performance in 1970 (5). Bulbs were lifted on July 8 with an accrued EU of 6 units (measured at WWREC) and received further chamber curing at 32.2°C for 0, 5 (+ 5 EU), 10 (+ 10 EU), and 15 (+ 15 EU) days for performance evaluation. The cumulative EUs, with correction, correlated with the flowering responses described earlier.

The accumulated EU values described here may have significance in connection with iris grown in other parts of the world.

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HortScience 16(4):564–565. 1981.

Influence of Nitrogen and Phosphorus on Shoot:Root Ratio of *Ilex crenata* Thunb. 'Helleri'[1]

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Additional index words. holly, nutrition, plant propagation, fertilizers

Abstract. Higher N rates applied to *Ilex crenata* 'Helleri' holly liners grown in the greenhouse increased shoot growth but decreased root growth resulting in a greater shoot:root ratio. Higher N rates reduced the time required for a shoot growth flush to occur. P at 85-500 ppm had no effect on shoot or root growth. Continued growth of liners at 50 ppm N lowered the shoot:root ratio due to stimulation of root growth while 300 ppm N caused the shoot:root ratio to increase due to increased shoot growth.

Liners of woody landscape plants often are maintained in protected environments (e.g. greenhouse, cold frame) for several months after rooting but prior to transplanting. This period of protective culture enables the grower to manipulate the environment and nutrition to produce a more vigorous and higher quality liner for successful transplanting.

The shoot:root ratio of some herbaceous plants has been shown to increase with increasing rates of N due to greater shoot growth while root growth remained unaffected or even decreased (1). P rates from 0 to 15 ppm have been shown to increase the shoot:root ratio of maize (11). Forestry nursery seedlings are fertilized with 63 ppm N, 143 ppm P and 88 ppm K soluble fertilizer to encourage root growth, and a 100 ppm N, 44 ppm P and 83 ppm K fertilizer to encourage shoot growth (12). Shoot:root ratio of 'Helleri' holly increased as the number of weekly applications of a 300 ppm N, 167 ppm P and 247 ppm K soluble fertilizer increased (6), and at increasing rates of a 20N-8.7P-16.7K soluble fertilizer (13). Root growth of spruce was most stimulated by N, less stimulated by P, and not stimulated by K (10). N and P together had a greater effect than either alone.

The purpose of this study was to investigate the influence of N and P rates and duration of 50 ppm N fertilization on the shoot:root ratio of *Ilex crenata* 'Helleri'.

Experiment 1. Liners of *Ilex crenata* 'Helleri' were greenhouse grown at 28°C (day) and 21° (night with 3 hr of incandescent light interrupting the dark period from 11 PM to 2 AM). Plants were grown in a medium (v/v/v) of 2 peat:2 perlite:1 Weblite (Webster Brick Co., Roanoke, Va 24012) in 6 cm plastic pots and fertilized weekly with 30 ml (pH 6.3) of 50, 100, 200 or 300 ppm N as NH_4NO_3, 85, 170, 340 or 500 ppm P as H_3PO_4, 150 ppm K as KCl, 150 ppm Ca and Mg as $CaSO_4$ and $MgSO_4$, respectively. Minor elements were supplied according to Hoagland and Arnon (7) with 5 ppm Fe as NaFeEDTA. The experimental design was a factorial arrangement with 16 treatments (4 N and P rates) replicated 4 times with 3 plants per treatment per replicate. Fertilizer treatments began November 13, 1978 and terminated after 1 shoot growth flush on January 19, 1979.

The higher rates of N resulted in more shoot dry weight, less root dry weight and a greater shoot:root ratio (Table 1). Two weeks after the initiation of fertilizer treatments there was a greater number of plants flushing at the higher N rates. Increasing P fertilization rates regardless of N rate had no effect on any of the above growth parameters (data not shown).

Experiment 2. The rates of N were changed to 10, 20, 30, 40, 50 or 100 ppm and those of P were changed to 17, 42 or 85 ppm. The experiment was started February 1, 1979 and terminated after 1 shoot growth flush on April 4, 1979.

Results of Experiment 2 (Table 2) reflect the same general response to N treatments as in Experiment 1 except that root growth increased with increasing levels of N. A response of this type has been observed with wheat where at moderate levels of N, root growth increased with a concurrent increase in shoot:root ratio (8).

As in Experiment 1, there was no re-

Table 1. Influence of N rate on growth parameters of 'Helleri' holly (Expt. 1).[z]

Treatment (ppm N)	Shoot dry wt (g)	Root dry wt (g)	Shoot:root ratio	No. plants flushing
50	1.12a	0.66a	1.66a	0.06a
100	1.17a	0.60b	2.00b	0.25a
200	1.50b	0.51c	2.90c	2.44b
300	1.69c	0.51c	3.33d	2.50b

[z]Data are averaged across P rates. Mean separation in columns by Duncan's multiple range test, 5% level, performed on arcsine transformation for no. of plants flushing. Data taken 2 weeks after initiation of fertilizer treatments.

[1]Received for publication October 22, 1980. This research was supported by the Virginia Nurserymen's Association.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must therefore be hereby marked *advertisement* solely to indicate this fact.

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Table 2. Influence of N rate on growth parameters of 'Helleri' holly (Expt. 2).[z]

Treatment (ppm N)	Shoot dry wt (g)	Root dry wt (g)	Shoot:root ratio	No. plants flushing
10	1.24a	0.54a	2.22a	0.33a
20	1.33a	0.56a	2.32a	0.41a
30	1.48b	0.58a	2.59b	1.75c
40	1.34a	0.59a	2.20a	0.83ab
50	1.55b	0.61ab	2.62b	1.33bc
100	2.21c	0.67b	3.28c	2.92d

[z]Data are averaged across P rates. Mean separation in columns by Duncan's multiple range test, 5% level, performed on arcsine transformation for no. of plants flushing. Data taken 2 weeks after initiation of fertilizer treatments.

Table 3. Influence of 50 ppm N duration and subsequent 6 weeks of 300 ppm N on growth parameters of 'Helleri' holly (Expt. 3).[z]

Treatment (No. weeks at 50 ppm N)	At end of 50 ppm N			After 6 weeks 300 ppm N		
	Shoot dry wt (g)	Root dry wt (g)	Shoot:root ratio	Shoot dry wt (g)	Root dry wt (g)	Shoot:root ratio
0	0.72a	0.15a	4.86a	2.62a	0.35a	7.42a
1	0.98b	0.21ab	4.76a	2.72ab	0.40a	6.84b
2	1.11bc	0.27cb	4.10b	2.76ab	0.41a	6.65b
3	1.14bc	0.30c	3.79b	3.01b	0.51b	5.87c
4	1.20cd	0.37d	3.21c	2.79ab	0.53b	5.30d
5	1.37d	0.46e	3.00c	2.60a	0.55b	4.72e
6	1.33d	0.55f	2.42d	2.73ab	0.67c	4.12f

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

sponse to P applications at any of the N rates (data not shown). The lack of response to P in these studies was probably because P was not rate limiting at the levels applied. Other studies have demonstrated that woody plant species grow well at soil solution P levels at or below those applied in this study (2, 4, 5) and increases in shoot:root ratio for corn occurred from 1-15 ppm P (11). Our results with P indicate the increase in root growth attained with forestry seedlings fertilized with 63 ppm N, 143 ppm P and 88 ppm K soluble fertilizer in contrast to the 100 ppm N, 44 ppm P and 83 ppm K (12) could be due to the lower N level and not to the increased P.

Experiment 3. This experiment was initiated July 19, 1979 to study root and shoot dry weight differences during a period of a low N rate followed by a 6 week period of high N. 'Helleri' holly liners were potted in 1 liter plastic containers using milled pine bark containing 6 kg/m^3 of dolomitic limestone and 3 kg/m^3 of Esmigran minor element mix (Mallinckrodt, Inc., St. Louis, MO 63147). There were 14 treatments in a randomized complete block design replicated 4 times with 3 plants per treatment per replicate. One group of plants received 200 ml per pot of 50 ppm N for 0, 1, 2, 3, 4, 5 or 6 weeks; another group of plants received the same N treatments followed by 6 weeks of 300 ppm N. All treatments received 50 ppm P and 150 ppm K. Shoot and root dry weights were determined at the end of the 50 ppm N fertilization period, and at the end of the 6 weeks of 300 ppm N.

Shoot and root dry weights were determined by drying the plant material for 48 hr at 70°C, and the shoot:root ratio calculated.

Shoot and root dry weight increased during the 50 ppm N treatment (Table 3). However, the shoot:root ratio decreased by 50% during the 6 weeks at 50 ppm N. After 6 weeks of 300 ppm N, differences in shoot dry weights (due to the length of time at 50 ppm N) were less evident than at the initiation of 300 ppm N. However, differences in root dry weight and shoot:root ratio due to the 50 ppm N treatment were still evident.

Shoot dry weight increased 264% (0.72 g to 2.62 g, Table 3) after 6 weeks at 300 ppm, compared to the 6 weeks at 50 ppm N in which shoot dry weight increased only 85% (0.72 g to 1.33 g). In contrast, root dry weight increased less during the 6 weeks of 300 ppm N (0.15 to 0.35, 133%) than during 6 weeks at 50 ppm (0.15 to 0.55, 267%). This difference in shoot and root growth at the 2 levels of N resulted in a 50% (4.9 to 2.4) decrease in shoot:root ratio during the 6 weeks at 50 ppm N and a 50% (4.9 to 7.4) plus increase in shoot:root ratio during 6 weeks of 300 ppm N. These data agree with other work that root growth is favored over shoot growth at low levels of N (3, 8, 9, 11) and that shoot growth is favored over root growth at high levels of N (3). Brouwer (3) has proposed that in the absence of other growth limiting factors, shoot growth continues at a rate that depends on the minerals and moisture supplied over and above the roots requirement. Root growth continues at a rate dependent on the carbohydrate supplied by the shoot. Considering this concept, at 50 ppm N the nutrients were preferentially utilized by the roots with less available for shoot growth; therefore, much of the photosynthate was available for root growth. When the plants were fertilized with 300 ppm N, more N was available for shoot growth which became the sink for photosynthate, limiting the supply of photosynthate to the root and consequently reducing root growth. Results from Experiments 1 and 2 are consistent with this idea; all treatments increased shoot growth more than root growth resulting in higher shoot:root ratios.

We conclude that shoot:root ratios can be controlled by N rates and duration of different N rates. If the shoot:root ratio appears too high, with a particular fertilizer regime, then a fertilization period of low N would be desirable to promote more root growth in relation to shoot growth, and vice versa. In these studies P concentrations of 17 ppm or higher in the medium solution did not have any effect on growth or the shoot:root ratio of 'Helleri' holly.

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