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Effect of Soil Management and Calcium Nitrate Fertilization on the Availability of Soil Nitrate and Cations in an Eastern Apple Orchard

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Abstract. **Four annual applications of $Ca(NO_3)_2$ were made to 'Golden Delicious' and 'Delicious' apple trees beginning in the second leaf at rates of 0.5 to 8 times the recommended rate (45 g/tree per year of age) in each of three soil management systems: cultivated, herbicide, and mowed sod. Soil samples were collected in Mar. and July 1983 (fifth leaf) to a 120-cm depth at the tree drip line. July samples were analyzed for available Ca, Mg, K, Mn, percentage of base saturation, NO_3-N, and soil pH (0.01 M $CaCl_2$); March samples only for NO_3-N. The sod system had the highest soil pH, Ca level, and percentage of base saturation; the herbicide had the lowest, and the cultivated treatment was intermediate. The rate of $Ca(NO_3)_2$ had no measurable effect on these values except in the surface pH levels (0–30 cm), where sod was unaffected but the cultivated and herbicide systems had a significant reduction in pH with increasing levels of $Ca(NO_3)_2$. Soil Mn availability and leaf Mn increased with increasing $Ca(NO_3)_2$ levels in association with the decreasing pH levels. Available soil Mg and leaf Mg decreased with increasing $Ca(NO_3)_2$ due to Ca displacement of soil Mg on the cation exchange complex. Leaf Ca was unaffected by $Ca(NO_3)_2$ rate or the soil management system. During the growing season (Mar.–July 1983), the herbicide system accumulated significantly more of the applied $Ca(NO_3)_2$ than the cultivated or sod systems. No yield response and minimal leaf N response suggested differences in NO_3 accumulation were due to variation in leaching due to the soil management systems.**

The predominant apple cultivars in the eastern United States exhibit physiological disorders due to low Ca (2, 4, 19). Disorders such as corking, bitter pit, scald, and internal breakdown have been moderated or reduced by $CaCl_2$ sprays and dips and liming of the orchard (5, 7, 13, 15, 20). In addition, $Ca(NO_3)_2$ has been recommended as a readily available source of Ca and N (3, 14). Nutrient solution and greenhouse studies have demonstrated that leaf and fruit Ca levels can be increased by increasing the availability of Ca (11, 17). In a field study, $Ca(NO_3)_2$ fertilizer increased Ca availability and uptake in apple (6). However, in other field studies, no response to $Ca(NO_3)_2$ was measured (13, 16). Calcium nitrate lacks the acidifying potential of NH_4-N fertilizers, but it can increase the pH of some soils (1).

Soil management systems interact with fertilizer source and rate to influence nutrient availability. It is important to under-

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stand these interactions as new production systems improve tree growth and reduce soil, water, and pesticide runoff and leaching from orchard systems. Miller and Glenn (16) examined the influence of $Ca(NO_3)_2$ and soil management on young apple trees. They demonstrated that soil management and rate of $Ca(NO_3)_2$ did affect leaf and soil N levels but had no effect on soil or leaf Ca levels. This study further evaluates the effects and interactions of five levels of $Ca(NO_3)_2$, adjusted annually to tree age, and three soil management systems on the availability of soil cations, soil NO_3, soil pH, and leaf mineral concentrations after 4 years of growth. We will demonstrate that the previously described plant responses (16) are, in large part, the result of soil chemical changes due to $Ca(NO_3)_2$.

Materials and Methods

The study plot was established in 1979 on a Hagerstown/Fredrick cherty silt loam (fine, mixed, mesic Typic Hapludalf). The soil is deep and well-drained with a high moisture-holding capacity and high natural fertility. Soil pH ranged from 5.4 to 5.9 in the surface 30 cm. One-year-old nursery trees of 'Topred Delicious' and 'Smoothee Golden Delicious' on M.7a rootstock were planted in May with a mechanical tree planter at a spacing of 5.5 × 5.5 m. All trees were headed at 72 ± 2 cm at planting and subsequently trained to a central leader system. A permanent cover crop of 'Kentucky 31' tall fescue was established in the orchard drive middles. In the first year, weeds were controlled in a 1.5-m strip on each side of the trees with a tree hoe. Permanent soil management systems were established in 1980.

The experimental design was a split-split plot with soil management systems as the main plots. Main plots were in two replications subdivided into 10 fertilizer subplots. Each cultivar was planted within a subplot with one tree/sub-subplot. Fertilizer-grade $Ca(NO_3)_2$ was applied annually in March to all trees within a subplot at five rates beginning in 1980: 22.5 g (0.5 N), 45 g (1 N), 91 g (2 N), 182 g (4 N), or 363 g (8 N) of actual N per tree per year of tree age. The five subplot levels were duplicated within each main plot. Fertilizer treatments were broadcast under the dripline of the tree. The fertilized area was extended each year with the growth of the tree.

The three soil management systems were clean cultivation, herbicide, and mowed sod. All cultivation was done with a Smitty tree hoe to a depth of 5 cm. Generally, three cultivations were required per year to maintain a weed-free surface. 'Kentucky 31' tall fescue was established as a monoculture in the mowed sod treatments to cover the entire orchard floor. In the herbicide treatment, a combination of 1,1′-dimethyl-4,4′-bipyridinium salts (paraquat) at 1.1 $kg \cdot ha^{-1}$ and 6-chloro-*N*,*N*′-diethyl-1,3,5-triazine-2,4-diamine (simazine) at 4.5 $kg \cdot ha^{-1}$ were applied annually in April beginning in 1980. *N*-(phosphonomethyl) glycine (glyphosate) at 3.4 $kg \cdot ha^{-1}$ was used as a spot treatment to control persistent weed species. Except for spot treatments, herbicides were applied as a directed spray with a tractor-mounted boom sprayer to a 1.5-m strip on each side of the tree row leaving a 2.5-m-wide strip of sod in the drive middles. A nonionic surfactant (X-77) at 0.125% (v/v) was added to all paraquat sprays. 'Kentucky 31' tall fescue was maintained in all drive middles.

A commercial spray schedule was followed for pest control. Leaf samples for analysis were taken annually in July from the mid-portion of current season's shoots. Following drying at 70°C and grinding in a stainless steel mill to pass a 40-mesh screen, samples were analyzed for N by micro-Kjeldahl. Total P, K, Ca, Mn, and Mg were determined by inductively coupled RF plasma emission spectrometry. Soil cores 4.1 cm in dimaeter were collected in March and July of 1983 to a 120-cm depth. One core was taken from a 30-cm band inside the dripline from each sub-subplot. Soil cores were divided into depth increments of 0–15, 15–30, 30–60, 60–90, and 90–120 cm. Each increment was air-dried and ground to pass a 0.2-cm screen. Soil NO_3-N was extracted by shaking 20 g of soil in 100 ml of 0.02 N KCl for 30 min. The solution was filtered through a coarse qualitative filter paper and analyzed the same day for NO_3-N using a NO_3-selective ion electrode. The reference electrode was a saturated calomel electrode with an outer reference solution of 0.04 M $(NH_4)_2SO_4$. The reference blank was 0.02 N KCl, and the diluent served for the reference standards. Measured recovery efficiency of this system was 100.3% ± 2.8% for additions of 0, 20, and 40 ppm NO_3-N in six soils ranging in native NO_3-N content from 6 to 67 ppm. Soil NO_3-N was determined for both March and July samplings. July soil samples were analyzed further for available K, Ca, Mg, Mn, pH, and percentage of base saturation. Soil pH was measured in a 1:2 soil/0.01 M $CaCl_2$ per gram mixture. Exchangeable soil acidity was determined by measuring the pH reduction of the ammonium acetate following extraction. A calibration technique related the pH reduction to known milliequivalents of acidity using acetic acid. The soil was extracted with 1 N NH_4OAC (pH 7) to determine available K, Ca, Mg, and Mn levels by atomic absorption spectrometry. Cation exchange capacity (CEC) was the sum of basic cations and exchangeable acidity. Base saturation was calculated as the meq/100 g of soil of (Ca + Mg + K)/CEC × 100. Main treatment effects were separated using analysis of variance for a split-plot design at each soil depth. There were no interactions between cultivar and system or cultivar and N rate for the variables examined. The values presented are pooled across cultivars. Correlation analysis was used for linear and curvilinear relationships.

Results and Discussion

Influence on soil cations and pH. The rate of $Ca(NO_3)_2$ had no effect on base saturation (%) or the amount of soil Ca (%) adsorbed on the cation exchange complex to a 120-cm depth as previously reported (13, 16) for the surface 30 cm. The soil management system did influence significantly base saturation and Ca availability within the root zone when averaged over $Ca(NO_3)_2$ rate (Table 1). The mowed sod system had the highest base saturation and Ca level, the herbicide had the lowest, and the cultivated system was intermediate. Leaf Ca was unaffected by system or rate in 1983 as previously demonstrated (16). There was a $Ca(NO_3)_2$ rate × soil management system interaction with soil pH in the 0–15 and 15–30 cm depths (Fig. 1), in contrast to our previous study (16). The mowed sod system was unaffected by rate of $Ca(NO_3)_2$. However, the cultivated and herbicide systems demonstrated a significant reduction in pH with increasing levels of $Ca(NO_3)_2$, contrary to other studies (8, 9). The cultivated and herbicide systems were significantly different in their soil pH response to $Ca(NO_3)_2$ levels. Soil pH in the herbicide treatment (30–90 cm) was lower than in the mowed sod treatments but there were no significant differences between the mowed and cultivated treatments. No pH effect was measured at 90–120 cm. The mowed sod treatment is a strongly buffered soil system due to increased organic matter (16) and the living roots of the grass. The higher pH in the mowed sod treatment is expected because of a higher base saturation than was present in the herbicide and cultivated systems.

Table 1. The effect of three soil management systems on soil pH, base saturation, and exchangeable Ca in July 1983. Values are pooled cross fertilizer level and cultivars.

Sample depth (cm)	pH			Base saturation (%)			Exchangeable Ca (% of CEC)		
	Managment system			Management system			Management system		
	Cultivation	Herbicide	Sod	Cultivation	Herbicide	Sod	Cultivation	Herbicide	Sod
0–15	*	*	*	52 b	47 b	65 a	42 b	39 b	55 a
15–30	*	*	*	53 b	51 b	68 b	45 b	43 b	61 a
30–60	5.7 abz	5.5 b	5.8 a	63 ab	61 b	73 a	56 ab	50 b	65 a
60–90	5.6 a	5.4 b	5.6 a	71 a	62 b	75 a	61 ab	49 b	66 a
90–120	5.4	5.3	5.3	70 ab	65 b	75 a	58 a	50 b	61 a

[z]Mean separation for main effects (systems) within variables, Duncan's multiple range test, 5% level.
*Significant fertilizer rate × soil management interaction, 5% level.

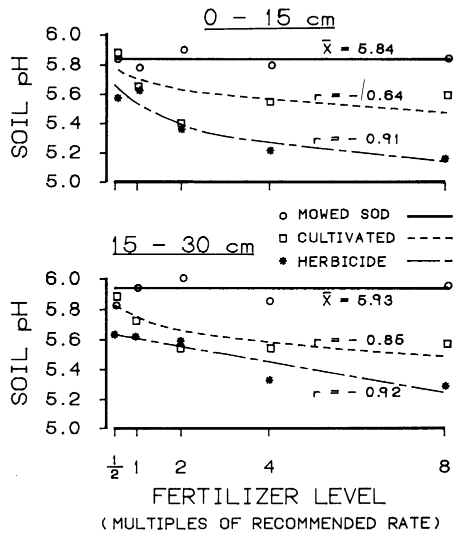

Fig. 1. Interaction of soil management system and rate of $Ca(NO_3)_2$ on soil pH at two depths.

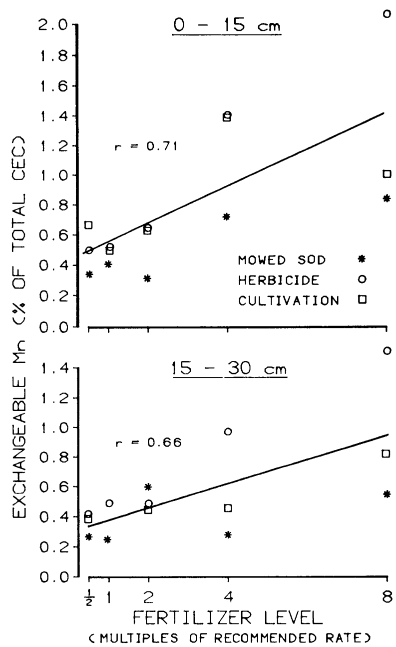

Fig. 2. The effect of $Ca(NO_3)_2$ rates on exchangeable soil Mn^{+2} at two depths. Values are pooled across cultivars.

Lolium perenne has increased the soil pH when fertilized with $Ca(NO_3)_2$ (1).

The soil management system significantly influenced other soil chemical properties throughout the soil profile. Since Mn availability is strongly dependent on soil pH (12), we expected Mn availability to increase in the cultivated and herbicide systems and to be unaffected in the mowed sod. However, there was no soil management system × $Ca(NO_3)_2$ rate interaction for Mn availability in the 0–15 and 15–30 cm depths. Although not significantly different, the sod system generally had a lower available Mn than the cultivated or herbicide systems (Fig. 2). The increased soil Mn availability was reflected in increased leaf tissue Mn concentrations in 3- and 4-year-old apple trees (Fig. 3), as we demonstrated previously (16). Leaf Mn concentrations were generally reduced for trees in the sod system; however, differences were not significant. While the levels of leaf Mn increased with $Ca(NO_3)_2$, they were still within the desirable range (<135 ppm) in all soil management systems (18).

The Hagerstown silt loam soil, like many soils of the Appalachian region, is derived from a calcitic limestone material low in Mg. The addition of Ca in the form of $Ca(NO_3)_2$ can displace Mg from the cation exchange complex, and Mg will leach from the root zone. We found that after 4 years of $Ca(NO_3)_2$ additions, available soil Mg as a percentage of CEC to a 60-cm depth was significantly reduced with increasing levels of $Ca(NO_3)_2$ (Fig. 4) across all three soil management systems. The reduction in soil Mg availability was reflected in leaf Mg levels (Fig. 5) (16). The leaf Mg levels in this study were already below the desirable level of 0.35% (18), and increasing $Ca(NO_3)_2$ intensified the condition. The use of $Ca(NO_3)_2$ requires sufficient available soil Mg; otherwise, Mg availability can be reduced. No rate or system effect was detected in soil or leaf K.

Influence on soil NO_3-N. Miller and Glenn (16) found that after three years of $Ca(NO_3)_2$ applications the herbicide and cultivated systems had greater residual NO_3-N than the sod system. In this study, we examined the fate of $Ca(NO_3)_2$ by following the N level change from application (Mar. 1983) to peak growth (July 1983). There was a $Ca(NO_3)_2$ rate × soil management system interaction for NO_3-N accumulation. Overall, the cultivated and sod systems had similar patterns of seasonal NO_3-N accumulation in the 0–120 cm profile (Fig. 6). The first significant increase in residual soil NO_3-N occurred at the 4 N level for the cultivated and mowed sod treatments. The herbicide system had increased levels of NO_3-N accumulation at all levels except 0.5 N, with the first significant increase occurring at the 1 N level. At the March sampling, the cultivated and herbicide treatments accumulated NO_3-N once the 1 N level was exceeded and the mowed sod had accumulation at the 4 N

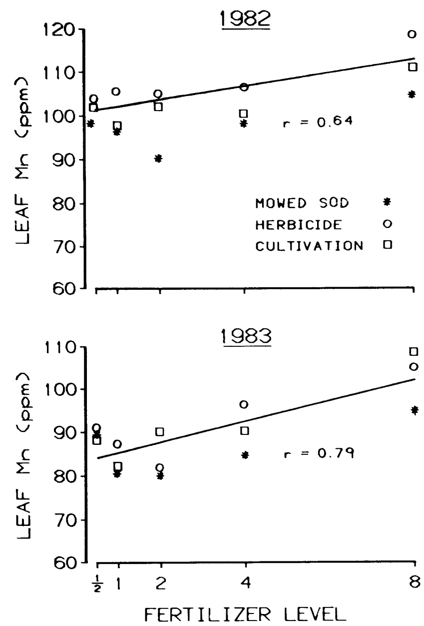

Fig. 3. The effect of $Ca(NO_3)_2$ rates on leaf Mn concentrations. Values are pooled across cultivars.

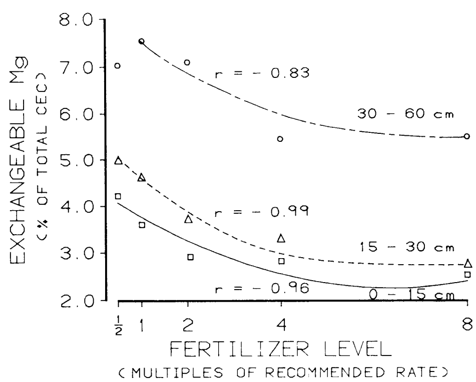

Fig. 4. The effect of $Ca(NO_3)_2$ rates on exchangeable soil Mg^{+2}. Values are pooled across systems and cultivars.

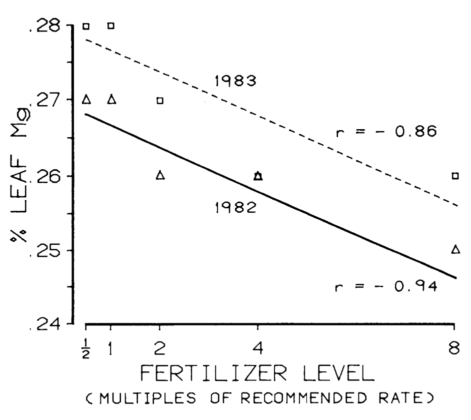

Fig. 5. The effect of $Ca(NO_3)_2$ rates on leaf Mg concentration. Values are pooled across systems and cultivars.

level (16). Nitrogen fertilizer will accumulate if applied in excess of plant uptake and leaching and denitrification potential. During the 1983 growing season, the trees in the cultivated and sod systems had a higher N requirement than trees in the her-

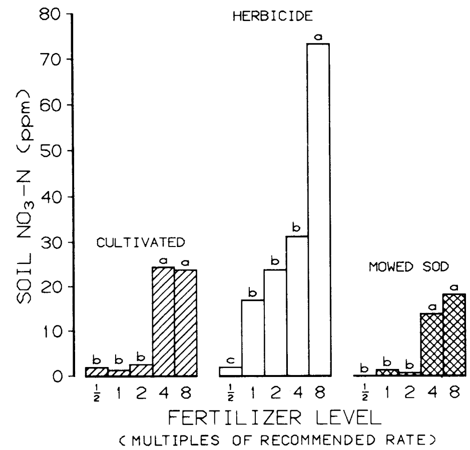

Fig. 6. The effect of $Ca(NO_3)_2$ rates on NO_3-N accumulation from Mar. to July 1983 in three soil management systems of a 4-year-old apple orchard. Mean separation using Duncan's multiple range test, $P = 0.05$.

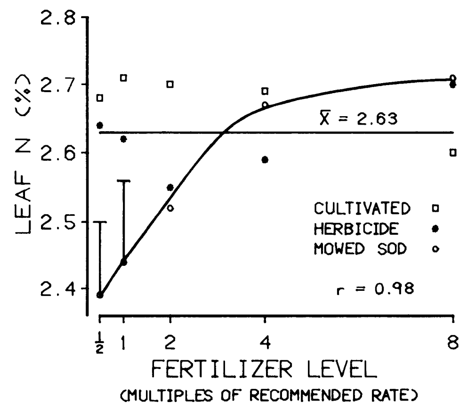

Fig. 7. Interaction of soil management system and $Ca(NO_3)_2$ rate on leaf N. Vertical bars represent the SE; absence of bars indicates nonsignificant differences.

bicide system, based on residual soil NO_3-N levels. The differences in fertilizer rates at which NO_3-N accumulated in the herbicide and cultivated systems may be due to differences in leaching potential of the soil management system rather than the N uptake by the tree. Researchers have shown infiltration rates to be lower for herbicide systems than cultivated systems when soil structure deteriorates (10). Infiltration studies on a similar site of the Hagerstown silt loam by us strongly supports this inference. There was a system × $Ca(NO_3)_2$ rate interaction for leaf N in which neither the herbicide nor the cultivated system had a significant leaf N response to increasing $Ca(NO_3)_2$. The leaf N percentage from the sod system did increase with increasing $Ca(NO_3)_2$ (Fig. 7). There were no leaf N cultivar differences in 1983. The increases N requirement of the mowed sod treatment is due primarily to the grass competition. The present fertility level of the soil in our study is sufficient to provide adequate N in all systems at 0.5 N level and perhaps at 0 N. Leaf N levels were >2%. There were no yield differences due to fertilizer level or soil management system for each cultivar in 1983.

In summary, we found that the soil management system influenced soil chemical characteristics such as pH and nutrient availability and distribution with a resulting change in plant nutrient status. Calcium nitrate did not increase leaf Ca, available soil Ca, or soil pH. In a 4-year period, $Ca(NO_3)_2$ demonstrated a potential to reduce soil pH, increase Mn availability, and decrease Mg availability. Fertilizer strategies should be sensitive to soil management differences in order to compensate for changes in soil pH and nutrient availability. Such an approach is necessary to meet plant nutrient requirements, prevent N leaching into ground waters, and to minimize N inputs, excessive growth, and costs in orchard production.

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