SURVEY OF CULTURAL PRACTICES USED IN PRODUCTION OF VIBURNUMS AND WATER USE AND GROWTH OF THREE VIBURNUM SPECIES GROWN UNDER DIFFERENT SHADE INTENSITIES

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Water is essential to plant life. Most plants contain about 90% water (Hartmann et al., 1988). Plant growth and survival depends on water availability. Throughout the world, irrigation (water for agriculture, or growing crops) is probably the most important use of water (except for drinking). Almost 60 percent of the world's freshwater withdrawals are used for irrigation (Solley et al., 1998). Likewise, irrigation is the largest water use in the United States. In 2005, an estimated 1,552,018,838 m^3/day (410 billion gallons per day) were used in the US. Thirty seven percent of total freshwater withdrawals were used for irrigation. When thermo-electric power is excluded from the estimates, 62 percent of total freshwater withdrawals were used for irrigation. Surface water accounted for 58 percent of the total irrigation withdrawals and groundwater was 42 percent (Kenny et al., 2009). Irrigation accounts for approximately 42% of water withdrawals in Oklahoma (Smith, 2007).

Like other agricultural crops, irrigation is essential for production of ornamental plants. The nursery/greenhouse industry ranks 5th (>$14.6 billion) in US agriculture commodities and is in the top 5 commodities for 26 states (USDA, 2004). Irrigation has large consequences on the productivity and profitability of this important sector of agriculture. Ornamental plants, whether grown in the ground, outdoors in containers, or in greenhouses, need water for optimum growth and development. Most ornamental plants grown in the United States are produced in container-nursery and greenhouse operations. Container plants are grown in substrates that must be well drained and container volume limits the amount of water that can be stored. This results in frequent irrigation applications and use of large volumes of water. In a recent survey, over 75% of nursery crops in 17 states (AL, CA, CT, FL, GA, IL, MI, NJ, NY, NC, OH, OR, PA, TN, TX, VA, WA) were grown in containers and required irrigation, often daily (USDA, 2007). In Florida, container nurseries annually apply 142 to 305 cm (56 to 120 inches) of water as irrigation per year in addition to the 102 to 127 cm (40 to 50 inches) of average annual rainfall. Container nurseries in Alabama were estimated to have used 3,700,445 to 49339274 m^3 (30,000 to 40,000 acre-feet) of water in 1985 (Fare et al., 1992).

Water is a finite resource. Although there has been plenty of fresh water on earth, that water has not always been available when and where it was needed, nor was it always of suitable quality for all uses. Water shortages are an increasing problem due to intensified competition for limited water supplies by agricultural, industrial and domestic users. Global population is expected to increase by three billion or more people over the next 50 to 75 years (Jury and Vaux, 2005). Oklahoma population increased by 36% between 1970 and 2000 and the population is projected to increase by 38% between 2000 and 2060 (Smith, 2007). Population growth and increased urbanization have increased competition for water. Over the past century, increased water demand from all economic sectors in the United States, including agriculture, were satisfied by increasing withdrawals from rivers, lakes and aquifers. Dam construction, ground water pumping, and interbasin transfers were the primary tools for meeting increased water needs. The ability to continue to expand the use of the nation’s fixed water resources, however, is becoming less favorable because of the absolute scarcity, reduced federal subsidies for construction projects, an improved understanding of the environmental effects of large-scale river modifications and water use, and new political and social constraints (Gleick, 2006). Drought and water conservation are not new issues in western states where availability has long been a limitation, but demographic changes are increasing competition among users. The record 2006-2008 drought in the eastern US had a severe impact on the nursery industry in that region. The Great Lakes region has implemented water use policies to comply with the ratified Great Lakes-St.Lawrence River Basin Water Resource Compact (Fernandez et al., 2009). Land-use change is the most significant local, regional, and global human impact on the hydrologic system (Bhaduri et al., 2000). Water shortages have resulted in water use restrictions in many areas of the United States (Urbano, 1986).

Irrigation efficiency must be improved to meet the long-term needs of the world’s population (Howell, 2001). There is increasing pressure on ornamental plant producers to use water more efficiently and thus make the nursery/greenhouse industry more sustainable (Beeson et al., 2004). For many years, it has been common practice to irrigate until water runs out of the bottom of the pots, but up to 50% of the water applied may be lost this way. In addition to inefficient water use, over-application of water results in fertilizer runoff and pollution of ground- and/or surface water. Nutrient leaching (nitrate and phosphate in particular) depends greatly on the amount of water that is applied. Legislation regarding water use and/or quality has been implemented in California, Delaware, Florida, Maryland, Michigan, North Carolina, Oregon, and Texas. Some legislation requires greenhouses and nurseries to develop nutrient management plans that describe their efforts to reduce nonpoint source pollution (Lea-Cox and Ross, 2001). To comply with new regulations and to meet increasing water demand, more efficient methods of irrigation need to be implemented. Good irrigation management is an important best management practice in ornamental crop production, reducing runoff of nutrient and pesticide-rich water from production sites (Briggs et al., 1998; Lea-Cox and Ross, 2001; Tyler et al., 1996). Better control of irrigation can have other benefits as well: better plant quality, more compact plants (Burnett and Van Iersel, 2008). In addition, more efficient irrigation can have direct economic benefits, because less electricity or fuel is needed to pump the irrigation water.

Different nursery production practices can influence irrigation efficiency. Incorporation of peat, clay, or composted municipal compost in container substrate increased available water and nutrient holding capacity (Catanzaro and Bhatti, 2005; Dunwell and McNiel, 2011; Owen et al., 2008). Narciso Pastor et al. (1999) reported that *Viburnum tinus* L. and *Spiraea japonica* L. grown with coarse pine bark in large containers grew better than those grown with fine pine bark in smaller containers when transplanted to a landscape with limited water. Evaluation of physiological conditions showed greater water stress hardening of plants grown with coarse pine bark, which led to a better adaptation to transplanting with low water application. Irrigation efficiencies vary with the type of irrigation system (Haman et al., 1998). With overhead irrigation, some water is lost by interception of plant parts, soil, mulch, and other surfaces during irrigation. Application efficiencies are reduced if water falls between widely spaced plants or outside the plant root zone, as in container nurseries. Application efficiencies of microirrigation systems are typically high, water losses due to wind drift and evaporation are typically small, as water is discharged near or within the root zone of the plants being irrigated.

Numerous other best management practices can be implemented by growers to improve irrigation efficiency. Shade (reduced solar radiation) is one management practice that can be used to reduce water needs in ornamental plant production. Plants lose water extracted from the soil through leaf stomata in the process of transpiration. Water also readily evaporates from the soil surface or the container substrate. The combination of evaporation and transpiration is known as evapotranspiration (ET). Because the amount of water assimilated by a plant is very small compared to water lost to ET, ET is considered to be the water requirement or water use of plants. Solar radiation intensity is one of the main climatic factors that determines the ET rate of plants and thus their water use. Shading reduces plant and soil temperatures (Franco and Nobel, 1989; Turner et al., 1966), decreases evaporation rates (Breshears et al., 1998; Valiente-Banuet and Ezcurra, 1991), and effects photosynthesis and plant morphology (Holmgren, 2000). At any given time, the overall balance of positive and negative effects of shade will determine plant performance (Holmgren et al., 1997). During hot and dry months, the positive shade effects of reduced soil temperatures and evaporation rates may be more important than any negative effects of reduced light levels.

Coffea arabica L. 'Costa Rica 95' transpired more per unit leaf area in full sun than under shade, an indication of higher environmental stress in non-shaded conditions (van Kanten and Vaast, 2006). Dancette and Poulain (1969) found that soil moisture was higher under *Acacia albida* Delile than in non-shaded areas in the top 120 cm (47 in) of the soil. Rhoades (1995) recorded increased soil water in the top 15 cm (6 in) of soil beneath *A. albida* canopies in Malawi. Greater soil moisture in tree sites is generally assumed to be due to reduced soil evaporation and plant transpiration caused by shading and resulting lower temperatures (Belsky et al., 1989). In Kenyan savannas, artificial shade increased herbaceous productivity (Belsky, 1994). This was attributed to the plant's capacity to reduce stomatal apertures and conserve moisture at low light levels (Amundson et al., 1995). Plants regulate water loss either by opening and closing their stomata or by varying their stomatal densities (Swarthout and Hogan, 2010). High light intensity correlates with higher stomatal density (Tichà, 1982). Shade leaves also usually have a lower stomatal index, lower stomatal and epidermal cell densities due to larger epidermal cells (Royer, 2001), and have larger interveinal areas, and a lower ratio of internal to external surface (Pallardy, 2008). *Viburnum opulus* L. had a mean stomatal density of 127 mm^{-2} (81,935 in^{-2}) on the lower surface in sun leaves and 65 mm^{-2} (41,935 in^{-2}) for shade leaves. In *V. lantana* L. there were 145 mm^{-2} (93,548 in^{-2}) stomata in sun leaves and 65 mm^{-2} (41,935 in^{-2}) in shade leaves (Kollmann and Grubb, 2002).

Research has shown that shading can reduce the water use of plants. Daily water use of 75 woody and herbaceous nursery crops, that represent common species and growth habits in the nursery trade, grown in full sun did not exceed 250 ml/day (0.06 gal/day) on any day, and usually was less than 200 ml/day (0.05 gal/day) while water use of plants grown under shade cloth never exceeded 200 ml/day (0.05 gal/day), and usually was less than 0.15 L/day (0.04 gal/day) (Evans and Dodge, 2007). Water use also varied among different plants. Cumulative water use ranged from 1.6 L (0.4 gal) for *Impatiens* *hawkeri* W. Bull 'Bonfire Orange' to 3.8 L (1 gal) for *I. walleriana* Hook.f. 'Double ole Rose' (Evans and Dodge, 2007). Water use efficiency of *Quercus alba* L., *Q. imbricaria* Michx. and *Q. palustris* Münchh. seedlings grown under three shade treatments (30, 55 and 73%) and two irrigation regimes (container capacity and mild drought) decreased significantly as shade intensity increased from 30 to 73% (McCarthy and Dawson, 1991). Water use of five foliage plants, *Araucaria heterophylla* (Salisb.) Franco., *Dieffenbachia maculata* (Lodd.) G. Don 'Camille', *Epipremnum aureum* (Linden and André) Bunt. 'Golden Pothos', *Polyscias fruticisa* (L.) Harms., and *Radermachera sinica* (Hance) Hemsl., decreased in lower light intensity. Amount of water used depended on light intensity and was specific to plant type (Poole and Conover, 1992). In a study by Medina et al. (2002), *Citrus sinensis* Osbeck and *C. limonia* Osbeck had a higher stomatal conductance and higher CO_2 assimilation rate in 50% shade than in the full sun. Despite increased stomatal conductance in shaded plants, transpiration rates were only 10% to 20% higher. This slight increase in transpiration rates under shade was attributed to lower leaf and air temperatures that resulted in a lower leaf-to-air vapor pressure gradient, and hence lower evaporative demand. Higher temperatures in full sun led to a high vapor pressure gradient, causing water loss from plants. The observed stomatal closure of plants in full sun did not largely restrain transpiration rates.

While shade is very useful for conserving moisture, not all plants can tolerate shade. Plant performance often shows spatial heterogeneity: the performance of plants growing under shade often differs from that of conspecifics growing in adjacent open spaces. Plants typically respond to shade in several ways. Shade-acclimation responses maximize light harvesting in shade conditions through increases in specific leaf area and reduced chlorophyll a:b ratio, whereas shade-avoidance responses maximize light capture by positioning the leaves out of the shade (Vandenbussche et al., 2005), increasing branching intensity and increasing side shoot:main shoot length ratios on the leader and selected side branches (Henry and Aarssen, 2001). Considerable differences in structure exist between leaves grown in the sun and in the shade. In general, shade-grown leaves are larger, thinner (Boardman, 1977; Pallardy, 2008; Valladares and Niinemets, 2008), and contain less palisade tissue and less conducting tissue than sun leaves (Pallardy, 2008). The chloroplasts of shade plants are larger in size, have a lower thylakoid volume but higher number of thylakoid membranes per chloroplast, and contain many more thylakoids per grana than chloroplasts of sun plants. Shade-grown plants have higher chlorophyll content per chloroplast, lower chlorophyll a: b ratio and a low ratio of soluble protein to chlorophyll (Brett and Singer, 1973; McWilliam and Naylor, 1967; Pallardy, 2008). Plants do not synthesize chlorophyll as rapidly as degradation occurs in high light intensity. Leaf-area ratio (LAR, leaf area / total plant dry weight) increases and specific leaf weight (SLW, leaf dry weight/leaf area), plant dry weight, and root-shoot ratio frequently decrease in shade compared to plants in higher light intensities (Boardman, 1977; McCarthy and Dawson, 1991; Royer, 2001; Valladares and Niinemets, 2008). Poorter and Nagel (2000) reported that high light intensity caused a decreased fraction of biomass allocated to leaves and an increased allocation to roots. However in many instances, biomass allocation to leaves is not particularly sensitive to growth irradiance and is an unimportant factor with respect to the change in plant growth rate.

Fini et al. (2010b) studied response of three ornamental shrubs to shading. In this study, *Camellia* × *williamsii* W.W.Sm. ‘Debbie’ showed great adaptability to light conditions. *Photinia* × *fraseri* Dress 'Red Robin' reduced root biomass under shade but leaf gas exchange was not altered. *Viburnum tinus* L. 'Eve Price' had increased leaf and stem biomass resulting in greater net photosynthesis and water use efficiency under shaded conditions. In *V. tinus*, plant height and internode length were significantly reduced in full sun compared to those in 30% and 60% shade. Viburnum dry weight, leaf number, leaf area ratio and net assimilation rate were not affected by shading. Leaf area index and relative growth rate were higher in plants in 60% and 30% shade than for plants in full sun (Fini et al., 2010b). Reduced light intensities can produce enlarged stems as a result of the partitioning of photosynthates by the plant. Research has shown that most *Stenotaphrum secundatum* (Walt.) Kuntz cultivars will grow better under 30% shade than under full sun (Trenholm, 2009). In another study, shade treatment (0% shade, 60% and 30% shade) influenced shoot development, foliar physiology and morphological characteristics of *Abies amabilis* (Dougl.) Forbes and *Tsuga heterophylla* (Raf.) Sarg. seedlings but in general, the effects were small (Mitchell and Arnott, 1995). A shade intensity of 60% was required to induce significant acclimation, and *T. heterophylla* appeared to respond more positively than *A. amabilis*. In a turfgrass study with *Cynodon dactylon* L. Pers., phenotypically diverse clones responded to reduced light intensity with shorter leaves, shorter internodes, reduced green color, lower chlorophyll concentration, and reduced dry weights (Gaussoin et al., 1988). Increased shade commonly reduces root and rhizome growth proportionately more than shoot growth (Dudeck and Peacock, 1992). Shade may also decrease the number of leaves, tillers and rhizomes (Patterson, 1980).

In another study by Robinson and Hamilton (1980), heavy shade (37% of available sun) and full sun significantly decreased foliar nitrogen content of *V. opulus* ‘Nanum’. *Viburnum opulus* receiving 70% and 53% of available sunlight grew larger than plants in full sun or heavy shade. The maximum rate of photosynthesis and dry matter production related closely to leaf nitrogen status (Pallardy, 2008). Relatively more nitrogen was partitioned to light-harvesting machineries in shade leaves (Laisk et al., 2005). However Kull (2002) suggested that the strong relationship between leaf nitrogen and photosynthetic performance may be because a certain amount of energy must be captured through photosynthesis to maintain nitrogen within the leaf and not because nitrogen is primarily in the photosynthetic apparatus. According to Evans and Poorter (2001), daily photosynthesis per unit leaf dry mass under low-light conditions was much more responsive to changes in specific leaf area than to nitrogen partitioning. Plants grown in high light generally have thick leaves with a low SLA, due in part to extra layers of palisade or longer palisade cells. This increases the number of chloroplasts and the amount of photosynthetic enzymes and thereby enhances the photosynthetic capacity per unit leaf area. However, by having more biomass in a given area, the increase in photosynthetic capacity of the high-light leaves comes at a cost of having less light capture per unit biomass at lower irradiances. Consequently, growth is stimulated by high light only half as much as photosynthesis per unit area (Poorter and Nagel, 2000). Photosynthetic response curves over a range of light intensities have been widely used to show differences in shade and sun grown plants to light intensities. Shade tolerant species generally have lower dark respiration rates and hence lower light compensation points and lower light saturation points for photosynthesis than do shade intolerant species. The leaves of shade-tolerant species also usually contain lower levels of Rubisco, ATP synthase, and electron carrier per unit of leaf surface (Pallardy, 2008).

At light intensities above the saturation point, carbon metabolism may limit consumption of photosynthetic energy resulting in excess photon absorption, consequently promoting reductions in photosynthetic efficiency, termed as photoinhibition (Demmig-Adams, 1990). High solar radiation during the summer results in excessive light and heat load on leaves. Naresh and Bai (2009) reported that in *Cocos nucifera* L., excess light energy harvested by chlorophyll antenna produced biologically toxic superoxide, hydrogen peroxide and hydroxyl radicals, that damaged the chloroplast and cell membrane integrity and caused leaf scorching resulting in reduced photochemically active leaf area and under prolonged conditions in seedling death. Leaf necrosis is a physiological disorder of frequent occurrence in many kinds of plants grown in warm or semi-arid climates. Huxley (1967) found that in full daylight the leaf margins of both *Coffee arabica* and *C. canephora* Pierre ex Froehner seedlings became yellow and on *C. canephora* leaves some interveinal chlorosis developed. Shade also increased leaf chlorophyll concentrations to improve quantum use efficiency for incident irradiance (Niinemets et al, 1998; Valladares and Niinemets, 2008). Grass growing in shade has less heat and drought stress and maintains a darker green color than that growing in full sunlight (Trenholm, 2009). Tong and Ng (2008) studied the effect of 4, 7, 25, 50 and 100% relative light intensities (RLI) on growth, leaf production, leaf lifespan and leaf nutrient budgets of *Acacia mangium* Willd., *Cinnamomum iners* Reinw. ex Blume, *Dyera costulata* (Miq.) Hook., *Eusideroxylon zwageri* Teysm. and Binnend. and *Shorea roxburghii* G. Don. *Acacia mangium* and *S. roxburghii* grew fastest at 100% RLI. The other three species grew fastest at 25% RLI. Leaf lifespan was maximum at 4% RLI and was shortened by a constant amount by each doubling of light intensity. Senescence and leaf abscission occurred much earlier in shade leaves of *V. lantana* and *V. opulus*. Shade leaves showed a greater tendency to wilt during senescence (Kollmann and Grubb, 2002).

Light gradients are ubiquitous in nature, so all plants are exposed to some degree of shade during their lifetime. According to Belsky et al. (1989), solar irradiance is reduced by 45% to 65% under *Acacia tortilis* Hayne and *Adansonia digitata* L. Kessler (1992) found that sunlight intensity is reduced to 45% under 10 to 13 m high *Vitellaria paradoxa* C. F. Gaertn. and 20% under 14 m high *Parkia biglobosa* (Jacq.) R. Br. ex G. Don. *V. paradoxa* of 7 m height and 4.7 m crown diameter also decreased photosynthetically active radiation (PAR) directly under and outside crowns by 40% and 20% respectively (Boffa et al., 1999). Light intensity may decrease as much as 90% to 95% with extensive cloud or tree cover (Barrios et al., 1986).

An experiment was conducted to examine the light environment and effect on pasture yield components of two artificial shading materials. *Medicago sativa* L. pasture was submitted to three light regimes: full sunlight (100% transmissivity); black shade cloth (40%) and wooden slats (45%). The pattern of light exposure for plants differed under slats and shade cloth, but light intensity and quality were similar. *Medicago sativa* dry matter (DM) yield and leaf area index under shaded treatments were about 60% of the open pasture. Numbers of stems per m^2, number of nodes and plant height were also similar in both shaded treatments, but lower than in full sunlight. Plants under shade cloth and slats had a greater leaf to stem ratio, but leaf temperature was cooler under both shaded treatments than in full sunlight. The results indicated that both slats and shade cloth can simulate the light environment under agroforestry (Varella et al., 2001). Water use can be determined by several methods. Determining water loss from each pot gravimetrically on a regular basis (for example, daily) and replacing part of the transpired water to control the rate of soil dry-down is well synchronized between experimental units (Earl, 2003).

Based on these studies, producing ornamental plants that have lower water use and perform better or retain their visual qualities in shaded environments would benefit the ornamental industry. Viburnums have long been one of the most popular flowering shrubs. The genus Viburnum belongs to the Adoxaceae family. This large group of plants consists of more than 150 species and numerous named cultivars. Viburnums include deciduous and evergreen shrubs and small trees, mostly native to North America or to Asia (Kluepfel and Polomski, 2007). Some species of Viburnums are very 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 (Dirr, 2007). Viburnums fit in anywhere and look good in every season and in any style of garden. Viburnums are relatively low maintenance ornamental plants and can prosper quite well with restricted fertilization (Dirr, 2007). They are grown in full sun or shade (Dirr, 2007). Viburnum species vary in their soil moisture requirements. Many species thrive in moist soil but some species are drought tolerant (García-Navarro et al., 2004; Myers, 2004).

Characteristics of agricultural plants, such as number and distribution of stomata, leaf coatings, etc. can affect evapotranspiration for a given crop or species. The volume of soil occupied by plant roots and the number of roots within this volume can significantly influence effective soil resistance to water movement. These can affect water use of different plant types or different species within a plant type (Jensen, 1968). The degree of response to shade can vary considerably within a family, within a genus, and even within a species. The plasticity of leaf structure in response to shading may vary considerably among closely related species or cultivars. According to Kollmann and Grubb (2002), *V. opulus* yielded more in 11% light intensity than in 66%; its mature lamina size was also largest in the 11% light intensity, whereas *V. lantana* had its largest leaves in 66% light intensity. In the same study, shading reduced the root mass fraction and increased the leaf mass fraction of *V. opulus* but not *V. lantana.* Shading caused a greater increase in the SLA of *V. opulus* than in that of *V. lantana*. *Quercus velutina* Lam., the most drought-tolerant and light-demanding species, showed the greatest leaf anatomical plasticity in different light environments. The most drought-intolerant species, *Q. rubra* L., showed least anatomical plasticity, and *Q. coccinea* Muenchh. showed plasticity that were intermediate between that of *Q. velutina* and *Q. rubra* (Pallardy, 2008). Anatomical response to light also differed between two Phaseolus cultivars (Chabot and Chabot, 1977).

To date, little information is available on water use and growth response of different viburnum species under different shade intensities. The ornamental industry needs research-based information to manage water resources and improve plant quality and profitability. The species tested in this research were Burkwood viburnum *(Viburnum × burkwoodii* Burkw. & Skipw. Ex Anon.), Korean spice Viburnum/ Mayflower viburnum (*Viburnum carlesii* Hemsl.) and leatherleaf viburnum (*Viburnum rhytidophyllum* Hemsl.). Burkwood viburnums are grown by 52% of the US nurseries growing Viburnums (Chapter 2). The parentage, *V. utile* × *V. carlesii*, and subsequent backcrosses and other genetic combinations have produced Burkwood viburnum. Burkwood viburnums reach 2.5 to 3 m (8 to 10 ft) tall and wide. They have lustrous black-green leaves that are grayish and tomentose below, ranging from 4 to 10 cm (1.5 to 4 in) long, 2 to 4.5 cm (0.75 to 1.75 in) wide and are serrated. Leaves may be fully deciduous to evergreen. Burkwood viburnums are adaptable to full sun or prominent shade (Dirr, 2007). Koreanspice viburnums are grown by 58% of the US nurseries growing Viburnums (Chapter 2). They are typically rounded in outline, dense in foliage, deciduous shrubs (Kluepfel and Polomski, 2007), 1.2 to 2.5 m (4 to 8 ft) tall and wide. Leaves are dull dark green, 2.5 to 10 cm (1 to 4 in) long and 2 to 6 cm (0.75 to 2.5 in) wide. This species is well adapted to soil extremes (except wet), sun and significant shade (Dirr, 2007). Leatherleaf viburnums are grown in 41% of the US nurseries growing Viburnums (Chapter 2). They are boldly textured, evergreen shrubs with large, leathery, 10 to 20 cm (4 to 8 in) long, 2.5 to 6 cm (1 to 2.5 in) wide leaves that are lustrous above and covered with gray pubescence below. They are gigantic in proportions and are easily 3 to 4.5 m (10 to 15 ft) tall and wide. Any well-drained soil, sun or shade provides best success (Dirr, 2007).

These viburnums are grown in the ground as well as in containers but most nurseries in the United States grow viburnums in containers more than in the field. Leatherleaf viburnums are considered high water users; Burkwood viburnums medium water users and Korean spice viburnums are regarded low water users (Mark Andrews, Greenleaf Nursery, Personal Communication). These classifications are based on field observations of the nursery personnal. However, no data on water use of these viburnums has been found.

The objectives of this research were to identify the cultural practices used by commercial nursery growers for the production of viburnums, to determine water use of leatherleaf viburnum and Burkwood viburnum under three shade intensities, and to determine growth and degree of leaf necrosis of the leatherleaf viburnum, Burkwood viburnum and Koreanspice viburnum species under three shade intensities

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CHAPTER II

SURVEY OF CULTURAL PRACTICES USED IN PRODUCTION OF VIBURNUMS

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Abstract

A survey of commercial nursery growers was conducted to identify cultural practices used in viburnum production. Viburnums composed less than 25% of the production inventory for most nurseries surveyed. Nurseries reported that viburnums are mostly spring planted and produced in containers in bark-based container substrates. They are mostly irrigated once a day during dry months with sprinklers using water from wells and ponds. Altering some production practices may increase plant growth and quality and improve irrigation efficiency.

Index words: viburnum, nursery production, irrigation.

Species used in this study: Korean spice viburnum (*Viburnum carlesii* Hemsl.); arrowwood viburnum (*V. dentatum* L.); Mohican viburnum (*V. lantana* L. 'Mohican'); winterthur smooth viburnum (*Viburnum nudum* L. 'Winterthur'); fragrant viburnum (*Viburnum* × *juddii* Rehd.); leatherleaf viburnum (*Viburnum rhytidophyllum* Hemsl.); Burkwood viburnum (*Viburnum* × *burkwoodii* Burkw. and Skipw. Ex Anon.); spring bouquet viburnum (*Viburnum tinus* L. 'Compactum'); eastern snowball (*Viburnum opulus* L.); pink dawn viburnum (*Viburnum* × *bodnantense* Stearn.); cardinal candy viburnum (*Viburnum dilatatum* Thunb.); summer snowflake doublefile viburnum **(***Viburnum plicatum* f. *tomentosum* (Thunb.*)* Rehd.); C. A. Hildebrant’s viburnum (*Viburnum wrightii* Miq.); southern blackhaw viburnum (*Viburnum rufidulum* Raf.).

Significance to the Nursery industry

Viburnums are popular garden or landscape plants that are considered relatively adaptable and low-maintenance plants compared to most woody plants. The nursery industry has many production options available including use of various container sizes, substrates, or irrigation methods. The cultural practices used for viburnum production may influence nursery production efficiency and plant growth and quality of viburnums. Survey results about growers' cultural practices provide useful information about the most and least frequently used practices. Nursery producers should consider fall potting in addition to the traditional spring potting. Viburnum producers should incorporate inorganic components like clay, sand and biological amendments like sphagnum peat, coir or municipal compost in the container substrate. They should consider alternative irrigation sources like recycled or reclaimed water and other efficient irrigation methods like capillary mats or multi-pot box system and use of cyclic irrigation that could improve water and nutrient management of viburnums and other ornamental crops. These changes in crop management practices may help increase production and quality from existing plantings while minimizing input cost and reducing environmental impact.

Introduction

Viburnum is a genus of more than 150 species of shrubs or (in a few species) small trees. The genus belongs to the Adoxaceae family. Its current classification is based on molecular phylogeny. It was previously included in the family Caprifoliaceae. Viburnum is found primarily in the northern hemisphere and extends into the southern hemisphere in the mountains of Southeast Asia and South America. The region of greatest diversity is in eastern Asia but eastern North America and the mountains of

Mexico and Central and South America are also areas of high species diversity. Only five species are native to Europe and adjacent regions. In Africa, viburnum is confined to the Atlas Mountains (Dirr, 2007; Pooler, 2010; Winkworth and Donoghue, 2005). The leaves of viburnum species are opposite or rarely whorled and the fruit is a drupe. Viburnum species show conspicuous diversity in numerous other characters, including growth pattern and leaf and fruit morphology (Dirr 2007; Donoghue, 1983; Winkworth and Donoghue, 2005). Viburnums are usually shrubs, but their growth habits vary. Some dwarf varieties are less than 1 m (3.3 ft) tall while others may grow up to 6 m (19.7 ft) tall. Some species are densely hairy on the shoots and leaves while other species are glabrous. Some viburnum species are very 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 (Dirr, 2007). Viburnums consist of evergreen, semi-evergreen, and deciduous species.

Viburnums are versatile shrubs that are popular in landscapes for their showy and often fragrant spring blooms, richly colored sometimes evergreen foliage, and persistent winter fruit. Viburnums are grown as specimen plants or as anchors in mixed borders. Some species are grown for hedges or for massing in groups. *Viburnum trilobum* Marshall provides lacey clusters of white flowers in spring, persistent bright red fruits, and orange, red and burgundy fall color. Some species have blooms similar to the flattened heads of *Hydrangea macrophylla* (Thunb.) Ser. *Viburnum rhytidophyllum* Hemsl. is popular for its foliage effect of large, dark green, leathery leaves with a strongly wrinkled surface. Some viburnums like *V. carlesii* Hemsl. and *V.* × *burkwoodii* Burkw. and Skipw. Ex Anon. have extremely fragrant flowers. Viburnums have attractive fruits and among the best fruiting viburnums is *V. dilatatum* Thunb. A few viburnums such as *V. plicatum* f. tomentosum (Thunb.) Rehd. and *V. carlesii* Hemsl. can be grown as standards (which can create height in the back of a border or in pots on each side of a terrace entrance, when under planted with annuals). In the U.S., viburnum species are commercially cultivated for their inflorescences, which are mainly used as bouquet fillers (Armitage and Laushman, 2003). Darras et al. (2010) evaluated the post-harvest performance of cut *V. tinus* L. inflorescences. *Viburnum tinus* has white, lightly scented flowers produced in dense cymes 5 to 10 cm (2 to 4 inches) in diameter. Some viburnum species have medicinal values also. A compound, 9'-O-methylvibsanol and its related compounds extracted from stem bark of *V. sargentii* Koehne has potential therapeutic application to cancer therapy (Bae et al., 2010). Kim et al. (2005) reported that the fruit of *V. dilatatum* has phenolic compounds, especially cyanidin 3-sambubioside and chlorogenic acids that may contribute to the antiradical activity of its fruits. Fruits of different genotypes of *V. opulus* L. contained large amounts of total phenolics, ascorbic acid, and reducing sugars. The presence of these large amounts of biologically active compounds enables their use as potent antioxidants (Cesoniene et al., 2010).

Viburnums are remarkably adaptable plants compared to most woody shrubs and are valued as tough and trouble-free flowering shrubs. They have few debilitating pests and diseases. They are grown in full sun or shade (Dirr, 2007). Viburnum species vary in soil moisture requirements. Many species thrive in moist soil while some are drought tolerant (García-Navarro et al., 2004; Myers, 2004).

Viburnums are produced in many nurseries throughout the United States. Over three million viburnums are sold annually in the United States with a wholesale value of over $22 million (Pooler, 2010). Nursery crop production requires a large amount of manual labor and careful management. An individual nursery may grow just a few to a few hundred types of plants. Each type of plant must be managed based on its cultural requirements (Adkins, C., 2010).

The nursery industry has many more production options available today than several years ago. Different production practices adopted by nurseries may influence nursery productivity and input efficiency. Irrigation is one of the most critical cultural practices in production of nursery crops. Existing irrigation water is rapidly diminishing due to population growth, rapid industrialization and urban development. Water stress is one the most influential factors affecting plant production. Plants have evolved to tolerate extremes in water availability to account for nature's inconsistent schedule of irrigation. However, the goal of the nursery producer is to produce quality plants and get maximum profit by efficient and effective use of resources while reducing impacts on the environment. *Photinia* × *fraseri* Dress ‘Red Robin’ and *V. tinus* 'Lucidum' were assessed for their adaptability to drought stress conditions. Net photosynthesis, transpiration, stomatal conductance, water use efficiency, chlorophyll a fluorescence and biometric parameters were periodically monitored during the experiment. Photinia adapted better to drought, especially when irrigation frequency was reduced. In contrast, viburnum was less adaptable and less stressed treatments resulted in more developed plants compared to plants exposed to greater stress (Cacini et al., 2010). Beikircher and Mayr (2009) reported that *Ligustrum vulgare* L. and *V. lantana* were less resistant to drought-induced embolism. *Viburnum lantana* was less drought tolerant than *L. vulgare,* but at the same time it was able to acclimate to altered soil moisture conditions within a broader range.

Various studies have reported the effect of different container substrates on plant growth and water savings. According to Guérin et al. (2001) a strong relationship existed between height growth of viburnum and physical parameters of the substrate. The tallest plants occured in substrates with the greatest water content and availability. A study by Arnold and McDonald (2006) showed that shoot growth of *Rosa* × ‘*Radrazz*’ L. was better in bark based substrate (4 parts pine bark : 1 peat moss : 1 sand) than in peat-based substrate (Sungro SB 400). Research conducted on *Acer rubrum* L. using substrate containing combinations of pine bark : peat and pine bark : coir or 100% pine bark resulted in a 17% and 12% increase in height in the pine bark : peat compared to the pine bark : coir and 100% pine bark, respectively. The peat or coir increased available water and possibly increased nutrient holding capacity to generate more growth in the species tested (Dunwell and McNiel, 2011). Many studies have investigated the use of numerous industrial and agricultural wastes such as animal wastes (Tyler et al., 1993), wood by-products (Chong and Lumis, 2000), rice hulls (Dueitt et al., 1993), and residential refuse (Kahtz and Gawel, 2004) as substitutes for bark and peat moss. Photosynthetic rate increased (*Phaseolus vulgaris* L.), decreased (*Nicotiana tabacum* L.), or did not differ (*Glycine max* (L.) Merr.) with decreasing pot size (Ray and Sinclair, 1998). Root and shoot dry weights and percentage of applied nitrogen used by shoots and roots of *Ligustrum japonicum* Thunb. were greatest for plants grown in 2.2 liter containers and smallest for plants grown in 0.75 liter containers (Yeager, 1995).

In a study by Bilderback and Lorscheider (1997), at low irrigation volumes or under conditions of irrigation conservation, use of a wetting agent in the substrate enhanced plant growth. Cyclic irrigation (changing the volume of water applied and the frequency of application) can also increase available water and reduce runoff and resulting fertilizer loss from the nursery with equal or increased growth (Dunwell and McNiel, 2011). Longer stems and greater plant fresh weight with more flowers and longer life span occurred in *Chrysanthemum indicum* L. irrigated four times per week compared to those irrigated twice per week (Budiarto et al., 2007). Drip ring treatments produced larger growth indices in *Lagerstroemia indica* (L.) Pers. (Witcher and Bush, 2005). Water quality can vary from source to source (Whipker, 2008). Water quality not only affects plant growth, but also influences fertilizer, pesticide, and growth regulator effectiveness (Adkins, 2010).

The average seed germination period of *V. lantana* was prolonged by the application of gibberellic acid; GA_3 (Rypak and Kamenicka, 1982). Seeds of *V. lantana* and *V. opulus* have the same morphological and anatomical structure and biochemical composition but seedlings of *V. lantana* emerged during the following season from either autumn or spring sowing, whereas seedlings of *V. opulus* emerged only a year later (Zaborovskij and Varasova, 1961).

It is important to optimize nursery cultural practices for increased production efficiency of the nursery. Therefore, the objective of this research was to identify cultural practices used in commercial production of viburnum species.

Materials and Methods

A list of production nurseries was obtained from the American Nursery and Landscape Association. Based on the name and information from websites, nurseries that obviously did not grow viburnums were eliminated from the list, leaving a mailing list of

459 nurseries. On January 14, 2009 the survey was mailed to each nursery along with a letter describing the project and a postage-paid envelope in which to return the completed survey. About 6 weeks after the first mailing, follow-up letters and surveys were mailed to nurseries that had not responded. The data were analyzed using SAS (PC SAS version 9; SAS Institute, Cary, NC). Relationships among the responses to various questions were assessed by constructing two-way contingency tables using PROC FREQ in SAS.

Results

Of 459 surveys mailed, 205 (44.7%) were completed and returned. Of those 205 surveys returned, 169 (82.4%) respondents indicated that they grow viburnums. Only surveys from nurseries that grow viburnums were included in data analyses. Viburnums were grown in nurseries in most regions of the United States with the smallest proportion of nurseries located in the southern United States (Fig 2.1). Most of the nurseries growing viburnums were located in USDA cold hardiness zones 4 to 8 (94.17%), with zones 5 and 6 having the greatest percentage of growers at 27.6% and 25.7%, respectively (Table 2.1). Viburnums composed less than 25% of the production inventory for about 99% of nurseries surveyed. Among the viburnum species listed in the survey, more than half of nurseries grew Korean spice viburnum, arrowwood viburnum, Mohican viburnum, fragrant viburnum, or Burkwood viburnum (Table 2.2). Spring was the most common planting time for all viburnum species included in the survey (Table 2.3), followed by fall. Summer and winter were the least common times to plant, likely due to hot and cold temperatures, respectively, that lead to slower rooting and growth. Nurseries were asked about the production system in which they grew viburnums. More nurseries grew most viburnum species in above-ground containers than in-ground with or without containers or any other system (Table 2.4). More nurseries grew their field-grown viburnums in sandy loam soil than in any other soil type (Table 2.5). Container-grown viburnums were mostly grown in bark-based substrate with 40% of nurseries using 100% bark (composted or milled pine bark, hardwood bark, or fir bark), among which 60% of nurseries used 100% composted pine bark. Most nurseries (57.3%) use composted pine bark as one of the container substrate components (Table 2.6). Other components that growers listed as being included in container substrates were Douglas fir bark, leaf compost, sawdust, rice hulls, soil, clay, pumice, and perlite. More nurseries used #3 or #5 (ANLA, 2004) pots than smaller or larger pots for growing viburnums (Table 2.7). Growers also reported using #SP4, #2, #3.5, #4, and #7 containers. Most viburnums were propagated vegetatively rather than by seed (Table 2.8).

More nurseries irrigated using water from a well (58.8%) or pond (44.9%) than from other water sources (Table 2.9). Most nurseries (85.1%) used sprinkler irrigation for irrigating viburnums (Table 2.10). About 72% of nurseries said that the irrigation frequency differs for different viburnum species; however, once a day was the most common irrigation frequency for viburnums during the dry months of the year (Table 2.11). During wet months, most viburnums were irrigated as needed, with no regular schedule (Table 2.12). About 96% of the nurseries did not use wetting agents or hydrogels in the potting substrate for viburnums. About 50% of the nurseries reported that they had observed water stress problems during viburnum production (Table 2.13). More nurseries experienced slow growth of plants due to water stress than stem dieback, susceptibility to diseases, lower yield, or loss of sale.

Viburnums had medium market demand according to about 66% of nurseries and low market demand according to 25% of nurseries. About 33% of nurseries reported that the market demand of viburnums differed among species. More nurseries responded that Korean spice viburnum and fragrant viburnum had higher market demand than the other viburnum species (Table 2.14). More than half of nurseries reported that arrowwood, Mohican, winterthur smooth, Burkwood, spring bouquet, cardinal candy, and summer snowflake doublefile viburnum had a medium market demand.

About 78% of the nurseries reported annual production costs of more than $100,000 (Table 2.15). About 96% of the nurseries reported that their irrigation cost was less than 25% of their production cost. About 90% of the nurseries had more than $100,000 in annual gross sales from their nursery in 2008, or the most recently completed fiscal year (Table 2.16). About 99% of the nurseries reported that viburnums contributed less than 25% percent of their gross sales.

Discussion

Based on the survey results, it appears that nurseries can improve some cultural practices used in viburnum production to increase plant growth and quality and improve irrigation efficiency. Spring was reported as the most common planting time for all viburnum species included in the survey. A study by Ivy et al. (2002) showed that growers can incorporate more fall potting in place of traditional spring potting. Soil temperature and moisture are favorable for rapid root growth which will help plants survive during the first year of transplanting in the landscape (Bevington and Castle, 1985). With fall planting and subsequent root establishment, plants are bigger in the spring and often can withstand dryer conditions during the summer. As size of the landscape industry increases, adoption of fall planting helps nursery growers to produce a quality plant and meet industry demand throughout the year. Ivy et al. (2002) reported that rooted stem cuttings of *V. awabuki* K. Koch., potted in September or October, were larger and had significantly greater N and P content than those potted in March. Viburnum potted in September produced the largest total dry weight compared to those potted in July, October, March or May when fertilized with Wilbro/Polyon 15N–1.8P–7.5K (15N–4P_2O_5–9K_2O), whereas plants potted in March were the smallest. Viburnum potted in July, September, and October and grown with Scotts 23N–1.8P–6.6K (23N–4P_2O_5–8K_2O) outperformed those potted in March or May. No plants were injured by winter temperatures regardless of potting date throughout the study period.

Viburnums are mostly container-grown which requires larger volumes of water than in-ground production without root restriction. Most nurseries irrigate viburnums using water from wells and ponds. In various parts of the U.S., ground water storage and surface water levels are declining and water shortages are becoming an increasing problem due to intensified competition by agriculture, industrial or domestic users (Jury and Vaux, 2005; McGuire, 2007; Smith, 2007). Groundwater is also being contaminated by saltwater intrusion as a result of removing groundwater faster than it is being recharged (Barlow, 2005) or infiltration of contaminants from nearby industrial, urban, and agricultural operations. In addition, environmental agencies are claiming more surface water to protect endangered flora and fauna along waterways. Excessive irrigation also has a direct impact on production costs. Growers using well water incur energy costs associated with pumping water and growers using surface water sources have to pay for the water.

Our survey results showed that about 40% of nurseries used 100% bark for container grown viburnums. Total porosity and air space are highest in the 100% bark substrate. However, previous research has shown that plant available water and shoot growth can be increased by adding sand or peat compared to 100% pine bark (Dunwell and McNiel, 2011; Kraus and Warren, 2005). In a study by Caron et al. (2004), amount of irrigation water needed to achieve marketable size in *V. odoratissimum* Ker Gawl was reduced by changing peat type from sedge to sphagnum and increasing the percentage of sphagnum peat to 60% on a volume basis, due to reduction in production time. Haydu et al. (2004) revealed that changing peat type from sedge to sphagnum can be profitable in the long run. Evans and Iles (1997) reported that *V. dentatum* L. grown in coir-based substrates were taller, wider and had greater root fresh mass than plants grown in peat-based substrates.

In this survey, only one nursery reported using clay as a component of the container substrate. Several studies have shown that clay can be an alternative to sand in container substrate to increase container capacity, available water, and substrate nutrient retention (Catanzaro and Bhatti, 2005; Owen et al., 2003; Owen et al., 2004; Owen et al., 2008). In addition, pine bark amended with calcined clay has been shown to decrease phosphorus leaching (Ruter, 2003). Currently, the U.S. Environmental Protection Agency has set goals for P not to exceed 0.10 mg P L^{-1} (0.1 ppm) in streams that do not drain into lakes or reservoirs (Sparks, 1993). Excess of these limits may result in a decline in water quality (Brady and Weil, 1999). Clay-amended pine bark can maintain plant growth with half the currently recommended leaching fraction and phosphorus application rate compared to sand-amended pine bark (Owen et al., 2005).

Few nurseries used municipal waste in container substrate. Composted municipal waste can reduce water useage in open irrigation systems (Catanzaro and Bhatti, 2005). Plants grown with 25% municipal solid waste compost had similar or better growth than plants in 100% pine bark for a wide range of container nursery crops (Lu et al., 2005). Kiermeier (1977) found that *V. lantana* grew more quickly with higher application rates of composted municipal waste. Viburnum produced in substrates with yard compost or raw coir or forest compost/cattle manure were similar in size to those produced in 1:1 peat:pine bark compost and were taller than those produced in mixtures of expanded perlite/composted manure or forest compost and composted bark (Guérin et al., 2001).

Composted pine bark was the primary component of growth substrates in most (57.3%) nurseries. However, the future availability of bark for horticultural usage might be limited due to alternative demands (e.g. industrial fuel) and reduced timber production (Cole et al., 2002; Haynes, 2003) and increased importation of logs already debarked (Lu et al., 2006). Whole chipped pine logs (“clean chips”) could be used as a suitable and economical alternative to conventional substrates (Wright and Browder, 2005).

Viburnums are reported to be mostly grown in #3 or #5 containers. Growing plants under different conditions could induce a series of differential characteristics that affect their adaptation to water shortage when transplanted into the landscape. Narciso Pastor et al. (1999) reported that *V. tinus* L. grown in #2 (8.83 L) containers with coarse pine bark had better development than that grown in 2.17 L containers and fine grade pine bark when they were transplanted in the landscape with limited water.

Irrigation efficiency also depends on irrigation method. Viburnums are mostly irrigated by sprinklers. Haydu et al. (2004) reported that overhead irrigation required the most water, followed by micro-irrigation, capillary mat and then trays for production of container-grown *V. odoratissimum*. Installation costs were lowest for overhead and greatest for the tray system followed by micro-irrigation, then capillary mat. Cumulative year profits were greatest with capillary mats, then trays, and overhead. Due to the substantial initial investment, profits were lowest for micro-irrigation. With overhead sprinklers, as little as 25% of the water applied enters containers. When plant spacing is considered a high proportion of water applied by sprinklers falls between containers (Beeson and Yeager, 2003; Haman et al., 1998), and thus is unavailable to the plants. Irmak et al. (2003) reported that the multi-pot box system (a modification of subirrigation that combines overhead and subirrigation concepts to capture the water falling between containers, making it available when needed by the plants) saved at least 92% and 76% of irrigation water relative to the conventional system (consisting of black containers spaced on 30 cm centers) in *V. odoratissimum* in the summer and fall, respectively. Growth indices and shoot and root dry weights were usually higher regardless of season for plants grown in the multi-pot box system.

Runoff water is an important avenue for the movement of agrichemicals from production sites into nearby receiving water bodies (Bjorneberg et al., 2002; Latimer et al., 1996; Meisinger and Delgado, 2002). However, if properly managed surface runoff can be reused in nursery production (Skimina, 1986). This process can save money and also provides an alternative irrigation source. Very few nurseries (13.2%) used recycled water. *Viburnum tinus* ‘French White’ irrigated with reclaimed wastewater (treated sewage effluent from the wastewater treatment facility) had better plant growth than those irrigated with well water. Reclaimed water increased leaf area, chlorophyll content, and leaf concentration of N, P and K (Gori et al., 2000). Reuse of treated municipal wastewater, especially when it is low in heavy metals, is beneficial since more water is available for irrigation in areas where scarce summer rainfall and high evapotranspiration can be problematic. Only 4.4% nurseries reported irrigating viburnums using municipal water.

About 72% of nurseries said that irrigation frequency differs for different viburnum species. However, most viburnum species were reported to be irrigated mostly once a day during dry months. Irrigating plants based on their actual water use is important to improve irrigation efficiency. According to Kollmann and Grubb (2002), in the natural habitat, there was extensive die-back of shoots of *V. opulus* which wilted early and severely in the dry summer of 1989, whereas shoots of *V. lantana* showed little damage. *Viburnum lantana* is most abundant on freely draining soils while *V. opulus* occurs typically on soils that are usually wet for at least part of the year, and its distribution extends to soils that are waterlogged through most of the profile all year. Viburnum species likely differ in their water requirement and drought tolerance. Appropriate selection of viburnum species that require less irrigation water and are more drought tolerant is important in dry arid regions due to limited water availability. Cyclic irrigation has been shown to increase nutrient and water use efficiency without sacrificing plant growth (Witcher and Bush, 2005).

In conclusion, using more sustainable production techniques that improve irrigation efficiency will reduce production costs, conserve water, and produce higher quality crops. Nursery producers should consider planting time; selection of components of container substrates, use of inorganic and biological amendments in the substrate; alternative irrigation sources; cost and water efficient irrigation methods; irrigation frequency and use of cyclic irrigation that could improve water and nutrient management of viburnums and other ornamental crops.

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Table 2.1. Distribution of U.S. nurseries growing viburnums based on USDA cold hardiness zone.

Hardiness Zone	Percentage of nurseries
2	0.7
3	1.3
4	10.5
5	27.6
6	25.7
7	18.4
8	11.8
9	3.3
10	0.7

Table 2.2. Percentage of U.S. nurseries growing different viburnum species.

	Percentage of nurseries	
Viburnum species	Growing	Not growing
Korean spice viburnum	58.0	42.0
Arrowwood viburnum	61.5	38.5
Mohican viburnum	52.7	47.3
Winterthur smooth viburnum	33.1	66.9
Fragrant viburnum	54.4	45.6
Leatherleaf viburnum	40.8	59.2
Burkwood viburnum	52.1	47.9
Spring bouquet viburnum	18.9	81.1
Eastern Snowball	49.7	50.3
Pink dawn viburnum	10.7	89.3
Cardinal candy viburnum	23.1	76.9
Summer snowflake doublefile viburnum	47.3	52.7
C. A. Hildebrant’s viburnum	3.6	96.4
Southern blackhaw viburnum	8.3	91.7

Table 2.3. Percentage of nurseries that plant various viburnum species in summer, fall, spring, or winter.

		Percentage of nurseries	
Viburnum species	Planting season	Growing	Not growing
Korean spice viburnum	Summer	20.6	79.4
	Fall	22.7	77.3
	Spring	85.6	14.4
	Winter	2.1	97.9
Arrowwood viburnum	Summer	16.5	83.5
	Fall	25.2	74.8
	Spring	80.6	19.4
	Winter	3.9	96.1
Mohican viburnum	Summer	14.9	85.1
	Fall	21.8	78.2
	Spring	89.7	10.3
	Winter	2.3	97.7
Winterthur smooth viburnum	Summer	8.9	91.1
	Fall	16.1	83.9
	Spring	80.4	19.6
	Winter	5.4	94.6
Fragrant viburnum	Summer	18.5	81.5
	Fall	21.7	78.3
	Spring	87.0	13.0
	Winter	2.2	97.8
Leatherleaf viburnum	Summer	13.2	86.8
	Fall	25.0	75.0
	Spring	82.4	17.7
	Winter	4.4	95.6
Burkwood viburnum	Summer	15.1	84.9
	Fall	16.3	83.7
	Spring	88.4	11.6
	Winter	1.2	98.8
Eastern Snowball	Summer	16.9	83.1
	Fall	30.1	69.9

	Spring	77.1	22.9
	Winter	7.2	92.8
Cardinal candy viburnum	Summer	7.7	92.3
	Fall	15.4	84.6
	Spring	84.6	15.4
	Winter	7.7	92.3
Summer snowflake doublefile viburnum	Summer	15.0	85.0
	Fall	15.0	85.0
	Spring	85.0	15.0
	Winter	10.0	90.0

Table 2.4. Percentage of nurseries reporting growing various viburnum species in the field with no root restriction, above ground in containers, in-ground in containers, or in other production systems.

		Percentage of nurseries	
Viburnum species	Root conditions	Growing	Not growing
Korean spice viburnum	field	45.4	54.6
	above ground	74.2	25.8
	in-ground	6.2	93.8
	other	1.0	99.0
Arrowwood viburnum	field	49.0	51.0
	above ground	74.5	25.5
	in-ground	7.8	92.2
	other	2.0	98.0
Mohican viburnum	field	43.7	56.3
	above ground	72.4	27.6
	in-ground	9.2	90.8
	other	_	100.0
Winterthur smooth viburnum	field	30.4	69.6
	above ground	69.6	30.4
	in-ground	7.1	92.9
	other	_	100.0
Fragrant viburnum	field	43.8	56.2
	above ground	69.7	30.3
	in-ground	10.1	89.9
	other	1.1	98.9
Leatherleaf viburnum	field	44.1	55.9
	above ground	69.1	30.9
	in-ground	8.8	91.2
	other		100.0
Burkwood viburnum	field	34.5	65.5
	above ground	73.6	26.4
	in-ground	8.1	92.0
	other	1.2	98.9

Eastern Snowball	field	30.5	69.5
	above ground	75.6	24.4
	in-ground	7.3	92.7
	other	_	100.0
Cardinal candy viburnum	field	33.3	66.7
	above ground	64.1	35.9
	in-ground	5.1	94.9
	other	_	100.0
Summer snowflake doublefile viburnum	field	30.8	69.2
	above ground	75.6	24.4
	in-ground	10.3	89.7
	other	_	100.0

Table 2.5. Types of soil used in field production of viburnums.

Types of Soil	Percentage of nurseries
Sand	_
Loam	4.5
Sandy loam	42.4
Clay loam	25.8
Silt	_
Clay	16.7
Silt loam	9.1
Others	1.5

Table 2.6. Container substrate components used for the production of viburnums.

	Percentage of nurseries	
Container substrate component	Using	Not using
Peat moss	35.5	64.5
Composted hardwood bark	15.3	84.7
Milled hardwood bark	4.0	96.0
Sand	25.8	74.2
Composted pine bark	57.3	42.7
Milled pine bark	20.2	79.8
Municipal compost	6.5	93.6
Other	29.8	70.2

Table 2.7. Container sizes used for nursery production of viburnums.

	Percentage of nurseries	
Container size	Using	Not using
#1	37.3	62.7
#3	62.7	37.3
#5	59.3	40.7
Larger than #5	33.9	66.1
Other	6.8	93.2

Table 2.8. Propagation methods used by nurseries for different viburnum species.

	Percentage of nurseries	
Viburnum species	Seed propagation	Vegetative propagation
Korean spice viburnum	5.6	94.4
Arrowwood viburnum	4.5	95.5
Mohican viburnum	_	100.0
Winterthur smooth viburnum	2.6	97.4
Fragrant viburnum	_	100.0
Leatherleaf viburnum	_	100.0
Burkwood viburnum	3.4	96.6
Eastern Snowball	_	100.0
Cardinal candy viburnum	_	100.0
Summer snowflake doublefile viburnum	1.8	98.2

Table 2.9. Source of irrigation water used by nurseries to irrigate viburnums.

Sources of irrigation water	Percentage of nurseries Using	Percentage of nurseries Not using
River/lake	10.3	89.7
Pond	44.9	55.2
Well	58.8	41.2
Municipal water	4.4	95.6
Rural water	2.9	97.1
Recycled water	13.2	86.8

Table 2.10. Irrigation methods used for viburnum production.

	Percentage of nurseries	
Irrigation method	Using	Not using
Drip Irrigation	25.4	74.6
Capillary Irrigation	1.5	98.5
Sprinkler Irrigation	85.1	14.9
Other	3.0	97.0

Table 2.11. Irrigation frequency for different species of viburnum during nursery production in dry periods.

	Percentage of nurseries					
Viburnum species	More than once a day	Once a day	Every other day	Twice a week	Once a week	Other
Korean spice viburnum	12.4	35.8	13.6	16.1	13.6	8.6
Arrowwood viburnum	19.3	47.7	9.1	4.6	11.4	8.0
Mohican viburnum	14.5	47.4	6.6	6.6	15.8	9.2
Winterthur smooth viburnum	16.0	48.0	8.0	10.0	8.0	10.0
Fragrant viburnum	13.0	36.4	14.3	14.3	15.6	6.5
Leatherleaf viburnum	6.8	44.1	17.0	8.5	15.3	8.5
Burkwood viburnum	11.1	41.7	9.7	15.3	13.9	8.3
Eastern Snowball	12.0	50.7	13.3	8.0	9.3	6.7
Cardinal candy viburnum	8.6	40.0	17.1	11.4	14.3	8.6
Summer snowflake doublefile viburnum	17.8	43.8	13.7	9.6	11.0	4.1

Table 2.12. Irrigation frequency for different species of viburnum during nursery production in wet periods.

	Percentage of nurseries					
Viburnum species	More than once a day	Once a day	Every other day	Twice a week	Once a week	Other
Korean spice viburnum	2.4	2.4	11.8	18.8	15.3	49.4
Arrowwood viburnum	3.4	6.8	21.6	13.6	11.4	43.2
Mohican viburnum	2.5	6.4	19.3	18.0	9.0	44.9
Winterthur smooth viburnum	1.9	3.9	15.4	15.4	9.6	53.9
Fragrant viburnum	2.5	3.8	16.3	15.0	18.8	43.8
Leatherleaf viburnum	3.2	1.6	14.3	15.9	14.3	50.8
Burkwood viburnum	1.4	1.4	17.6	12.2	21.6	46.0
Eastern Snowball	3.9	3.9	16.7	19.2	15.4	41.0
Cardinal candy viburnum	_	5.6	16.7	11.1	11.1	55.6
Summer snowflake doublefile viburnum	4.2	1.4	18.1	16.7	13.9	45.8

Table 2.13. Water stress symptoms noted by growers during viburnum production.

	Percentage of nurseries	
Water stress problems	Yes	No
Slow growth	34.6	46.0
Stem dieback	24.1	32.0
More susceptible to disease	17.2	23.0
Insect damage	–	–
Reduced quality	–	–
Lower yield	14.2	25.0
Loss of sale	18.4	25.0
Other (specify)	5.8	8.0

Table 2.14. Market demand of different viburnum species as perceived by nursery producers.

	Percentage of nurseries		
Species	High	Medium	Low
Korean spice viburnum	63.5	25.7	10.8
Arrowwood viburnum	15.8	56.6	27.6
Mohican viburnum	1.6	60.9	37.5
Winterthur smooth viburnum	7.3	51.2	41.5
Fragrant viburnum	55.9	36.8	7.4
Leatherleaf viburnum	33.3	41.2	25.5
Burkwood viburnum	15.2	57.6	27.3
Spring bouquet viburnum	30.4	65.2	4.4
Eastern Snowball	10.2	39.0	50.9
Pink dawn viburnum	14.3	21.4	64.3
Cardinal candy viburnum	24.2	54.6	21.2
Summer snowflake doublefile viburnum	32.7	60.0	7.3
C. A. Hildebrant’s viburnum	20.0	20.0	60.0
Southern blackhaw viburnum	10.0	30.0	60.0

Table 2.15. Annual production cost of the total crops produced in nurseries that grow viburnums.

Annual production cost	Percentage of nurseries
Less than $10,000	11.0
$10,000 to $24,999	5.5
$25,000 to $49,999	1.6
$50,000 to $100,000	3.9
More than $100,000	78.0

Table 2.16. Annual gross sales of the total crops produced in nurseries that grow viburnums

Gross sales	Percentage of nurseries
Less than $10,000	2.3
$10,000 to $24,999	1.6
$25,000 to $49,999	0.8
$50,000 to $100,000	5.5
More than $100,000	89.9

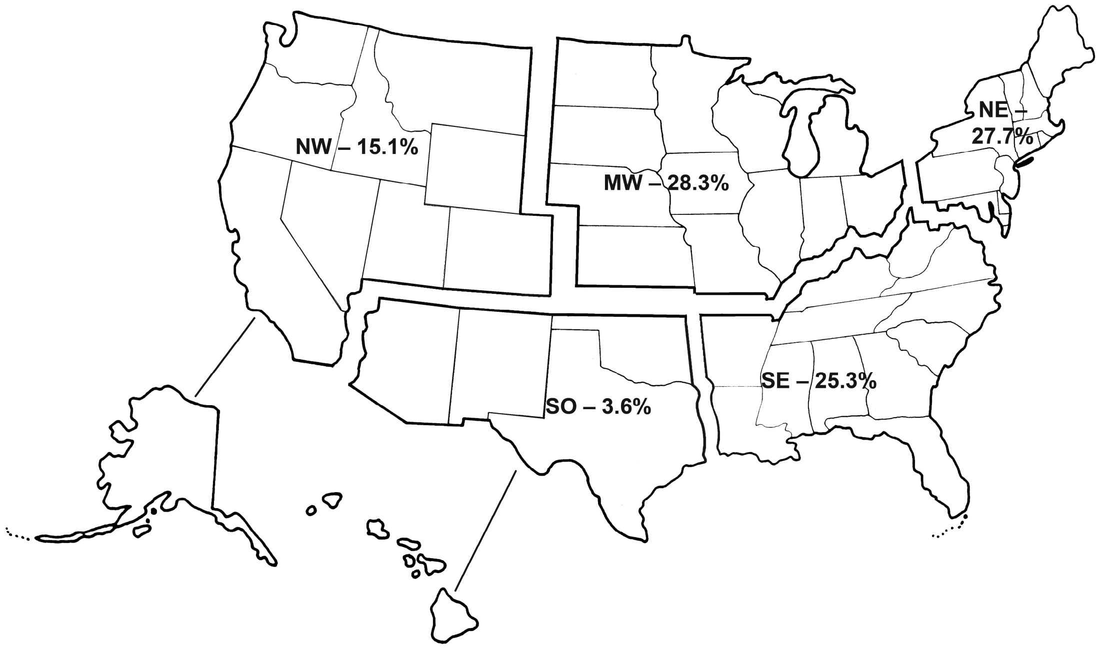

Figure 2.1. Percentage of nurseries in each U.S. region growing viburnums. NW=northwest, MW=Midwest, NE= northeast, SO= South, SE=Southeast

CHAPTER III

WATER USE AND GROWTH OF THREE VIBURNUM SPECIES GROWN UNDER DIFFERENT SHADE INTENSITIES

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Abstract

Water use, growth and degree of leaf necrosis of Burkwood viburnum (*Viburnum × burkwoodii* Burkw. & Skipw. Ex Anon.), Korean spice viburnum (*Viburnum carlesii* Hemsl.) and leatherleaf viburnum (*Viburnum rhytidophyllum* Hemsl.) were evaluated in 0%, 30%, or 60% shade. Water use of Burkwood viburnum decreased with increasing shade intensity. Water use of leatherleaf viburnum was lowest in 0% shade and highest in 30% shade. Leatherleaf plants had lower water use in 0% shade than in 30% or 60% in later months of the study due to greater leaf necrosis, leaf abscission, and less growth in height and width. Height, width, and leaf number of all three species increased with increasing shade intensity. All species had a larger leaf area, root dry weight, and shoot dry weight in 30% and 60% shade than in 0% shade. Shade intensity did not influence root to shoot ratio in Burkwood viburnum. Root to shoot ratio of Korean spice and leatherleaf viburnum decreased with increasing shade. Degree of leaf necrosis was lower in shaded plants of all three species. The results suggest that the three species of viburnums can be better grown in shade than without shade for maximum water use efficiency and maximum plant growth and quality.

Index words: *Viburnum* × *burkwoodii* , *Viburnum carlesii*, *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

Artificial shading can reduce plant water needs. However plant response to shading is species-specific and improper light levels can negatively affect plant growth and aesthetic quality. Excessive light intensity can cause necrosis, photoinhibition and damage of photosynthetic machinery 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. Shade increased plant height, width, leaf number, leaf area and dry weights in all species. Degree of leaf necrosis was lower in shaded plants for all three species. Water use of Burkwood viburnum was reduced by 60% shade. Leatherleaf viburnum in 0% shade used less water than those in 30% or 60% shade; however, the plants in 0% shade had less growth, lower dry weights, greater leaf necrosis and leaf loss which is not desirable in commercial viburnum production. Reduced growth, less leaves and increased necrotic leaves will increase nursery production time and decrease the aesthetic quality of plants. Lower root weights in 0% shade may limit plant growth and survival during nursery production or after transplanting in the landscape. Therefore shading of Burkwood viburnum, Korean spice viburnum and leatherleaf viburnum during production may increase plant growth and quality resulting in increased profitability of viburnum crops.

Introduction

Water availability is one of 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 (Pessarakli, 1994). Water shortages are increasing due to limited water supplies, increasing water prices, and urbanization (Smith and St. Hilaire, 1999; Urbano, 1986). Like other agricultural crops, irrigation is essential for production of ornamental plants. Irrigation efficiency must be improved to make ornamental plant production more sustainable and profitable (Beeson et al., 2004). 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 evapotranspiration (ET) of the plants. Plants lose water extracted from the soil through leaf stomata in the process of transpiration. Water also readily evaporates from the soil surface of the container substrate. The combination of evaporation and transpiration is evapotranspiration. Because the amount of water assimilated by a plant is very small compared to water lost to ET, ET is considered to be the water requirement or water use of plants. Applying more water than needed by a particular plant species will not improve growth and productivity because the plant will only transpire more water. Research has shown that shading can reduce water use of plants. Plant growth and water use is regulated by internal conditions such as plant hormones and genetic factors and external conditions such as intensity and duration of light and temperature. Shading reduces light intensity, plant and soil temperatures (Franco and Nobel, 1989; Turner et al., 1966), and reduces leaf-to-air vapor pressure deficit. Shading also decreases evaporation rates (Breshears et al., 1998; Valiente-Banuet and Ezcurra, 1991), and has complex effects on plants through photosynthesis and morphological plasticity (Holmgren, 2000; Ryser and Eek, 2000). Shade leaves usually have a lower stomatal index, lower stomatal and epidermal cell densities due to larger epidermal cells (Royer, 2001), have larger interveinal areas, and a lower ratio of internal to external surface (Pallardy, 2008).

Light is essential for normal growth of plants. Plants grown in shade respond differently than plants grown in darkness. 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. Shaded plants may be taller and have larger leaves because of a larger water supply in the growing tissues. Heavy shade, however, can reduce photosynthesis, reduce plant growth, and result in reduced capacity to survive drought (Kramer and Decker, 1994). Exposure of plants to excessive radiation and high temperature may lead to photoinhibition, damage the photosynthetic components, and cell death (Medina et al., 2002; Mishra and Singhai, 1992). Different light intensities greatly influence plant growth, leaf gas exchange and water use efficiency (Fini et al., 2010a, 2010b; Robinson and Hamilton, 1980). Successful growth of plants at low light intensity requires capacity to efficiently trap available light and convert it into chemical energy, maintenance of a low respiration rate, and partitioning of a large fraction of the carbohydrate pool into leaf growth.

Viburnums have long been one of the most popular flowering shrubs. The genus Viburnum belongs to the Adoxaceae family. This large group of plants consists of more than 150 species and numerous named cultivars. Viburnums include deciduous and evergreen shrubs and small trees, mostly native to North America or to Asia (Kluepfel and Polomski, 2007). Some species of Viburnums are very 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 (Dirr, 2007). Viburnums are grown in full sun or shade (Dirr, 2007). Viburnum species vary in their soil moisture requirements. Many species thrive in moist soil but some species are drought tolerant (García-Navarro, et al., 2004; Myers, 2004).

Little research has been done on the growth response of viburnum species to shade (Kollmann and Grubb, 2002; Robinson and Hamilton, 1980). 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/ Mayflower viburnum and leatherleaf viburnum. These viburnum species can be grown in sun or shade (Dirr, 2007). 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 experience with various plants. Determining the optimal shade levels for these viburnum species would be useful to commercial growers to reduce water consumption, hasten growth, decrease time needed for preparing plants for sale, and increase plant quality thus improving sustainability and efficiency of viburnum production. The objectives of this study were to determine water use, growth and degree of leaf necrosis of three viburnum species under three shade intensities.

Materials and Methods

Research was conducted at the Oklahoma State University Botanical Garden, Stillwater, OK. 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/yd^3)18N-13.7P-14.4K (Osmocote 18N-16 P_2O_5-12K $_2O$, The Scotts Co., Marysville, OH), 3 $kg{\cdot}m^{-3}$ (5 lb/yd^3) dolomitic limestone and 74.2 $g{\cdot}m^{-3}$ (0.1 lb/yd^3) Micromax (The Scotts Co.). On April 6, 2010, the plants were transplanted into #2 pots with the same substrate. All containers received an equal amount of substrate (3300 g) by weight. The plants were grown outdoors under 0% (full sun), 30% or 60% reduced photosynthetic photon flux (PPF). The shade was created with woven shade cloth. Maximum PPF measured at plant height for the 0%, 30% and, 60% shade treatments were 1985, 1452, 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 Technology, Inc., Plainfield, IL) at the height of the plant canopy in each shade treatment.

Three plants from each species were used to determine plant available water (PAW) before the start of the experiment. Plant available water is the water content difference between container capacity (CC) and permanent wilting point (PWP). The three plants from each species were watered until water drained from the bottom of the containers and then allowed to drain for two hours. The plants were weighed on an electronic precision balance (Scout Pro SP6001, Ohaus Corporation, Pine Brook, NJ) when no more leaching was apparent. Average weight of the three plants was used as container capacity (CC) of the respective species. The plants were then allowed to dry until the apical leaves wilted overnight and did not recover in the early morning of the following day. The plants were weighed at that point and the weights of the three plants were averaged to determine the permanent wilting point of each species. Fifty percent of plant available water was calculated as PAW = 0.5 (CC – PWP).

From May 20, 2010, daily plant water use of leatherleaf viburnum and Burkwood viburnum was determined gravimetrically by weighing each pot on an electronic precision balance (Scout Pro SP6001, Ohaus Corporation, Pine Brook, NJ). 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 with a graduated cylinder. Saucers were placed under each pot to collect the leachate which was measured after 2 hours. The leachate was subtracted from the amount of water applied to get the actual water use of the plants. Rainfall was measured with a rain gauge in each shade treatment.

Plant heights and widths were measured at the beginning of the experiment on May 20, 2010 and on August 20, 2010. Plant heights were measured from the substrate to the highest canopy point. Plant widths were determined at the widest portion and then perpendicular to the widest portion. Each month, every plant in each shade intensity was assigned a numerical value according to the percentage of total leaf area showing leaf necrosis, on a scale of 1 to12 (modified Horsfall and Barratt, 1945). The Horsfall and

Barratt scoring system was based on 50% as a midpoint, as the human eye sees the amount of diseased or affected tissues below 50% while it sees amount of healthy tissues above 50%; 1=0 percent leaves had necrosis, 2=1 to 3 percent, 3=4 to 6 percent, 4=7 to 12 percent, 5=13 to 25 percent, 6=26 to 50 percent, 7=51 to 75 percent, 8=76 to 87 percent, 9=88 to 93 percent, 10=94 to 96, 11=97 to 99, and 12=100 percent. Plants were visually rated for leaf necrosis by two independent raters at each rating time and the ratings were averaged.

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

Statistics. Species were completely randomized within each shade intensity. Species were nested within shade level. The effects of species and the interaction of shade level x species were examined. SAS general linear models analysis of variance and trend analysis by species were performed on all data, except on degree of leaf necrosis, using SAS Statistical Software (SAS Institute, Cary, NC). The statistical analysis for degree of leaf necrosis was by SAS general linear models analysis of variance with mean separation by the PDIFF (t test).

Results

The total volume of water used throughout the experiment (total water use) by Burkwood viburnum decreased linearly with increasing shade intensity (Table 3.1). Total water use of leatherleaf viburnum responded curvilinearly to shade intensity such that water use was lowest in 0% shade and highest in 30% shade (Table 3.1). Burkwood daily water use decreased linearly with increased shade intensity in May, 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 (Table 3.2). Daily water use of leatherleaf viburnum decreased curvilinearly in May and linearly in June but increased curvilinearly in August and September as shade intensity increased (Table 3.2).

Height and width of all species increased linearly with increasing shade intensity (Table 3.3). Leaf number of Burkwood and leatherleaf viburnum increased linearly with increasing shade intensities. A curvilinear relationship between leaf number and shade intensity occurred for Korean spice viburnum such that leaf number was highest in 30% shade and lowest in 0% shade. A quadratic relationship between leaf area and shade intensity existed for all three species. Burkwood viburnum, plants in 30% shade had the largest and those in 0% shade had the smallest leaf area. In contrast, leaf area was greatest in 60% and lowest in 0% shade for Korean spice and leatherleaf viburnum. A quadratic relationship occurred between leaf dry weight and shade intensity for Burkwood viburnum and Korean spice viburnum such that leaf dry weight was largest in 30% shade and smallest in 0% shade. Leaf dry weight of leatherleaf viburnum increased curvilinearly as shade intensity increased. A curvilinear relationship between stem dry weight and shade intensity existed for Burkwood and Korean spice viburnum. Burkwood stem dry weight was greatest in 30% shade and smallest in 0% shade, while Korean spice stem dry weight was greatest in 60% shade and smallest in 0% shade. Stem dry weight of leatherleaf viburnum increased linearly with increasing shade. A curvilinear relationship existed between root dry weight and shade intensity in all species. Burkwood and Korean spice plants had the largest root dry weight in 30% shade and the smallest in 0% shade. Root dry weight of leatherleaf viburnum was larger in 60% shade compared to 30% and 0% shade. Shade intensity did not influence root to shoot (R/S) ratio of Burkwood viburnum. Koreanspice and leatherleaf R/S ratio decreased linearly with increasing shade intensity. Shade intensity did not affect leaf area ratio (LAR) regardless of species (Table 3.4). Specific leaf area (SLA) of all three species increased linearly with increasing shade intensity.

Degree of leaf necrosis was higher in 0% shade for all three species in July and August than in May and June (Table 3.5). In May, no difference in leaf necrosis occurred among shade treatments for Burkwood and Korean spice viburnum. Leatherleaf viburnum had lower leaf necrosis in 60% shade than in 0% or 30% shade and no difference existed between 0% and 30% shade. Leaf necrosis was not significantly different between Burkwood viburnum and Korean spice viburnum but was higher in leatherleaf viburnum. In June, no difference existed between shade treatments for Burkwood viburnum. Korean spice viburnum had the highest leaf necrosis in 0% shade and the lowest in 60% shade. No difference occurred between 0% and 30% and 30% and 60% shade for leatherleaf viburnum, but 0% shade and 60% shade were different such that leatherleaf on 0% shade had higher leaf necrosis than that in 60% shade. Degree of necrosis of Burkwood viburnum in 0% shade was lower that that of Korean spice and leatherleaf viburnum in 0% shade. No difference existed between Korean spice and leatherleaf viburnum in 0% shade. Burkwood viburnum in shade was not different than Korean spice in shade but leatherleaf viburnum had higher necrosis than Burkwood viburnum. No difference occurred between Korean spice in 30 % and leatherleaf in 30% or 60% shade but leatherleaf in 60% shade had more leaf necrosis than Korean spice in 60% shade. In July, Burkwood viburnum had a higher degree of necrosis in 0% shade than in 30% or 60% shade. Burkwood in 30% and 60% shade did not differ in leaf necrosis. Korean spice and leatherleaf viburnum had more necrosis in 0% shade and less in 60% shade. In 0% shade, necrosis was lowest in Burkwood and highest in Korean spice viburnum. In 30% shade, necrosis was lowest in Burkwood and highest in leatherleaf viburnum. No difference occurred among species in 60% shade. In August, Burkwood and Leatherleaf viburnum had more necrosis in 0% shade than in 30% or 60% shade, while 30% and 60% did not differ for either species. Leaf necrosis was highest in 0% shade and lowest in 60% shade for Korean spice viburnum. Species differed in 0% shade such that necrosis was greatest in leatherleaf and lowest in Burkwood viburnum. Burkwood in 30% shade did not differ from Korean spice in 30% or 60% or leatherleaf in 60% shade but was less affected by necrosis than leatherleaf in 30% shade. Burkwood viburnum in 60% shade did not differ from Korean spice or Leatherleaf in 60% shade. Shade treatment did not affect air temperature in our study (Table 3.6).

Discussion

This research investigated responses of three viburnum species to various shade intensities. Previous researchers (Evans and Dodge, 2007; Poole and Conover, 1992) found that shade or reduced light intensity reduced total water use of plants. These findings support our results in which the total water use was reduced by increasing shade in the early months of the experiment: in June for Burkwood and in May and June for leatherleaf viburnum. Light, both as a single factor and in combination with others (temperature, relative humidity), was the most decisive factor with the strongest effect on total water-consumption rate over time (Löfkvist et al., 2009). Reduced light intensity might have reduced stomatal conductance (Burrows and Milthorpe, 1976; Kaufmann, 1976; Pieruschka et al., 2010) or decreased stomata density in shade (Kürschner, 1997; Swarthout and Hogan, 2010; Tichà, 1982). Pieruschka et al. (2010) found that under uniform conditions of vapor pressure deficit, stomatal conductance was proportional to light intensity. In our study, air temperature differed little among the shade treatments (Table 3.6). Martin et al. (1999) reported that over a two-month period, the maximum difference between leaf and air temperatures exceeded 6 °C in his study. Leaf temperature can become substantially higher than air temperature when radiation is high and wind speed is low. In a study by Medina et al. (2002), shade decreased leaf and air temperatures resulting in lower evaporative demand. Leaf temperatures of plants in 0%, 30% and 60% shade intensity will be determined in the second year of the experiment to see the effect of leaf temperatures on the water use of plants. In our study, water use of Burkwood and leatherleaf viburnum was reduced in 0% shade compared to 30% or 60% shade in the later months of the experiment. This is likely attributed to reduced plant growth, leaf number and leaf area due to greater leaf necrosis and abscission in 0% shade compared to 30% or 60% shade.

Greater shade intensity resulted in increased plant height of Burkwood virburnum, leatherleaf viburnum and Korean spice viburnum. Similar results were noted by Fini et al. (2010a) in *V.* × *pragense* Vik and Fini et al. (2010b) in *V. tinus* L. 'Eve Price' where 60% shade increased the plant height compared to 30% shade or full sun. Huxley (1967) found increased stem height in shade compared to no shade in *Coffee arabica* L. and *C. canephora* Pierre ex Froehner. In contrast, Cole and Cole (2000); Kephart et al. (1992); McCarthy and Dawson (1991) found no effect of shade on plant height, while Santelmann et al. (1963) reported that 60% shade suppressed height of *Setaria lutescens* Weigel. Hubb.). Robinson and Hamilton (1980) showed that plant height of *V. opulus* L. 'Nanum' was greater in 30% and 47% shade 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 (Bello et al. 1995) until production of photosynthesis is limited (Patterson, 1979). Our result of increased height with increasing shade in the three species might be due to higher production of photosynthates in the 60% shade than in 0% or 30% shade. Increased shading increased plant width of the three viburnum species in our study. This result is consistent with the observations of Cole and Cole (2000) for *Briza media* L., *Pennisetum alopecuroides* L. Spreng., and *Lirope muscari* Decne. L.H. Bail. However, plant width of *Pachira aquatica* Aubl. was not affected by shade (Li et al., 2009), and Robinson and Hamilton (1980) showed that plant width of *V. opulus* L. 'Nanum' decreased in 63% shade.

The three viburnum species in 0% shade had fewer leaves and smaller leaf area per plant 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 (Fini et al., 2010a). However, Fini et al. (2010b) found that total leaf number per plant of *V. tinus* and *Camellia* × *williamsii* W.W.Sm. 'Debbie' was not affected by shade while leaf number of *Photinia* × *fraseri* Dress 'Red Robin' decreased with shade. Leaf area per plant of *Coffee arabica* and *C. canephora* increased with increasing shade (Huxley, 1967). Lower leaf number and smaller leaf area in 0% shade in our study may be attributed to the combined effect of decreased growth and greater incidence of leaf necrosis followed by leaf abscission in plants in 0% shade compared to 30% or 60% shade.

Our results showed that leaf, stem, root and total dry weight of the three viburnum species were higher in 30% or 60% shade compared to 0% shade. In contrast, Fini et al. (2010a) found that *V.* × *pragense* in full sun and in 60% shade had similar plant dry weights while those in 30% shade had lower dry weights. Fini et al. (2010b) found that leaf, stem, root and total dry weight of *V. tinus* and *Camellia* × *williamsii* were not affected by shade, but dry weights of *Photinia* × *fraseri* decreased with increasing shade. McCarthy and Dawson (1991) found a negative linear relationship between shade intensity (30, 55 and 73%) and dry weights of *Quercus alba*, *Q. imbricaria* and *Q. palustris*. *Coffee arabica* and *C. canephora* attained maximum dry weight at a moderate shade level (46% and 62% shade) compared to 0% shade, 73% and 88% shade (Huxley, 1967). Our results also showed that the dry weights were mostly higher in 30% shade compared to 60% shade except stem dry weight of Korean spice viburnum and all dry weights of leatherleaf viburnum were higher in 60% shade than in 0% or 30% shade. Root to shoot ratio decreased in plants grown under shade in research findings of Allard et al. (1991) and Samarakoon et al. (1990). These findings support our results of lower R/S ratio with increasing shade in Korean spice and leatherleaf viburnum. But no significant effect of shade occurred on 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 on top. Shade intensity did not affect leaf area ratio (LAR) of any viburnum spcecies tested in this study, as observed by Fini et al. (2010b) who found that LAR of *V. tinus* and *Camellia* × *williamsii* were not affected by shade. In the same study however, shade increased LAR of *Photinia* × *fraseri*. Leaf area ratio of *V.* × *pragense* increased with increasing shade (Fini et al., 2010a). Specific leaf area (SLA) increased with increasing shade for the three viburnum species in our study. Increased SLA suggests that a given amount of biomass is spread over larger areas which increase light capture per unit biomass in shade. Our result is supported by the findings of Evans and Poorter (2001) and Kollmann and Grubb (2002) where shading caused an increase in the SLA.

Our result of greater leaf necrosis in 0% shade than in 30% or 60% shade is consistent with the observations of Mock and Grimm (1997). 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 (Mishra and Singhal, 1992). Higher degree of necrosis in leatherleaf than in Korean spice and Burkwood viburnum in 0% shade might be due to leaf size. Leatherleaf have larger leaves than Korean spice and Burkwood viburnum.

In conclusion, 60% shade can result in water savings for Burkwood viburnum. Leatherleaf total water use was lowest in 0% shade, however, the greater degree of leaf necrosis and leaf abscission and reduced growth can make the plants less salable which is detrimental in commercial viburnum production. Water use of leatherleaf was lower in

60% than in 30% shade. Shade increased plant height and width, leaf number and leaf area, leaves, stems, roots and total dry weights, and specific leaf area in all species. Root to shoot ratio was reduced by shade in Korean spice and leatherleaf viburnum but was not affected in Burkwood viburnum. Degree of leaf necrosis decreased with increasing shade intensity in all three species. Reduced growth, fewer leaves and higher leaf necrosis may increase nursery production time and decrease the aesthetic quality of plants. Lower root weights in 0% shade may limit plant growth and survival during nursery production or after transplanting in the landscape applications. Therefore shading can be a useful means, at least during the hot summer months, for reducing water use and improving growth and quality in Burkwood, Korean spice and leatherleaf viburnum.

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Table 3.1. Total volume of water used during the growing season (total water use) of two viburnum species grown under 0%, 30% or 60% shade.

Species	Shade intensity	Total water use (L/plant)
Burkwood viburnum	0%	23.82
	30%	23.80
	60%	20.83
	Linear	*[z]
	Quadratic	ns
Leatherleaf viburnum	0%	46.60
	30%	54.04
	60%	48.70
	Linear	ns
	Quadratic	**

[z] ns, *, ** nonsignificantat $p \geq 0.05$ or significant at $p \geq 0.05$ or 0.01, respectively.

Table 3.2. Daily water use of two viburnum species, for each month, grown under 0%, 30% and 60% shade.

Species	Shade intensity	Daily water use for each month (ml)				
		May	June	July	Aug	Sep
Burkwood viburnum	0%	135	219	223	248	143
	30%	96	167	217	291	269
	60%	88	125	196	267	243
	Linear	ns[z]	**	ns	ns	**
	Quadratic	ns	ns	ns	ns	**
Leatherleaf viburnum	0%	409	497	439	381	194
	30%	385	492	501	530	395
	60%	249	409	458	527	431
	Linear	**	**	ns	**	**
	Quadratic	*	ns	ns	**	**

[z] ns, *, ** nonsignificantat p≥0.05 or significant at p≥0.05 or 0.01, respectively.

Table 3.3. Plant height and width difference, mean leaf number per plant, leaf area per plant (LA), leaf , root, stem and, total dry weight, Root to shoot ratio (R/S ratio) in the three viburnum species grown under 0%, 30% or 60% shade.

Species	Shade intensity	Height$^{\square}$ (cm)	Width^{y} (cm)	Leaf number plant^{-1}	LA (cm^{2})	Dry weight (g)				R/S ratio
						Leaf	Stem	Root	total	
Burkwood viburnum	0%	0	8.6	190.7	1425.5	27.5	22.1	15.7	65.4	0.3
	30%	11	18	283	2613	47	43	30	120	0
	60%	22	24	296	2366	36	41	27	105	0
	Linear	**^{x}	**	**	**	ns	**	**	**	ns
	Quadratic	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
	30%	20.1	14.7	195.4	3040.6	46.1	42.7	41.3	130.3	0.5
	60%	35.1	28.8	180.2	3331.3	42.6	46.9	39.1	128.8	0.4
	Linear	**	**	**	**	**	**	**	**	**
	Quadratic	ns	ns	**	**	**	**	**	**	ns
Leatherleaf viburnum	0%	9.5	0.0	78.3	1020.3	29.7	44.2	47.6	121.5	0.7
	30%	17.3	12.9	137.7	4064.8	70.9	59.9	83.7	214.6	0.6
	60%	21.3	29.9	148.6	5750.9	75.3	73.3	84.9	233.7	0.6
	Linear	**	**	**	**	**	**	**	**	*
	Quadratic	ns	ns	ns	*	**	ns	**	**	ns

$^{\square}$Height = (Height in September)-(Height in May)

^{y}Width = (Width in September)-(Width in May)

^{x}ns, *, ** nonsignificant at p≥0.05 or significant at p≥0.05 or 0.01, respectively.

Table 3.4. Leaf area ratio (LAR) and specific leaf area (SLA) of three viburnum species grown under 0%, 30% or 60% shade intensities.

Species	Shade intensity	LAR (cm^2 g^{-1})	SLA (cm^2 g^{-1})
Burkwood viburnum	0%	3.9	51.0
	30%	2.4	55.2
	60%	2.9	66.6
	Linear	ns	**
	Quadratic	ns	ns
Koreanspice viburnum	0%	1. 9	60.8
	30%	1.5	66.6
	60%	1.4	77.8
	Linear	ns	**
	Quadratic	ns	ns
Leatherleaf viburnum	0%	0.6	26.0
	30%	0.6	55.7
	60%	0.6	76.8
	Linear	ns	**
	Quadratic	ns	ns

ns, *, ** nonsignificant or significant at p=0.05 or 0.01, respectively.

Table 3.5. Monthly leaf necrosis ratings in three viburnum species grown under 0, 30 or 60% shade.

Species	Shade intensity	Leaf necrosis rating							
		May		June		July		August	
Burkwood	0%	1.0	a[z]	1.5	ac	2.2	a	3.8	ag
viburnum	30%	1.1	a	1.5	ac	1.5	b	1.5	bch
	60%	1.1	a	1.3	a	1.3	b	1.3	bh
Korean spice	0%	1.1	a	2.3	b	3.9	c	6.5	d
viburnum	30%	1.0	a	1.6	cd	1.9	d	2.3	aci
	60%	1.0	a	1.2	a	1.2	b	1.4	b
Leatherleaf	0%	1.9	b	2.1	b	3.0	e	8.1	e
viburnum	30%	1.8	b	1.9	bde	2.0	f	2.9	afg
	60%	1.5	c	1.6	e	1.7	bd	1.7	fhi

[z] Mean separation within columns by paired t-test at $p \leq 0.05$.

Table 3.6. Daily mean high and low temperatures (°F and °C) by month from May 20, 2010 to September 8, 2010 recorded by data loggers in 0%, 30% and 60% shade.

	Average Temperature											
	0% shade				30% shade				60% shade			
	°F		°C		°F		°C		°F		°C	
Month	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
May[□]	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	88.7	62.0	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

[□] Temperature record is from May 20, 2010 to May 31, 2010

[y] Temperature record is from September 1, 2010 to September 8, 2010

Figure 3.1. Burkwood viburnum leaf necrosis in August at 0%, 30% and 60% shade (from left to right).

Figure 3.2. Korean spice viburnum leaf necrosis in August at 0%, 30% and 60% shade (from left to right).

Figure 3.3. Leatherleaf viburnum leaf necrosis in August at 0%, 30% and 60% shade (from left to right).

CHAPTER IV

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APPPENDIX 1

DAILY HIGH AND LOW TEMPERATURES (°F AND °C)

Table A-1. Daily average, maximum and minimum temperature from 20 May, 2010 to 8 September, 2010, recorded by data loggers in 0%, 30% and 60% shade.

				Temperature (^{o}F)			Temperature (^{o}C)	
Shade	Month	Day	Average	Maximum	Minimum	Average	Maximum	Minimum
0	May	20	65.5	79.5	53.8	18.6	26.4	12.1
0	May	21	71.1	90.3	51.0	21.7	32.4	10.6
0	May	22	79.0	88.1	70.4	26.1	31.2	21.3
0	May	23	82.0	94.8	73.9	27.8	34.9	23.3
0	May	24	81.0	91.8	72.5	27.2	33.2	22.5
0	May	25	77.8	93.3	67.0	25.4	34.1	19.4
0	May	26	79.4	94.8	64.9	26.3	34.9	18.3
0	May	27	78.8	97.9	64.9	26.0	36.6	18.3
0	May	28	80	98.7	64.2	26.7	37.1	17.9
0	May	29	79.9	98.7	62.8	26.6	37.1	17.1
0	May	30	80.4	97.9	64.9	26.9	36.6	18.3
0	May	31	77.2	95.6	64.9	25.1	35.3	18.3
0	June	1	84.4	101.9	69.7	29.1	38.8	20.9
0	June	2	85.0	100.3	72.5	29.4	37.9	22.5
0	June	3	80.8	100.3	66.3	27.1	37.9	19.1
0	June	4	82.7	99.5	67.7	28.2	37.5	19.8
0	June	5	85.4	101.1	71.1	29.7	38.4	21.7
0	June	6	83.1	94.8	74.6	28.4	34.9	23.7
0	June	7	76.0	86.6	65.6	24.4	30.3	18.7
0	June	8	85.8	99.5	75.3	29.9	37.5	24.1
0	June	9	79.4	93.3	68.4	26.3	34.1	20.2
0	June	10	80.5	93.3	72.5	26.9	34.1	22.5
0	June	11	85.0	95.6	76.7	29.4	35.3	24.8
0	June	12	84.1	94.8	78.1	28.9	34.9	25.6
0	June	13	85.7	98.7	73.9	29.8	37.1	23.3

0	June	14	69.0	75.3	66.3	20.6	24.1	19.1
0	June	15	78.3	95.6	64.9	25.7	35.3	18.3
0	June	16	79.7	96.4	68.4	26.5	35.8	20.2
0	June	17	85.3	100.3	73.9	29.6	37.9	23.3
0	June	18	87.6	101.1	76.7	30.9	38.4	24.8
0	June	19	88.3	101.1	76.0	31.3	38.4	24.4
0	June	20	87.0	100.3	76.0	30.6	37.9	24.4
0	June	21	87.1	101.1	76.0	30.6	38.4	24.4
0	June	22	87.7	101.9	73.9	30.9	38.8	23.3
0	June	23	88.9	103.5	72.5	31.6	39.7	22.5
0	June	24	86.9	101.9	74.6	30.5	38.8	23.7
0	June	25	87.0	101.9	73.9	30.6	38.8	23.3
0	June	26	87.9	103.5	73.9	31.1	39.7	23.3
0	June	27	85.4	101.1	76.7	29.7	38.4	24.8
0	June	28	82.1	96.4	72.5	27.8	35.8	22.5
0	June	29	81.8	98.7	67.7	27.7	37.1	19.8
0	June	30	82.3	97.1	67.0	27.9	36.2	19.4
0	July	1	82.4	96.4	69.0	28.0	35.8	20.6
0	July	2	81.7	94.1	71.8	27.6	34.5	22.1
0	July	3	75.7	79.5	73.2	24.3	26.4	22.9
0	July	4	78.5	91.8	73.2	25.8	33.2	22.9
0	July	5	80.7	92.5	72.5	27.1	33.6	22.5
0	July	6	77.4	101.9	70.4	25.2	38.8	21.3
0	July	7	79.1	94.1	69.0	26.2	34.5	20.6
0	July	8	79.6	91.8	72.5	26.4	33.2	22.5
0	July	9	80.4	95.6	72.5	26.9	35.3	22.5
0	July	10	83.5	100.3	69.0	28.6	37.9	20.6
0	July	11	86.5	103.5	76.0	30.3	39.7	24.4
0	July	12	80.3	100.3	74.6	26.8	37.9	23.7

0	August	5	87.9	102.7	78.1	31.1	39.3	25.6
0	August	6	85.3	101.9	71.8	29.6	38.8	22.1
0	August	7	88.7	105.1	76.0	31.5	40.6	24.4
0	August	8	91.7	109.4	77.4	33.2	43.0	25.2
0	August	9	91.9	107.7	77.4	33.3	42.1	25.2
0	August	10	90.8	107.7	75.3	32.7	42.1	24.1
0	August	11	91.4	108.5	74.6	33.0	42.5	23.7
0	August	12	92.6	112.0	76.7	33.7	44.4	24.8
0	August	13	95.1	112.0	78.8	35.1	44.4	26.0
0	August	14	92.6	112.0	76.7	33.7	44.4	24.8
0	August	15	80.3	96.4	71.1	26.8	35.8	21.7
0	August	16	82.0	100.3	69.7	27.8	37.9	20.9
0	August	17	79.9	91.8	72.5	26.6	33.2	22.5
0	August	18	80.0	95.6	69.0	26.7	35.3	20.6
0	August	19	83.6	104.3	64.9	28.7	40.2	18.3
0	August	20	91.1	106.8	78.8	32.8	41.6	26.0
0	August	21	88.2	105.1	74.6	31.2	40.6	23.7
0	August	22	85.7	104.3	70.4	29.8	40.2	21.3
0	August	23	88.3	106	72.5	31.3	41.1	22.5
0	August	24	76.6	85.9	69.0	24.8	29.9	20.6
0	August	25	74.6	91	60.1	23.7	32.8	15.6
0	August	26	71.6	93.3	52.4	22.0	34.1	11.3
0	August	27	74.8	98.7	53.1	23.8	37.1	11.7
0	August	28	77.1	97.9	58.7	25.1	36.6	14.8
0	August	29	81.6	99.5	64.2	27.6	37.5	17.9
0	August	30	84.5	97.1	73.2	29.2	36.2	22.9
0	August	31	86.9	103.5	76.0	30.5	39.7	24.4
0	September	1	83.8	95.6	76.7	28.8	35.3	24.8
0	September	2	81.1	106	67.7	27.3	41.1	19.8

0	September	3	71.2	88.8	56.6	21.8	31.6	13.7
0	September	4	69.9	92.5	50.3	21.1	33.6	10.2
0	September	5	76.5	97.1	54.5	24.7	36.2	12.5
0	September	6	84.2	97.9	73.9	29.0	36.6	23.3
0	September	7	77.5	90.3	71.1	25.3	32.4	21.7
0	September	8	72.0	74.6	69.7	22.2	23.7	20.9
30	May	20	65.4	78.1	54.5	18.6	25.6	12.5
30	May	21	70.5	86.6	51.7	21.4	30.3	10.9
30	May	22	78.8	87.4	70.4	26.0	30.8	21.3
30	May	23	81.6	94.1	73.9	27.6	34.5	23.3
30	May	24	80.4	91.0	73.2	26.9	32.8	22.9
30	May	25	76.8	89.6	67.7	24.9	32.0	19.8
30	May	26	79.0	93.3	65.6	26.1	34.1	18.7
30	May	27	78.5	95.6	65.6	25.8	35.3	18.7
30	May	28	79.0	94.8	64.2	26.1	34.9	17.9
30	May	29	79.2	95.6	62.8	26.2	35.3	17.1
30	May	30	79.8	95.6	64.9	26.6	35.3	18.3
30	May	31	76.5	91.0	64.9	24.7	32.8	18.3
30	June	1	83.7	100.3	69.7	28.7	37.9	20.9
30	June	2	84.0	97.1	72.5	28.9	36.2	22.5
30	June	3	79.4	96.4	65.6	26.3	35.8	18.7
30	June	4	82.1	96.4	67.7	27.8	35.8	19.8
30	June	5	84.7	98.7	70.4	29.3	37.1	21.3
30	June	6	82.0	92.5	74.6	27.8	33.6	23.7
30	June	7	75.3	83.7	65.6	24.1	28.7	18.7
30	June	8	85.2	97.1	74.6	29.6	36.2	23.7
30	June	9	78.8	90.3	68.4	26.0	32.4	20.2
30	June	10	80.1	92.5	72.5	26.7	33.6	22.5
30	June	11	84.4	93.3	76.7	29.1	34.1	24.8

30	June	12	83.4	91.8	78.1	28.6	33.2	25.6
30	June	13	85.0	97.9	73.9	29.4	36.6	23.3
30	June	14	69.2	76.7	66.3	20.7	24.8	19.1
30	June	15	77.7	91.8	65.6	25.4	33.2	18.7
30	June	16	79.3	94.1	69.0	26.3	34.5	20.6
30	June	17	84.9	97.9	73.9	29.4	36.6	23.3
30	June	18	87.0	99.5	76.7	30.6	37.5	24.8
30	June	19	87.5	98.7	76.0	30.8	37.1	24.4
30	June	20	86.6	99.5	75.3	30.3	37.5	24.1
30	June	21	86.2	99.5	74.6	30.1	37.5	23.7
30	June	22	87.0	100.3	73.9	30.6	37.9	23.3
30	June	23	88.0	101.9	71.8	31.1	38.8	22.1
30	June	24	85.5	97.9	74.6	29.7	36.6	23.7
30	June	25	86.1	99.5	73.9	30.1	37.5	23.3
30	June	26	87.3	101.9	73.2	30.7	38.8	22.9
30	June	27	84.5	99.5	76.0	29.2	37.5	24.4
30	June	28	80.8	92.5	71.8	27.1	33.6	22.1
30	June	29	81.0	95.6	67.7	27.2	35.3	19.8
30	June	30	81.5	94.1	67.0	27.5	34.5	19.4
30	July	1	81.1	93.3	68.4	27.3	34.1	20.2
30	July	2	80.5	91.0	71.1	26.9	32.8	21.7
30	July	3	75.6	79.5	73.2	24.2	26.4	22.9
30	July	4	78.2	89.6	73.2	25.7	32.0	22.9
30	July	5	80.3	90.3	72.5	26.8	32.4	22.5
30	July	6	76.9	97.9	70.4	24.9	36.6	21.3
30	July	7	78.4	91.8	69.0	25.8	33.2	20.6
30	July	8	78.7	88.8	71.8	25.9	31.6	22.1
30	July	9	79.2	91	72.5	26.2	32.8	22.5
30	July	10	82.1	95.6	69.0	27.8	35.3	20.6

30	July	11	85.5	101.1	75.3	29.7	38.4	24.1
30	July	12	79.3	91.8	74.6	26.3	33.2	23.7
30	August	5	85.7	97.9	77.4	29.8	36.6	25.2
30	August	6	84.0	97.9	71.1	28.9	36.6	21.7
30	August	7	87.5	101.9	76.0	30.8	38.8	24.4
30	August	8	90.4	105.1	76.7	32.4	40.6	24.8
30	August	9	90.2	104.3	76.7	32.3	40.2	24.8
30	August	10	89.5	104.3	74.6	31.9	40.2	23.7
30	August	11	89.8	105.1	74.6	32.1	40.6	23.7
30	August	12	91.4	109.4	76.0	33.0	43.0	24.4
30	August	13	94	110.2	78.8	34.4	43.4	26.0
30	August	14	91.3	109.4	76.0	32.9	43.0	24.4
30	August	15	79.5	93.3	70.4	26.4	34.1	21.3
30	August	16	80.9	97.1	69.0	27.2	36.2	20.6
30	August	17	79.3	88.8	71.8	26.3	31.6	22.1
30	August	18	78.6	92.5	68.4	25.9	33.6	20.2
30	August	19	82.3	100.3	64.2	27.9	37.9	17.9
30	August	20	89.9	105.1	78.8	32.2	40.6	26.0
30	August	21	86.9	103.5	73.9	30.5	39.7	23.3
30	August	22	84.1	101.1	69.7	28.9	38.4	20.9
30	August	23	86.9	103.5	71.8	30.5	39.7	22.1
30	August	24	75.8	83.7	68.4	24.3	28.7	20.2
30	August	25	73.3	88.8	60.1	22.9	31.6	15.6
30	August	26	70.5	91.0	52.4	21.4	32.8	11.3
30	August	27	73.5	96.4	52.4	23.1	35.8	11.3
30	August	28	76.1	97.1	58.7	24.5	36.2	14.8
30	August	29	80.7	97.9	63.5	27.1	36.6	17.5
30	August	30	83.8	95.6	72.5	28.8	35.3	22.5
30	August	31	86	101.9	76.0	30.0	38.8	24.4

30	September	1	82.9	94.1	76.0	28.3	34.5	24.4
30	September	2	80.4	102.7	67.7	26.9	39.3	19.8
30	September	3	70.2	86.6	55.9	21.2	30.3	13.3
30	September	4	68.5	89.6	49.6	20.3	32.0	9.8
30	September	5	75.6	95.6	53.8	24.2	35.3	12.1
30	September	6	83.3	96.4	72.5	28.5	35.8	22.5
30	September	7	76.6	88.1	70.4	24.8	31.2	21.3
30	September	8	72.0	74.6	70.4	22.2	23.7	21.3
60	May	20	64.5	78.1	53.1	18.1	25.6	11.7
60	May	21	69.4	85.2	51.0	20.8	29.6	10.6
60	May	22	77.5	86.6	68.4	25.3	30.3	20.2
60	May	23	80.5	92.5	72.5	26.9	33.6	22.5
60	May	24	79.4	90.3	71.8	26.3	32.4	22.1
60	May	25	76.0	88.8	67.0	24.4	31.6	19.4
60	May	26	78.1	91.8	64.9	25.6	33.2	18.3
60	May	27	78.0	95.6	64.9	25.6	35.3	18.3
60	May	28	78.2	94.1	63.5	25.7	34.5	17.5
60	May	29	78.3	95.6	62.2	25.7	35.3	16.8
60	May	30	79.0	95.6	64.9	26.1	35.3	18.3
60	May	31	75.5	88.8	64.9	24.2	31.6	18.3
60	June	1	82.2	97.9	69.0	27.9	36.6	20.6
60	June	2	82.8	96.4	71.1	28.2	35.8	21.7
60	June	3	75.1	92.3	55.9	23.9	33.5	13.3
60	June	4	69.6	87.4	54.5	20.9	30.8	12.5
60	June	5	74.7	90.2	64.5	23.7	32.3	18.1
60	June	6	70.0	84.5	69.4	21.1	29.2	20.8
60	June	7	69.1	82.3	55.9	20.6	27.9	13.3
60	June	8	71.7	81.1	64.5	22.1	27.3	18.1
60	June	9	72.0	86.0	61.0	22.2	30.0	16.1

60	June	10	69.0	74.9	61.5	20.6	23.8	16.4
60	June	11	74.9	80.4	63.0	23.9	26.9	17.2
60	June	12	73.9	80.2	63.0	23.3	26.8	17.2
60	June	13	74.8	86.6	64.9	23.8	30.3	18.3
60	June	14	66.6	81.6	61.7	19.2	27.6	16.5
60	June	15	70.3	81.1	61.7	21.3	27.3	16.5
60	June	16	65.5	83.7	60.3	18.6	28.7	15.7
60	June	17	75.0	83.0	65.9	23.9	28.3	18.8
60	June	18	78.9	87.4	66.7	26.1	30.8	19.3
60	June	19	75.0	85.2	62.4	23.9	29.6	16.9
60	June	20	74.1	93.3	61.0	23.4	34.1	16.1
60	June	21	75.4	84.6	64.5	24.1	29.2	18.1
60	June	22	77.6	91.1	60.0	25.4	32.8	15.6
60	June	23	77.9	92.8	62.4	25.5	33.8	16.9
60	June	24	70.6	86.0	68.8	21.4	30.0	20.4
60	June	25	76.1	83.7	65.2	24.5	28.7	18.4
60	June	26	74.0	91.6	64.2	23.3	33.1	17.9
60	June	27	77.5	84.2	60.3	25.3	29.0	15.7
60	June	28	73.1	82.8	63.8	22.8	28.2	17.7
60	June	29	73.3	80.4	57.3	22.9	26.9	14.1
60	June	30	72.2	88.1	55.9	22.3	31.2	13.3
60	July	1	63.6	77.4	52.4	17.6	25.2	11.3
60	July	2	63.7	76.0	51.0	17.6	24.4	10.6
60	July	3	61.8	72.5	55.2	16.6	22.5	12.9
60	July	4	64.5	78.1	53.1	18.1	25.6	11.7
60	July	5	69.9	85.2	51.0	21.1	29.6	10.6
60	July	6	77.8	86.6	68.4	25.4	30.3	20.2
60	July	7	80.5	92.5	72.5	26.9	33.6	22.5
60	July	8	79.4	90.3	71.8	26.3	32.4	22.1

60	July	9	75.9	88.8	67.0	24.4	31.6	19.4
60	July	10	78.2	91.8	64.9	25.7	33.2	18.3
60	July	11	77.9	95.6	64.9	25.5	35.3	18.3
60	July	12	74.2	91.8	63.5	23.4	33.2	17.5
60	August	5	85.0	97.1	77.4	29.4	36.2	25.2
60	August	6	83.3	95.6	71.8	28.5	35.3	22.1
60	August	7	86.6	100.3	76.0	30.3	37.9	24.4
60	August	8	89.4	103.5	76.7	31.9	39.7	24.8
60	August	9	89.3	102.7	76.7	31.8	39.3	24.8
60	August	10	88.6	103.5	75.3	31.4	39.7	24.1
60	August	11	88.6	102.7	74.6	31.4	39.3	23.7
60	August	12	90.0	105.1	76.7	32.2	40.6	24.8
60	August	13	92.0	106.8	78.8	33.3	41.6	26.0
60	August	14	90.2	106.8	76.7	32.3	41.6	24.8
60	August	15	79.2	90.3	71.1	26.2	32.4	21.7
60	August	16	79.9	94.8	69.7	26.6	34.9	20.9
60	August	17	78.5	86.6	71.8	25.8	30.3	22.1
60	August	18	77.9	91.0	68.4	25.5	32.8	20.2
60	August	19	81.1	99.5	64.9	27.3	37.5	18.3
60	August	20	88.1	101.1	77.4	31.2	38.4	25.2
60	August	21	85.9	99.5	74.6	29.9	37.5	23.7
60	August	22	83.4	97.9	70.4	28.6	36.6	21.3
60	August	23	86.2	101.1	73.2	30.1	38.4	22.9
60	August	24	75.4	81.6	68.4	24.1	27.6	20.2
60	August	25	73.0	85.9	60.8	22.8	29.9	16.0
60	August	26	70.5	89.6	53.8	21.4	32.0	12.1
60	August	27	72.8	93.3	54.5	22.7	34.1	12.5
60	August	28	75.5	94.1	60.1	24.2	34.5	15.6
60	August	29	80.2	96.4	64.9	26.8	35.8	18.3

60	August	30	83.1	94.8	72.5	28.4	34.9	22.5
60	August	31	85.3	101.1	76.0	29.6	38.4	24.4
60	September	1	82.5	93.3	76.0	28.1	34.1	24.4
60	September	2	79.9	101.1	67.0	26.6	38.4	19.4
60	September	3	69.6	85.2	57.3	20.9	29.6	14.1
60	September	4	68.3	88.8	51.0	20.2	31.6	10.6
60	September	5	75.0	94.8	54.5	23.9	34.9	12.5
60	September	6	82.1	95.6	72.5	27.8	35.3	22.5
60	September	7	76.4	88.1	71.1	24.7	31.2	21.7
60	September	8	71.5	73.9	69.0	21.9	23.3	20.6

APPENDIX 2

RAINFALL MEASUREMENT (mm)

Table A-2 Rainwater (mm) collected in rain gauge from 20 May, 2010 to 8 September, 2010 in 0%, 30% and 60% shade.

Date	Rainfall (mm)		
	0% shade	30% shade	60% shade
30 May, 2010	1.8	1.8	1.8
3 June, 2010	0.5	0.4	0.4
7 June, 2010	1.1	1.0	1.0
14 June, 2010	1.8	1.8	1.8
15 June, 2010	0.5	0.5	0.6
27 June, 2010	0.5	0.5	0.5
3 July, 2010	1.0	1.0	1.3
5 July, 2010	0.5	0.4	0.4
6 July, 2010	1.4	1.3	1.1
5 August, 2010	0.2	0.2	0.2
16 August, 2010	0.1	0.1	0.1
17 August, 2010	1.7	1.6	1.2
24 August, 2010	0.1	0.1	0.1
2 September, 2010	0.5	0.5	0.5

APPENDIX 3

PLANT HEIGHTS AND WIDTHS OF THREE VIBURNUM SPECIES GROWN UNDER THREE SHADE INTENSITIES

Table A-3. Height and width of three viburnum species in May and September in 0, 30 or 60% shade.

Species	Shade intensity	Height in May (cm)	Height in Sep (cm)	Width in May (cm)	Width in Sep (cm)
Burkwood viburnum	0	43.7	43.3	41.9	50.5
	30	45.8	56.7	38.9	57.4
	60	45.4	67.3	39.3	63.6
Korean spice viburnum	0	41.3	47.8	44.0	46.1
	30	41.8	61.9	46.1	60.7
	60	43.2	78.3	40.2	69.0
Leatherleaf viburnum	0	45.3	54.8	45.9	45.9
	30	42.7	60.0	48.0	60.9
	60	44.3	65.6	42.6	72.6

VITA

Arjina Shrestha

Candidate for the Degree of

Master of Science

Thesis: SURVEY OF CULTURAL PRACTICES USED IN PRODUCTION OF VIBURNUMS AND WATER USE AND GROWTH OF THREE VIBURNUM SPECIES GROWN UNDER DIFFERENT SHADE INTENSITIES

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Title of Study: SURVEY OF CULTURAL PRACTICES USED IN PRODUCTION OF VIBURNUMS AND WATER USE AND GROWTH OF THREE VIBURNUM SPECIES GROWN UNDER DIFFERENT SHADE INTENSITIES

Pages in Study: 136 Candidate for the Degree of Master of Science

Major Field: Horticulture

Scope and Method of Study:
A nationwide survey of the commercial nursery growers was conducted to identify the cultural practices used in production of viburnums. Daily plant water use of leatherleaf viburnum and Burkwood viburnum in 0%, 30% and 60% shade was determined gravimetrically by weighing each pot on an electronic precision balance. Plant heights, widths, leaf necrosis, number of leaves per plant, leaf area, root and shoot dry weights, root to shoot ratio (R/S) and specific leaf area were determined for leatherleaf, Korean spice and Burkwood viburnum in 0%, 30% and 60% shade.

Findings and Conclusions:
Survey results suggest that using more sustainable production techniques that improve irrigation efficiency will reduce production costs, conserve water, and produce higher quality crops. Nursery producers should consider planting time; selection of components of container substrates, use of inorganic and biological amendments in the substrate; alternative irrigation sources; cost and water efficient irrigation methods; irrigation frequency and use of cyclic irrigation that could improve water and nutrient management of viburnums and other ornamental crops.

Sixty percent shade can result in water savings for Burkwood viburnum. Leatherleaf total water use was lowest in 0% shade, however, the greater degree of leaf necrosis and leaf abscission and reduced growth can make the plant less salable. Water use of leatherleaf was lower in 60% than in 30% shade. Shade increased plant height and width, leaf number and leaf area, leaves, stems, roots and total dry weights, and specific leaf area in all species. Root to shoot ratio was reduced by shade in Korean spice and leatherleaf viburnum but was not affected in Burkwood viburnum. Degree of leaf necrosis decreased with increasing shade intensity in all three species. Shading can be a useful means, at least during the hot summer months, for reducing water use and improving growth and quality in Burkwood, Korean spice and leatherleaf viburnum.

ADVISER’S APPROVAL: Janet C. Cole