.

Lime treatments resulted in significant changes in most RN elements analyzed. There was a general increase in root N, P, K, Ca, and Mg and a decrease in root Mn and Zn with increased lime (Table 4). The changes in root K, Mn, and Zn had a nonlinear component to their response. Neither Cu nor Fe was affected by lime treatments.

Soil P additions resulted in general increases in root N, P, Ca, and Fe and a decrease, at the high rate, in root Cu (Table 4). Both root Cu and root P responses were curvilinear with maximum levels falling within the range of P treatments applied. Root Mg, Mn, and Zn were not affected by P treatments.

*Interrelationships among soil fertility factors and root nutrient elements.* There were some general similarities in RN and SF responses to lime and P treatments. Disregarding departures from strict linearity in some instances, additions of lime caused increases in both soil and root K, Ca, and Mg and decreases in Zn (Tables 2 and 4). Manganese response was curvilinear with a concave upward attitude in both sites; however, the change in Mn level in root tissue was much greater than in soil. Lime caused no change in P content of the soil but resulted in a linear increase in this element in the root tissue. Zinc was lowered by the high rate of lime in the soil and in root tissue; however, soil response was concave downward, while root response was concave upward.

Among the six elements analyzed that were common to both soil and root tissue (P, K, Ca, Mg, Mn, Zn), applied P affected

only soil P, causing an increase in this element (Table 2). Root P also increased with rate of P applied (Table 4), as did root Ca. Root K, Mg, Mn, and Zn were not affected by P treatment.

*Roof weight vs. root nutrients.* Simple correlations were calculated for RW with each of the nine RN elements. Positive correlations of RW with P, K, Ca, and Mg (Table 3) suggest the possible importance of these elements to ginseng root growth. Negative correlations with tissue Mn and Zn suggest the possibility of their detriment to growth with increased tissue content.

The relationship of RW with RN elements was similar in some respects to its relationship with SF factors (Table 3); RW was positively correlated with K, Ca, and Mg in both source materials. RW also was positively correlated with P and negatively correlated with Mn and Zn in root tissue but was not related to variation in these elements in soil.

A regression analysis of RW with the six RN elements with which it was correlated (Table 3) was calculated to identify elements most responsible for variation in RW. Nonsignificant ( $P > 0.05$ ) terms were deleted in sequence until only significant ( $P \leq 0.05$ ) ones remained. The resulting equation:

$$RW = 2.5517 + 102.0801 \text{ Mg} - 0.1879 \text{ Zn}, \quad [2]$$

with an  $R^2$  of 0.64 ( $P = 0.001$ ), indicated that RW responded positively to increases in root Mg but negatively to root Zn.

The results presented in this report do not lead to a clear understanding of the nutritional needs of American ginseng as measured by root growth. The uncomplicated RW responses to soil lime and P additions (Table 1) were not easily interpreted in terms of the resulting soil chemistry and plant nutrition. Lime additions significantly affected several SF factors (pH, K, Ca, Mg, Mn, Zn); except for slightly influencing soil Na, P additions affected only soil P (Table 2). However, the regression

Table 4. Root tissue nutrient response to three rates each of dolomitic limestone (lime) and P in a pot experiment with American ginseng.

Addition (kg·m <sup>-3</sup> )	Nutrient element								
	N	P	K	Ca	Mg	Mn	Cu	Zn	Fe
Lime <sup>a</sup>			%				ppm		
0.0	1.69	0.23	1.25	0.24	0.10	117	8.2	32	262
4.42	1.76	0.28	1.44	0.29	0.12	20	8.3	23	241
8.84	1.87	0.31	1.48	0.33	0.12	13	8.5	22	251
P <sup>a</sup>									
0.0	1.68	0.23	1.34	0.27	0.11	45	8.6	25	213
0.16	1.83	0.30	1.44	0.30	0.12	48	8.9	26	254
0.32	1.81	0.30	1.41	0.30	0.12	44	7.4	24	286
Significance <sup>y</sup>									
Lime	L <sup>a</sup>	L <sup>a</sup>	L <sup>a</sup> Q <sup>b</sup>	L <sup>a</sup>	L <sup>b</sup>	L <sup>a</sup> Q <sup>a</sup>	NS	L <sup>a</sup> Q <sup>a</sup>	NS
P	L <sup>b</sup>	L <sup>b</sup> Q <sup>c</sup>	NS	L <sup>c</sup>	NS	NS	L <sup>b</sup> Q <sup>a</sup>	NS	L <sup>a</sup>
R (lime)	0.64 <sup>a</sup>	0.72 <sup>a</sup>	0.86 <sup>a</sup>	0.82 <sup>a</sup>	0.57 <sup>b</sup>	0.99 <sup>a</sup>	NS	0.92 <sup>a</sup>	NS
R (P)	0.48 <sup>b</sup>	0.64 <sup>b</sup>	NS	0.39 <sup>c</sup>	NS	NS	0.82 <sup>a</sup>	NS	0.72 <sup>a</sup>

<sup>a</sup>Rates applied to potting medium at initiation of the 4-year experiment.

<sup>y</sup>L = linear; Q = quadratic; R = multiple correlation coefficient.

NS,<sup>a,b,c</sup>Nonsignificant or significant at  $P = 0.001$ , 0.01 or 0.05, respectively.

equation relating RW to soil fertility [Eq. 1] implicated only soil Ca and Na as significant factors for explaining the RW response observed. Calcium is a major constituent of the form of lime used. Its concentration in the soil was linearly related to liming rate (Table 2) (as were pH, K, and Mg) and could be largely responsible for the RW response attributed to lime (Table 1) or even to soil pH (Konsler, 1979, 1980).

However, the regression of RW on RN status [Eq. 2] implicated root Mg and Zn as the predominant predictors of root growth. Lime rate had a positive linear effect on root Mg as well as on root Ca, N, and P, and caused a nonlinear, but positive, response in root K (Table 4). Each or all of these elements may have contributed to the increase in RW with liming rate (Table 1). The successive elimination of terms in the regression analysis involving these RN elements, except Mg, probably resulted from the similarity of their response to lime and probable correlation among them.

The foregoing discussion presumes a relationship between ginseng root nutritional status and root growth, whereas foliar status may be more closely related to potential for growth. Ginseng roots are sinks for storage of plant foods whose mineral nutritional status may differ from that of the foliage.

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