RED MAPLE (*ACER RUBRUM* L.) GROWTH AND FOLIAR NUTRIENT RESPONSES TO SOIL FERTILITY LEVEL AND WATER REGIME

by C. H. Pham
Howard G. Halverson
Gordon M. Heisler

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370 REED ROAD, BROOMALL, PA. 19008

The Authors

C. H. PHAM was a research associate at Rutgers University during the course of this study. He received his Bachelor of Forestry from the Australian National University in 1967, and a Ph. D. in forestry from the same university in 1971. He was a lecturer at the College of Forestry, Saigon, from 1972 to 1975. Dr. Pham is now a research associate studying silviculture and forest ecology at the School of Forestry, Fisheries, and Wildlife, University of Missouri, Columbia.

HOWARD G. HALVERSON is Research Forester and Project Leader for forest amenities and municipal watershed research at the Northeastern Forest Experiment Station, Pennington, New Jersey. He received his B.S. degree in forest management from Iowa State University, and M.S. and Ph. D. degrees from the University of Arizona. He began his career with the Forest Service in 1965 and came to the Northeastern Station in 1975.

GORDON M. HEISLER has been a Research Forest Meteorologist at the forest amenities and municipal watersheds project, Northeastern Forest Experiment Station, Pennington, New Jersey, since 1972. He received his B.S. degree in forestry from The Pennsylvania State University, a Master of Forestry in silviculture from Yale University, and his Ph. D. in forest influences from the State University of New York, College of Environmental Science and Forestry.

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Abstract

Red maple (*Acer rubrum* L.) seedlings were grown in a greenhouse using three treatments: two soil horizons, two soil moisture regimes, and three nutrient levels. Fertilization increased growth under moist conditions on the more fertile topsoil. Under dry conditions, fertilization had no effect on growth in subsoil, and slightly increased growth in topsoil. Without fertilization, growth was greater in the moist topsoil. Growth was most balanced when available soil N was 25 ppm, P was 25 to 75 ppm, and K was 75 to 100 ppm. Multiple regression equations relating growth to foliar nutrients were significantly different only for the subsoil.

INTRODUCTION

URBAN AREAS CREATE unique forest environments. Trees can be stressed by infertile soil, soil water deficit, pollution, and surfaces that act as heat traps. Vandalism and natural enemies also threaten new urban forests. Therefore, good survival and growth rates in the first few years are particularly important for the successful establishment of forests in urban areas. Appropriate fertilization may help seedlings to survive and improve their growth. Fertilization of urban forests is also thought to be potentially useful on sites recently developed on stripped soils or poor quality fill (Richards and Leonard 1973). However, optimum concentrations of soil nutrients for northeastern hardwoods are not well documented (Auchmoody and Filip 1973).

We studied the growth responses of red maple (*Acer rubrum* L.) seedlings to soil fertility levels and water regimes in a greenhouse. The general purpose of the study was to define the near optimum soil macronutrient level for urban forest trees that can be attained with complete fertilizers. Since complete fertilization was tested, nitrogen, phosphorus, and potassium levels were all adjusted in each treatment.

METHODS

Three fertility levels and two water regimes were used in a randomized block design on two soil horizons. Each treatment was replicated four times so that there were 48 experimental units.

The red maple plants were genetically identical 2-0 budded nursery stock of the cultivar 'October Glory.' They were closely matched in size with a height of about 62 cm and a diameter of about 1 cm at the root collar. Treatment pots of 11-liter capacity were filled with the prepared soil samples. After cold storage to break dormancy, the seedlings were planted one to a pot and allowed to establish for 6 weeks until the first flush of growth started on 4 March 1976. Soil moisture was maintained near field capacity during the establishment period, then controlled moisture treatments were begun and growth measurements were started.

The seedlings received 50 to 90 percent of full sunlight with a photoperiod of 11-1/2 to 15 hours. Temperatures varied from 19° to 24°C while relative humidity fluctuated from 45 to 80 percent.

Treatments

Soil horizons. Samples were taken from two soil layers: the subsoil, (silty clay loam, 30 to 84 cm depth) which had been exposed by the construction of a parking lot, and the topsoil, (silt loam, 0 to 30 cm depth) from an adjacent open area. Both soils were somewhat poorly drained variants of the Nixon series in Middlesex County, N.J. (U.S. Soil Conservation Service 1976). Soil fertility and physical properties immediately after collection are given in Table 1.

Table 1.—Physical and chemical properties of the two soil horizons

Soil property	Topsoil	Subsoil
Texture (%)		
Silt	50	59
Clay	16	35
Sand	35	6
pH	6.8	5.0
Organic matter[a] (% dry weight)	5.2	3.9
Bulk density (g/cc)	1.40	1.43
Total nitrogen (semimicro Kjeldahl, % dry weight)	0.173	0.072
Cation exchange capacity[b] (meg/100g)	15.93	15.60
Available nutrients[c] (ppm)		
Mg	432	307
P	64	11
K	106	50

[a] Loss on ignition.
[b] Extraction with NH_4OAC, pH = 7.
[c] Extraction with North Carolina reagent of 0.25N H_2SO_4 and 0.05N HCl with 4:1 ratio.

Macronutrient levels. Fertility levels (low and high) for each soil layer were established by adding nutrients in proportions based on an assumed soil mass of 2.24×10^6 kg/ha. The concentrations in the topsoil and subsoil controls were: N, 35 and 14 ppm; P, 64 and 11 ppm; and K, 106 and 50 ppm. Soils were amended to 25 ppm N, 75 ppm P, and 106 ppm K in the low fertility treatment and to 50 ppm N, 150 ppm P, and 212 ppm K in the high fertility treatment. Phosphorus was added in the form of monocalcium phosphate $Ca(H_2PO_4)_2$ (24.6 percent P); potassium as potassium sulphate K_2SO_4 (41.5 percent K). Both were thoroughly mixed with the soils before potting. Nitrogen was not added until the first flush of seedling growth. Equal amounts of nitrogen as ammonium nitrate NH_4NO_3 (35.5 percent N) were applied in solution at the beginning of the experiment then 4 and 8 weeks later, with each application representing 1/3 of the total applied N.

To increase the pH of the subsoil, 40 g of pulverized dolomitic limestone (minimum $CaCO_3$ 51.5 percent, minimum $MgCO_3$ 44.0 percent) was mixed thoroughly with the soil in each pot. This raised the subsoil pH to near 6.0.

Moisture regimes. To establish the watering schedule, soil samples were maintained at −0.3, −1, −3, and −15 bars as determined by a pressure membrane apparatus. The moisture tension curves and gravimetric soil moisture percentages were used to compare the two soils and determine the corresponding water potentials (Table 2).

The potted seedlings were subjected to two soil moisture treatments by simulated droughts of 2 and 7 days. At the end of each dry-down period, the pots (with soil, plants, and water) were weighed, moisture content was determined, and distilled water was added to return the soil to field capacity. This technique produced water potentials of approximately −1 bar for the moist treatment and −3 bars for the dry.

Measurement and analysis

The height of each plant was measured for 12 consecutive weeks after it was established. At the end of the 12 weeks, total height and diameter at 5 cm above the soil were measured. Dry weights of all plant parts (including roots $\geq$ 0.5 mm diameter) were determined after drying in a forced-draft oven at 80°C for 48 hours. All healthy, full-sized leaf blades of each plant (about 80 percent of all leaves) were dried separately and ground for chemical analyses. Nitrogen was determined by the semimicro-Kjeldahl method; phosphorus, magnesium, and potassium by the colorimetric method with an autoanalyser; and iron and manganese by atomic absorption techniques after digestion with a mixture of 80 percent nitric acid and 20 percent perchloric acid by volume.

Growth variables were not based on the nutrients that would be present in the soil if all the added nutrients were available. Rather, we reanalyzed the soil at the close of the experiment to determine the nutrients actually available. The reanalysis was done to correct for immobilization or fixation of the macronutrients so that recommendations for best seedling growth based on available nutrients, not fertilizer additions, could be made.

Table 2.—Soil moisture content (in percent dry weight) at different water potentials (in bars), with percentage of remaining available water

Item	Field capacity (-0.3 bar)	Wet treatment (-1.0 bar)	Dry treatment (-3.0 bar)	Wilting point (-15.0 bar)
		TOPSOIL		
Moisture content	22.5	21.2	14.3	8.4
Available water	100	91.0	42.0	.0
		SUBSOIL		
Moisture content	24.2	23.7	17.3	11.3
Available water	100	96.0	46.5	.0

RESULTS AND DISCUSSION

Optimum soil fertility depends on how growth is defined. In this study, we defined growth in terms of increased diameter and height, and the top-root dry biomass of the seedlings. We also examined foliar nutrient and soil nutrient levels for possible relationships that might suggest optimum conditions.

Disposition of added nutrients in the soil

Nutrients added to soils are not all available to the plant. Nitrogen may be leached, volatilized, or immobilized by microbes in the soil. Phosphorus becomes unavailable through chemical conversion to compounds only slightly soluble in the soil. Potassium may undergo fixation in the expanding lattice of some clay minerals.

The calculated available nutrients in the fertilized soils were compared with the measured available nutrients (Table 3). Since we added nitrogen in thirds, we assume it was available throughout the experiment at levels of 25 and 50 ppm in the low and high fertility treatments. The topsoil did not immobilize phosphorus at the low fertility level, and potassium was unaffected; however, some potassium was fixed at the highest fertility level under the driest condition. The subsoil, with a greater clay fraction, immobilized an average of about 75 percent of the added phosphorus and fixed about 45 percent of the added potassium.

Diameter growth

Diameter growth was significantly related to soil horizon and to water regime but not to fertility (Table 4). Diameter growth of seedlings was greatest in the topsoil maintained with the wet treatment. Reducing the water potential to −3 bars (dry treatment) reduced the diameter growth by about 12 percent. Our results and the results of other studies (Stransky and Wilson 1964, Loftus 1975) suggest that water availability is the major determining factor of diameter growth in young seedlings. And in our study, fertilization did not accelerate diameter growth.

Table 3.—Available nutrients and dry weight of tree biomass under three fertility levels and two water regimes after 12 weeks

Treatment	Nutrients			Biomass			Foliage
	N[a]	P	K	Top	Root	Total	
	- - - - -ppm- - - -			*- - - - - - - -gm- - - - - - - -*			
TOPSOIL							
Wet							
Control	20	73	102	20.0	15.1	35.1	8.3
Low	20	76	101	22.0	16.2	38.1	8.9
High	21	118	205	16.2	10.9	27.1	5.5
Dry							
Control	22	71	109	12.4	10.8	23.2	3.3
Low	21	75	108	11.1	12.6	23.7	3.0
High	22	106	161	10.5	10.6	21.1	2.5
SUBSOIL							
Wet							
Control	10	14	52	18.0	16.8	34.8	5.1
Low	10	28	75	20.6	16.3	36.9	6.7
High	13	48	162	23.7	11.2	34.9	10.2
Dry							
Control	9	13	51	11.3	11.5	22.8	2.5
Low	10	27	77	13.8	12.3	26.1	3.5
High	12	42	148	11.8	10.1	21.9	3.3

[a] Assumed available at 25 and 50 ppm in the low and high fertility levels.

Table 4.—Summary of analyses of variance of plant growth variables

Variable	Factor						
	Soil horizon (S)	Water regime (W)	Fertility level (F)	SxW	SxF	WxF	SxWx
Stem diam (mm)[a]	*	**					
Height (cm)		**			**		
Ht increment (cm)		**			*		**
Dry weights (gm)							
Total		**					
Top		**					
Root		**	**				
Foliage		**			**		**
Stem		**					
Top/root ratio		**	*		*	*	
Foliar nutrients							
Nitrogen(%)		**	**				
Phosphorus(%)	**						
Potassium(%)	*		*	*			
Calcium(%)							
Magnesium(%)	**		**				
Manganese(ppm)	**	**		*			
Iron(ppm)	**	*				*	

* = $p<0.05$,
** = $p<0.01$.
[a]Measured at 5 cm above soil.

Table 5.—Foliar nutrient levels for all treatments[a]

Treatment	N	P	K	Ca	Mg	Mn	Fe
	- - - - - - - *percent* - - - - - - -					- - *ppm* - -	
				TOPSOIL			
Wet							
Control	2.23	0.223	0.84	1.16	0.41	413	199
Low	2.59	.215	.76	1.19	.41	384	212
High	2.88	.193	.89	1.20	.43	373	198
Dry							
Control	2.71	.210	.72	1.23	.43	546	189
Low	3.19	.205	.63	1.21	.48	577	230
High	2.96	.175	.86	1.24	.45	570	231
				SUBSOIL			
Wet							
Control	2.08	.138	.66	1.06	.47	568	302
Low	3.09	.168	.60	1.22	.52	540	231
High	2.51	.135	.77	1.10	.49	450	201
Dry							
Control	2.59	.148	.80	1.15	.44	577	279
Low	3.10	.148	.66	1.20	.52	581	278
High	3.22	.170	.73	1.33	.51	575	306

[a] Each value is the mean of four seedlings.

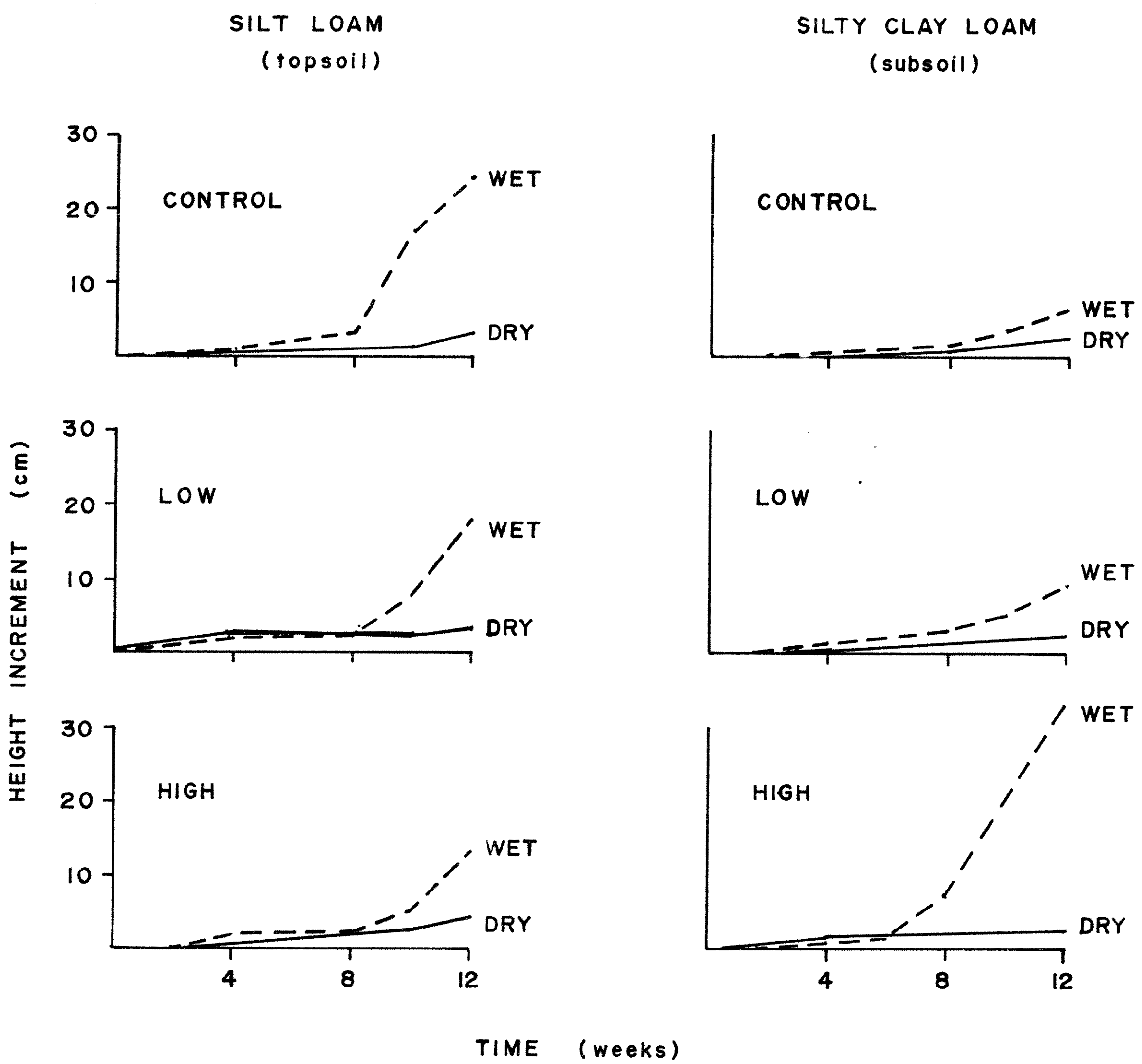
Height and height increments

Seedling height growth was related to water regime and to interactions of water, soil horizon, and fertility (Table 5 and Fig. 1).

Height growth was only 2 to 4 cm for seedlings in the dry treatments, but between 6 and 32 cm in the wet. Height growth was enhanced by fertilization when water was adequate, but fertilization without sufficient water tended to depress height growth. Among the wet treatments, the best height growth was on soil with fertility levels between 48 and 73 ppm phosphorus and 102 and 162 ppm potassium. Concentrations above or below these levels depressed growth even when water was plentiful.

Nitrogen is evaluated separately in this work because available nitrogen in the soil is highly variable. The best growth was obtained with soil nitrogen at the highest level, 50 ppm. As with the other nutrients, the best height growth was the result of the wet treatment and high fertility level.

Figure 1.—Cumulative height increment of red maple seedlings in two soil horizons, under two water regimes (wet or dry) and three fertility levels (control, low, and high).



Dry weights

Dry weights of stems, foliage, and roots were affected by water regime (Tables 3 and 4). Water was a significant factor for all the various plant parts measured, but fertility levels and interactions were also significant for some variables. The interactions are probably related to the chemical reactions and the proportion of clay in the soil, and to the quantity of water present—in much the same way that these factors influenced height growth. Under dry conditions, fertilization had only slight effects on stem, root, or foliage weight. With the moisture treatments, however, the responses varied within different plant parts (Table 4).

Seedlings on topsoil with low fertilization and on subsoil with high fertilization had the maximum total dry weights. These weights correspond to nutrient levels of 25 ppm nitrogen, 76 ppm phosphorus, and 101 ppm potassium in the topsoil and 50 ppm nitrogen, 48 ppm phosphorus, and 162 ppm potassium in the subsoil. Stem weights and foliage weights followed the same pattern.

There was maximum root growth in topsoil with the low fertility treatment. Root growth in the subsoil was greatest in the control treatment; in fact, maximum root growth for all treatments was in this soil with the lowest fertility.

Top/root ratio

Top/root ratio on a dry weight basis has been used as a measure of seedling balance. The interpretation of this ratio is not precise because it varies with species and seedling size. In our experiment, there were high top/root ratios when top growth was enhanced and root development inhibited. On the heavily fertilized and watered subsoil, the ratio was 2.19; for all the other treatments, it ranged from 0.91 to 1.50. Heavy fertilization in these soils could be detrimental to the tree under drought conditions.

Foliar nutrient levels

Foliar nutrient levels in the red maple seedlings (Table 5) were compared to measured growth variables using multiple regression analysis. Equations derived for the topsoil were not significant at $p \geq 0.8$. However, total height, total dry weight, and foliage weight did have a significant relationship to foliar nutrient levels in the subsoil where:

$$\text{Height} = 124.4 - 4.48\,(\text{N\%}) - 79.46\,(\text{P\%}) + 50.79\,(\text{K\%}) + 21.07\,(\text{Ca\%}) + 0.9222\,(\text{Mg\%}) - 0.1224\,(\text{Mn ppm}) - 0.0759\,(\text{Fe ppm}),\ R^2 = 0.923$$

$$\text{Total Weight} = 350.3 + 8.32\,(\text{N\%}) - 87.89\,(\text{P\%}) - 23.51\,(\text{K\%}) - 0.023\,(\text{Ca\%}) - 25.53\,(\text{Mg\%}) - 0.4464\,(\text{Mn ppm}) - 0.1766\,(\text{Fe ppm}),\ R^2 = 0.926$$

and

$$\text{Foliage Weight} = 54.9 + 2.26\,(\text{N\%}) - 16.25\,(\text{P\%}) - 1.14\,(\text{K\%}) - 0.366\,(\text{Ca\%}) + 0.501\,(\text{Mg\%}) - 0.0848\,(\text{Mn ppm}) - 0.0211\,(\text{Fe ppm}),\ R^2 = 0.939$$

The levels of foliar nutrients may be poorly related to growth. Stone and Christenson (1975) for example, concluded that foliar nutrients may be distributed throughout the biomass of a rapidly growing sugar maple (*Acer saccharum* Marsh.). Thus rapid growth may mask any relationship between optimum foliar nutrient levels for long-term growth and measured levels at a single time during tree growth.

Manganese was the nutrient common to all the regression equations. The prominence of manganese in these equations suggests that a Mn deficiency may have limited the growth in the subsoil. But because both manganese and iron were significant in two regression equations, another possibility is that a manganese-iron antagonism may have existed.

CONCLUSIONS

Although this study was designed to examine the optimum fertility levels for red maple, the interactions of soil moisture and soil fertility were also shown. For red maple seedlings on these soils, any growth enhancement through fertilization required high soil moisture content. Even modest water potentials, −3 bar, reduced both top and root growth.

With water readily available in these soils, seedling growth of both root and top was improved by the low level of fertilization—that is, roughly 25 ppm nitrogen, 25 to 75 ppm phosphorus, and 75 to 100 ppm potassium available in the soil. Available nutrients exceeding these quantities accelerated top growth, but tended to depress root growth. For similar soils and species we would not recommend heavy fertilization—soil nitrogen greater than 50 ppm, available phosphorus greater than 100 ppm, and available potassium greater than 150 ppm—unless accelerated top growth is the primary objective and the seedlings have an assured water supply. In that case, continued care would be necessary since greater shoot and leaf growth could subject the trees to moisture stress during drought periods.

Only three significant correlations were found between foliar nutrient levels and growth variables. Foliar nutrient levels that resulted in the greatest growth and the best top/root balance were in the low fertility treatment. This suggests that foliar nutrient levels of at least 2.6 percent N, 0.17 percent P, 0.6 percent K, 1.2 percent Ca, 0.4 percent Mg, 384 ppm Mn, and 212 ppm Fe indicate adequate tree nutrition.

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