Shade Intensity Influences Water Use and Growth of Three Viburnum Species[1]

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Abstract

Water use, growth, and leaf necrosis of Burkwood viburnum, Korean spice viburnum, and leatherleaf viburnum were evaluated on plants grown in 0 (full sun), 30, or 60% shade during 2010 and 2011. In both years, total water use of Burkwood viburnum decreased with increased shade intensity. Water use of leatherleaf viburnum was lowest in 0% and highest in 30% shade. Daily water use was lower in 0% than in 30 or 60% shade for leatherleaf viburnum plants in August of both years and September of 2010 due to greater leaf necrosis, leaf abscission, and less growth in height and width. In both years, growth in height and width, and leaf number at harvest generally increased in all three species with increased shade intensity. All species had a larger leaf area, stem dry weight, and root dry weight in 30 and 60% than in 0% shade. Shade intensity did not influence root to shoot (R/S) ratio in Burkwood viburnum in 2010, but in 2011, a curvilinear relationship occurred between R/S ratio and shade intensity. Root to shoot ratio of Korean spice and leatherleaf viburnum decreased linearly in 2010 but curvilinearly in 2011 with increasing shade. Leaf necrosis ratings were lower in shaded plants of all three species in both years. Results indicate that greater plant growth, quality, and water use efficiency occurs when these three viburnum species are grown in shade than when they are grown in full sun.

Index words: *Viburnum* × *burkwoodii*, *Viburnum carlesii*, and *Viburnum rhytidophyllum*.

Species used in this study: Burkwood viburnum (*Viburnum* × *burkwoodii* Burkw. & Skipw. Ex Anon.); Korean spice viburnum (*Viburnum carlesii* Hemsl.); leatherleaf viburnum (*Viburnum rhytidophyllum* Hemsl.).

Significance to the Nursery Industry

Growing plants in shade usually reduces plant water needs; however, plant response to shade is species-specific. Improper light intensities can negatively affect plant growth and aesthetic quality. Excessive light intensity can cause leaf necrosis, photoinhibition and damage to photosynthetic processes while excessive shading can reduce photosynthesis and plant growth. Our study evaluated the response of Burkwood viburnum, Korean spice viburnum and leatherleaf viburnum to 0, 30, or 60% shade. Plant height, width, leaf number, leaf area and root and shoot dry weights increased with shade intensity in all species. Leaf necrosis ratings were lower in shaded plants compared to plants in full sun for all three species. Total water use of Burkwood viburnum was lower in 60% shade compared to 0 or 30% shade. Leatherleaf viburnum in 0% shade used less water than those in 30 or 60% shade; however, the plants in 0% shade grew less, had lower dry weights, greater leaf necrosis, and leaf abscission that decreased plant quality resulting in plants that were not saleable. Lower root weights in 0% shade may limit plant growth and survival during nursery production or after transplanting into the landscape. Shading of Burkwood viburnum, Korean spice viburnum, and leatherleaf viburnum during production can increase plant growth and quality resulting in increased profitability of viburnum crops.

Introduction

Water availability is among the most limiting environmental factors affecting crop productivity. Water stress reduces plant growth and can reduce protein synthesis, photosynthesis, respiration, and nucleic acid synthesis in plants (31). Water shortages are increasing due to limited water supplies, increased water prices, and urbanization (38, 42). Irrigation is essential for production of ornamental plants, especially those grown in containers. Irrigation efficiency must be improved to make ornamental plant production more sustainable and profitable (3). Optimum growth and development of ornamental plants, whether grown without root restriction in the ground, in containers outdoors in the ground or above ground, or in greenhouses, depends on plant evapotranspiration (ET). Because the volume of water assimilated by a plant is very small compared to water lost to ET, ET can be considered the volume of water needed to maintain plant growth and quality. Applying more water than needed by a particular plant species will not improve growth and productivity because plants assimilate and transpire a limited water volume. Plant growth and water use are influenced by environmental conditions including light intensity and duration, temperature, humidity, and wind. Shading reduces light intensity, plant and soil temperatures (12, 41), and leaf-to-air vapor pressure deficit. Shading also decreases evaporation rates (5, 43), and has complex effects on plants through photosynthesis and morphological plasticity (14, 36). Shade leaves usually have a lower stomatal index, lower stomatal and epidermal cell densities due to larger epidermal cells (35), larger interveinal areas, and a lower ratio of internal to external surface (29).

Light is essential for normal plant growth. Plants can acclimate to changes in light intensity. At the whole plant level, the biomass partitioning among leaves, stems, and roots can change. Leaves are the most exposed plant organ to aerial conditions and the variation in light intensity can induce morphological, physiological and ultrastructural modifications in leaf tissues. Moderate shading tends to reduce transpiration more than photosynthesis (1). Shaded plants may be taller and have larger leaves because of a favorable water supply in the growing tissues. Dense shade can reduce photosynthesis

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enough to affect growth, and can reduce a plant's ability to survive drought (20). Exposure of plants to excessive radiation and/or high temperature may lead to photoinhibition, photodegradation, and/or photorespiration (24, 25). Different light intensities influence plant growth, leaf gas exchange and water use efficiency (10, 11, 34). Successful growth of plants at low light intensity requires a capacity to efficiently capture available light and convert it into chemical energy. Plants that maintain a low respiration rate and partition a large fraction of the carbohydrate pool into leaf growth also perform well in shade.

Viburnums have long been one of the most popular flowering shrubs. Viburnums include deciduous and evergreen shrubs and small trees, mostly native to North America or Asia (18). Some viburnum species are fragrant while others have an undesirable odor. Flower color ranges from white to pink (rose), and fruit color may be yellow, orange, red, pink, blue or black (7). Viburnums are grown in full sun or shade (7), and species vary in soil moisture requirements. Many species thrive in moist soil but some species are drought tolerant (13, 27).

Little research has been done on growth responses of viburnum species to shade (19, 34). Plant acclimation to different light intensities depends on environmental conditions and plant genotype, and thus is species-specific. Therefore, different viburnum species may respond differently to different shade intensities. The three viburnum species tested in this research were Burkwood viburnum, Korean spice viburnum, and leatherleaf viburnum. These viburnum species can be grown in sun or shade (7). However, no information is available regarding the optimal light intensity for reduced water use and improved growth and quality. Usually, shading practices are based on grower experience with various plants. Determining the optimal shade intensities for these viburnum species would be useful to commercial growers in reducing water consumption, hastening growth, decreasing time to prepare plants for sale, and increasing plant quality, thus improving sustainability and efficiency of viburnum production. The objectives of this study were to determine water use, growth and leaf necrosis of three viburnum species grown under three shade intensities.

Materials and Methods

2010. Research was conducted at The Botanic Garden at Oklahoma State University, Stillwater, OK. Uniform commercially produced (Greenleaf Nursery Co., Park Hill, OK) rooted cuttings of three viburnum species, Burkwood viburnum, Korean spice viburnum, and leatherleaf viburnum, were planted on May 12, 2009. The plants were potted in #1 black plastic containers with a pine bark:peat:sand substrate (3:1:1 by vol) amended with 3.7 $kg \cdot m^{-3}$ (6.2 $lb \cdot yd^{-3}$) 18N-13.7P_2O_5-14.4K_2O (Osmocote 18-16-12, The Scotts Co., Marysville, OH), 3 $kg \cdot m^{-3}$ (5 $lb \cdot yd^{-3}$) dolomitic limestone and 74.2 $g \cdot m^{-3}$ (0.1 $lb \cdot yd^{-3}$) Micromax (The Scotts Co.). On April 6, 2010, the plants were transplanted into #2 pots with the same substrate. All containers received the same amount of substrate by weight [3300 g (7.3 lb)]. Plants were grown outdoors under 0 (full sun), 30 or 60% reduced photosynthetic photon flux (PPF). Shade was created with woven shade cloth. Maximum PPF measured at plant height for the 0, 30, and 60% shade treatments were 1985, 1452, and 742 $\mu mol \cdot m^{-2} \cdot s^{-1}$ respectively. The experiment was conducted from May 20, 2010, to September 7, 2010. The plants were hand watered as needed until the beginning of the experiment. The plants were hand weeded throughout the study. Daily temperatures were recorded using data loggers (Watchdog 425 or Watchdog 2000, Spectrum Technologies, Plainfield, IL) at the plant canopy height in each shade treatment.

Three plants from each species were used to determine plant available water (PAW) before the experiment began. Plants were watered until water leached from the bottom of the containers and then allowed to drain for 2 hr at which time no more leaching was apparent. Each plant was weighed on an electronic precision balance (Scout Pro SP6001, Ohaus Corporation, Pine Brook, NJ). Average weights of the three plants within each species provided container capacity (CC) of the respective species. Plants were then allowed to dry until apical leaves wilted overnight and did not recover the following morning. Each plant was weighed and weights of the three plants within each species were averaged to determine permanent wilting point (PWP) of each species. Fifty percent of plant available water (PAW_{50}) was calculated as $PAW_{50} = 0.5$ (CC – PWP) for each species.

Beginning May 20, 2010, daily plant water use of leatherleaf viburnum and Burkwood viburnum was determined gravimetrically by weighing each pot. Plants were watered to container capacity plus a 10% leaching fraction when weights indicated that 50% of available water had been used. Each day the pots were weighed at 1000 HR and the plants were watered between 1100 and 1230 HR using a graduated cylinder. Saucers were placed under each pot to collect leachate, and leachate volume was measured after 2 hours. Leachate volume was subtracted from the volume of water applied to get the actual water use of the plants. Rainfall was measured with a rain gauge (Model 90107, Springfield Instruments, Montreal) in each shade treatment.

Plant heights and widths were measured at the beginning of the experiment on May 20, 2010, and at harvest on August 20, 2010. Plant heights were measured from the substrate to the highest apparent canopy point. Plant widths were measured at the widest portion and then perpendicular to the widest portion, and the two measurements were averaged. Each month, leaf necrosis was rated using a scale of 1 to 12 (modified Horsfall and Barratt rating scale, (15, 16)) in which 1 = 0 percent of leaves necrotic, 2 = 1 to 3 percent necrotic, 3 = 4 to 6 percent necrotic, 4 = 7 to 12 percent necrotic, 5 = 13 to 25 percent necrotic, 6 = 26 to 50 percent necrotic, 7 = 51 to 75 percent necrotic, 8 = 76 to 87 percent necrotic, 9 = 88 to 93 percent necrotic, 10 = 94 to 96 necrotic, 11 = 97 to 99 necrotic, and 12 = 100 percent necrotic and plants dead. Plants were visually rated for leaf necrosis by two independent raters at each rating time and the ratings were averaged. On the same dates that plants were rated for leaf necrosis, relative leaf greenness was measured with a SPAD chlorophyll meter (Minolta SPAD 502 meter, Spectrum Technologies, Plainfield, IL). Leaves from the upper half of the plant were selected for relative leaf greenness measurements. Three measurements from the interveinal area on one leaf from each plant were collected and averaged.

At termination, plants were defoliated, number of leaves per plant was counted and leaf area was measured using an area meter (LI-3100C, LiCor, Inc., Lincoln, NE). Plants were harvested and stems, leaves and washed roots were dried at 65C (149F) for 7 days. The dried roots, stems and leaves were weighed. Root to shoot ratio was calculated as R/S ratio = root dry weight / shoot dry weight. Leaf area ratio (LAR)

Table 1. Total water use and daily water use by month of two viburnum species grown under 0, 30 and 60% shade in 2010 and 2011. n = 20.

Species	Shade intensity	Total water use (L)	Daily water use (mL) by month				
			May	June	July	August	September
2010							
Burkwood viburnum	0%	23.8	135	219	223	248	143
	30%	23.8	96	167	217	291	269
	60%	20.8	88	125	196	267	243
	Linear	*	NS	**	NS	NS	**
	Quadratic	NS	NS	NS	NS	NS	**
Leatherleaf viburnum	0%	46.6	409	497	439	381	194
	30%	54.1	385	492	501	530	395
	60%	48.8	249	409	458	527	431
	Linear	NS	**	**	NS	**	**
	Quadratic	**	*	NS	NS	**	**
2011							
Burkwood viburnum	0%	8.8	—	123	166	87	—
	30%	7.7	—	96	140	91	—
	60%	5.7	—	67	109	53	—
	Linear	**	—	**	**	**	—
	Quadratic	**	—	NS	NS	**	—
Leatherleaf viburnum	0%	10.8	—	160	213	75	—
	30%	11.7	—	154	224	120	—
	60%	10.8	—	141	205	110	—
	Linear	NS	—	**	NS	**	—
	Quadratic	**	—	NS	*	**	—

NS, *, **Nonsignificant or significant at $p \leq 0.05$ or 0.01, respectively.

was calculated as LAR = leaf area / total plant dry weight and specific leaf area (SLA) was calculated as SLA = leaf area / leaf dry weight.

2011. The 2010 study was repeated except that rooted cuttings were planted into #1 containers with 2000 g (4.4 lb) substrate on December 7, 2010. The plants remained in #1 containers throughout the study. Relative leaf greenness was not measured. The experiment was initiated June 13, 2011, and plants were harvested beginning August 17, 2011.

Statistics. Species were completely randomized within each shade intensity. Shade was not replicated, but each species was replicated within each shade intensity (species were nested within shade intensity), thus the main effect of species and the interaction of species × shade intensity were tested. There were 20 replications of the factorial combination of species × shade intensity. Data for each year were analyzed independently. Data were analyzed using the GLM procedure in SAS and trend analyses were performed (SAS 9.1, SAS Institute, Cary, NC).

Results and Discussion

Total water use throughout the experiment by Burkwood viburnum decreased linearly in 2010 and curvilinearly in 2011 with increasing shade intensity (Table 1). Total water use of leatherleaf viburnum responded curvilinearly to shade intensity in both years such that water use was greater in 30% shade than in 0 or 60% shade. Burkwood daily water use decreased linearly with increased shade intensity in June of 2010, but a curvilinear relationship existed between daily water use and shade intensity in September such that water use was lowest in 0% shade and highest in 30% shade. In 2011, daily water use of Burkwood decreased linearly in June and July as shade intensity increased, but in August a curvilinear relationship between daily water use and shade intensity existed such that plants in 30% shade used the most water and those in 60% shade used the least. Daily water use of leatherleaf viburnum decreased curvilinearly in May and linearly in June but increased curvilinearly in August and September of 2010 as shade intensity increased. In 2011, daily water use of leatherleaf viburnum decreased linearly in June as shade intensity increased, but a curvilinear relationship existed between daily water use and shade intensity in July and August such that the greatest water use occurred in 30% shade in both months, but the lowest water use in July occurred in 60% shade while the lowest water use in August occurred with no shade.

Growth in height and width of all species increased linearly during both years with increasing shade intensity (Table 2). Number of leaves on Burkwood viburnum at harvest increased linearly with increasing shade intensity in both years. A curvilinear relationship between leaf number and shade intensity occurred for Korean spice viburnum such that leaf number was greatest in 30% shade and lowest in 0% shade in 2010, but no relationship between Korean spice leaf number and shade intensity occurred in 2011. Number of leaves on leatherleaf viburnum increased linearly with increased shade intensity in 2010, but no trend occurred in 2011. A quadratic relationship between leaf area and shade intensity existed for all three species in 2010. Burkwood viburnum plants in 30% shade had the largest and those in 0% shade had the smallest leaf area. In contrast, leaf area

Table 2. Plant growth in height and width, number of leaves, leaf area (LA), leaf, stem, root, and total dry weight, root to shoot ratio (R/S ratio), leaf area ratio (LAR) and specific leaf area (SLA) of three viburnum species grown under 0, 30 or 60% shade in 2010 and 2011. n = 20.

Species	Shade intensity	Growth in height[z]	Growth in width[y]	Number of leaves	LA (cm^2)	Dry weight (g) Leaf	Stem	Root	Total	R/S ratio	LAR ($cm^{-2} \cdot g^{-1}$)	SLA ($cm^{-2} \cdot g^{-1}$)
2010												
Burkwood viburnum	0%	0	8.6	190.7	1425.5	27.5	22.1	15.7	65.4	0.3	3.9	51.0
	30%	11	18	283	2613	47	43	30	120	0	2.4	55.2
	60%	22	24	296	2366	36	41	27	105	0	2.9	66.6
	Linear	**	**	**	**	NS	**	**	**	NS	NS	**
	Quadratic	NS	NS	NS	*	**	**	*	**	NS	NS	NS
Koreanspice viburnum	0%	6.4	2.1	99.8	634.9	11.2	22.1	17.1	50.5	0.6	1.9	60.8
	30%	20.1	14.7	195.4	3040.6	46.1	42.7	41.3	130.3	0.5	1.5	66.6
	60%	35.1	28.8	180.2	3331.3	42.6	46.9	39.1	128.8	0.4	1.4	77.8
	Linear	**	**	**	**	**	**	**	**	**	NS	**
	Quadratic	NS	NS	**	**	**	**	**	**	NS	NS	NS
Leatherleaf viburnum	0%	9.5	0.0	78.3	1020.3	29.7	44.2	47.6	121.5	0.7	0.6	26.0
	30%	17.3	12.9	137.7	4064.8	70.9	59.9	83.7	214.6	0.6	0.6	55.7
	60%	21.3	29.9	148.6	5750.9	75.3	73.3	84.9	233.7	0.6	0.6	76.8
	Linear	**	**	**	**	**	**	**	**	*	NS	**
	Quadratic	NS	NS	NS	*	**	NS	**	**	NS	NS	NS
2011												
Burkwood viburnum	0%	9.8	29.9	21.4	200.4	3.5	3.6	2.9	9.9	0.5	17.7	54.7
	30%	13.6	32.3	35.9	378.7	6.8	4.3	3.4	14.5	0.3	26.0	55.8
	60%	19.2	34.7	37.1	389.2	6.3	4.6	4.2	15.1	0.4	25.6	61.3
	Linear	**	**	**	**	**	NS	NS	**	NS	**	*
	Quadratic	NS	NS	NS	NS	**	NS	NS	NS	*	**	NS
Koreanspice viburnum	0%	8.5	25.4	0.8	5.2	0.1	1.9	1.7	3.7	0.9	1.3	43.7
	30%	13.7	31.1	24.9	210.7	3.3	2.0	2.5	7.8	0.4	27.0	63.5
	60%	—	—	23.7	297.9	4.3	3.0	3.3	10.9	0.5	28.3	67.8
	Linear	**	**	NS	**	NS	NS	*	**	**	**	**
	Quadratic	—	NS	NS	**	NS	NS	NS	NS	**	**	NS
Leatherleaf viburnum	0%	7.9	10.6	0.0	0.0	0.0	8.5	6.2	14.5	0.7	0.0	—
	30%	12.0	32.6	41.8	1265.6	18.6	9.8	11.8	40.9	0.4	32.1	68.4
	60%	12.1	36.9	40.4	1427.4	20.5	10.4	14.2	45.1	0.5	31.8	70.0
	Linear	**	**	NS	**	*	**	**	**	**	**	NS
	Quadratic	NS	NS	—	—	—	NS	**	**	**	**	—

[z]Height = (Height in September) – (Height in May).

[y]Width = (Width in September) – (Width in May).

[NS, *, **]Nonsignificant or significant at $p \leq 0.05$ or 0.01, respectively.

increased curvilinearly for Korean spice and leatherleaf viburnum as shade intensity increased. In 2011, leaf area increased curvilinearly as shade intensity increased with Korean spice, but an increasing linear relationship between leaf area and shade intensity existed for Burkwood and leatherleaf viburnum. A quadratic relationship occurred between leaf dry weight and shade intensity for Burkwood viburnum in both years such that leaf dry weight was largest in 30% shade and smallest in 0% shade. Leaf dry weight increased curvilinearly as shade intensity increased in 2010 for Korean spice viburnum, but no trend occurred in 2011. Leaf dry weight of leatherleaf viburnum increased curvilinearly in 2010 but linearly in 2011 as shade intensity increased. Lack of leaves on leatherleaf viburnum in full sun at harvest in 2011 made analysis of quadratic effects between measured leaf parameters and shade intensity impossible.

A curvilinear relationship between stem dry weight and shade intensity existed for Burkwood in 2010 such that stem dry weight was greatest in 30% shade and lowest in no shade, but no trend occurred in 2011. An increasing curvilinear relationship between stem dry weight and shade intensity existed for Korean spice viburnum in 2010, but no trend occurred in 2011. Stem dry weight of leatherleaf viburnum increased linearly with increasing shade in both years. A curvilinear relationship existed between root dry weight and shade intensity in Burkwood and Korean spice viburnum in 2010 such that plants had the largest root dry weight in 30% shade and the smallest in 0% shade. In contrast, in 2011 no trend between root dry weight and shade intensity occurred for Burkwood viburnum, but root dry weight increased linearly as shade intensity increased for Korean spice viburnum. Root dry weight of leatherleaf viburnum increased curvilinearly as shade intensity increased in both years. Shade intensity did not influence R/S ratio of Burkwood viburnumin 2010. In 2011, a curvilinear relationship existed between R/S ratio and shade intensity such that the greatest R/S ratio occurred with no shade and the smallest occurred in 30% shade. Korean spice and leatherleaf viburnum R/S ratio decreased linearly with increasing shade intensity in 2010, but a curvilinear relationship occurred for both species in 2011 such that R/S ratio was greatest with no shade and lowest with 30% shade. Shade intensity did not affect LAR regardless of species in 2010. In 2011, LAR increased curvilinearly for Korean spice viburnum as shade intensity increased, but a curvilinear relationship existed between LAR and shade intensity for Burkwood and leatherleaf viburnum such that the greatest LAR occurred with 30% shade and the lowest LAR occurred with 0% shade. Specific leaf area increased linearly as shade intensity increased for all three species in 2010 and for Burkwood and Korean spice viburnum in 2011, but no trend occurred for leatherleaf viburnum in 2011.

Leaf necrosis ratings of Burkwood viburnum increased linearly as shade intensity increased in May of 2010 though the increase was small and not likely horticulturally significant (Table 3). Burkwood viburnum leaf necrosis did not differ among shade intensities in June of either year, but it declined linearly in July of 2010, and curvilinearly in July of 2011 and in August of both years as shade intensity increased. Korean spice viburnum leaf necrosis did not differ among shade intensities in May of 2010 or June of 2011, but it declined linearly in June of 2010 and curvilinearly in July and August of both years as shade intensity increased. Leatherleaf viburnum leaf necrosis decreased linearly during May, June, and July, but curvilinearly in August of 2010 as shade intensity increased. In 2011, no relationship occurred between leaf necrosis ratings in June, while leaf necrosis ratings decreased curvilinearly with increased shade intensity in July and August. Relative leaf greenness increased linearly as shade intensity increased for Burkwood viburnum in all months of 2010 (Table 4). Korean spice relative leaf greenness increased linearly in May and June, but curvilinearly in July as shade intensity increased. In August a curvilinear relationship between relative leaf greenness and shade intensity occurred for Korean spice viburnum such that plants in 0% shade had the lowest relative leaf greenness and those in 30% shade had the greatest relative leaf greenness. Relative leaf greenness of leatherleaf viburnum increased linearly as shade intensity increased in June, July, and August.

This research investigated the response of three viburnum species to various shade intensities. Previous researchers (9, 33) found that shade or reduced light intensity reduced total water use of plants. Reduced water use with increasing

Table 3. Monthly leaf necrosis ratings in three viburnum species grown under 0, 30 or 60% shade in 2010 and 2011. n = 20.

Species	Shade intensity	Leaf necrosis rating[z] May	June	July	August
2010					
Burkwood viburnum	0%	1.0[z]	1.5	2.2	3.8
	30%	1.1	1.5	1.5	1.5
	60%	1.1	1.3	1.3	1.3
	Linear	**	NS	**	**
	Quadratic	NS	NS	NS	**
Korean spice viburnum	0%	1.1	2.3	3.9	6.5
	30%	1.0	1.6	1.9	2.3
	60%	1.0	1.2	1.2	1.4
	Linear	NS	**	**	**
	Quadratic	NS	NS	**	**
Leatherleaf viburnum	0%	1.9	2.1	3.0	8.1
	30%	1.8	1.9	2.0	2.9
	60%	1.5	1.6	1.7	1.7
	Linear	**	**	**	**
	Quadratic	NS	NS	NS	**
2011					
Burkwood viburnum	0%	—	1.0	2.2	4.4
	30%	—	1.0	1.0	1.6
	60%	—	1.0	1.0	1.4
	Linear	—	NS	**	**
	Quadratic	—	NS	**	**
Korean spice viburnum	0%	—	1.0	3.1	10.4
	30%	—	1.0	1.0	2.0
	60%	—	1.0	1.1	1.4
	Linear	—	NS	**	**
	Quadratic	—	NS	**	**
Leatherleaf viburnum	0%	—	1.0	3.2	10.6
	30%	—	1.0	1.4	2.6
	60%	—	1.0	1.1	1.3
	Linear	—	NS	**	**
	Quadratic	—	NS	**	**

[z]Ratings were based on the Horsfall-Barrett rating scale (see text).

[NS, *, **]Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 4. **Monthly relative leaf greenness measurements on three viburnum species grown under three shade intensities. n = 10.**

Species	Shade intensity	Relative leaf greenness			
		May	June	July	August
Burkwood viburnum	0%	75.2	73.5	72.8	61.9
	30%	82.0	80.5	79.8	68.9
	60%	82.6	83.0	79.9	68.4
	Linear	**	**	**	*
	Quadratic	NS	NS	NS	NS
Korean spice viburnum	0%	68.0	65.0	63.1	55.0
	30%	73.8	73.8	72.2	61.8
	60%	76.1	75.7	73.5	58.2
	Linear	**	**	**	NS
	Quadratic	NS	NS	*	*
Leatherleaf viburnum	0%	63.5	58.2	53.3	47.9
	30%	64.0	63.1	58.9	54.0
	60%	67.4	66.8	62.3	61.6
	Linear	NS	**	**	**
	Quadratic	NS	NS	NS	NS

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

shade may be due to lower light intensity in shade rather than decreased temperature. In the current study, temperature did not differ under the three different shade intensities (Table 5) so differences in growth and water use among the different shade intensities must be due to some other factor. Nutman (28) showed that fluctuations in transpiration rate were closely related to solar radiation, rather than temperature changes. Light, both as a single factor and in combination with other factors (temperature, relative humidity), has been shown to largely affect total water consumption rate over time (22). Reduced light intensity might have reduced stomatal conductance (6, 17, 32) or decreased stomatal density (21, 39, 40). Pieruschka et al. (32) found that under uniform conditions of vapor pressure deficit and CO_2 concentration, stomatal conductance was proportional to light intensity. Our results contrasted those of Medina et al. (24) in which shade decreased leaf and air temperatures resulting in lower evaporative demand. In our study, water use of Burkwood and leatherleaf viburnum was reduced in 0 compared to 30 or 60% shade in the later months of the experiment. This is attributed to reduced plant growth, leaf number and leaf area due to greater leaf necrosis and leaf abscission in 0% compared to 30 or 60% shade.

Greater shade intensity resulted in increased plant height of Burkwood, leatherleaf, and Korean spice viburnum. Similar results were noted by Fini et al. (10) in *V.* × *pragense* Vik and Fini et al. (11) in *V. tinus* L. 'Eve Price' where 60% shade increased plant height compared to 30% shade or full sun.

Table 5. **Daily mean high and low temperatures (F and C) by month from May 20, 2010, through September 8, 2010, and from June 9, 2011, through August 17, 2011, recorded by data loggers in 0, 30 and 60% shade.**

Month	Temperature											
	0% shade				30% shade				60% shade			
	F		C		F		C		F		C	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
2010												
May[z]	93.5	64.6	34.1	18.1	91.1	65.0	32.8	18.3	90.3	64.1	32.36	17.82
June	97.9	72.1	36.6	22.3	95.6	71.9	35.4	22.2	78.7	52.0	25.94	11.12
July	95.2	72.0	38.2	22.9	91.8	71.8	36.5	22.7	85.6	61.3	34.28	20.45
August	102.1	70.9	38.9	21.6	99.4	70.4	37.4	21.3	97.1	70.9	36.18	21.58
September[y]	92.9	65.1	33.8	18.4	91.0	64.5	32.8	18.1	90.1	64.8	32.28	18.22
2011												
June[x]	104.0	73.0	40.0	22.8	102.3	72.7	39.1	22.6	102.4	72.5	39.1	22.5
July	109.0	76.9	42.8	24.9	108.1	77.3	42.3	25.2	108.5	77.1	42.5	25.1
August[w]	107.2	74.0	41.8	23.3	106.2	74.5	41.2	23.6	106.5	74.4	41.4	23.6

[z]Average temperatures from May 20, 2010, through May 31, 2010.

[y]Average temperatures from September 1, 2010, through September 8, 2010.

[x]Average temperatures from June 9, 2011, through June 30, 2011.

[w]Average temperatures from August 1, 2011, through August 17, 2011.

Robinson and Hamilton (34) showed that plant height of *V. opulus* L. 'Nanum' was greater in 30 and 47% than in 63% shade or in full sun. Increasing shade can produce enlarged stems as a result of the partitioning of photosynthates by the plant (4) until production of photosynthates is limited (30). Our result of increased height with increasing shade in the three species might be due to higher production of photosynthates in 60% than in 0 or 30% shade.

Increased shading increased plant width of all three viburnum species in this study. This is in contrast to Robinson and Hamilton (34) who showed that plant width of *V. opulus* L. 'Nanum' decreased in 63% shade compared to 30 or 47% shade.

The three viburnum species in 0% shade had fewer leaves and smaller leaf area per plant at harvest than those in either shade treatment. *Viburnum* × *pragense* grown under 60% shade had more leaves and larger leaf area than those grown under 30% shade (10). However, Fini et al. (11) found that total leaf number per plant of *V. tinus* was not affected by shade. Lower leaf number and smaller leaf area in 0% shade in our study can likely be attributed to the combined effect of decreased growth and greater incidence of leaf necrosis followed by leaf abscission in plants under 0% shade compared to 30 or 60% shade.

Leaf, stem, root and total dry weight of the three viburnum species were greater in 30 or 60% shade compared to 0% shade. In contrast, *V.* × *pragense* in full sun and in 60% shade had similar plant dry weights while those in 30% shade had lower dry weights (10). Leaf, stem, root and total dry weight of *V. tinus* were not affected by shade (11). In our study, dry weights were mostly higher in 30% shade compared to 60% shade except stem dry weight of Korean spice viburnum and dry weights of all plant parts of leatherleaf viburnum were greater in 60% shade than in 0 or 30% shade. Larger photosynthetic area and higher net photosynthesis per area might have resulted in greater dry weights in 30 or 60% shade compared to 0% shade for the three species.

Root to shoot ratio has been shown to decrease in plants grown under shade (2, 37). In the current study, R/S ratio decreased with increasing shade in Korean spice and leatherleaf viburnum, but shade did not affect R/S ratio of Burkwood viburnum. The higher R/S ratio in 0% shade in Korean spice and leatherleaf viburnum might be due to greater leaf abscission reducing leaf biomass. Shade intensity did not affect leaf area ratio (LAR) of any viburnum species tested in this study in 2010, as observed by Fini et al. (11) who found that LAR of *V. tinus* was not affected by shade. Leaf area ratio of *V.* × *pragense* increased with increasing shade (10). Specific leaf area increased with increasing shade for the three viburnum species in our study. Increased SLA indicates that a given amount of biomass is spread over a larger area, increasing light capture per unit biomass in shade. Our results were similar to those of Evans and Poorter (8) and Kollmann and Grubb (19) in which shading increased SLA.

Greater leaf necrosis in 0% shade than in 30 or 60% shade is consistent with the results of Mock and Grimm (26). Exposure of leaves to higher light intensity in 0% shade might have led to chlorophyll damage, increased lipid peroxidation and, consequently, cell death and leaf abscission (25). Greater leaf necrosis in leatherleaf than in Korean spice and Burkwood viburnum in 0% shade might be due to leaf size since leatherleaf viburnums have larger leaves than Korean spice or Burkwood viburnum. Relative leaf greenness of viburnums grown under different shade intensities has not been previously studied; however, Korean spice and leatherleaf viburnum leaf greenness was similar to leaf greenness of *V. tinus* in a previous study investigating plant nutrition (23). In the current study, Burkwood viburnum had the darkest green leaves of the three species, and relative leaf greenness measurements were higher for that species. As the growing season progressed, leaf greenness declined in all species due to greater leaf chlorosis and necrosis.

In conclusion, growing plants of these three viburnum species under 30 or 60% shade can result in greater plant growth, greater leaf number and leaf area throughout the growing season, and a better quality plant. Total water use of plants of these three species generally declined as shade intensity increased. This can result in lower water costs for growers who grow viburnums under shade than those who grow them in full sun.

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