

CALCIUM AND MAGNESIUM REQUIREMENTS OF
ILEX CRENATA THUNB. 'HELLERI'

by

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(ABSTRACT)

Rooted cuttings of Ilex crenata 'Helleri' were grown in sand culture with four rates of Ca and Mg (0, 5, 10, and 40 ppm) in a factorial experiment. No increase in total dry weight was achieved by increasing Ca and Mg rates above 5 ppm. Necrosis of shoot apices occurred at the 0 ppm Ca rate. A second rate experiment supported the results of the initial research. In addition to symptoms of Ca deficiency on the 0 Ca treatments, symptoms of severe Mg deficiency appeared on the 0 Mg treatments. These began as a discoloration of the lower leaves followed by abscission. A third experiment was performed on 'Helleri' holly growing in pine bark. Calcium was supplied at 0 and 120 ppm and Mg at 0 and 60 ppm. No differences in dry weight were observed. A third experiment studied the influence of four dolomitic limestone rates (0, 2, 4, and 8 kg/m³) and two gypsum rates (1 and 2 kg/m³) mixed with pine bark on Ca availability, Mg availability, and pH over time. Although the addition of dolomitic limestone increased Ca and Mg in the medium solution, unamended bark supplied sufficient quantities of both elements for the growth of Ilex crenata 'Helleri'. The addition of gypsum caused a large initial increase in Ca in the medium solution, but supplies dropped drastically thereafter.

DEDICATION

This thesis is dedicated to my wife, Sharon and our daughter, Erin.

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INTRODUCTION

Nurserymen have traditionally designed fertilization programs for container-grown ornamentals without being aware of the precise nutritional requirements for growth. To a large degree, this type of information has been unavailable. However, continuing research has begun to provide a data base for recommendations, particularly for N, P, and K. Niemiera and Wright (14) obtained the greatest shoot weight of Ilex crenata Thunb. 'Helleri' in sand culture at 87-100 ppm N. Yeager and Wright (23), growing 'Helleri' holly in a pine bark medium, observed that 10 ppm P resulted in the greatest plant dry weight. Other unpublished results from a factorial experiment in sand culture have demonstrated that 75 ppm N, 15 ppm P, and 25 ppm K in the medium solution may be the levels needed for maximum growth (dry weight and shoot length) of 'Helleri' holly.

Nutrient requirements for Ca and Mg, however, are lacking for woody ornamentals. The goals of this research were to: 1) establish the level of Ca and Mg in the media solution required for maximum growth of Ilex crenata 'Helleri'; 2) determine if a pine bark medium needed supplemental Ca or Mg for maximum plant growth; 3) measure Ca and Mg availability over time in unamended pine bark and pine bark amended with different rates of dolomitic limestone and gypsum; and 4) establish Ca and Mg tissue levels of 'Helleri' holly required for maximum shoot elongation and dry weight production.

LITERATURE REVIEW

Information on the levels of Ca and Mg needed for the maximum growth of container-grown woody ornamentals is limited. The Cooperative Extension Service at Michigan State University has published recommendations stating that the saturated medium extract for a container medium should possess 80-200 ppm Ca as an "acceptable" level with 200-350 ppm being considered "optimum" (3). The same publication recommends 35-60 ppm Mg as "acceptable" and 75-100 ppm as "optimum" in the saturated medium extract. No definition is given for the terms "acceptable" and "optimum" as used in this publication.

Calcium and Mg requirements for different species vary over a wide range. Dunham and Tatnall (6) grew Ilex crenata 'Convexa' in a 3/4 sand and 1/4 German peat moss mixture. Increasing Ca in the nutrient solution from 1 to 10 ppm did not cause a significant increase in dry weight production. Potassium levels varied slightly between these two treatments, being at 196 ppm when Ca was at 10 ppm and 213 ppm when Ca was at 1 ppm. All remaining nutrients were held constant. Brewer (1) grew Ilex crenata 'Green Island' in sand culture. Based on his studies, he suggested 90 ppm Mg as the level needed to achieve maximum growth.

Cox and Seeley (4) grew poinsettias in nutrient culture while supplying Mg at 0, 1, 2, 5, 12, and 24 ppm. No statistical differences in dry weight occurred among the rates greater than 1 ppm. Plant height was not increased above 5 ppm Mg. Poole and Seeley (17) grew three

genera of orchids at 25, 50, and 100 ppm Mg while supplying Ca at 200 ppm. The greatest dry weight occurred at 25 ppm for Phalaenopsis and Cymbidium, while Cattleya grew best at 50 ppm.

Recognizing the interactions among Ca, Mg, and K, Shear et al. (18) grew tung trees (Aleurites fordii Hemsl.) in sand culture while varying the concentrations of these three elements. Regardless of the K level, increasing Mg from 2 to 15 ppm increased plant dry weight. However, increasing Mg from 15 to 45 ppm increased dry weight only when K was at 8 ppm. Increasing Ca from 12 to 72 ppm increased dry weight while an increase from 72 to 216 ppm decreased dry weight regardless of the K and Mg level.

Therios and Sakellariadis (20) studied olive plants (Olea europea L. 'Chondrolia Chalkidikis') in a 1:1 mix of sand and perlite. At 160 ppm Ca in the nutrient solution, fresh weight was maximized with 10-49 ppm Mg in the solution. At 20 ppm Ca, the greatest fresh weight was achieved with 243 ppm Mg. Fresh weights were dramatically less when Ca was supplied at 20 ppm rather than at 160 ppm. However, it should be noted that the rates of Mg were substantially increased at the lower rate of Ca. These authors state that the Ca/Mg ratio needed in the nutrient solution for the maximum vegetative growth of olive plants is 2:1.

The importance of the Ca/Mg ratio in the medium solution has been emphasized by various authors with a 2:1 Ca/Mg ratio normally recommended. Davidson and Mecklenburg (5) state that saturated soil extract levels for container-grown nursery stock should contain levels

of Mg which are less than half the Ca levels. Based on a review of the literature, Tinus and McDonald (21) have published recommendations for tree seedlings which state that the Ca/Mg ratio should be kept between 2:1 and 6:1.

There is an increasing body of evidence which suggests that Ca is needed in very small quantities by some species and in these cases might be more appropriately considered a micronutrient than a macronutrient. For instance, Wallace et al. (24) grew healthy plants of tobacco and corn at Ca levels as low as 2 ppm. Studying the growth of tomatoes (Lycopersicon esculentum Mill. 'Ailsa Craig') in solution culture, Hall (9) varied Ca concentrations from 1 to 600 ppm. Increasing Ca from 1 to 4 ppm produced a dramatic increase in total dry weight but further increases resulted in lower dry weights.

Edwards and Horton (8) grew peach seedlings in nutrient solutions and concluded that 0.3 ppm Ca was sufficient for these seedlings under greenhouse conditions. These same researchers studied peach seedlings in nutrient solutions containing various levels of Mg (7). They were able to increase the relative growth rate by increasing Mg from 0.01 to 0.5 ppm but achieved no further increases at higher levels. Magnesium deficiency symptoms were observed in the 0.01, 0.5, 1, and 3 ppm treatments. No visual evidence of deficiency symptoms occurred when the Mg concentrations exceeded 6 ppm.

Various recommendations have been made concerning Ca and Mg concentrations in the leaf tissue of ornamentals. Smith (19) lists 0.96% Ca and 0.23% Mg as average values for various evergreen species grown

at commercial nurseries. For Ilex crenata 'Convexa', Smith lists 0.87% Ca and 0.48% Mg. Lumis (11) lists 1.4% Ca and 0.21% Mg as low values for broadleaf evergreens in southern Ontario.

Any information which is obtained concerning the Ca and Mg requirements of woody ornamentals must ultimately be related to actual production systems. Dolomitic limestone is typically used by nurserymen to supply Ca and Mg for container-grown plants in addition to its ability to raise pH. Nelson (13) states that North Carolina growers experienced success by using 5.9 kg of dolomitic limestone plus 1.2 kg of hydrated lime per cubic meter of pine bark. If no change in the pH of the medium is desired, calcium sulfate at the rate of 1.5 kg per cubic meter as a source of Ca and S was suggested. Such recommendations do not provide information on the amounts of Ca and Mg actually supplied to the plants by these products. Pokorny (16) states that 4.9 kg of dolomitic limestone per cubic meter of pine bark will add 4 meq of Ca to 10 g of pine bark and that milled pine bark contains 7.6 ppm Ca and 1.6 ppm Mg (water extractable) as well as a total of 0.51% Ca and 0.14% Mg. Still to be answered is the question of the availability of Ca and Mg in a medium over time, both when unamended and when amended with various products.

The above literature has shown that certain species are able to grow quite well with very modest supplies of Ca and Mg. This is in contrast to recommendations which call for levels of Ca and Mg up to 350 and 100 ppm, respectively. Also, there is little real substantiation for the claims of the necessity of any particular Ca/Mg ratio.

at least when both elements are supplied at low rates. Finally, there seems to be little in the way of controlled experimentation to support existing tissue level standards for Ca and Mg. In view of all these factors, this investigation is well justified.

MATERIALS AND METHODS

Experiment 1

Single-stemmed, rooted cuttings of Ilex crenata 'Helleri' were potted in 500 cm³ plastic pots containing No. 18 white quartz sand. The particle analysis of this sand was as follows: 2.5% less than 0.6 mm (U.S. Series sieve #30), 12.5% less than 0.84 mm (U.S. Series sieve #20), 50% less than 1.19 mm (U.S. Series sieve #16), and 92.5% less than 1.68 mm (U.S. Series sieve #12). The sand was leached with distilled water prior to the beginning of the experiment. Four rates of Ca (0, 5, 10, and 40 ppm) and four rates of Mg (0, 5, 10, and 40 ppm) were applied in a 4 x 4 factorial, arranged in a randomized complete block design with 2 plants per pot, 2 pots per cell, and four replications. A cell is used here to mean two pots which were adjacent to one another on the bench and which received the same treatment. All four plants within a cell were pooled and treated as one plant for all measurements. Based on the work of Wright (unpublished results), Niemiera and Wright (14), and Yeager and Wright (23), the plants were fertilized with N at 75 ppm, P at 15 ppm, and K at 30 ppm. The remaining nutrients were applied at the following concentrations according to Hoagland and Arnon (10): Fe-5 ppm, B-0.5 ppm, Mn-0.5 ppm, Zn-0.05 ppm, Cu-0.02 ppm, Mo-0.01 ppm. Calcium was supplied as CaSO₄·2H₂O and Mg as MgSO₄·7H₂O. The nutrient solutions were prepared with distilled water and were adjusted to pH 5.3-5.5. Plants were fertilized daily with 200 ml of

nutrient solution except on Sunday when an equivalent amount of distilled water was used to leach the sand. The plants were grown in a greenhouse and treatments were begun on February 12, 1982 and continued through April 22, a period of 10 weeks. Night interruption was provided from 11 p.m. to 2 p.m. with incandescent lights supplying $14 \mu\text{Em}^{-2}\text{s}^{-1}$ in order to increase vegetative growth while daylength was short. Temperatures averaged 24°C during the day and 18°C at night.

At the conclusion of the experiment, plants were harvested and divided into roots and shoots and the most recently fully expanded leaves removed for analysis of Ca, Mg, and K. After drying at 70°C for 48 hours, shoot and root weights were obtained.

Experiment 2

This experiment was a continuation of Experiment 1 except that Ca and Mg were each supplied at 0, 2, 5, 10, and 40 ppm while holding the other element constant at 10 ppm. To determine if higher rates of Ca and Mg would result in increased growth over the lower rates, each was supplied at either 60 or 120 ppm while varying the other element at 60 or 120 ppm. A night interruption was not utilized. Fertilization began on March 21, 1983 and continued through June 4, a period of approximately 11 weeks. In addition to data taken in Experiment 1, the lengths of the three longest shoots on each plant were obtained and all lengths within a cell were averaged.

Experiment 3

Two rates of Ca (0 and 120 ppm) and two rates of Mg (0 and 60 ppm) in a factorial arrangement were applied to 'Helleri' holly growing in

sieved pine bark in one liter containers. The pine bark had the following particle size analysis by weight: 36% less than 0.5 mm (U.S. Series sieve #35), 28% between 0.5 and 1.19 mm (U.S. Series sieve #16), 22% between 1.19 and 2.36 mm (U.S. Series sieve #8), and 14% between 2.36 and 6.3 mm (U.S. Series sieve #3). The bulk density was 0.37 g/cm^3 . All nutrient concentrations other than Ca and Mg were the same as in Experiment 1. There were two plants per pot, two pots per cell, and four replications. Plants were fertilized every three days with 250 ml of nutrient solution which had been adjusted to pH 5.3-5.5. Once every two weeks, the bark medium was leached with 250 ml of distilled water. Fertilization began on June 29, 1982 and continued through September 7, 1982, a period of 10 weeks. Prior to harvest, 75 ml of distilled water were applied to the surface of the medium in each pot, leachates collected, and analyzed for Ca and Mg content.

Experiment 4

Sieved pine bark as in Experiment 2 was amended with either 0, 2, 4, or 8 kg/m^3 dolomitic limestone containing 20% Ca from CaCO_3 , 10% Mg from MgCO_3 , and having a calcium carbonate equivalent of 104%. Screen analysis of the limestone was as follows: min. 100% passing 20 mesh screen, min. 80% passing 50 mesh screen, min. 80% passing 60 mesh screen, min. 75% passing 100 mesh screen, max. 0.0% retained on 10 mesh screen. One and 2 kg/m^3 gypsum (min. Ca from $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$: 19.5%) were applied as two additional treatments plus there was a control with no amendment. No additional Ca or Mg was supplied but the remaining nutrients were applied at the same rates as in the previous experiments.

One single-stemmed, rooted cutting of 'Helleri' holly was potted in each one-liter container of pine bark. There were two containers in each cell and four replications. Containers were arranged in a randomized complete block design. A volume of 250 ml of nutrient solution was applied to the containers every three to five days depending on the moisture status of the pine bark. In order to simulate actual nursery production and unlike the previous three experiments, tap water containing approximately 15 ppm Ca and 5 ppm Mg was used to prepare the nutrient solution and the pH was not adjusted. On a bi-weekly basis for the first nine weeks and on a monthly basis thereafter, 75 ml of distilled water was applied to each container and leachates were collected. Leachates were analyzed for Ca and Mg content and pH. Fertilization of this experiment began on September 20, 1982 and continued through April 23, 1983, a period of approximately 30 weeks.

RESULTS

Experiment 1

Increasing the Ca rate up to 5 ppm increased the shoot and total dry weight (Table 1). Calcium rate had no influence on root dry weight. Calcium percentage in leaf tissue increased as applied Ca increased but tissue Mg did not increase beyond 5 ppm applied Ca. Potassium percentage was not influenced by applied Ca levels. Near the end of the ten-week experiment, Ca deficiency appeared on some of the plants receiving no Ca, manifesting itself as necrosis of new shoot tips and necrotic spots on new foliage.

Shoot and total dry weight were increased by increasing applied Mg from 0 to 5 ppm but further increases in Mg supply did not influence these parameters (Table 1). The highest rate of Mg significantly decreased root dry weight. An increase in the Mg supply led to an increased Mg concentration in the leaf tissue while the Ca and K content tended to decline. There was no indication of Mg deficiency at any of the rates.

The analysis of variance for Experiment 1 revealed a significant interaction between Ca and Mg rates for K percentage in tissue (Table 2). Increasing Ca at 0 Mg tended to reduce the amount of K in tissue while at 40 ppm Mg, increasing Ca supply tended to increase the K percentage in tissue.

The ratio of the rates of applied Ca and Mg had no consistent effect on the total dry weight of 'Helleri' holly (Table 3). Plants

Table 1. Influence of Ca and Mg fertilization rate on growth and nutrient content of *Ilex crenata* 'Helleri' in a sand culture (Experiment 1).

Treatments	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Tissue nutrient concentration		
				Ca (%)	Mg (%)	K (%)
<u>Calcium (ppm)</u>						
0	4.7	.75	5.5	.17	.29	.86
5	5.3	.84	6.2	.26	.33	.83
10	5.2	.81	6.0	.31	.34	.83
40	5.3	.82	6.1	.43	.31	.86
HSD ^z	0.5	NS	0.5	.03	.02	NS
<u>Magnesium (ppm)</u>						
0	4.5	.86	5.3	.32	.08	1.01
5	5.2	.81	6.0	.30	.27	.83
10	5.4	.83	6.2	.29	.38	.79
40	5.6	.72	6.3	.27	.55	.75
HSD ^z	0.5	.11	0.5	.03	.02	.07

^zHSD for each column determined by Tukey's test, 5% level.

NS - No significant differences at the 5% level.

Table 2. Interaction^z of Ca and Mg rates on tissue potassium concentration of Ilex crenata 'Helleri' grown in a sand culture (Experiment 1).

Calcium (ppm)	Magnesium (ppm)			
	0	5	10	40
	- - - - - Foliar K% - - - - -			
0	1.18	.84	.75	.68
5	1.03	.80	.76	.76
10	.92	.81	.87	.73
40	.92	.89	.79	.82

^zInteraction significant at 5% level.

Table 3. Influence of Ca and Mg treatment combinations on the total dry weight of Ilex crenata 'Helleri' grown in a sand culture (Experiment 1).

Calcium (ppm)	Magnesium (ppm)			
	0	5	10	40
	- - - - Total dry wt (g) - - - -			
0	4.8 ^z	5.5	6.1	5.5
5	5.3	6.2	6.4	6.7
10	5.6	6.5	5.9	6.2
40	5.8	5.8	6.3	6.7

^zAn HSD of 1.4 for all means was determined by Tukey's test, 5% level.

at the 10 ppm Ca and 5 ppm Mg treatment (the recommended 2:1 ratio) were no larger than any of the other treatment combinations except the 0 Ca, 0 Mg treatment and the 5 ppm Ca, 0 Mg treatment.

Experiment 2

No increase in shoot length was observed beyond the 10 ppm rate of both Ca and Mg (Table 4). Calcium level had no effect on shoot, root, or total dry weight. When Mg was held constant at 10 ppm, Ca percent in tissue tended to increase as Ca in the nutrient solution was increased. Calcium increases from 0 to 2 ppm in the nutrient solution caused an increase in tissue Mg but further increases had no effect on Mg percent when Mg was at 10 ppm in the solution. The fact that all four of the highest treatment combinations resulted in higher Mg percentages in tissue is no doubt due to the high Mg rates in these treatments. Increases in Ca supply had little consistent influence on K percent in tissue. As in the first experiment, some of the plants not receiving Ca exhibited necrotic shoot tips and young foliage with necrotic spots.

Increasing Mg rate up to 5 ppm increased shoot length while shoot and total dry weight was not increased beyond 2 ppm Mg (Table 5). Magnesium rate had no effect on root dry weight. Increasing Mg in the nutrient solution tended to increase Mg percentage in tissue and tended to decrease Ca percentage. Potassium content in tissue was decreased when Mg was present in the nutrient solution. Unlike Experiment 1, lower leaves of the plants not receiving Mg abscised near the end of the experimental period. This abscission was preceded by affected

Table 4. Influence of Ca fertilization rate on growth and nutrient content of *Ilex crenata* 'Helleri' in a sand culture (Experiment 2).

Treatments (ppm)		Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Tissue nutrient concentration		
						Ca %	Mg %	K %
<u>Ca</u>	<u>Mg</u>							
0	10	4.4	4.6	1.0	5.7	.16	.28	.81
2	10	6.3	5.3	1.3	6.6	.22	.34	.94
5	10	5.9	5.6	1.3	6.9	.29	.32	.86
10	10	7.2	5.5	1.2	6.7	.35	.33	.92
20	10	7.1	5.4	1.2	6.7	.41	.32	.89
40	10	6.8	5.3	1.1	6.4	.46	.30	.89

60	60	8.6	5.7	1.1	6.9	.46	.46	.93
60	120	8.0	6.1	1.1	7.2	.44	.54	.88
120	60	7.4	5.5	1.1	6.6	.55	.44	.99
120	120	7.3	5.4	1.1	6.5	.53	.49	.95
HSD ^z		1.9	NS	NS	NS	.08	.05	.14

^zHSD for each column determined by Tukey's test, 5% level.
NS - No significant differences at the 5% level.

Table 5. Influence of Mg fertilization rate on growth and nutrient content of Ilex crenata 'Helleri' in a sand culture (Experiment 2).

Treatments (ppm)		Shoot length (cm)	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Tissue nutrient concentration		
						Ca %	Mg %	K %
<u>Ca</u>	<u>Mg</u>							
10	0	4.6	3.0	.8	3.9	.50	.09	1.11
10	2	4.6	4.8	1.3	6.1	.38	.12	.89
10	5	6.7	5.4	1.2	6.6	.38	.23	.96
10	10	7.2	5.5	1.2	6.7	.35	.33	.92
10	20	6.1	4.8	1.0	5.8	.33	.38	.81
10	40	6.6	5.1	1.2	6.3	.31	.43	.82

60	60	8.6	5.7	1.1	6.9	.46	.46	.93
60	120	8.0	6.1	1.1	7.2	.44	.54	.88
120	60	7.4	5.5	1.1	6.6	.55	.44	.99
120	120	7.3	5.4	1.1	6.5	.53	.49	.95
HSD ^z		1.8	1.7	NS	2.1	.08	0.5	.16

^zHSD for each column determined by Tukey's test, 5% level.
NS - No significant differences at the 5% level.

leaves turning a gray-green color. There was no chlorosis as would normally be anticipated in Mg deficiency.

Experiment 3

When Ilex crenata 'Helleri' was grown in a pine bark medium, adding either Ca or Mg to the fertilizer solution did not increase dry weight (Table 6). Adding Ca to the nutrient solution increased Ca percentage, decreased Mg percentage, and did not affect K percentage. Adding Mg increased Mg percentage in the tissue, decreased Ca percentage, and decreased K percentage. A pour-through test performed prior to harvesting this experiment revealed that the medium solution in the 0 Ca, 0 Mg treatment contained 16 ppm Ca and 7 ppm Mg.

Experiment 4

Dolomitic limestone rates of 2, 4, and 8 kg/m³ added varying amounts of Ca to the medium solution (Table 7). The amount of Ca in the leachates could not be predicted strictly according to limestone rate since the 8 kg/m³ rate actually provided less Ca than did the 2 and 4 kg/m³ rates late in the experiment. There was a marked increase in Ca concentration for the 2, 4, and 8 kg/m³ rates beginning at week 17. At the 0 lime rate, Ca concentration increased significantly at week 25. Both gypsum rates produced high concentrations of Ca in the leachates at week 1 but the Ca content of leachates at week 3 was dramatically reduced. The 1 kg/m³ rate of gypsum produced leachates which contained significantly more Ca than did the unamended control through week 13. The 2 kg/m³ rate of gypsum always resulted in greater leachate Ca concentrations than did the control.

Table 6. Influence of Ca and Mg fertilization rate on growth and nutrient content of Ilex crenata 'Helleri' in pine bark (Experiment 3).

Treatments	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Tissue nutrient concentration		
				Ca %	Mg %	K %
<u>Calcium (ppm)</u>						
0	5.7	.82	6.5	.36	.37	1.53
120	5.7	.87	6.5	.55	.30	1.52
F value ^z	NS	NS	NS	**	**	NS
<u>Magnesium (ppm)</u>						
0	5.6	.83	6.4	.52	.23	1.60
60	5.8	.85	6.7	.39	.44	1.44
F value ^z	NS	NS	NS	**	**	**

^zNS - Not significant at 5% level.

** - Significant at 1% level.

Table 7. Influence of dolomitic limestone and gypsum rate on leachate concentration of Ca (Experiment 4).

	Weeks										HSD ^y	
	1	3	5	7	9	13	17	21	25	29		
	- - - - - ppm Ca in solution - - - - -											
<u>Line rate (kg/m³)</u>												
0	29	26	24	25	23	21	25	26	34	39	7	
2	28	21	20	21	19	18	36	42	81	91	17	
4	27	18	19	21	26	38	53	56	80	80	10	
8	29	22	22	35	33	34	44	48	59	64	6	
<u>Gypsum rate (kg/m³)</u>												
1	153	50	39	40	33	28	31	30	38	45	14	
2	358	81	54	49	40	34	39	40	49	55	23	
HSD ^z	28	7	4	5	4	5	10	15	11	11		

^zHSD for each column determined by Tukey's test, 5% level.

^yHSD for each row determined by Tukey's test, 5% level.

Magnesium concentrations also tended to increase in the latter portion of the experiment (Table 8). Unlike Ca, there was always a tendency toward increasing Mg concentration as the rate of dolomitic limestone was increased. The initial leachate from pine bark amended with gypsum resulted in much higher concentrations of Mg than did later tests. Since gypsum does not contain Mg, this high concentration of Mg at week 1 is likely due to either impurities or the mass-action displacement of Mg from the exchange complex by the Ca supplied.

The pH of unamended bark varied from 3.8-4.1 during the experimental period (Table 9). The pH at 2, 4, and 8 kg/m³ of dolomitic limestone was initially 4.9, 6.2, and 7.4, respectively. These figures increased at week 3 but soon began a gradual decline of approximately one pH unit over the remainder of the experiment. The addition of gypsum to the pine bark medium had little effect on leachate pH.

Table 8. Influence of dolomitic limestone and gypsum rate on leachate concentration of Mg (Experiment 4).

	Weeks										HSD ^y	
	1	3	5	7	9	13	17	21	25	29		
	- - - - - ppm Mg in solution - - - - -											
<u>Lime rate (kg/m³)</u>												
0	12	11	10	10	8	8	9	9	13	13	3	
2	26	21	20	20	17	16	29	32	48	49	12	
4	30	23	24	28	33	47	58	60	73	66	8	
8	37	31	32	52	50	52	64	64	78	72	7	
<u>Gypsum rate (kg/m³)</u>												
1	34	11	8	9	7	8	8	6	9	11	4	
2	57	10	7	7	6	6	7	6	8	11	4	
HSD ^z	5	2	2	3	3	4	8	11	8	6		

^zHSD for each column determined by Tukey's test, 5% level.

^yHSD for each row determined by Tukey's test, 5% level.

Table 9. Influence of dolomitic limestone and gypsum rate on leachate pH (Experiment 4).

	Weeks										HSD ^y	
	1	3	5	7	9	13	17	21	25	29		
	- - - - - pH - - - - -											
<u>Lime rate (kg/m³)</u>												
0	3.8	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.0	3.9	0.1	
2	4.9	5.1	5.2	5.1	5.1	4.9	4.8	4.8	4.3	4.3	0.2	
4	6.2	6.6	6.3	6.1	5.9	5.3	5.2	5.2	4.9	5.1	0.3	
8	7.4	7.8	7.5	7.0	7.0	6.6	6.4	6.2	6.0	6.2	0.4	
<u>Gypsum rate (kg/m³)</u>												
1	3.7	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.0	3.9	0.1	
2	3.5	3.8	3.9	3.9	4.0	4.0	4.0	4.0	3.9	3.9	0.1	
HSD ^z	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2		

^zHSD for each column determined by Tukey's test, 5% level.

^yHSD for each row determined by Tukey's test, 5% level.

DISCUSSION

The results of this study indicate that 'Helleri' holly grows well with 5 to 10 ppm Ca and Mg supplied to the plants. No rate of Ca or Mg above this range increased shoot length or dry weight. Our findings agree with those of other researchers. Dunham and Tatnall (6) found that 1 ppm Ca was sufficient for the growth of Ilex crenata 'Convexa'. Wallace et al. (24) grew tobacco and corn successfully at 2 ppm Ca. Hall (9) discovered that Ca increases above 4 ppm were detrimental for dry weight production in tomato. Edwards and Horton (8) observed that peach seedlings required only 0.3 ppm Ca for growth. Edwards and Horton (7) also found that Mg rates above 0.5 ppm were unnecessary for the growth of peach seedlings. Growing poinsettia, Cox and Seeley (4) reported that no Mg rate above 2 ppm produced more dry weight nor did a Mg rate above 5 ppm increase plant height.

Further, at the levels of Ca and Mg utilized in this study, the ratio does not seem to be an important factor. This contrasts with the 2:1 Ca to Mg ratio recommended by Davidson and Mecklenburg (5) for nursery crops, by Tinus and McDonald (21) for tree seedlings, and by Therios and Sakellariadis (20) for olive plants.

Good growth at relatively low levels of Ca and Mg was achieved in spite of the fact that the higher rates of Ca and Mg were able to increase the concentrations of these elements in the leaf tissue. In synthesizing the results of Experiments 1 and 2, it can be observed that at Ca and Mg levels of 5 to 10 ppm, Ca percentage in tissue ranged from

0.26-0.38% while Mg percentage in tissue ranged from 0.23-0.38%. Such Ca levels in leaf tissue are far below the 0.96% Ca which Smith (19) lists as an average for evergreen species and the 1.4% Ca that Lumis (11) reports as a low value for broadleaf evergreens. Our range for Mg content is in keeping with the 0.23% Mg which Smith (19) gives for evergreen species and the 0.21% Mg which Lumis (11) lists as a low value for broadleaf evergreens.

It is worthwhile to view the tissue concentrations found in our study in terms of the critical concentration or critical level needed. Various definitions have been offered for such a level but perhaps one of the most useful describes the critical concentration of an element as that level of the element in plant tissue at which no further increases in yield can be achieved even if the tissue concentration of the element is increased (12). Using this definition, it appears the critical concentration of both Ca and Mg in the leaf tissue of Ilex crenata 'Helleri' is on the order of 0.25-0.30%.

The discrepancy between the results of this study and typical recommendations for Ca tissue content are likely due to the large supplies of Ca to which plants often have access. Soils are often high in Ca either due to their native properties or to the addition of limestone. Pharis et al. (15) have pointed out that the ability of pines to accumulate considerable Ca in their foliage may have helped lead to the belief that conifers require greater amounts of Ca than they actually do, at least during the first year of growth.

Since Ilex crenata 'Helleri' is priced according to plant

diameter, higher rates of Ca and Mg would have to increase this parameter markedly in order to be considered worthwhile. An added 10 cm in plant diameter per growing season would represent an achievement of the next higher price grade for a container-grown 'Helleri' holly. Based on our observations on shoot length growth, rates above 10 ppm Ca and 10 ppm Mg do not provide significant increases in shoot length and are not likely to produce the shoot elongation required to increase the selling price of a plant.

Other problems arise if the grower decides to add additional Ca and Mg to a container medium. Dolomitic limestone is normally used to provide Ca and Mg but the research of Chrustic (2) demonstrated that adding limestone to a pine bark medium actually resulted in less dry weight production of 'Helleri' holly indicating that an increased pH was not desirable.

The results of Experiment 3 show that the addition of large quantities of Ca and Mg to a pine bark medium do not increase the dry weight of 'Helleri' holly. This is supportive of the Ca and Mg requirements established in Experiments 1 and 2, since the pine bark alone (Experiments 3 and 4) supplies sufficient Ca and Mg for growth.

The lower levels of Ca in solution at the higher lime rates in Experiment 4 confirms the results of Chrustic (2). This phenomenon was attributed in part to the higher cation exchange capacity at the higher lime rates resulting in more Ca being adsorbed by the bark and lower levels in the leachates. This was not observed until week 25 of the experiment. Lime improves the CEC of an organic medium due to the

hydroxyl ion concentration being raised in the medium solution and the subsequent ionization of carboxyl and phenolic hydroxyl groups by way of reaction with the hydroxyl ions supplied.

While this research has shed new light on the nutritional requirements of Ilex crenata 'Helleri', it should not be viewed as a basis for making recommendations for other woody ornamentals. For instance, Chrusic (2) observed that Juniperus chinensis 'San Jose' benefitted from the addition of 2 kg/m³ dolomitic limestone to its pine bark medium. Preliminary investigations on our part have revealed that this benefit probably lies in the additional Ca and/or Mg supplied by the limestone rather than in its effect on pH.

CONCLUSIONS

Ilex crenata 'Helleri' grows well with 5-10 ppm Ca and Mg in its medium solution. When the plants are grown in a pine bark medium, sufficient Ca and Mg are available without the addition of amendments. This study has shown that levels of Ca and Mg beyond 10 ppm do not produce significant increases in dry weight or shoot length.. Also, the Ca to Mg ratio does not seem to be a factor at the levels studied in this research.

Tissue analysis recommendations for Ca need to be revised downward for 'Helleri' holly. Based on our research, the critical concentration of both Ca and Mg in leaf tissue appears to be 0.25%-0.30%.

While dolomitic limestone can supply varying amounts of Ca and Mg to a pine bark medium over time and gypsum can supply Ca, such additions are unnecessary. Nurserymen should investigate the possibility of growing 'Helleri' holly without amendments such as dolomitic limestone and gypsum. If our findings hold true under nursery conditions, the grower will be able to avoid the needless addition of such amendments when growing Ilex crenata 'Helleri' in pine bark.

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