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Effect of Placement of Phosphorus Fertilizer and Lime upon Growth of 'Delicious' and 'Golden Delicious' Apple Trees[1]

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Additional index words. Malus domestica, superphosphate

Abstract. **Surface applications of dolomitic limestone raised the pH from 4.3 to 6.2 with diminishing effect to 15 cm. Although the pH was affected to 15 cm the available Ca was raised only to a depth of 7.5 cm. When the lime was applied in discrete zones as subsurface applications, the pH was raised to 6.1 and maintained at 5.8 to a depth of 30 cm. When lime and superphosphate were applied on the surface the distribution of Ca and P with depth was improved. Concentrations of Ca and P in leaf tissue of 'Delicious' and 'Golden Delicious' (*Malus domestica* Borkh.) apple trees were increased more by subsurface than surface applications of lime and superphosphate. However, the greater effectiveness of subsurface over surface applications in maintaining leaf concentrations was not sustained and did not result in increased growth.**

Growth responses were obtained from applications of superphosphate and lime, regardless of method of application. Leaf Ca and P concentrations of 0.95–1.10 and 0.20–0.25, respectively, were associated with maximum growth.

Although lack of responses of deciduous fruit trees to P fertilization have been noted (2, 8, 15, 16), Lilleland (11, 12) reported short term responses of deciduous fruit trees to P. Serr (17) also reported a response of Persian walnut to heavy P fertilization and Weeks (19) suggested that P may become a limiting factor in apple production with high rates of inorganic N.

Many orchards in North Carolina are located on soils inherently low in P, pH, and Ca with a high P fixing capacity and moderate supplies of native K. As a result of these conditions, Walker and Mason (18) found that 58% of North Carolina orchards had leaf levels of Ca and P below the 1.0% Ca and 0.18% P lower critical levels proposed by Emmert (6). Tissue analyses performed by the Plant Analysis Laboratory of the Department of Soil Science at North Carolina State Univ. in 1972 indicated that this condition had not improved and 76% of orchard leaf samples were low in Ca. Under these conditions, one would expect responses to lime and P applications. However, Walker and Mason (18) reported concn of N, P, K, Ca, or Mg in leaf samples from growers orchards were not related to past use of P and K. Under soil conditions previously described, this lack of relationship may not be surprising. Growers using P and K have generally used a complete fertilizer at a rate to supply the recommended level of N. The P applied remained fixed at or near the soil surface thus resulting in very low utilization by the tree. Also, failure to establish a desirable pH prior to planting and to maintain a good liming program results in poor soil physical conditions with much of the Ca applied remaining in the top few cm of soil.

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Table 1. Lime and phosphorus treatments applied to a Hayesville clay loam for growth studies of 'Delicious and Golden Delicious' apple trees.

	Material				
	Lime		C. S. P.		
Trt. no.	Method of placement	Ca (kg)	Method of placement	Ca (kg)	P (kg)
1	Subsurface	1.6	Subsurface	3.0	5.0
2	Surface	1.6	Subsurface	3.0	5.0
3	Subsurface	1.6	None	0	0
4	Surface	1.6	None	0	0
5	Subsurface	1.6	Surface	3.0	5.0
6	Surface	1.6	Surface	3.0	5.0
7	None[z]	0	None	0	0
8	None[y]	0	None	0	0

[z]Soil preparation as for surface application.
[y]Soil preparation as for subsurface application.

Many investigators have related the level of Ca in apples to nutritional disorders (3, 4, 7, 13, 14). However, growth and fruiting responses to Ca have not been thoroughly investigated.

The purpose of this investigation was to evaluate the Ca and P levels in soil and in leaf tissue necessary for optimum growth and production of 'Delicious and Golden Delicious' apples and to study the influence of lime and superphosphate placement on Ca and P uptake by apple trees.

This paper is concerned only with influence of lime and superphosphate treatments upon soils and vegetative growth responses as yield and fruit quality will be the subject of a later paper.

Materials and Methods

Dolomitic limestone and concd superphosphate were applied in 1962 to a Hayesville (Typic Hapludult) clay loam soil low in available P with a high P fixing capacity and a low pH. The concd superphosphate (22.9% P) was a granular material about 1 cm in size used to delay fixation. Surface treatments were broadcast over the entire surface area of a circle 3 m in diam around each tree. Subsurface applications were mixed with soil removed from the planting hole and from 3 surrounding holes 60 cm diam, 35.5 cm deep, with centers located 0.9 m from the center of the planting hole. The mixture was then returned to the holes. Treatments are given in Table 1. Treatments were reapplied prior to the 7th growing season using conventional concd superphosphate and in the case of subsurface applications 6 holes were used in the second application and were located at a distance of 1.8 m from the tree trunk. 'Delicious' and 'Golden Delicious' trees on seedling rootstocks were planted 10.7 m apart in a randomized block design with 4 replications of each cultivar. Soil samples were taken annually at 2.5 cm increments to a depth of 30 cm. Soil samples for subsurface applications were taken in the zone of placement and between zones of placement. Soil analyses were determined by the Agronomic Division, North Carolina Department of Agriculture using 0.05 N HC1 + 0.025 N H_2SO_4 as an extractant of available nutrients in the soil. Leaf samples were taken annually during the first week of July and consisted of 40 midshoot leaves selected at random. A relative leaf area (RLA) was determined as the average product of length by width measurements of all leaves sampled, which was shown by Ackley, et. al. (1) to be highly correlated with leaf area. Leaves were dried, ground, and analyzed for N, P, K, Ca, Mg, B, Fe, Mn, and Zn by the Analytical Service Laboratory, Department of Soil Science, North Carolina State University. Trunk circumferences (TC) at 30 cm above ground level, were measured annually during the dormant season.

Results and Discussion

During the first 2 years following applications of lime and superphosphate, the soil test results of samples taken at 2.5 cm increments were erratic and extremely variable with respect to the applied treatment. However, by the 3rd year, levels had stabilized and the results are presented in Fig. 1 for pH, ppm

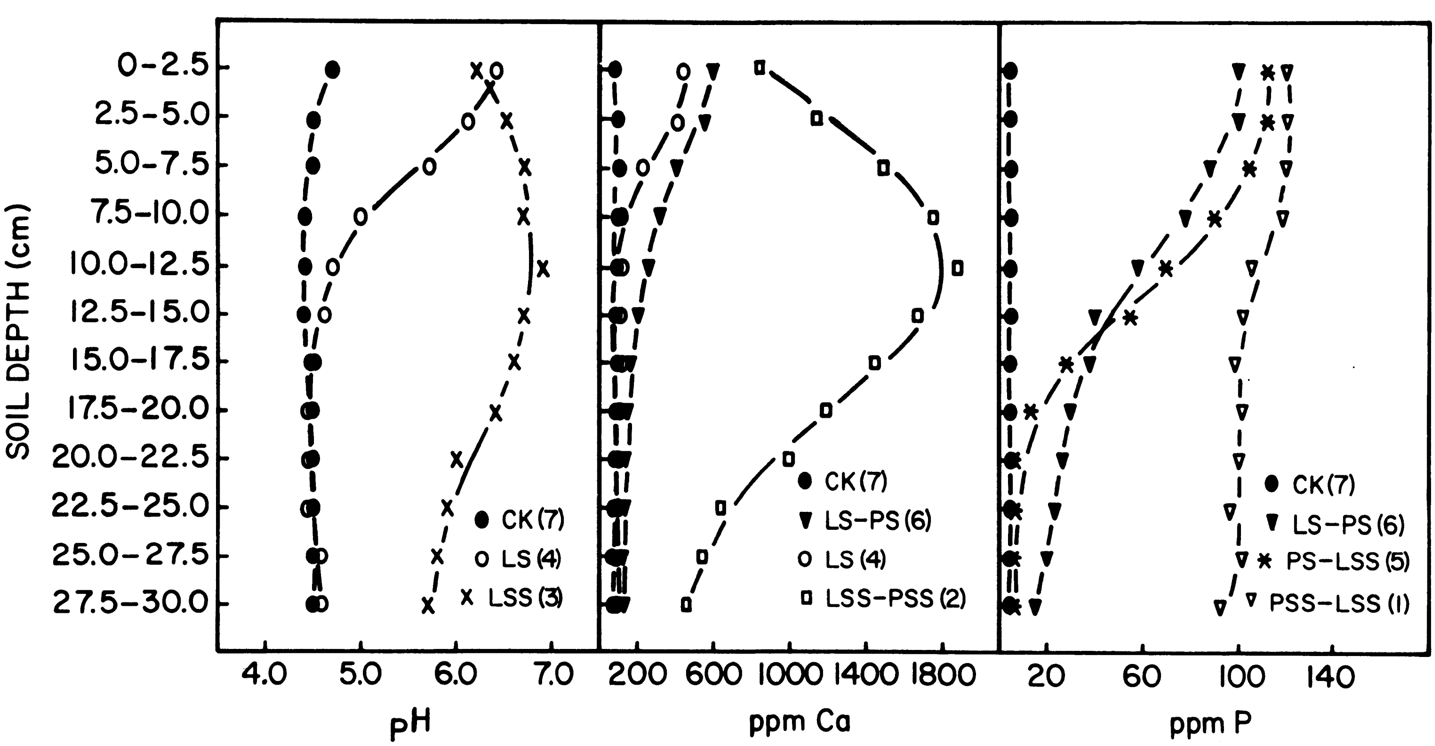

Fig. 1. Effect of surface (S) and subsurface (SS) applications of lime and superphosphate on pH, available Ca, and available P in soil profile. Treatment numbers given in parenthesis.

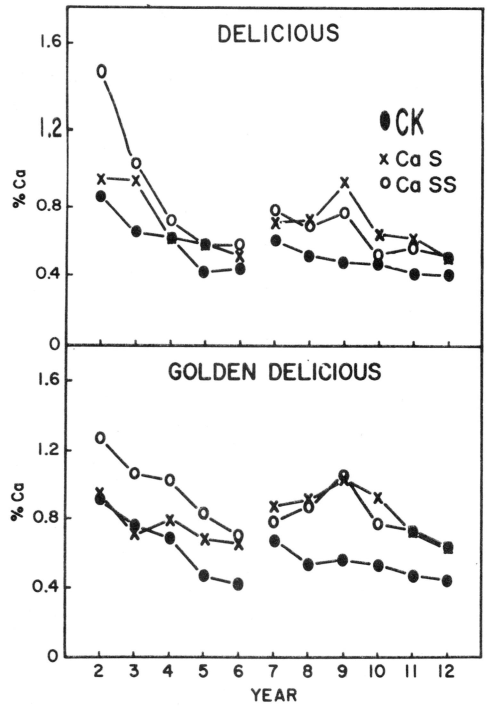

Fig. 2. Effect of surface (S) and subsurface (SS) applications of Ca on yearly leaf Ca content of 'Delicious' and 'Golden Delicious' apple trees. Treatments applied at planting and repeated prior to 7th growing season.

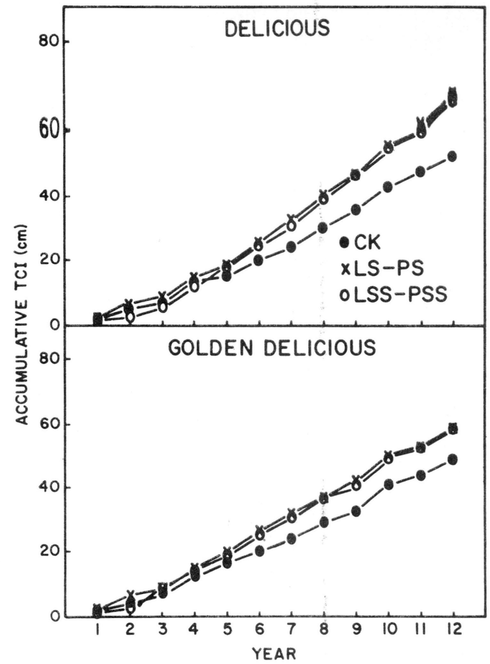

Fig. 4. Accumulative trunk circumference increase (TCI) of 'Delicious' and 'Golden Delicious' apple trees resulting from surface and subsurface application of lime and superphosphate.

Ca and P. Surface applications of lime raised the pH from 4.3 to 6.2 at the surface with diminishing effect to 15 cm depth below which no difference in pH resulted. Although the soil pH was affected to 15 cm following surface applications of lime, the available Ca was raised only to a depth 7.5 cm. Subsurface applications of lime raised the pH of the soil in the placement zone to 6.1 and maintained a pH of 5.8 to a depth of 30 cm. These results are consistent with results reported by Gamble and Kenworthy (9) who found that surface applied lime had not altered the pH below 15 cm 5 years after application. Soil test Ca levels were raised to a higher level (Fig. 1) by surface applications of lime and superphosphate than by lime alone and Ca levels were increased to a greater depth. The deeper penetration of Ca may have resulted from the additional Ca supplied by the superphosphate or from improved physical conditions of soil resulting from superphosphate application. Subsurface applications of superphosphate resulted in a very high soil test P throughout the zone of placement. Surface applied superphosphate increased soil test P levels to 20 cm depth when applied separately from the lime. However, when both lime and superphosphate were applied on the surface, the distribution of soil test P was improved with slightly less accumulation near the surface and greater accumulation to

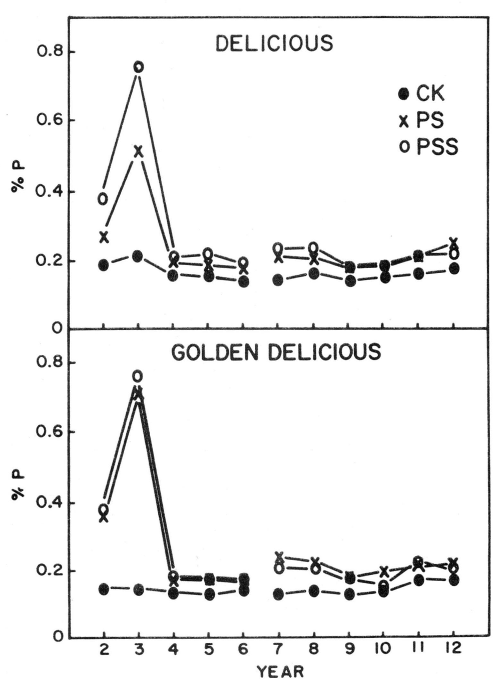

Fig. 3. Effect of surface (S) and subsurface (SS) applications of superphosphate on yearly leaf P content of 'Delicious' and 'Golden Delicious' apple trees. Treatments applied at planting and prior to 7th growing season.

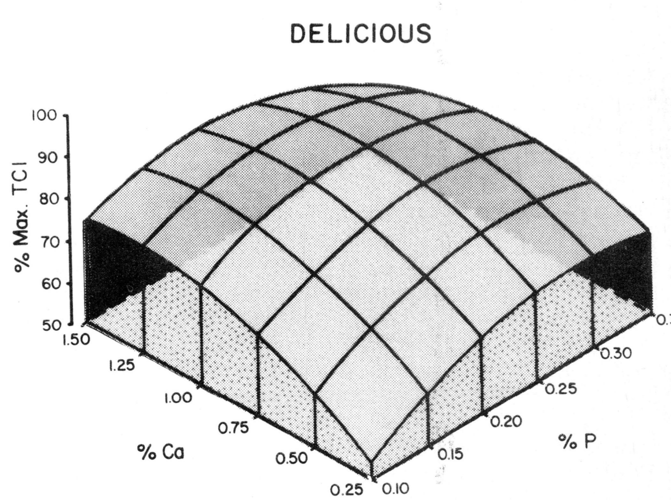

Fig. 5. Growth response surface of 'Delicious' apple trees as influenced by leaf Ca and P content.

Table 2. Regression coefficients (R) and correlation coefficients (r) for variables indicated.

Variables	2	3	4	5	6	7	8	9	10	11	12
	Growing season										
	Trunk circumference increase										
R %Ca %P in leaves	.25	.60**	.60**	.68**	.50**	.57**	.32	.22	.23	.27	.32
r %P in leaves	–.20	–.43*	.50**	.65**	.45**	.54**	.21	–.05	.18	–.05	.13
r %Ca in leaves	–.25	–.14	.53**	.57**	.33	.50**	.31	–.21	.21	.14	.20
	Relative leaf area										
R %Ca %P in leaves	.26	.45*	.60**	.68**	.50**	.47*	.32	.33	.23	.14	.16
r %P in leaves	–.20	–.39	.50**	.65**	.45**	.42*	.21	–.002	.18	–.07	–.06
r %Ca in leaves	–.26	–.12	.53**	.57**	.33	.44*	.31	.23	.21	–.14	.08
	Leaf area index vs. Trunk circumference increase										
r	.34	.43*	.72**	.66**	.57**	.19	.31	.39	.27	.17	.30

*Significant at 0.05%.
**Significant at 0.01%.

the 30 cm depth. Such penetration of applied superphosphate should increase P absorption. Eggert et. al. (5) found that when surface applied P penetrated to a depth of only 5 cm that no fertilizer P was absorbed by the trees. When the penetration of P was 10 cm between 2.68 and 3.78% of the leaf tissue P was from applied fertilizer and when the penetration was 20 cm, 5.77% of tissue P was from that applied.

Although some downward movement of Ca and P resulted from surface applications, there was no consistent evidence of horizontal movement of either nutrient from the zone of subsurface placement. Soil samples taken midway between the zones of subsurface placement were not significantly different in soil P, Ca, or pH, from samples of untreated soil.

The percentage of Ca in leaf tissue of 'Delicious' and 'Golden Delicious' apples resulting from surface and subsurface placement of lime and superphosphate are presented in Fig. 2. Lime and superphosphate placed in the same zone were more effective in maintaining leaf Ca than when placed in separate zones. The Ca concn indicated in Fig. 2 represents the influence of calcium added in both lime and superphosphate. For both apple cultivars subsurface applications resulted in higher leaf Ca than did surface applications. In the case of 'Golden Delicious' trees the leaf Ca content from surface applied Ca was not significantly different from that of the check trees during the first 3 growing seasons. However, by the 4th year, surface applied Ca had established a higher leaf Ca concn than the check. Neither method of Ca application maintained Ca above 1% in the foliage. The higher leaf Ca established initially by the subsurface Ca application decreased at a more rapid rate than that resulting from surface applications. This rapid decrease in leaf Ca when lime was subsurface applied may have been a result of feeder root development beyond the placement zone. When treatments were reapplied between the 6th and 7th growing season there was no difference during the following 2 seasons between leaf Ca concn resulting from the 2 methods of application. However, with 'Delicious', the repeated application of calcium on the surface, established a higher leaf Ca concn, by the 9th year, which was maintained until the 11th year after which there was no difference in leaf Ca concn due to method of application. Leaf Ca in 'Golden Delicious' was raised equally by either method of application following a second application of lime and was maintained throughout the experiment.

Since cross feeding or surface washing of applied treatments would have resulted in increased P concn, as well as increased Ca concn, the general increase in Ca conc of check trees which occurred during the 7th growing season was not a result of Ca absorption from treated areas but may have been due to fruiting which was shown by Hansen (10) to increase leaf Ca.

Leaf P content (Fig. 3) of 'Delicious' and 'Golden Delicious' trees was significantly increased by either method of superphosphate application. Initially, subsurface applied superphosphate on 'Delicious' trees was more effective than surface applied superphosphate and tended to remain more effective. However, on 'Golden Delicious' trees there was no difference in leaf P content due to method of application. Both methods of application were effective in maintaining leaf P content above the presently accepted (6) 0.18% P critical level. When leaf P content approached 0.18% P, repeat application between the 6th and 7th growing season re-established adequate P levels in both varieties. As with the initial application, subsurface applied superphosphate tended to be more effective on 'Delicious' and surface applied superphosphate on 'Golden Delicious'.

The initially high leaf P levels shown in Fig. 3 for 'Delicious' was accompanied by a slower growth rate than trees which had received no P fertilization (Fig. 4). After the 2nd year the rate of trunk circumference increase (TCI) of 'Delicious' was greater from subsurface applied phosphorus than from check trees. The initially high leaf P levels accompanied by delayed growth were not overcome until the 5th growing season. The TCI of P fertilized trees continued to be greater than check trees regardless of the method of application.

The peak P concn in the leaves occurred the 3rd growing season and was followed by a sharp decrease (Fig. 3). This occurrence was probably a result of a combination of factors. The growth rate during the first 2 seasons was relatively low during this period of establishment and root growth and development was taking place in soil high in available P. Thus, leaf P concn reached a maximum during this period. As roots developed into areas of lower P availability a smaller percentage of roots remained in the P enriched zone and a drop in concn occurred. Also, the growth rate increase which occurred during the 4th growing season would also tend to dilute leaf P concn.

Although the method of lime and superphosphate application resulted in differences in leaf tissue levels of Ca and P, there was no prolonged difference in tree size associated with method of application.

Since superphosphate supplied both Ca and P, responses to the individual elements cannot be separated. Therefore, the response surface shown in Fig. 5 was developed using multiple regression analyses using data from all growing seasons with the percent maximum TCI calculated for each year for the analyses. The equation used for the model was: % Max TCI = $b_0 + b_1P + b_2Ca + b_3P^2 + b_4Ca^2 + b_5PCa$, with be values representing computed regression coefficients indicating linear, quadratic, or interaction effects of the nutrient concentration in leaf tissue. The b values and indicated significance (** = 0.01, * = 0.05) were: b_0 = 15.030; b_1 = 330.23**; b_2 = 60.102*; b_3 = –550.000**; b_4 = –20.200; b_5 = –80.001*. The percent maximum TCI (% Max TCI) increased with an increase in both leaf Ca and leaf P and there was a significant interaction of Ca and P concn on % Max TCI (Fig. 5). In the case of 'Delicious' the maximum growth rate calculated from the above regression equation was obtained at a leaf concn of 0.224% P and 1.049% Ca. Leaf P concn above the optimum were associated with a reduced growth rate but the decline with higher than optimum leaf Ca concn was not significant.

There was a significant linear correlation between the TCI and the RLA until the trees came into production the 7th season (Table 2). Also, the regression coefficient R for TCI and RLA as dependent variables and leaf P and leaf Ca as independent variables were generally significant through the first season of production which represented a light crop due to spring frost damage. Ca and P leaf concn were related to the tree growth and to increased leaf area produced (Table 2). The lack of correlation between TCI, RLA and leaf content after production may be due to the effects of cropping upon leaf nutrient content as reported by Hansen (10). Although tree growth after fruiting was not significantly correlated with leaf P and Ca levels, those trees receiving lime and superphosphate treatments continued to increase in size at a more rapid rate than check trees (Fig. 4). A slower initial growth rate of trees receiving subsurface application of lime and superphosphate resulted in negative partial correlation coefficients during the first three years (Table 2).

The leaf element content other than P and Ca varied with season and with treatment but differences were not generally significant and were not correlated with growth indexes measured.

Compared to conventional surface applications, subsurface applications of lime and P fertilizers resulted initially in higher leaf concn of Ca and P, but there was no evidence of sustained maintenance of those levels above conventional surface applications. However, if the lime and P materials had been distributed throughout the soil volume rather than located in discrete zones, the response obtained from subsurface applications might have been sustained.

Surface applied lime influenced the pH and Ca level of 10–12 cm of the soil and resulted in a deeper penetration of P than when superphosphate was applied alone.

The influence of increasing concn of leaf Ca and P on tree growth indexes were correlated only until production began. However, this influence resulted in larger trees at the time of first fruiting and the trunk circumference continued to increase at a more rapid rate than trees low in Ca and P. Maximum vegetative growth of 'Delicious' was obtained at leaf P and Ca concn of 0.224 and 1.049%, respectively. With 'Golden Delicious' the corresponding values for maximum vegetative growth were 0.208% P and 1.082% Ca.

The results of this experiment indicate that leaf concn of 0.20–0.25% P and 0.95–1.1% Ca are desirable for growth of North Carolina orchards and that subsurface applications of lime and superphosphate were more effective in establishing high leaf concn of Ca and P but the effectiveness was not sustained.

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