density of azalea was influenced by planting method. Growth index and shoot dry weight were greater in peat-based media than in media not containing peat moss. Root density of plants grown in pine bark + sandy loam soil or peat moss was greater than root density in 100% pine bark or peat moss-shavings medium (data not shown).

Shoot and root growth of 2 species in 2 experiments were either greater or not influenced when the planting hole was excavated rather than dibbled. This response was media-dependent, occurring in media with a range of pine bark:sandy loam ratios but not in peat-based media. Alterations in the physical properties of the media during formation of the planting hole or differences in moisture holding capacity of excavated and dibbled media may explain growth differences.

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Growth Analysis of 'Plumosa Compacta' Juniper and 'Coral Beauty' Cotoneaster Subjected to Different Nitrogen Fertilizer Regimes[1]

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Abstract

'Plumosa Compacta' juniper (*Juniperus horizontalis* Moench.) and 'Coral Beauty' cotoneaster (*Cotoneaster dammeri* C.K. Schneid.) were container grown in a bark:peat:sand medium (2:1:1 by vol.). Plants received either 70, 140, 280 or 420 mg (0.003, 0.005, 0.010 or 0.015 oz) N per week from nutrient solutions. Growth was assessed on plants harvested from each treatment regime on May 22 and then at monthly intervals until September 16. Juniper plants grown with 140 mg (0.005 oz) N per week were larger at the end of the season than those in the other treatments. In cotoneaster, growth increased as weekly N application increased from 70 to 420 mg (0.03 to 0.015 oz) N per week. Path analysis was used to quantify the effect of plant relative growth rate (RGR) during each month on RGR in subsequent months and on total seasonal relative dry weight gain (TRWG). RGR during each month significantly influenced TRWG, with the periods from June 21 to July 20, and from July 21 to August 18 exerting the greatest influence in cotoneaster. In juniper, the influence of RGR in each month on TRWG was equal. For both cotoneaster and juniper, increasing RGR during one month tended to have a negative influence on RGR during subsequent months.

Index words: path analysis, containers, nitrogen, Andorra juniper, *Juniperus horizontalis*, *Cotoneaster dammeri*

Significance to the Nursery Industry

This research provides insights to the patterns of growth of container grown landscape plants. Maximum productivity of 'Plumosa Compacta' juniper and 'Coral Beauty' cotoneaster may be achieved by optimizing growing conditions throughout the season. Suboptimal conditions during any month can significantly diminish growth. Growth optimization, however, does not always mean increasing the rate of fertilizer application. While some plants such as 'Coral Beauty' cotoneaster will develop greater mass as weekly N application is increased, others such as 'Plumosa Compacta' juniper grow best at intermediate rates of N.

Introduction

Increases in shoot length and new branch formation are important factors influencing the development of size and quality of landscapes shrubs in the nursery. New shoot growth occurs either as periodic flushes, or continuous growth from the shoot tips. Patterns of growth flush, and the influence of environmental conditions on the timing and magnitude

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of flushes have been studied (2, 3, 9), but similar analysis of continuously-growing woody plants has received less attention. Growth analysis is important since it allows definition of critical stages in the growth cycle which may have a preeminent effect on total seasonal growth and which may be manipulated to enhance dry matter production and quality. In *Populus deltoides* × *nigra* hybrids, for example, early growth following planting is a major determinant of biomass production during the first growing season (11) and in *Ilex crenata* 'Helleri', seasonal growth can be increased by the correct phasing of fertilizer application and growth flushes (3).

Growth analysis for continuously-growing plants can be performed by assessing the rate of dry matter production during finite periods of the season. For comparison, rates can be expressed as the increase in plant weight per unit of weight per unit of time, otherwise known as relative growth rate (RGR) (6). The interrelationships between mean RGR for discrete time intervals and their contribution to dry weight gain over the season can then be quantified.

This study defines seasonal growth patterns of 2 container grown woody plants, 'Coral Beauty' cotoneaster and 'Plumosa Compacta' juniper; both have continuous growth characteristics but differ in leaf form, growth habit and growth potential. Monthly assessment was made of plants grown at different nitrogen rates from potting until the end of the growing season, and path analysis (12) was used to quantify interactions among growth rates and establish their contribution to full season growth.

Materials and Methods

Rooted cuttings of 'Coral Beauty' cotoneaster and 'Plumosa Compacta' juniper and were weighed, free of soil, and planted on May 15, 1989 into 3.8 l (#2) containers filled with a pine bark, sphagnum peat, sand medium (2:1:1 by vol.). The medium was amended with single superphoshate, 100 mesh-size dolomitic lime and Nutritrace[2] at 2.3, 2.3 and 0.5 kg/m^3 (3.8, 3.8 and 0.8 lbs/yd^3), resp. Plants were arranged in groups according to their fresh weight. There were 5 plants per group with a maximum weight difference of 0.2 g (0.01 oz) between plants within a group. Six groups of plants were randomly assigned to one of four treatments, so that at the start of the experiment there were 30 plants each of cotoneaster and juniper per treatment. Treatments were 70, 140, 280 or 420 mg (0.003, 0.005, 0.010 or 0.015 oz) N per plant per week supplied from nutrient solutions containing ammonium nitrate and potassium sulphate. The weekly K application was 280 mg (0.01 oz) per plant. Plants received 350 ml of nutrient solution on Monday, Wednesday, Friday and Sunday, and 350 ml of water on the other days of each week.

On May 22, June 20, July 21, August 18 and September 16, 6 plants were harvested from each treatment. Plants with similar original fresh weights were harvested on consecutive dates, washed and divided into roots and shoots for dry weight determinations. Medium soluble salt content, expressed as electrical conductivity, was measured at 25°C (77°F) on leachate obtained from application of 200 ml (6.8 fl oz) of distilled water to media surfaces (13). Soluble salt determinations were conducted on June 20, July 21 and August 18 on containers designated for harvest.

[2]Chisso-Ashai Fertilizer Co. Ltd., Tokyo.

The experimental design was a randomized complete block with 6 replications, one plant per replicate. Dry weight data for roots, shoots and whole plants were converted to logarithms in order to equalize variances prior to analysis of variance. Root:shoot ratio data were subjected to an arcsin transformation (10). Initial plant fresh weight was a significant covariate in all analyses involving primary dry weight data. All values except root:shoot ratios are therefore reported as the back transformed least squares means adjusted for the covariate. Percentage standard errors of the mean were calculated, where appropriate, to facilitate comparisons between means on the original (non-logarithmic) scale.

Plant relative growth rates (RGR) were calculated for growth periods corresponding to the time interval between each harvest date.

$$RGR_i = (\ln W_i - \ln W_{i-1})/(t_i - t_{i-1})$$

W_{i-1} and W_i are plant dry weights at the beginning and end of each growth period, and $(t_i - t_{i-1})$ is the duration in days of the period. Total seasonal relative dry weight gain (TRWG) was calculated as $\ln W_5 - \ln W_1$.

To determine the contribution of each RGR to subsequent RGR and to TRWG, a path analysis (8, 12) was performed by computing a series of least-square regressions with one RGR_i or TRWG at a time as the dependent variable and the preceding RGR_i as independent variables. Partial regression coefficients were tested for significance by t-test and then standardized to yield path coefficients. All computations were performed using Genstat 5 (1).

Path analysis allows assessment of the direct effect of each variable (in this case, monthly growth rate) on another with the indirect effects exerted by other variables removed. Path coefficients which are significantly different from zero indicate that a change in the selected independent variable will significantly affect the associated dependent variable. Moreover, the magnitude of the path coefficients indicate the relative influence of successive independent variables on a single dependent variable. The greater the path coefficient, the greater is the direct effect.

Results and Discussion

The interrelational effects of mean monthly RGR for cotoneaster and juniper are shown in Figure 1. The magnitude of the path coefficients reveals the relative direct effect of RGR during one month on RGR during a subsequent month or on TRWG. For both taxa, RGR over successive 30-day periods each had a strong effect on seasonal growth as shown by the significance of path coefficients relating the variables RGR_{1-4} to TRWG. In cotoneaster RGR_2 and RGR_3 had the greatest effect on TRWG, whereas in juniper RGR during each growth period had about equal effect. These results reveal an important criterion for production management of these taxa, namely that growing conditions must be optimized throughout the season to promote maximum growth. This differs from the situation with some herbaceous plants such as chrysanthemum where total dry weight gain from planting to flower has been shown to depend primarily on the vigor of early growth (4, 7).

RGR for cotoneaster (Table 1) and for juniper (Table 2) were affected by N fertilization, but differences were only significant for growth periods 2 (May 22 to June 20) and 4 (August 19 to September 16). In cotoneaster, RGR increased

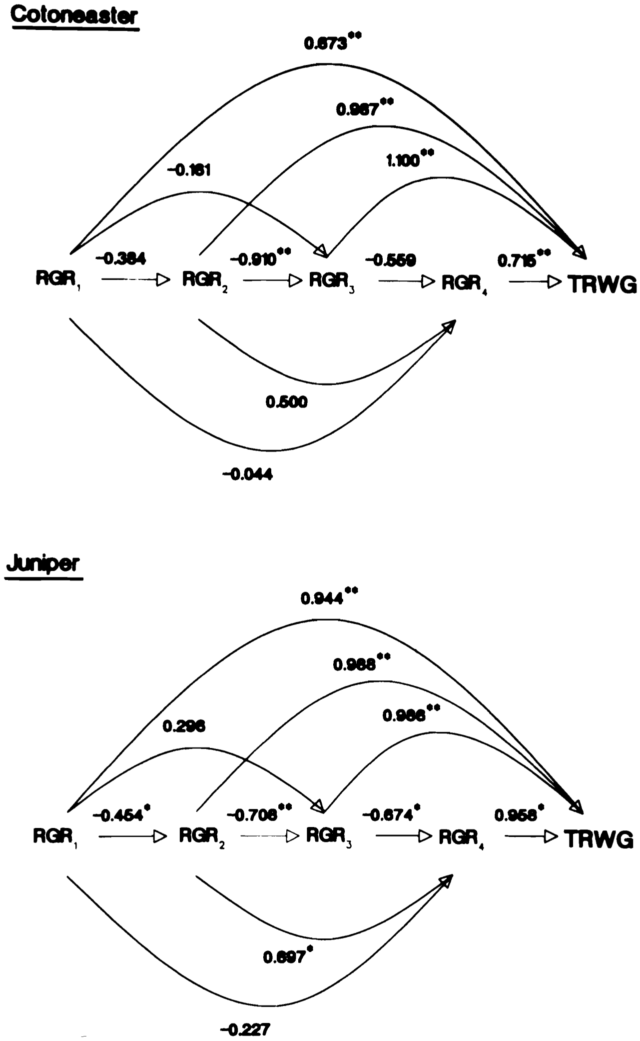

Fig. 1. Path diagram depicting the interrelationships between successive monthly plant relative growth rates (RGR) and between RGR and total seasonal relative dry weight gain (TRWG) for 'Coral Beauty' cotoneaster and 'Plumosa Compacta' juniper. Subscripts define the growth periods: RGR_1 = May 22 to June 20; RGR_2 = June 21 to July 20; RGR_3 = July 21 to August 18; RGR_4 = August 19 to September 16. Levels of significance are indicated by: ** = $P < 0.01$ and * = $P < 0.05$.

linearly with N concentration, whereas in juniper there was a quadratic relationship. The N treatment effects on RGR were reflected in differences in total seasonal growth (Tables 3 and 4). In cotoneaster, weights of roots, shoots and whole plants were greatest in those plants which received 420 mg (0.015 oz) N per week, but in juniper maximum weights occurred in the 140 mg (0.005 oz) N treatment. Reduced growth at higher N concentrations in juniper was probably a consequence of high medium soluble salt concentrations (Table 5) since the results of previous work have indicated a limited tolerance of the 'Plumosa Compacta' cultivar to soluble salt accumulation (5). Cotoneaster, on the other hand is tolerant of the salt levels which result from weekly applications of 420 mg (0.015 oz) N, and responded positively to increases in N availability.

Plants which showed the highest RGR in growth periods 1 and 4 ultimately showed the greatest seasonal TRWG. However, high RGR during the first growth period did not lead to higher growth rates in subsequent months. Instead, RGR_i were often negatively related to RGR_{i+1} and sometimes to RGR_{i+2} (Figure 1). An example is the significant correlation between RGR_2 and RGR_4, and between RGR_3 and RGR_4 in juniper (path coefficients -0.697 and -0.674, respectively) indicating that as RGR_2 and RGR_3 increased RGR_4 decreased. These relationships are surprising since high RGR during one period was expected to result in more leaf area at the end of that period and therefore greater RGR in subsequent months. However, similar effects have been observed in other comparisons between fast- and slow-growing plants (7). Plants showing high RGR early in development may partition proportionally more dry matter to root and/or stem systems than those showing less vigorous growth (7). Typically, such differences in partitioning are reflected in an increase in root:shoot ratio in plants showing early vigor (11). In the present study, however, growth differences between N treatments in either cotoneaster or juniper were not correlated with root:shoot ratios (Tables 6 and 7) suggesting that other traits such as increased radial stem growth or branch initiation may be better indicators of differential partitioning in these plants.

To summarize, RGR of 'Coral Beauty' cotoneaster and 'Plumosa Compacta' juniper over successive 30-day periods significantly influenced TRWG over the growing season. In both taxa, however, high RGR during one period was

Table 1. Relative growth rates of 'Coral Beauty' cotoneaster grown with different rates of nitrogen fertilization.

N level (mg/plant/week)	RGR ($mg\ g^{-1}\ day^{-1}$) May 22–Jun 20 (Period 1)	Jun 21–Jul 20 (Period 2)	Jul 21–Aug 18 (Period 3)	Aug 19–Sep 16 (Period 4)
70	34.5	56.0	33.3	19.0
140	36.5	57.8	33.8	21.0
280	36.3	49.5	41.5	26.7
420	43.5	49.2	40.8	26.0
SEM (n = 6 df = 15)	1.6	3.3	4.0	2.4
Significant terms[z]				
Linear	**	NS	NS	*
Quadratic	NS	NS	NS	NS

[z]NS, *, **: Non significant (NS) or significant at 1% (**) or 5% (**) level.

Table 2. Relative growth rates of 'Plumosa Compacta' juniper grown with different rates of nitrogen fertilization.

	RGR (mg g^{-1} day^{-1})			
N level (mg/plant/week)	May 22–Jun 20 (Period 1)	Jun 21–Jul 20 (Period 2)	Jul 21–Aug 18 (Period 3)	Aug 19–Sep 16 (Period 4)
70	11.8	31.7	17.8	20.8
140	19.3	26.0	21.5	25.5
280	16.0	29.7	20.2	25.0
420	15.5	31.5	19.5	20.5
SEM (n = 6 df = 15)	1.4	3.2	3.5	3.0
Significant terms[z]				
Linear	**	NS	NS	NS
Quadratic	*	NS	NS	*

[z]NS, *: Non significant (NS) or significant at 5% (*) level.

Table 3. End of season (September 16) dry weight of roots, shoots and whole plants of 'Coral Beauty' cotoneaster grown with different rates of nitrogen fertilization.

N level (mg/plant/week)	Root dry weight (g)	Shoot dry weight (g)	Plant dry weight (g)
70	9.6	46.4	56.0
140	10.1	67.7	77.9
280	11.4	79.4	90.9
420	13.9	82.9	96.8
% SEM (n = 6 df = 14)	6.8	3.3	3.5
Significant terms[y]			
Linear	**	**	**
Quadratic	NS	**	**

[z]Data transformed to logarithms for analysis and the presented means are back transformed log means. Standard error for an individual mean = mean × % SEM/100%.

[y]NS, *, **: Non significant (NS) or significant at 5% (*), 1% (**) level.

Table 4. End of season (September 16) dry weight of roots, shoots and whole plants of 'Plumosa Compacta' juniper grown with different rates of nitrogen fertilization.

N level (mg/plant/week)	Root dry weight (g)	Shoot dry weight (g)	Plant dry weight (g)
70	3.6	14.9	18.5
140	4.0	21.0	25.0
280	3.0	18.6	21.6
420	2.6	17.4	20.1
% SEM (n = 6 df = 14)	10.3	8.3	8.5
Significant terms[y]			
Linear	NS	NS	NS
Quadratic	*	*	*

[z]Data transformed to logarithms for analysis and the presented means are back transformed log means. Standard error for an individual mean = mean × % SEM/100%.

[y]NS, *: Non significant (NS) or significant at 5% (*) level.

Table 5. Electrical conductivity of leachate collected following addition of 200 ml distilled water to media surfaces for 'Coral Beauty' cotoneaster and 'Plumosa Compacta' juniper on 3 dates.

	Electrical conductivity EC_{25}[z](ds/m)					
	Cotoneaster			Juniper		
N level (mg/plant/week)	Jun 20	Jul 20	Aug 18	Jun 20	Jul 20	Aug 18
70	772	518	875	728	550	523
140	830	570	792	845	595	643
280	1007	900	1517	1027	907	1208
420	1098	1087	1993	1073	1265	1293
SEM (n = 6, df = 15)		121			60.8	
Sig. effects (N-treatment)[y]						
Linear	**	**	**	**	**	**
Quadratic	**	**	**	**	NS	**

[z]Electrical conductivity of medium leachate measured at 25 C.

[y]NS, *, **: Non significant (NS) or significant at 1% (**) level.

Table 6. Root dry weight: Shoot dry weight ratio for 'Coral Beauty' cotoneaster grown with different rates of nitrogen fertilization, on 4 dates.

N level (mg/plant/week)	Root dry weight:Shoot dry weight			
	Jun 20	Jul 20	Aug 18	Sep 16
70	0.39	0.16	0.17	0.21
140	0.32	0.13	0.13	0.15
280	0.38	0.14	0.11	0.15
420	0.38	0.15	0.12	0.17
SEM (n = 6 df = 15)	0.04	0.02	0.01	0.01
Significant terms[z]				
Linear	NS	NS	**	**
Quadratic	NS	NS	**	**

[z]NS, **: Non significant (NS) or significant at 1% (**) level.

Table 7. Root dry weight: Shoot dry weight ratio for 'Plumosa Compacta' juniper grown with different rates of nitrogen fertilization, on 4 dates.

N level (mg/plant/week)	Root dry weight:Shoot dry weight			
	Jun 20	Jul 20	Aug 18	Sep 16
70	0.18	0.14	0.18	0.24
140	0.14	0.13	0.13	0.19
280	0.16	0.12	0.13	0.16
420	0.16	0.12	0.12	0.15
SEM (n = 6 df = 15)	0.01	0.01	0.01	0.01
Significant terms[z]				
Linear	NS	NS	**	**
Quadratic	*	NS	**	NS

[z]NS, *, **: Non significant (NS) or significant at 5% (**) or 1% (**) level.

negatively correlated with RGR during a subsequent period, suggesting that vigorously growing plants partition more dry matter to non-photosynthetic tissue than their slower growing counterparts. In cotoneaster, seasonal dry matter production increased linearly with applied N, whereas in juniper maximum growth occurred at an intermediate (140 mg, 0.005 oz N per week) rate.

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