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Effect of Soil Buffer Capacity on Soil Reaction (pH) Modification and Subsequent Effects on Growth and Nutrient Uptake of *Platanus occidentalis* L. Seedlings

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ABSTRACT

The buffer capacity of a soil is a significant factor in determining the longevity of soil reaction (pH) adjustments by aluminum sulfate, $Al_2(SO_4)_3$, or calcium carbonate, $CaCO_3$. After 12 weeks the modified pH values of the highly buffered Emory silt loam had changed substantially toward the original pH value of 7.6. Modified pH values for the Groseclose silt loam soil remained essentially unchanged under the same conditions. These differences in soil response to modified soil pH are related to the differences in the percentage of vermiculite-chlorite and chlorite in the clay fractions of the two soils.

The longevity of soil pH modification is related to total sycamore seedling dry weight and nutrient uptake. Though these components were significantly affected for plants grown in a Groseclose soil, the lack of significant response differences, except at the extremely low pH adjustment (5.21), in the Emory soil suggests a rapid change in modified soil pH toward the original soil pH value.

The condition of the seedlings coupled with total dry weight accumulation and foliar nutrient content elimiates acid toxicity as a factor affecting growth and nutrient uptake. Plants grown in the Groseclose soil at pH 4.31 could be the exception.

INTRODUCTION

Most published reports concerning soil pH modification have described the time of effectiveness as the length of time required to produce the initial desired pH change after amendment application (Peech 1941, Coleman et al. 1958, Hall and Barker 1971). However, only meager data have been presented to describe the longevity of soil reaction modification (Coleman et al. 1958, Hutcheson and Freeman 1965). Those data which are available are concerned primarily with the effects of liming (Lund 1970, Reeve and Summer 1970, White et al. 1970, Hall and Baker 1971) and supply little information about the period of time that "effective" soil acidification can be expected to be maintained after applications of acidifying materials.

The amount of an amendment required to raise or lower soil pH to the desired value is dependent on the resistance of that soil to changes in pH, i.e. buffer capacity (Buckman and Brady 1967). Other factors being equal, the buffer capacity is highly correlated with cation exchange capacity (CEC) (Buckman and Brady 1967). Both the CEC and the buffer capacity of a soil are affected by changes in soil pH (de Villiers and Jackson 1967a), amount of organic matter (Hallsworth and Wilkinson 1958), clay content (McLean and Owen 1969), and type of clay (de Villiers and Jackson 1967b). Percentage base saturation is linked to the degree of buffering (Peech 1941) and where extremes in base saturation are found at high and low pH values, the buffer capacity of a soil is at its lowest (Mehlich 1941, Peech 1941). Previous investigations on the effect of soil type and soil reaction demonstrated that the dry matter accumulation of sycamore seedlings (*Platanus occidentalis* L.) was affected significantly by adjustments to soil pH for a Groseclose soil but not for an Emory soil (Pope 1973). The lack of significant growth differences of sycamore seedlings for adjusted pH levels of the Emory soil apparently was related to a substantial change in the adjusted pH values toward the original pH of the soil. The purpose of this report is to explain the possible causes for the change in the adjusted pH values in the Emory soil and to relate these facts to the growth response of sycamore seedlings.

MATERIALS AND METHODS

The soils used in this study were the A_1 horizon of an Emory silt loam derived from a colluvial limestone with an original pH of 7.6 and the Ap_1 horizon of a Groseclose silt loam derived from alluvial deposition and having an original pH of 6.2 (Obenshain et al. 1966). Chemical and mechanical analyses were conducted by the Soils Testing Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Identification of clay minerals was achieved by the techniques of differential thermal analysis (DTA) (Mackenzie 1957) and X-ray defraction (Brown 1961, Rich, 1969). The soils were fertilized to an equivalent of 1000 lbs/acre of 10-10-10 commercial fertilizer and the soil pH was adjusted to either 4.25, 5.50, 6.75, or 8.00 by the addition of $Al_2(SO_4)_3$ or $CaCO_3$ as determined from a standard curve for each soil type. The standard curves for the Groseclose and Emory soils were derived from the procedures for soil pH adjustment described by Rich and Obenshain (1955) and Hutcheson and Freeman (1965). The soil pH was determined after equilibration and after plant harvest by using a 1:1 ratio of soil to water. The initial pH was within ± 0.1 pH unit of the desired value.

Sycamore seed was collected in mid-April after overwintering on the tree. After germination and the development of the first two true leaves, the seedlings were transplanted into 6-in. (20-cm) pots containing the fertilized and pH adjusted soil media. After 12 weeks of growth, the plants were harvested and the total dry weight of the plant determined by oven drying at 80C to a constant weight. The foliage was analyzed for percentage nitrogen, phosphorus, and potassium. Nitrogen was determined by the semi-micro Kjeldahl technique, phosphorus by the ammonium-molybdate vanadate method, and potassium by use of a flame photometer.

The experimental design was composed of 2 soil types, 4 pH treatments, and 24 replications of 192 seedlings. Within a replication the seedlings were located in a randomized complete block design. The dependent variables were analyzed by an analysis of variance for the independent variables replication, soil type, soil pH, and all possible interactions. Variation about the mean values was examined by use of Duncan's Multiple Range Test.

RESULTS

Chemical, mechanical, and mineralogical data for the Groseclose and Emory soils are reported in Table I. With regard to the chemical characteristics, the Emory soil has a higher pH value (7.58 vs. 6.15), greater exchangeable calcium (11.49 vs. 2.82 milli-equivalents, MEQ) and magnesium (3.41 vs. 0.66 MEQ), greater total exchangeable cations (17.42 vs. 10.09 MEQ), and a greater percentage base saturation (88.69 vs. 39.84%). The values for the exchangeable cations, hydrogen (H) and aluminum (Al), are substantially greater in the acid Groseclose soil.

The mechanical analyses show that the A_1 horizon of Emory soil contains 20% more sand, 24% less silt, and 4% more clay than the Ap_1 horizon of the Groseclose soil.

The mineralogical data indicate higher percentages of vermiculite-chlorite and chlorite clay minerals in the Emory soil and a higher percentage of vermiculite in the Groseclose soil.

The standard curves for soil acidification and liming (Fig. 1) indicate that at the extremes in soil pH (below 5.0 and above 7.6) the Groseclose soil exhibited a larger change in pH than did the Emory when equivalent amounts of $CaCO_3$ or $Al_2(SO_4)_3$ were added. The ability of the Emory soil to resist such pH changes suggests it has a higher buffer capacity than the Groseclose soil in accordance with Peech (1941).

There were pronounced differences between the initial and final adjusted soil pH values for the two soils (Table II). For the Emory soil the final pH approached the original pH of the soil. However, the magnitude of difference decreased as the initial adjusted pH approached the original soil pH. In contrast, for the Groseclose soil, the differences in initial and final pH values were very small.

Plant dry weight and the percentage of foliar ash, nitrogen (N), phosphorus (P), and potassium (K) were affected significantly by the final soil pH value for a given soil type (Table III). Plant dry weight was affected markedly by the adjusted pH levels in the Groseclose soil. Plant dry weight increased from 0.49 grams at a pH of 4.31 to 8.91 grams at a pH of 6.67 and then declined to 7.72 grams at a pH of 7.97. There were no significant differences in dry weight among plants grown on the Emory soil adjusted to different pH values. Reduced growth rate normally is accompanied by an increase in percentage ash and in elemental levels if the plant is not subjected to elemental deficiency.

The percentage ash declined to a constant level for all plants grown at adjusted soil pH values greater than 4.31 in the Groseclose soil. This trend is reversed for the Emory soil. Percentage ash was greatest for plants grown at a pH of 7.93 and declined to a constant level for all plants grown at lower pH values.

For the Groseclose soil, the percentage of foliar N and K respectively decreased from a maximum of 3.61 and 2.73 to a minimum of 3.00 and 1.81 as the adjusted soil pH increased. Soil pH had little effect on the percentage of N and K for plants grown on the Emory soil. For the Groseclose soil, the concentration of foliar P increased from a minimum of 0.32% at pH 4.31 to a maximum of 0.46% at pH 6.67, then declined to 0.38% at a soil pH of 7.97. The foliar concentrations of P were unaffected by the adjusted soil pH of the Emory soil except at a pH of 6.13.

DISCUSSION

For the Emory soil, plant dry weight was not significantly different over the range of adjusted soil pH levels because of the substantial pH shift back toward the original pH. After adjustment, Hutcheson and Freeman (1965) reported a rapid change in soil pH toward the initial pH for both limed and acidified plots of a Burgin soil which has properties approximating those of the Emory soil. Hutcheson and Freeman concluded that such pH changes occurred within 6 weeks of initial equilibration and were caused by the strong buffer capacity of the soil. The similar soil characteristics of the Burgin and the Emory soils plus the 12-week duration of this study suggest that the same explanation may apply to the Emory soil. The differences in pH response between the Emory and Groseclose soil can be explained in terms of the differences in buffer capacity at the extreme adjusted levels of soil pH.

Obenshain et al. (1966) concluded that in CEC the two soil types are not substantially different (18.7 for the Emory and 18.3 for the Groseclose). The differences in the buffering ability of soil cannot be explained solely by differences in CEC but rather by the variables which are important in the makeup of the soil CEC (Buckman and Brady 1967), namely organic matter and clay (Hallsworth and Wilkinson 1958, McLean and Owen 1969). Generally, the Emory soil has a higher percentage of organic matter and clay than does the Groseclose. These facts alone would suggest a higher buffer capacity for the Emory soil; however, on the basis of the CEC of the soil the buffer capacity should not differ significantly. de Villiers and Jackson (1967b) demonstrated that chloritized 2:1 layer silicates having an initial high soil pH retained a large increment of the CEC as long as the soil pH was not reduced below 5.0. Release of the initially blocked isomorphous and interlayer substitional negative charge by deprotonation of the positive hydroxyalumina in clays is the indicated mechanism. Pionke and Corey (1967) found results similar to those of de Villiers and Jackson (1967b) but with organic matter. The mechanism of CEC retention and subsequent soil pH increase may be operating in the Emory soil.

The buffer capacity is related not only to clay and organic matter but also to percentage base saturation and type of clay. The higher percentage base saturation in the Emory soil under natural conditions indicates that a larger number of cations can be fixed in the interlayers of the clay minerals (Rich 1964). When soil pH is lowered with $Al_2(SO_4)_3$, the surface exchangeable cations are replaced by Al(OH)x polymers but the fixed cations are still present in the interlayers (Rich 1964). The type of clay present will determine the rapidity with which these interlayer cations can be replaced by H_3O+ (Rich 1964). The higher natural pH of the Emory soil suggests it has a higher percentage base saturation. It is generally reported that the percentage of 2:1 clay is higher in the Emory soil (Obenshain et al.

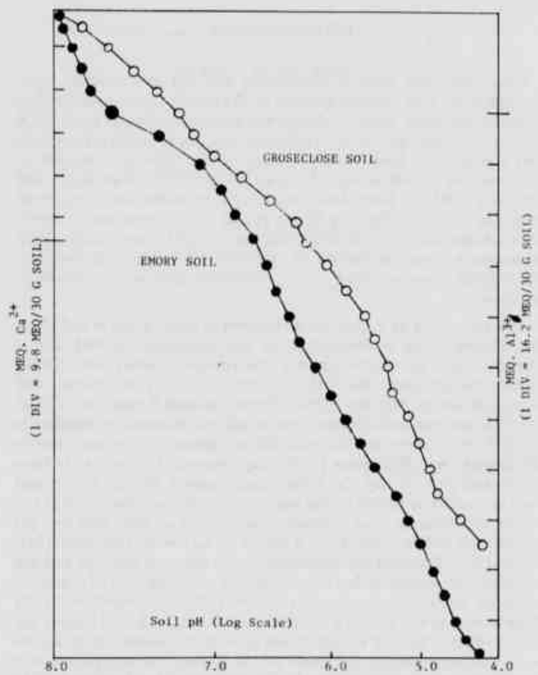

Figure 1. The standard curves for soil pH adjustment for a Groseclose and an Emory soil by the addition of $Al_2(SO_4)_3$ or $CaCO_3$. (Soil pH lowered below the original pH of the Emory (●) and the Groseclose (O) soils with $Al_2(SO_4)_3$ and raised above the original pH with $CaCO_3$.)

1966). The facts suggest that a larger number of cations are trapped in the clay interlayers and are released at low soil pH.

When cations are replaced from the interlayers, they may deprotonate Al(OH)x polymers in clays or organic matter or replace them altogether and increase the pH of the soil solution. From the data presented by Obenshain et al. (1966) and on the basis of the results of this study, it appears that the Emory soil is capable of overriding changes in pH.

After the changes in the adjusted pH values, the nutrients available for plant uptake were not appreciably different over the pH range for the Emory soil. In the Groseclose soil, where adjusted soil pH did not change significantly with time, the ranges in available nutrients, as reflected in foliar concentrations, were much wider and resulted in significant differences in plant dry weights with changes in soil pH. Although no chemical analyses were made for foliar content of aluminum (Al) or manganese (Mn), the general appearance of the seedlings coupled with the growth rates and foliar nutrient contents practically eliminates "acid toxicity" as a factor affecting growth and nutrient uptake. Plants grown in the Groseclose soil at pH 4.31 could be the possible exception.

CONCLUSIONS

The study findings support the idea that the buffer capacity of a soil cannot be explained solely by its CEC. Other factors such as percentage base saturation, organic matter, clay content, and types of clay must also be considered. The buffer capacity of a soil is responsible for the substantial changes in adjusted soil pH values toward the initial pH, and frequent soil pH checks should be made in studies where plant growth is measured in response to adjusted soil pH. These results raise doubts about the conclusions drawn from earlier studies (Kipps 1947, Vlamis 1953) where plant response to adjusted soil pH was investigated and final soil pH was not measured.

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Table I. Chemical, Mechanical, and Mineralogical Analysis for the A Horizons of a Groseclose and an Emory Soil

CHEMICAL CHARACTERISTICS

Soil Type	pH	Organic Matter(%)	Exchangeable Cations (Milli equivalents/100 grams soil) Ca	Mg	K	H	Al	Total	Base Saturation %
Groseclose(sl)	6.15	2.30	2.82	0.66	0.54	7.07	0.54	10.09	39.84
Emory(sl)	7.58	2.15	11.49	3.41	0.55	1.97	0.00	17.42	88.69

MECHANICAL ANALYSIS

Soil Type	Particle Size Distribution (%) Sand	Silt	Clay
Groseclose(sl)	17.8	64.2	18.0
Emory(sl)	37.4	40.6	22.0

MINERALOGICAL DATA

Soil Type	C.E.C*	Montmorillonite %	Vermiculite %	Vermiculite-chlorite %	Chlorite %	Kaolinite and/or Halloysite %
Groseclose(sl)	18.3	8	40	0	0	15
Emory(sl)	18.7	10	10	13	20	15

*C E C expressed as me/100 grams of soil. Determination made by the Soil Testing Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

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Table II. Predicted, Mean Initial, and Final pH after 12 Weeks for a Groseclose and an Emory Soil Whose pH was Adjusted with $CaCO_3$ or Al_2SO_4

Predicted Soil pH	Groseclose Soil Means for Adjusted pH values		Emory Soil Means for Adjusted pH values	
	Initial	Final	Initial	Final
4.25	4.28	4.31	4.27	5.21
5.50	5.47	5.50	5.60	6.13
6.75	6.75	6.67	6.79	7.11
8.00	8.01	7.97	7.98	7.93

Table III. Effect of Soil Type and Final Soil pH on Dry Weight and Percentage of Foliar Ash, Nitrogen, Phosphorus, and Potassium of Sycamore Seedlings after 12 Weeks

Variables	Groseclose Soil				Emory Soil			
Final soil pH	4.31 a	5.50 b	6.67 c	7.97 d	5.21 a	6.13 b	7.11 c	7.93 d
% Ash	13.86 a*	11.7 b	11.6 b	11.4 b	10.8 a*	10.8 a	10.7 a	11.6 b
% N	3.61 a	3.41 a	3.04 b	3.00 b	2.62 a	2.53 ab	2.46 b	2.49 b
% P	.32 a	.36 ab	.46 b	.38 b	.35 a	.41 b	.38 a	.36 a
% K	2.73 a	2.40 a	1.99 b	1.81 b	1.76 a	1.83 a	1.81 a	1.77 a
Plant Dry Weight (g)	0.49 a	3.00 b	8.91 d	7.72 c	5.01 a	5.22 a	5.29 a	5.13 a

*Row values for a variable, over the pH range and within a soil type, not followed by the same letter were significantly different at 0.01 for Duncan's Multiple Range Test.