J. Amer. Soc. Hort. Sci. 108(1):142–145. 1983.

Mineral Nutrient Content of *Ilex crenata* 'Helleri' as Influenced by Ambient Temperature[1]

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Additional index words. holly, photoperiod, nutrition, fertilization

Abstract. **Rooted stem cuttings of *Ilex crenata* Thunb. 'Helleri' were grown in a series of experiments for 3 or 6 weeks at day/night temperatures ranging from 6°/2° to 26°/22°C. Percentage of tissue N increased over time at all temperatures but at progressively slower rates as temperature decreased. Temperatures of 18°/14° or less prevented visible shoot elongation, although plant dry weights increased at all temperatures. Percentage of dry weight K increased and P, Ca, Mg, Mn, and Zn decreased with time for plants grown at 10°/6°, 14°/10° and 18°/14°, whereas the total amounts of each nutrient per plant increased. Nutrient content increased at greater rates as temperature increased. Nitrogen accumulation data were used to develop a method of timing fertilizer application in the fall. The proposed procedure ensures adequate nutrient accumulation to support vigorous spring growth without jeopardizing proper cold acclimation in the fall.**

Many woody nursery crop species exhibit multiple flushes of growth if mineral nutrients, water, and other environmental factors are adequate. Mertens and Wright (6) showed that *Ilex crenata* 'Helleri' initiates a growth flush about every 6 weeks under good growing conditions. The frequency and/or number of flushes is at least partially controlled by the accumulation of N in the tissue (3). Growers of nursery crops strive to promote as many flushes as possible during the growing season without the last flush being predisposed for frost injury.

It has been shown in several species that the first flush of growth in the spring is strongly influenced by nutritional levels during the previous fall. With *Taxus* and *Forsythia,* spring growth was correlated with the tissue levels of N, P, and K during the preceding dormant season (8). Tissue N and subsequent spring growth of lilac (*Syringa vulgaris*) increased as a result of N applications made during the previous year (7). Fertilizing 3 *Ilex* cultivars at different rates in the spring, prior to the first spring growth flush, did not influence the amount of growth on the first flush but did on the second (2). Spring shoot growth of Douglas-fir (*Pseudostuga menziesii*) was dependent on nutrient reserves accumulated during the previous year (5).

Timing of fertilization during the fall may be critical. If fertilizer is applied too early, nutrients can accumulate to levels in the tissue which, in conjunction with warm temperatures, could lead to a new flush of growth. Conversely, if fertilization is delayed until temperatures are consistently low, nutrient uptake may be inhibited and spring growth reduced. Nutrient uptake by *Forsythia intermedia* at 4.4° and 2.6°C resulted in increased spring growth compared to plants receiving no fertilizer at these temperatures (9). Good and Tukey (4) grew *Ligustrum ibolium* and *Euonymous alatus* 'Compacta' at 1.7°, 7.2°, and 12.8° and found increased P^{32} uptake at 7.2° compared to 1.7°. Subsequent field experiments demonstrated that root growth and nutrient uptake occurred when air and soil temperature were above freezing (4).

The purpose of this study was to determine the effect of temperature on the absorption of mineral nutrients by 'Helleri' holly as a basis for scheduling fall fertilizer applications.

Materials and Methods

Expt. 1. 'Helleri' holly stem cuttings were rooted in a greenhouse under intermittent mist in 6-cm^2 pots containing a medium (v/v/v) of 1 sphagnum peatmoss:1 perlite:1 Weblite (Webster Brick Co., Roanoke, VA 24012). Following rooting, cuttings were fertilized twice, 1 week apart with a nutrient solution containing 300 ppm N, 130 ppm P, and 247 ppm K. After 1 growth flush in a greenhouse, plants were transferred to the Southeastern Plant Environment Laboratory (Phytotron) at Raleigh, N.C. and grown for 3 weeks in controlled-environment chambers which provided 9 hr/day of photosynthetically active radiation of about 700 $\mu E\ m^{-2}s^{-1}$ and about 13 w m^{-2} of far-red radiation (1). Three day/night temperature regimes were employed (26°/22°, 22°/18° and 18°/14°C) with the day temperature concurrent with the 9 hours of light. The plants at each temperature were grown under 2 different light regimes: a short photoperiod (SD)—9 hr of light described above and a long photoperiod (LD)—9 hr of light plus 3 hr of incandescent light interrupting the dark period from 2300 to 0200 HR. Plants were irrigated daily with a solution containing the following nutrients in ppm: N = 108, P = 10, K = 27, Ca = 54, Mg = 12, Fe = 5, S = 13, Mn = .11, B = .24, Zn = .13, and Cu = .0054. Each of the 6 treatments (3 temperature × 2 photoperiods) was replicated 4 times with 9 plants per replicate. Twelve plants per treatment were removed at weekly intervals, dried for 24 hr at 70°, weighed, roots and shoots ground together in a Wiley mill through a 20-mesh screen, and total plant N content determined by micro-Kjeldahl (11).

Expt. 2. In this experiment 4 day/night temperature regimes were used: 18°/14°, 14°/10°, 10°/6°, and 6°/2°C under a long day photoperiod as described for expt. 1. The experiment was conducted for 6 weeks with weekly destructive sampling of 12 plants per treatment for plant dry weight, percentage of nutrients, and total N. There were 2 replications with 36 plants per treatment per replicate.

[1]Received for publication April 14, 1982.

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[4]The authors express appreciation to R. J. Downs and C. M. Farrell of the Phytotron for technical assistance.

Table 1. Effect of day/night temperature and photoperiod on accumulation of N in 'Helleri' holly (Expt. 1).

Day	Day/night temp (°C)	Total N content (mg/plant) Photoperiod LD	SD
7	18/14	5.5a[z]	5.6a
	22/18	5.5a	5.7a
	26/22	6.0a	5.5a
14	18/14	6.0b	5.6a
	22/18	7.2a	6.4a
	26/22	7.6a	6.1a
21	18/14	6.8b	6.6b
	22/18	9.2a	8.1a
	26/22	9.7a	9.2a

[z]Mean separation within columns at each sampling time by Duncan's multiple range test, 5% level.

Expt. 3. Plants were grown as in expt. 2 at 18°/14°, 14°/10° and 10°/6°C to determine if other nutrients accumulated similarly to N at low temperatures. Every 2 weeks, plants were destructively sampled, dried for 24 hr at 70°, weighed, and percentage of nutrients and total N determined as above. P was determined colorimetrically (14) and atomic absorption spectroscopy was employed to determine K, Ca, Mg, Mn, Fe, and Zn levels. There were 3 replicates with 12 plants per treatment per replicate.

Results and Discussion

Expt. 1. There was no difference in the amount of N per plant due to treatments after 1 week, but by week 3, plants at 22°/18° and 26°/22°C contained more total N than plants at 18°/14° (Table 1). There was no difference in the amount of N accumulated by plants grown under LD and SD photoperiods. Plants in the 2 higher temperatures began shoot elongation by week 2; however, there was no evidence of shoot elongation for plants grown at 18°/14° even by week 3. This suggests that fall fertilization of 'Helleri' holly should be accomplished so that plant nutrient levels necessary for plant growth will be reached when temperatures are at or below 18°/14° to prevent shoot elongation.

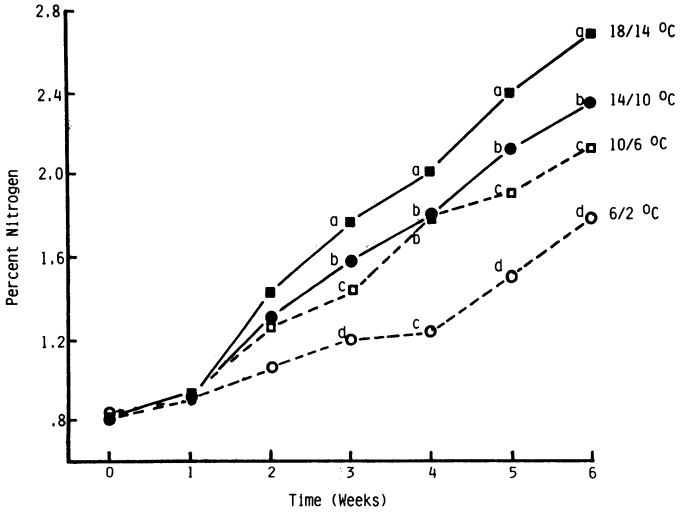

Fig. 1. Influence of temperature on the percentage of plant N over a 6-week period (Expt. 2). Mean separation at each time beginning at week 3 by Duncan's multiple range test, 5% level.

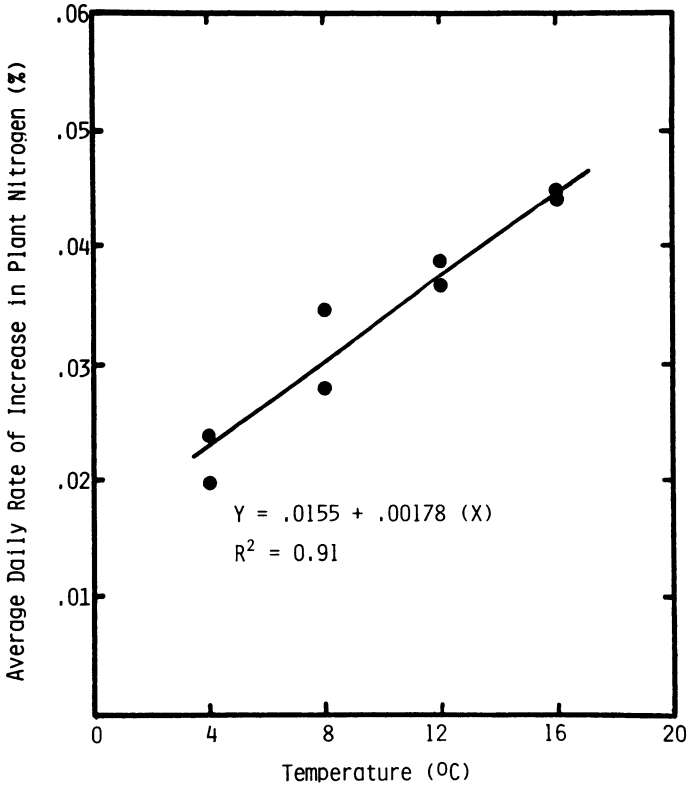

Fig. 2. The relationship between mean daily temperature and the mean daily increase in the percentage of plant N (Expt. 2). The 2 data points were generated from the 2 replicates at each temperature.

Expt. 2. Results show that the percentage of N in the plants increased over the 6-week experimental period at all tempera-

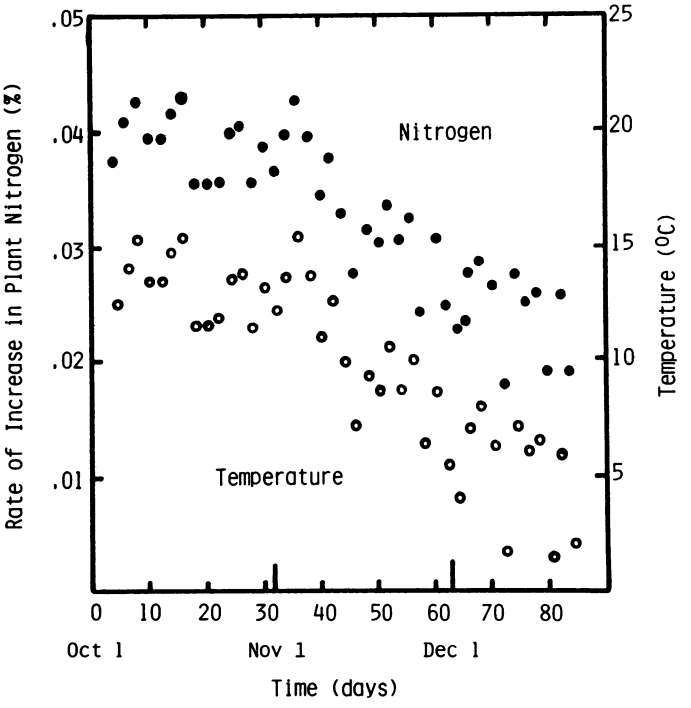

Fig. 3. Influence of decreasing temperature on the theoretical rate of increase in the percentage of plant N in 'Helleri' holly at Holland, Va.

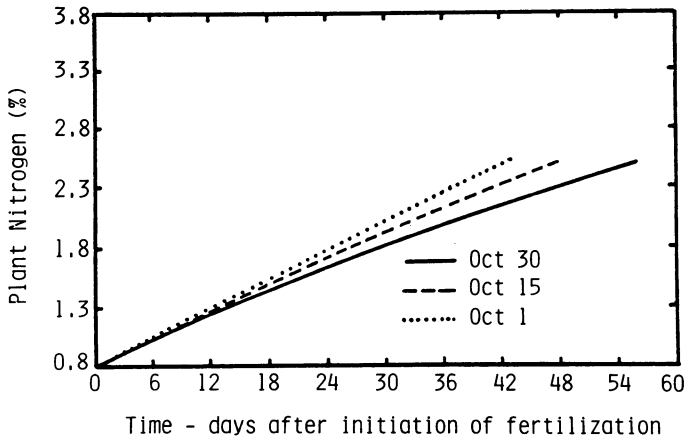

Fig. 4. Effect of fertilizer application date on the projected accumulation of plant N.

tures (Fig. 1). At week 3 and thereafter, the percentage of N was significantly greater at higher temperatures with the exception of 14°/10° and 10°/6° at week 4. The daily rate of N uptake at each temperature was calculated and plotted against the mean of the day/night temperature (Fig. 2). The regression equation ($r^2 = 0.91$) was used to predict daily incremental increases in the percentage of N, based upon mean daily temperatures at Holland, Va. from Oct. 1 to Dec. 30 for 1975 through 1979 (Fig. 3). As temperatures decreased, there is a corresponding decrease in the rate of increase in the percentage of N. Using this same relationship and starting fertilization on Oct. 1 at 0.8% plant N, it would take 43 days for the level of N to reach 2.5% and 56 days if fertilization started on Oct. 30 (Fig. 4). Because of the decreasing temperature, the later that the fall fertilization begins, the more days it takes to reach a desired N level.

It is conceivable that this technique could be applied to any location where mean daily temperature data are available. By knowing the percentage of N in the foliage, and the mean daily temperature, one could estimate how many days it would require to attain a certain percentage of N level if fertilization were started on a particular date. The objective is to ensure N accumulation to a level in the fall, after fall temperatures average below 18°/14°C, which will promote vigorous growth the following spring.

N level in the soil solution also plays an important part in the rate of N uptake (10) and should be maintained at a level in which the rate of N uptake at different temperatures was calculated. If data were available on the interaction of soil N level and temperature on nitrogen uptake, one could conceivably alter N levels to compensate for unusually high or low temperature periods to ensure the desired schedule of N accumulation during the fall. Care must be exercised in using the above data as absolute, since environmental factors such as soil nutrient levels, light, and moisture can influence uptake and translocation of mineral nutrients.

Table 2. Plant nutrient accumulation over time and at different day/night temperatures (Expt. 3).

Variable	Nutrient accumulation (dry wt basis) N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Temp (°C)				0.66a				
18/14	1.92a[z]	0.26a	1.28a		0.42a	125a	156a	149a
14/10	1.79b	0.27a	1.14b	0.64a	0.39b	120ab	145a	151a
10/6	1.68b	0.27a	1.10b	0.65a	0.39b	109b	156a	165a
Time								
1 (2 wk)	1.46b	0.29a	1.05c	0.73a	0.44a	125a	191a	195a
2 (4 wk)	1.73b	0.25b	1.14b	0.63b	0.39b	119ab	147b	147b
3 (6 wk)	2.07a	0.26b	1.29a	0.61c	0.39b	108b	133c	143b

[z]Means in columns for temperature and time separated by Duncan's multiple range test, 5% level.

Expt. 3. Percentage of N as observed for the first 2 experiments and percentage of K as determined for this experiment increased with time at all temperatures. Since there were no interactions between time and temperature, the nutrient data were averaged across temperatures and times (Table 2). All other nutrients decreased in concentration by week 6. The decrease in concentration over time can be attributed to the increase in plant dry weight, while uptake of nutrients with the exception of N and K did not occur at a rate necessary to maintain the initial concentration. This might explain why Sheppard et al. (12) reported a decrease in Ca and Mg concentration in container-grown *Cotoneaster dammeri* during October and November, although they did not report plant dry weights. In contrast to our results, they did not show a decrease in the percentage of P. Plants grown at the 18°/14°C temperature in our study had the highest percentages of N, K, Mg, and Fe, while temperature had no significant effect on concentration of other nutrients. N and K concentration of *Forsythia intermedia* have been shown to increase with increasing temperature for experiments conducted in controlled-environment chambers (9). Also Fe levels in peach (15) and citrus (13) have been affected by temperature in this way when only root temperature was varied.

Table 3. Total plant nutrient accumulation over time and at different day/night temperatures (Expt. 3).

Variable	Nutrient accumulation per plant N (mg)	P (mg)	K (mg)	Ca (mg)	Mg (mg)	Fe (μg)	Mn (μg)	Zn (μg)	Plant dry wt (g)
Temp (°C)									
18/14	20.8a[z]	2.83a	13.8a	6.73a	4.38a	131a	153a	148a	1.04a
14/10	19.2b	2.74a	12.1b	6.44a	3.99b	125a	141ab	147a	1.03a
10/6	14.7c	2.24b	9.7c	5.50b	3.34c	93b	132b	138a	0.86b
Time									
1 (2 wk)	10.4c	2.08c	7.4c	5.13c	3.08c	88c	134b	135b	0.70c
2 (4 wk)	16.6b	2.39b	11.0b	6.07b	3.70b	116b	140b	136b	0.96b
3 (6 wk)	24.8a	3.14a	15.6a	7.23a	4.66a	133a	156a	172a	1.19a

[z]Means in column for temperature and time separated by Duncan's multiple range test, 5% level.

The total amount of each plant nutrient increased over time at all temperatures and was greater at the higher temperature compared to lower temperature (Table 3). Again, since there were no temperature × time interactions, only means across time and temperature are given. Even though the concentration of all nutrients except N and K decreased over time (Table 2), these data show that all nutrients were being absorbed by the plant at all temperatures.

In conclusion, it appears that low ambient temperatures above freezing do not prevent the uptake of plant nutrients by 'Helleri' holly. This demonstrates that sufficient time exists in the fall to fortify plants with nutrients to support vigorous plant growth the following spring. Further, with the generation of data for other genera and plant types, such as reported in this study, and the relative ease of regulating nutrient applications in respect to timing and amounts, fall fertilization can be approached with confidence.

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J. Amer. Soc. Hort. Sci. 108(1):145–148. 1983.

Effectiveness of Selected Herbicides and Discing on Volunteer Horseradish Control[1]

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Additional index words. weed, integrated pest management, glyphosate, dicamba, atrazine, *Armoracia rusticana*

Abstract. **Methods were compared for controlling volunteer horseradish (*Armoracia rusticana* Gaertn, Mey. & Scherb.) resulting from commercial horseradish production. The most effective treatment was glyphosate [N-(phosphonomethyl) glycine] (4.5 kg/ha) applied in mid-September 6 to 8 weeks after discing. 2,4,5-T [2,4,5-trichloro-phenoxy acetic acid] was also effective, while dicamba [3,6,dichloro-o-anisic acid] and a dicamba plus glyphosate mixture provided less control. Horseradish roots can sprout from 90-cm deep and still be susceptible to a mid-September glyphosate application.**

Horseradish, a perennial member of the Brassicaceae, is grown for its large pungent fleshy taproot. It is produced as an annual in Illinois. A 2-year rotation is usually used with alternate crops consisting primarily of sweet corn, soybeans, and other vegetable crops.

Each spring, sets (crownless root pieces 0.6 to 1.3 cm wide and 30 to 35 cm long) are planted horizontally in furrows and covered with soil to a depth of 5 to 10 cm. In late fall or early spring, a mechanical harvester removes the roots to a depth of 30 to 50 cm. Secondary roots trimmed from the main taproot are bundled and stored for planting stock for the following season (12).

A small region adjacent to East Saint Louis, Ill., accounts for more than half of the U.S. horseradish production. Horseradish culture has been continuous in the area since the early 1890s (4). Throughout this time, volunteer horseradish has been a persistent weed problem, especially within rotation crops.

Volunteer plants do not arise from seed. They rapidly sprout from branch roots left in the soil at harvest. In 1904, Bailey

[1]Received for publication May 27, 1982. Cooperative project of the Illinois Natural History Survey and the Department of Horticulture, Illinois Agricultural Experiment Station, Urbana, IL 61801.

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