Viburnum spp.: Examining the relationship between greenhouse-growth studies for heat and drought tolerance to determine correlation to landscape survival

by

Joshua Roy Pool

B.S., Kansas State University, 2002
M.S., Kansas State University, 2012

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Horticulture and Natural Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Abstract

Three studies were designed to evaluate *Viburnum* spp. and their physiological adaptation to drought, heat, and other environmental stresses found in the Great Plains, specifically Kansas. Nursery crop growers, landscape contractors, and consumers desire low-maintenance landscapes with plants suited to their environment. The Great Plains can be a challenging environment for ornamental landscape plants. *Viburnum* plants were potted into 2-gal (6.3 L) containers during the summer of 2012 with field trials installed Fall 2012. Field-study sites were selected to capture variability in precipitation and temperature across Kansas. Field trials in Eastern Kansas had greater survival. Shaded sites resulted in larger plants and greater survival. Plants designated for greenhouse drought and heat trials were overwintered in an unheated hoop-house the winter of 2012. Drought and heat trial cultivars were selected based on performance in field-trials as well as one Southern ecotype spp. for comparison. Drought and heat trials were conducted within a controlled greenhouse environment (Manhattan, KS) during June 2013 and April 2014, respectively. Plants acclimated in a greenhouse maintained at 25C/18C (77F/64F; day/night) for 28 days and were watered as needed until treatments were initiated. *Viburnum dentatum, V. nudum*, and *V. tinus* were exposed to both heat and drought separately. Results indicate that *V. nudum* responded to drought stress by reducing biomass, though photosynthetic capacity was not significantly affected. *Viburnum dentatum* was able to maintain similar shoot growth with moderate drought (MD) and severe drought (SD), while root growth significantly declined. Whole plant responses to increased day/night temperatures during acclimation prior to temperature curve measurements resulted in growth of all species slowing compared to control plants. All acclimated plants exhibited increased temperature optimum for P_{net} with a less severe rate of increase and decline when compared to control. *Viburnum dentatum* and *V. nudum* were

species which performed well in all studies and could be recommended for use in the Great Plains.

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Chapter 1 - Literature Review

Homeownership rates in the United States (U.S.) have begun to climb after a 12-year decline ending in 2016 (U.S. Census Bureau, 2018). In the third quarter of 2018, homeownership rates were 64.3%, with a national average vacancy rate dipping down to 1.6% (U.S. Census Bureau, 2018). The Midwest United States (states) had the highest home ownership rates, 69.0% (U.S. Census Bureau, 2018). Median asking prices of homes continue to climb out of the recent housing slump that bottomed out in 2013, currently the median asking price is $206,400 United States dollars (USD) (Figure 1.1; U.S. Census Bureau, 2018). Well-planned and maintained landscaping is a contributing factor effecting home values positively by adding curb appeal. Curb appeal is defined as the combined quality of the home exterior quality and the landscape appearance including the maintenance (Elam & Stigrall, 2012). Landscaping has the largest return of any home improvement project (Hall and Hodges, 2011). Landscape appearance and maintenance can increase home values between 5% and 20% (Behe, et al., 2005; Elam & Stigrall, 2012). A well-planned landscape can also decrease utility bills through reducing the need for heating and cooling by providing shading and wind reduction (Akbari et al., 2001; Heisler, 1986; Maco et al., 2002; McPherson, 1993). Other benefits of landscape include dust abatement, noise reduction, and a visual barrier, creating a sense of privacy within busy urban areas (Brandle, et al., 2000). Landscapes can be a sanctuary for wildlife and insects.

Landscapes can create atmospheres that are calming, thus reducing stress. Research has shown that both resting heart rate and total mood disturbance (stress) were significantly reduced in cardiovascular rehabilitation patients, when participating in Horticulture Therapy activities such as gardening or just being within the landscape (Ulrich et al., 1991; Rodiek, 2002;

Wichrowski et al., 2005). Warr et al. (2004) showed that home and garden activities created an affective sense of well-being and life satisfaction among older generations of Americans.

The Great Plains region of the U.S. has unpredictable weather and, in recent years has experienced severe drought. Many counties in Kansas have been declared disaster areas within the last decade (Brewer and Love-Brotak, 2012). Greater than 75% of land in the state of Kansas experienced extreme to exceptional drought in 2012-2013 (Fig 1.2; United States Department of Agriculture (USDA), 2013; Brewer and Love-Brotak, 2012). These extremes came in the forms of both high and low temperatures and periods of drought followed by periods of prolonged precipitation. The cycle of extreme drought and then torrential downpours can cause flooding and land degradation when drought has decreased soil absorption rates and land cover. Kansas, specifically, has had temperature extremes ranging from -40C (-40F) in 1905 to 49.4C (121F) in 1936 [Kansas State University (KSU), 2018]. In 2018, temperatures have ranged from a high of 40.55C (105F) to a low of -29.44C (-21F) within the state. Precipitation in Kansas follows a North to South gradient line with a slight tilt to Southwest to Northeast gradient as you move East across the state. Southeast portions of Kansas receive on average 114.3 cm (45in) to 45.72 cm (18 in) in the Southwest (Figure 1.3). In 2018, a portion of the state was declared a disaster area due to flooding that occurred after 27.94 cm (11 in) of rainfall fell over Labor Day weekend. (Kansas Climate Summary September 2018). Even with the rainfall, a good portion of the land in East Central to the Eastern part of Kansas is still experiencing exceptional drought (Figure 1.4; USDA Drought Monitor, 2018).

United States Department of Agriculture plant hardiness zones have recently been updated (2012), the first time since 1990, indicating warmer temperature trends in Northern regions (Heller, 2012). With the change in cold hardiness zones and a seemingly warmer and drier climate for the region, a concerted effort to find ornamental plants that will withstand the rigors of the Great Plains is necessary. These plants should transplant easily, be drought tolerant, and withstand high and low temperatures that commonly occur throughout the region.

Viburnum L. are one of the most highly produced genus of landscape plants according to a recent Census of Horticulture Specialties (USDA, 2014). Nine hundred forty-one producers sold 2.1 million *Viburnum* in 2014, grossing $21.9 million in revenue (USDA, 2014). The species is known for its adaptability to sometimes-harsh environments. It has been on many lists as a plant tolerant of environmental stresses including urban settings due to its adaptability, much of which is anecdotal (Flint, 1985). The sum of flowering (Figure 1.5), attractive foliage, and sometimes radiant fruit, makes *Viburnum* stand above many other shrub genera. There are approximately 160 species of *Viburnum* that have been characterized by their genetic makeup, with several hundred cultivars to choose from within the species (Dirr, 2009). The species is found worldwide. Kenyon (2001) noted over 250 species with 20 from North America, 60 from Central and South America, four from Europe, 30 from North Africa, and the remainder from Asia. *Viburnum* is a diverse genus that exhibits very distinct growth habits that lend to their classification. Within the genus, 10 sections represent all the species (Hara, 1983). The sections are based upon growth and flowering characteristics. All *Viburnum* exhibit two common themes; opposite leaf arrangement and terminal umbel-like or panicle-like corymb inflorescences which form a fruit that is a flattened single seed drupe (Edwards et al., 2014). Characteristics of the species are variable. Habit can be a single stem tree to shrub, evergreen, semi-evergreen, deciduous, and large [18.3 m (60 ft.)] to small [0.91 m (3 ft.)]. Leaves can be small, large, serrated, smooth, lobed, shiny, and hairy, and any combination of the aforementioned attributes. Flowers can be flat-topped cymes to drooping panicles in shades of pink, pure white, and creamy white. Odor can either be intoxicating, unpleasant, or no discernable smell at all. Fruits range in color from green, yellow, orange, red, pink, purple, blue, and black. A mixture of the colors can be found on one infructescence, as in *V. nudum* L. Fruit set is highly dependent on cross-pollination between closely related *Viburnum* species; otherwise, flowers are self-sterile and will not set fruit (Dirr, 2007).

Along with the ability to adapt to varying climates, plants must be aesthetically pleasing or useful within an ornamental landscape setting. Sometimes plants that are well adapted to severe drought or heat conditions are not aesthetically pleasing to homeowners and landscapers. Currently, homeowners are looking for plants that are low-input, low maintenance, and have aesthetically pleasing traits across all seasons. Low-input plants are plants that require little or no supplemental water or fertilizer after establishment. Low-maintenance plants require little pruning, fertilization, or pesticides. These plants tend to grow slower with a compact habit thus reducing the need for maintenance to keep them at the desired shape and size. Aesthetically pleasing plants are, for all intents and purposes, plants that "look good." Flowering time, color, and abundance are important characteristics to be accepted for use within a landscape. With abundant flowering comes, with most plants, abundant fruit set. Fruits make for sometimes-interesting color displays that can range across many colors of the visible spectrum and sometimes are in combinations within one infructescence. The fruit are also attractants to wildlife and can draw them into the home landscape. Fruit can also be edible and be used by the homeowner. Some fruits will only stay on the plant a few weeks while others may last through the winter, adding a color contrast to the winter landscape and extending the season of interest.

Viburnum leaves may persist throughout a growing season or remain indefinitely as with evergreens. Leaf color can be any shade of green, variegated, red, purple, or yellow during the growing season and in deciduous species, may change to varying hues of red, yellow, and orange. Size and texture can be important as well as it dictates the texture the plant plays within a landscape, whether it is a fine/soft texture or a coarse/hard texture. Leaf thickness and life span can be a factor when selecting plants as well. Thin leaves may not be suited for high wind exposure as they tend to become perforated and desiccated when exposed to significant winds. Thick leaves can have a coarse appearance, and cut edges, when pruning, can be an eyesore.

Unfortunately, homeowners and landscape contractors often must rely on anecdotal advice for plants that survive and thrive in their area due to lack of research on establishment for their desired plants. Otherwise, they rely upon research and ratings from resources that may not be an exact fit for their region or microclimate. Consumers then must rely on trial and error to select plants for their landscape which can be costly and time consuming. Universities, industry, and botanical gardens often have research available on plant varieties for landscapes and have found the best method for making recommendations is by using field trials over a several year period (2 to 5 yrs) in native soils (Lindstrom et al., 2001; Jones and Cregg, 2006). Plant trials in the U.S. began in the late 1800's as a means to compare American seed-produced plants with other competitive lines from Europe (Nau, 2007). The premise of a plant trial is based upon the idea of comparison. Trials are used to generate research-based comparisons between species or cultivars to observe growth habit, flowering, fruiting, vigor, pest problems or lack thereof, color, environmental stress tolerance, exposure, and survivability. Trial sites are set up to identify superior selections or cultivars when compared to "industry standard" plants. Trials can also be used to evaluate anecdotal plant selections for regional retailers to ensure research-based evidence for use of the selected plants. If multiple sites are available, as well as resources to effectively manage multiple sites, then a state- or region-wide trial would provide information that could be used to make region-wide recommendations for selected plants. Consumers then will have confidence in recommended plants if they are within those geographic regions.

When conducting region-wide trials, many challenges may arise. Weather will vary across a region, where one area may be extremely dry, other areas may have too much rainfall. Variability in weather is why multiple sites and years are necessary to make recommendations for a region. Widrlechner (1998) identified interactions between moisture index, mean January temperature and mean July temperature that predicted survivability of ornamental landscape plants from Japan across sites in the North Central U.S. Greater than 70% of the variability between sites was due to these three variables with the greatest effect contributed to the moisture index. Greatest percent survival for ornamental landscape plants in the trial was seen in sites with the wettest and warmest climates. Trials also require adequate space, available water, funding, and collaborators that will care for plants using best management practices set forth by the researcher. Even with all the above requirements being met, plants may still fail for unknown reasons. Multiple sites and replication within those sites, allows for anomalies to be accounted for so that recommendations can be made for the region. Researchers, with all the complications of conducting field trials, have investigated ways to trial plants in controlled settings to overcome the challenges of field studies (Adkins, et al., 2002, Dirr and Lindstrom Jr., 1990, Garcia-Navarro, et al., 2004, Sakai, et al., 1986)

Water Stress

Water is the essential resource required for all life and as of recent has become more scarce across parts of the world. Climatologists and researchers agree on the fact that our world is warming at a faster rate than predicted and that mankind plays a role (Barnett et al., 2005). Predictions also state that precipitation will become less available especially across the middle latitudes (Watson et al., 1996). When precipitation does occur, it will be more intense, resulting in more flooding and erosion on already dry soil. Increases in temperature coupled with less moisture will have a significant impact on production agriculture and horticulture alike. Therefore, it is imperative that research is conducted to find landscape plants that can withstand long periods of drought along with increasing temperatures.

Field studies to identify water stress can be difficult to conduct due to the need to exclude uncontrolled precipitation from entering the study site. Rainout shelters or other means of moisture exclusion can and often do fail in keeping water from all plants within a drought study. Effective drought studies can be conducted within a controlled environment, allowing the researcher to withhold water from plants at varying media moisture contents. In doing so, drought can be decoupled from heat and other stresses that may be encountered during a field trial that could otherwise confound results.

Water stress is thought to be one of the main factors contributing to transplant failure or poor overall plant growth (Gilman et al., 1998; Mathers et al., 2007). All transplanted trees and shrubs depend on water that can be retained within the root ball until the root system begins to expand and explore the surrounding soils. Most media are porous, by design, to allow for adequate drainage in a container-grown plant, making the ability of a plant to withstand drought conditions critical when supplemental water is not available. Research has shown that container-grown plants can lose up to 85% of the available moisture to the surrounding soil within one day after transplanting into native soils, with most soilless media only having enough water to sustain a plant for two days after transplant (Nelms and Spomer, 1983; Day and Cary, 1974). Most trees 7.6 cm (3 in) caliper or less can take up to 3 years to establish (Gilman, 1990). Establishment is defined by Gilman (1990), as the point in time where roots begin exiting the root ball into the native soil. In recent years, municipalities have turned to water restrictions more frequently during periods of extended drought, thereby limiting the ability of landowners and industry alike, to irrigate landscape plants. During many periods of extreme drought, land in Kansas has also experienced some of the hottest temperatures on record for the area. Extreme heat can impair a plant's ability to photosynthesize effectively, damage is often compounded when heat is accompanied by periods of drought, therefore limiting the plants ability to grow. Drought can be defined in many ways and is a topic of much discussion. The two major categories of drought either approach drought conceptually or operationally (Wilhite and Glantz, 1985). Conceptually is identifying the boundaries of drought, i.e. a period of time with no moisture. Operational definitions will attempt to predict the onset, length and severity of the drought (Wilhite and Glantz, 1985). Drought often is coupled with period of high heat and sometimes strong drying winds. For the duration of this study drought will be defined as a period of low to no precipitation for a period of time.

Temperature Stress

Temperature stress can elicit a host of responses within a plant. Many plants cannot survive temperatures greater than 45C (113F) for longer than a few minutes as this can cause considerable damage to the photosynthetic light harvesting apparatus (Taiz and Zeiger, 2006). Extreme elevated temperature may cause plants to lose membrane stability allowing cell contents to aggregate with heavy metals and other compounds that have leaked from vacuoles (Berry and Bjorkman, 1980; Bjorkman et al. 1980). Heat stress will cause proteins to unfold or become misfolded which may aggregate together forming Heat shock granules and can cause considerable damage and even cell death when the cells ability to remove these aggregates is hampered (Planas-Marquès et al., 2016; Nakajima and Suzuki, 2013). Elevated temperatures

[>35C (95F)] can cause Ribulose bisphosphate carboxylase/oxygenase (rubisco) activity to decrease which reduces the amount of carbon fixed by photosynthesis (Crafts-Brandner and Law, 2000). A decrease in photosynthesis as well as an increase in respiration from the elevated temperatures effectively starves the plant and can cause the plant to cannibalize itself to create energy. This results in senescing leaves and a reduction in overall plant growth. Heat stress has also been shown to induce several heat shock protein's (HSP's). Although the role of HSP's is not clearly understood, most agree that they play a role in membrane stabilization and cell protection. Protection occurs by maintaining the fluidity of cells by stopping the denaturing of proteins and assisting in the refolding of proteins that have been damaged by elevated temperatures. Research has shown that HSP's are induced at the induction of high temperatures within 3 to 5 minutes and can last several hours after elevated temperatures subside (Sachs and Ho, 1986). An improved thermotolerance has also been shown to occur when a plant is subjected to a heat shock (>40C) for a brief period and then returned to a more optimum temperature (Queitsch et al., 2000). Queitsch (2000) showed that plants subjected to a heat shock treatment were able to maintain a higher rate of photosynthesis at higher temperatures over control plants. A plant's ability to acclimate and maintain photosynthesis under high temperatures by maintaining membrane stability and protecting the light harvesting mechanism is crucial to its ability to survive.

Cold temperatures are also of concern for temperate plants such as some *Viburnum* spp. All plants experience cold stress differently, but most plants experience some kind of temperature stress between 32F -59F (0C-15C; Yadav, 2010). Exposure to these temperatures can elicit a response within 48h – 72h (Yadav, 2010). Phenotypic type responses can be leaf curling, yellowing, necrosis, or reduced overall growth. If exposed for long periods of suboptimal temperatures or during severe cold snaps membranes may be damaged causing electrolyte leakage and disruption of metabolism within cells (Guy, 1990; Yadav, 2010). In response to these temperatures' plants will produce osmolytes to help lower the freezing point of the call and to protect cell membranes from crystallizing (Nayyar et al., 2005; Farook et al., 2009).

Stress Detection

Several techniques have been identified as effective in detecting stress within a plant. The light harvesting mechanism can be easily damaged by stress. Mohammed et al. (1995) showed that chlorophyll fluorescence can be easily measured in the field to do a quick assessment of the functioning of photosystem II with the use of the modulated chlorophyll fluorometer such as the Mini-PAM (WALZ, Effeltrich, Germany). These units' function by emitting a very weak pulse-modulated light from a light emitting diode (LED) that excites fluorescence within the leaf and then exclusively detects the fluorescence from the excited state. Maximal photochemical yield ratio of photosystem II (F_v/F_M) can be measured on dark-adapted leaves (20 min) resulting in a reading that can be used to estimate how stressed a plant is due to the efficiency of non-photochemical quenching (heat dissipation of energy; Maxwell and Johnson, 2000). Typical values for plants that are unstressed and all light harvesting centers are open are within a few hundredths of 0.83 (Björkman, 1987; Johnson et al., 2004). If this system is damaged, light energy (photons) are not captured and used to efficiently to harvest electrons from water molecules. This in return will hinder the photosynthetic process, reducing sugar production used for energy in the plant. Photosystem II is responsible for the splitting of water to evolve oxygen and hydrogen as well as electrons to be used in the production of chemical adenosine triphosphate (ATP) for use in photosynthesis. If the system is damaged light is fluoresced out or is dissipated as sensible heat, creating an imbalance in light energy absorbed for use in photosynthesis. Without the necessary components of photosynthesis, the plant will reduce overall growth and may eventually die.

Purpose and Objectives

It is of interest to provide research-based recommendations for plants that are aesthetically pleasing, provide energy savings by reducing heating and cooling of structures, and are sustainably produced using proven horticultural practices that reduce inputs. These plants should also be easily maintained, requiring minimal inputs of water and fertilizer, as well as being able to withstand the rigors of our ever-changing climates. A relatively quick greenhouse assay of an interesting plant species by subjecting it to the challenges of the trial region will shorten the time and expense required to trial several hundred plants over several years to only find a handful of acceptable species for use in Kanas landscapes. The question we are investigating is, how well do controlled-environment studies for extreme temperature and water stress, correlate with a plant's ability to survive in a field trial? Viburnum was chosen because it is a widely available, popular shrub species, with enough variability in species characteristics to examine environmental stress adaptability in an effort to develop an assay for future plant evaluations.

Tables and Figures

Figure 1.1 Median asking price for homes that were vacant and for sale for the periods of 1995-2018 in the continental United States (U.S. Census Bureau, 2018).

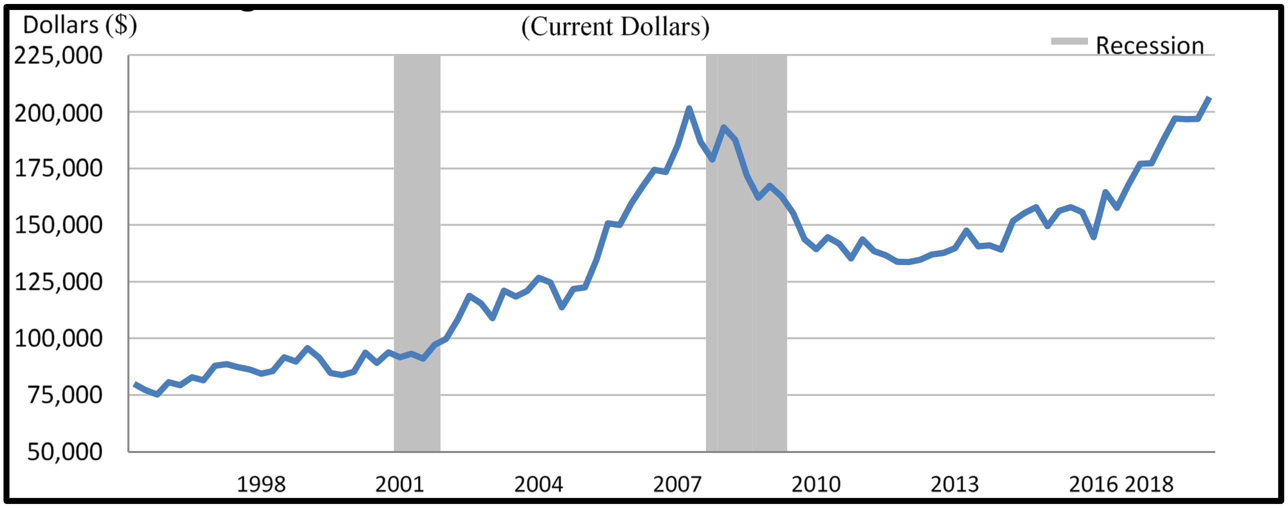

Figure 1.2 United States drought severity conditions during the period ending October 30, 2012.

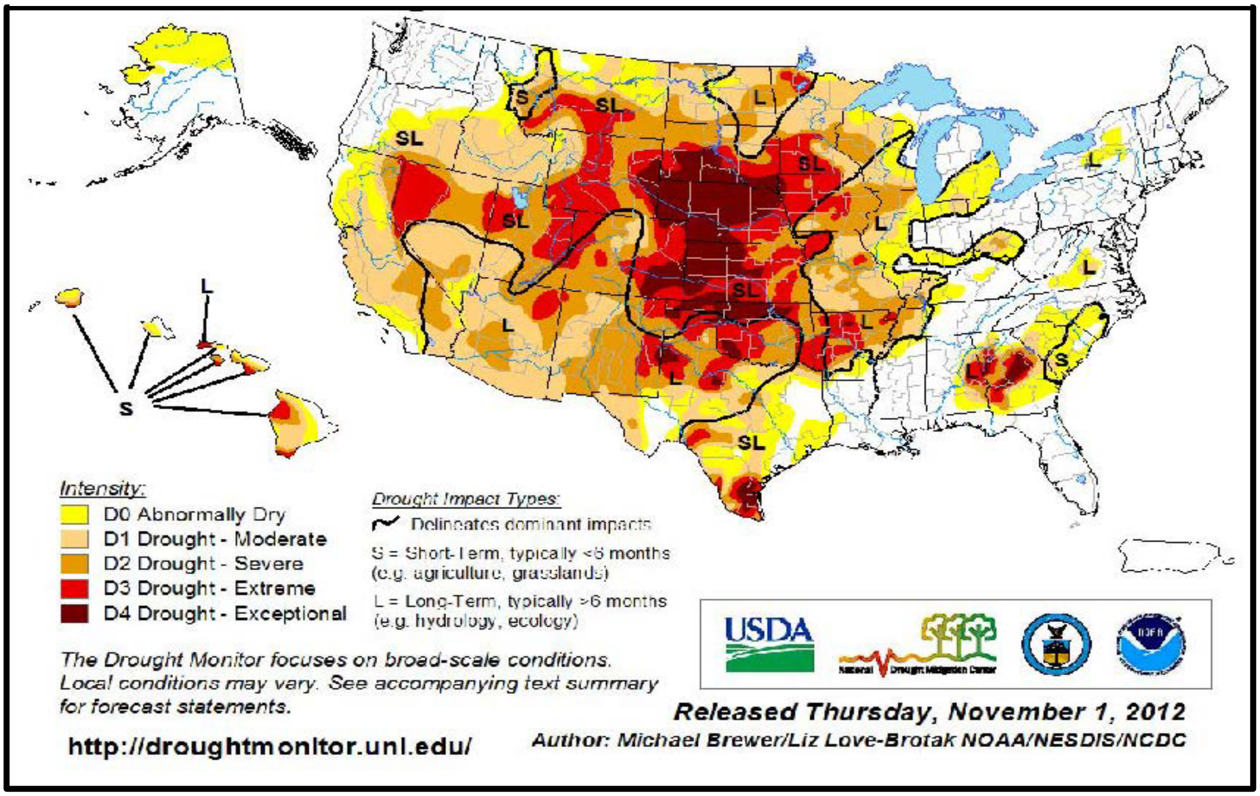

Figure 1.3 Average annual precipitation gradients (in) for the state of Kansas (United States) during the period of 1981-2010.

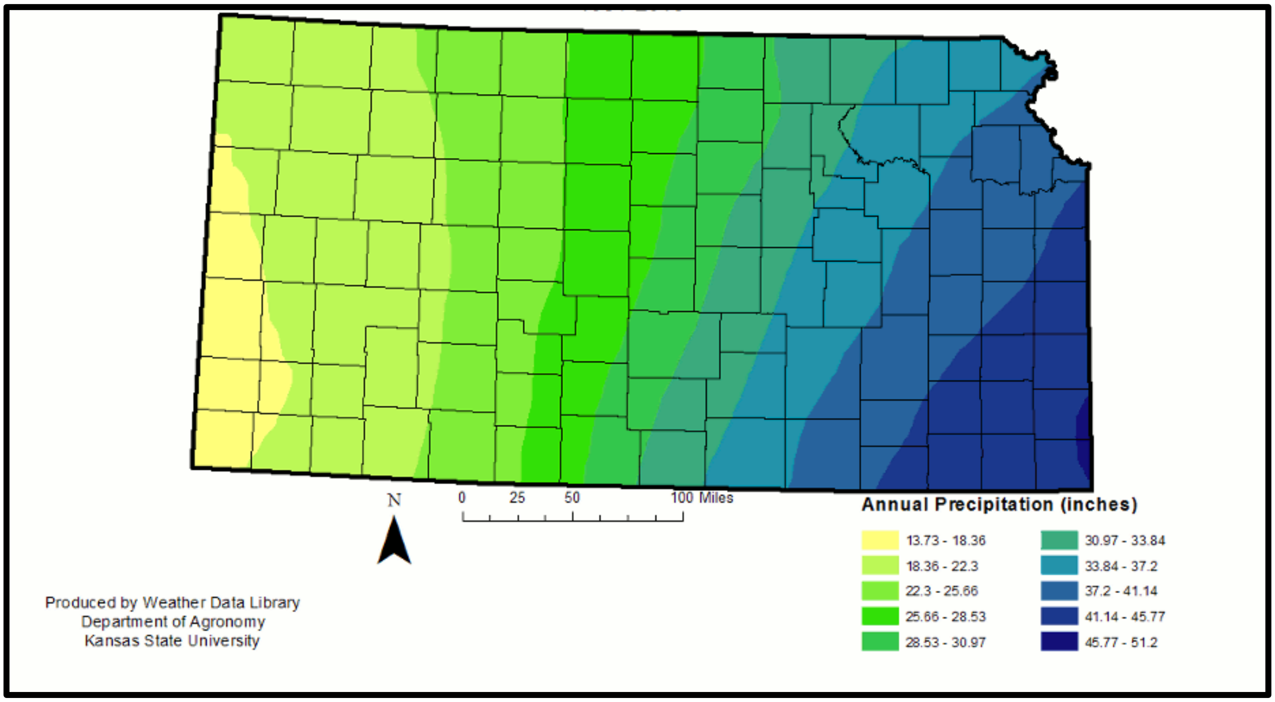

Figure 1.4 Kansas drought severity conditions during the period ending September 11, 2018 following several days of daily precipitation.

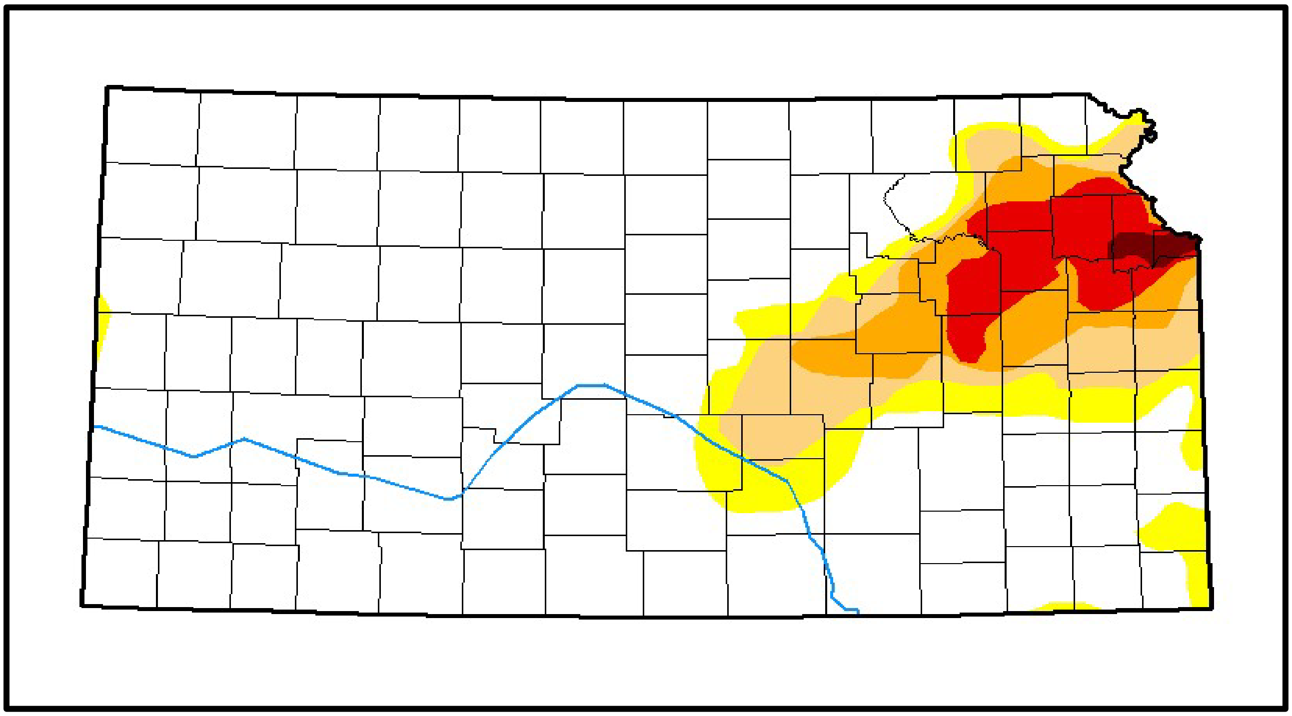

Figure 1.5 ***Viburnum dilatatum*** **'Michael Dodge' exhibiting large, showy flowers the first Spring season (2013) following Fall transplant at the Parsons City Arboretum in Parsons, KS.**

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Chapter 2 - Drought affects physiology and growth of select *Viburnum* spp.

Abstract

The Great Plains can be a challenging environment for ornamental landscape plants. The area can be prone to periods of short-term recurring drought. *Viburnum* plants were potted into 2-gal (6.3 L) containers during the summer of 2012. Drought studies were conducted within a controlled greenhouse environment (Manhattan, KS) during June 2013 and April 2014, respectively. Plants acclimated in a greenhouse maintained at 25C/18C (77F/64F; day/night) for 28 days and were watered as needed until treatments were initiated. *Viburnum awabuki* 'Chindo', *Viburnum dentatum* 'Chicago Lustre', *Viburnum nudum* 'Winterthur', *Viburnum tinus* 'Robustum', *Viburnum trilobum* 'Compactum', and *Viburnum x rhytidophylloides* 'Alleghany' had irrigation withheld to initiate drought conditions of either moderate drought (MD) or severe drought (SD). Moderate drought was determined to be when leaves began to flag, and SD was set as -1.5 megapascal as determined by a Scholander pressure bomb. Results indicate that *V. nudum* responded to drought stress by reducing biomass, though photosynthetic capacity was not significantly affected. *Viburnum dentatum* was able to maintain similar shoot growth with moderate drought (MD) and severe drought (SD), while root growth significantly declined. Root growth was reduced and several of the plants died due to overwatering on *V. tinus* and *V. x rhytidophylloides*. *Viburnum awabuki* reduced growth and photosynthetic rate between treatments. *Viburnum dentatum* and *V. nudum* are species that can withstand drought making them a good choice for areas that experience short-term recurring drought.

Introduction

The Great Plains region of the United States (U.S.) has unpredictable weather and in recent years has experienced severe drought. Many counties in Kansas have been declared disaster areas within the last decade (Brewer and Love-Brotak, 2012). Greater than 75% of the land in the state of Kansas experienced extreme to exceptional drought in 2012-2013 [Fig 2.1; United States Department of Agriculture (USDA); Brewer and Love-Brotak, 2012]. The cycle of extreme drought followed by torrential downpours can cause flooding and land degradation when drought has decreased soil absorption rates and land cover. Precipitation in Kansas follows a North to South gradient line with a slight tilt to Southwest to Northeast gradient as you move East across the state. Southeast portions of that state receive on average 114.3 cm (45 in) to 45.7 cm (18 in) in the Southwest (Figure 2.2). In 2018, a portion of the state was declared a disaster area due to flooding that occurred after 27.9 cm (11 in) of rainfall fell over Labor Day weekend. (Kansas Climate Summary, September 2018). Even with the rainfall, a good portion of the land in East Central to the Eastern part of Kansas is still experiencing exceptional drought (Figure 2.3; USDA Drought Monitor, 2018). Drought can be defined in many ways and is a topic of much discussion. The two major categories of drought either approach drought conceptually or operationally (Wilhite and Glantz, 1985). Conceptually is identifying the boundaries of drought, i.e. a period of time with no moisture. Operational definitions will attempt to predict the onset, length and severity of the drought (Wilhite and Glantz, 1985). Drought often is coupled with period of high heat and sometimes strong drying winds. For the duration of this study drought will be defined as a period of low to no precipitation for a period of time.

No other resource determines plant growth as much as water (Castro et al, 2005; Kozlowski, 1968). Water stress is one of the main factors contributing to transplant failure

(Gilman et al., 1998; Mathers et al., 2007). Frequently, municipalities are turning to water restrictions during periods of extended drought, thereby limiting the ability of consumers to irrigate landscape plants. Therefore, there is a demand for drought-tolerant landscape plants in the Great Plains that establish easily and tolerate a range of environmental stresses. With many of the attributes of *Viburnum* L. being anecdotal, nursery production professionals and consumers desire research-based evidence to expand their plant palette. Ideally, these plants should transplant easily and be able to withstand rigors of the region.

Establishment has been defined by Gilman (1990), as the point in time when roots begin exiting the root ball into surrounding soil. All transplanted trees and shrubs depend on water that can be retained within the root ball until the root system begins to expand and explore native soils. Most media are porous, by design, to allow for adequate drainage in a container-grown plant, making the ability of a plant to withstand drought conditions critical when supplemental water is not available. Research has shown that container-grown plants can lose up to 85% of the available moisture, to the surrounding soil, within 1 day after transplanting into native soils, with most planting media only having enough water to sustain a plant for 2 days after transplant (Nelms and Spomer, 1983; Day and Cary, 1974). Plants that transplant well in the Great Plains then should have the ability to withstand periods of short-term recurring drought as well as longer extended drought periods.

Methods by which plants resist drought vary. Plants may either be drought tolerant, drought resistant, or escape drought by setting seed for propagation (Kooyers, 2015). Drought avoidance is the ability of a plant to complete its entire life cycle prior to moisture becoming limiting (Newton and Goodin, 1989). The plant will allocate all energy into reproduction to prolong its species. All resources will be allocated to set flowers, go to seed, and then senesce if moisture becomes limiting. Drought-tolerant plants change stomatal conductance to compensate for water deficit, as well as place considerable energy into root expansion (Newton and Goodin, 1989). Species that tolerate low water potential accumulate solutes to protect membranes and leaf plasticity while keeping stomata closed to maintain water content. Conversely, a high-water potential drought tolerant plant will reduce stomatal conductance, leaf shape/size, hairs, and the amount of radiation absorbed by in an effort to maintain flow of water at a high-water potential (Newton and Goodin, 1989).

Population growth in the U.S. causes high demand on water supplies with many municipalities issuing water restrictions during periods of drought. With these restrictions occurring, many consumers and landscape contractors desire landscape plants that can survive and thrive in their region. Data on drought-tolerant plants for the Great Plains is limited and a proven method for rapidly determining drought tolerance is needed. The purpose of this study is to develop a tool to help with development of landscape plant recommendations for the Great Plains. *Viburnum* L. was chosen for its wide breadth of interesting aesthetic qualities and that it is widely available in many plant nurseries with enough variability in species characteristics to examine environmental stress adaptability in an effort to develop an assay for future plant evaluations. This study examines the drought tolerance of six *Viburnum* L. species for landscape use in the Great Plains.

Materials and Methods

On 3 May 2012, 64 plants each of *Viburnum awabuki* ‘Chindo’, *Viburnum dentatum* ‘Chicago Lustre’, *Viburnum nudum* ‘Winterthur’, *Viburnum tinus* ‘Robustum’, *Viburnum trilobum* ‘Compactum’, and *Viburnum x rhytidophylloides* ‘Alleghany’ (Table 2.1) rooted liners (192 mL;

(4x8 propagation liner inserts, Landmark Plastics, Akron, OH) had containers removed and potted to 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA). (Spring Meadow Nursery, Grand Haven, MI) filled with an amended pine bark: Eastern redcedar:sand (2:2:1, v/v.). Eastern redcedar (*Juniperus virginiana* L.) is a native conifer species with a native range in the Eastern half of the U.S. It has become a pest to native grasslands in the Great Plains due to its aggressiveness and the ease with which it proliferates from seed (Briggs et al., 2002). Studies to verify its suitability as a substrate media showed that non-native pine bark can be supplemented using this locally available resource (Starr et al., 2012). The substrate was amended with 1.2 $kg \cdot m^{-3}$ (2.0 $lbs \cdot yd^{-3}$) micronutrient package (Micromax®, Scotts, Marysville, OH) and 9.5 $kg \cdot m^{-3}$ (16 $lbs \cdot yd^{-3}$) controlled release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH). Eastern redcedar was ground to a particle size of 9.5 mm (3/8 in.) utilizing a hammermill (Model 30HMBL, C.S. Bell Co., Tiffin, OH). Plants were grown under partial shade (50%) for the remainder of the growing season at the Kansas State University John C. Pair Horticultural Research Center (Haysville, KS). Plants were overwintered in an unheated hoop house covered in white polyurethane plastic and vented with fans when inside temperatures reached 10C (50F) and watered as needed. On 15 June 2012 *V. awabuki* and *V. tinus* were propagated from apical softwood cuttings (Classic Viburnums, Upland, NE). Fully rooted liners were transplanted into 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA) containing the previously mentioned substrate on 15 August 2012. *Viburnum awabuki* and *V. tinus* are southern ecotype viburnums (≥ USDA hardiness zone 7) and consequently were grown out within the greenhouses at the Throckmorton Plant Sciences Center, Kansas State University (Manhattan, KS). Plants were grown under natural photoperiod and irradiance with greenhouse temperatures maintained at 25C/18C (77F/64F; day/night) and watered as needed. Plants were monitored weekly for pests and if found, were controlled with appropriate chemicals, horticultural oils, or cultural controls. *Tetranychus urticae* (spider mites) were found during the trial and water was used to knock them off leaves. On 13 June 2013 plants grown in the cold-frame at John C. Pair Horticulture Center (Haysville, KS) were moved into a glass greenhouse at Throckmorton Plant Sciences Center, Kansas State University (Manhattan, KS), and allowed to acclimate for 4 w. Plants were grown under natural photoperiod and irradiance and watered as needed to avoid moisture stress. Greenhouse temperatures were set to 25C/18C (77F/64F; day/night). Prior to treatment initiation, five plants of each species were selected at random for fluorescence measurements and destructive analysis. Growth data was collected which included: height, width, shoot dry weight, and root dry weight. Growth Index (GI) was calculated as (plant height + maximum plant width + perpendicular plant width) ÷3. Photosynthetic capacity (P_{net}) of each plant was measured using a Li-Cor (Li-Cor, Lincoln, NE) infrared gas analyzer and a climate-controlled cuvette. Cuvette environmental parameters were set to achieve 400 $\mu L \cdot L^{-1}$ CO_2, 2000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (PAR), and leaf temperature near ambient outside air temperature (25C/77F). All plants were irrigated 1 day prior to photosynthetic measurements to minimize stomata limitations. A terminal leaf containing current season's growth was placed in the cuvette and data recorded when carbon assimilation stabilized. Following data collection, plants were destructively harvested, where roots were separated from shoots at the soil line and washed free of substrate. Roots and shoots were then placed in a forced air-drying oven (model SC-400, The Grieve Co., Round Lake, IL) at 65C (149F) and dried to a constant weight.

Similar to methods of Pool et al. (2012), initial substrate water holding capacity was determined by sub-irrigating individual containers in a large reservoir until water was observed glistening on the surface of the container substrate. Water was then allowed to drain slowly from the bottom of the reservoir and containers simultaneously. Containers were allowed to drain 2 hr and then weighed to obtain weight at container capacity (CC). Treatments were initiated on 22 July 2013 by withholding irrigation. Treatments were moderate drought (MD) or severe drought (SD) and were determined by measuring pre-dawn water potentials on a fully expanded excised leaf with a Scholander pressure chamber (Model 600, PMS Instrument Co., Albany, OR). Moderate drought was determined to be when plants exhibited signs of wilt. Severe drought CC treatment was determined, when plants reached -1.5 megapascal [(MPa) -15 bar] with the Scholander pressure chamber. This pressure is considered the permanent wilting point and is considered by many as a measure that is how to overcome. Container weights were then correlated to pre-dawn water potentials to determine percentage water loss and treatment set point (Table 2.1). Once treatment set points were determined plants were weighed daily at 0600. When plants reached one of three predetermined treatments: well-watered control (WW; 90% CC), MD, (Table 2.1) or SD (Table 2.1), they were irrigated back to CC using the sub-irrigation method. Well-watered treatments were watered on alternating days. This repeated drought cycle was continued until termination (22 October 2013).

Growth and photosynthetic measurements began on 22 October 2013. Growth data was collected which included: height (H), width (W), shoot dry weight (SDW), and root dry weight (RDW). Growth Index (GI) was calculated as (plant height + maximum plant width + perpendicular plant width) ÷3. Growth index and Pnet were determined as previously described. Following data collection, plants were destructively harvested, where roots were separated from shoots at the soil line and washed free of substrate. Roots and shoots were then dried as previously described.

The experimental design was a randomized complete block design with five single plant replicates. Data were subjected to ANOVA and means separation using Fisher's Protected LSD at $\alpha = 0.05$ (SAS Institute Inc., Cary, NC). No statistical comparisons were made between species.

Results and Discussion

At the time of treatment initiation, roots occupied distinctively different volumes within the container (Table 2.2). The volume occupied by roots within the containers correlated with how rapidly the media was depleted of available water. *Viburnum nudum* [69.9 g (2.5 oz)], *V. dentatum* [38.3 g (1.4 oz)], and *V. awabuki* [23.4 g (0.8 oz)] had the largest root systems, respectively, reaching initial treatment set points more rapidly. Conversely, *V.* x *rhytidophylloides* [13.3 g (0.5 oz)], *V. trilobum* [10.0 g (0.4 oz)], and *V. tinus* [4.2 g (0.1 oz)] were the smallest and took the longest to reach treatment set points, respectively. Throughout the duration of the experiment WW plants (90%) were watered on alternating days, much to the detriment of *V.* x *rhytidophylloides* as the percent survival of 0% indicated that the plant does not tolerate wet soils and the root systems rotted. Species reached MD and SD at differing frequencies and had differing percent container capacities (Table 2.1) based on when the plant showed signs of wilt. Frequency of reaching set point prior to trial termination were as follows: *V. dentatum* (19 times MD, 8 times SD), *V. nudum* (20 times MD, 11 times SD), *V.* x *rhytidophylloides* (3 times MD, 2 times SD), *V. awabuki* (15 times MD, 7 times SD), *V. tinus* 'Robustum' (5 times MD, 2 times SD), and *V. trilobum* (8 times MD, 5 times SD).

Viburnum trilobum was able to maintain SDW and RDW from control to MD yet significantly reduced growth when experiencing SD (Table 2.3). The species shed leaves when experiencing both MD and SD, but visible green turgid buds were observed, leading us to believe that once moisture returned the species would recover. Plants that experienced MD also had a lower SDWS/RDW (S/R) ratio indicating that plants were compensating for drought by extending root growth to mine for available moisture, yet SD was no different than control. With the still-viable buds and evidence of root extension, the plant may be able to recover from drought once moisture returns.

Viburnum dentatum (Table 2.4) and *V. awabuki* (Table 2.8) were able to maintain similar shoot growth with MD and SD, while root weight significantly declined resulting in a 62%, 85%, 38%, and 63% reduction, respectively (Table 2.4, 2.8). Visual observation of *V. dentatum* during the study revealed that the species shed leaves when drought stressed and once a rewetting occurred, would produce a new flush of leaves. This maintained shoot growth but resulted in a reduction causing a significant difference between treatments for *V. dentatum* with respect to S/R. With the resulting reduction in S/R the plant may be a drought escaper (drought tolerant), as photosynthesis was not affected on a per area basis by treatment. While S/R increased for *V. awabuki* from control to SD, there was no difference between control and MD. Photosynthesis was lower for plants in MD and SD than control plants for both treatments with no difference between MD and SD. This reduction in carbon assimilation coupled with reduction in both roots and shoots indicates an attempt to avoid drought by shutting metabolic processes down to hold onto any available water in the media and maintain functionality of photosynthetic systems. With no reduction in S/R, *V. awabuki* may be able to tolerate MD and still recover once water becomes available again. The significant reduction in root growth and carbon assimilation when experiencing SD may make recovery difficult for *V. awabuki*.

Results indicate that *V. nudum* was the most responsive to treatment across all 6 species. It responded to drought stress by significantly reducing biomass (roots and shoots), though photosynthetic capacity was not significantly affected (Table 2.5). Shoot dry weight was reduced by 47% (MD) and 77% (SD), while RDW was reduced 65% (MD) and 87% (SD). Growth index was also reduced due to drought treatment between control, MD, and SD, while S/R increased from the control to MD with no difference from SD, indicating more energy was put into above ground tissue. Reductions in shoot growth were to be expected as shoot growth is dependent on ample water being available to maintain cell turgidity and sustained growth. The increase in S/R was unexpected and indicates that root growth had slowed at a faster rate than shoot growth as the plant transitioned into severe drought. This may have been an attempt to tolerate drought and sustain life by prioritizing above ground growth to capture light for photosynthesis and energy production that it could then store if it were to go dormant. Hinckley et al. (1983) noted that *V. lantana* L. maintained stomatal conductance during periods of drought and was shallow rooted, leading them to believe that the species tolerated drought while other species avoided drought by reducing stomatal conductance. The species is native to the Eastern U.S. where it must out-compete larger trees as it is an understory shrub. The ability to maintain photosynthesis on a per area basis and maintain above ground growth at a slower rate than the control may be an effort to capture as much energy as possible to store or to go into a reproductive phase and set seed. This ability to flower and set seed rapidly has been studied and classified as drought escape (Ludlow, 1989). With the plant either tolerating or escaping drought, its ability to maintain this pattern and recover in following seasons may be difficult.

Viburnum x rhytidophylloides experienced significant losses across all treatments and control. Percent survival was 0%, 60%, 40% for control, MD, SD, respectively (Table 2.6). This evidence suggests that the species does not tolerate either being well-watered or in a severe drought. *Viburnum x rhytidophylloides* took the longest to reach the SD set point (40 days).

These losses may be a result of the acclimation period causing damage to the root systems prior to treatment initiation. This would have resulted in poor water uptake by all treatments and led to the length of time it took the plant to reach treatment set points.

Viburnum tinus exhibited no differences between control and drought treatment for RDW while the species had a significant difference between control and MD/SD for SDW (Table 2.7). Plants subjected to SD shed their leaves during the study and none of the replicates survived. Plants subjected to MD also significantly reduced their photosynthetic capacity compared to control plants on a per area basis. This resulted in less carbohydrates for energy to grow resulting in a lower S/R ratio. With no survival when subjecting the plant past wilt, down to 40% CC, *V. tinus* may not be a good choice for the Great Plains considering the frequency with which the region experiences sometimes severe extended drought conditions.

Conclusions

The data herein suggest that *V. dentatum*, *V. nudum*, and *V. trilobum* are species that have potential to be recommended as drought-tolerant species able to withstand the rigors of the Great Plains, specifically Kansas. With the three shrubs being deciduous, their ability to shed leaves, go dormant and then recover once moisture returns is to their advantage. *Viburnum dentatum* and *V. nudum* also were able to maintain photosynthesis across all treatments leading us to believe that the plants can tolerate periods of short-term drought without detrimental effects on plant physiology so that once moisture returns the plants can begin vigorously growing. *Viburnum tinus*, *V. awabuki*, and *V. x rhytidophylloides* exhibited significant challenges when managing drought and overwatering. *Viburnum awabuki* exhibited the most promise to be used in the Great Plains but it is a Southern ecotype selection that will have difficulty acclimating to the cold winter temperatures of the region. Further studies on the ability of *V. awabuki* to survive the cold temperatures of the region would be of interest. To recommend *V. x rhytidophylloides* further studies are needed paying close attention to the well-watered treatment to ensure that the root system is not subjected to flooding conditions causing root damage prior to drought treatment. Pests were also a problem for the deciduous species that caused *V. dentatum* and *V. trilobum* to shed leaves throughout the study. Water was used to knock them off the leaves, but a severe infestation caused considerable leaf drop, making photosynthetic measurements impossible on *V. trilobum*. From this study, a field trial of *V. dentatum*, *V. nudum*, and *V. trilobum* can be recommended to evaluate the survival of the species over several years to account for the variability in the Great Plains climate and the many environmental stresses that can be encountered.

Tables and Figures

Figure 2.1 United States drought severity conditions for the period ending October 30, 2012.

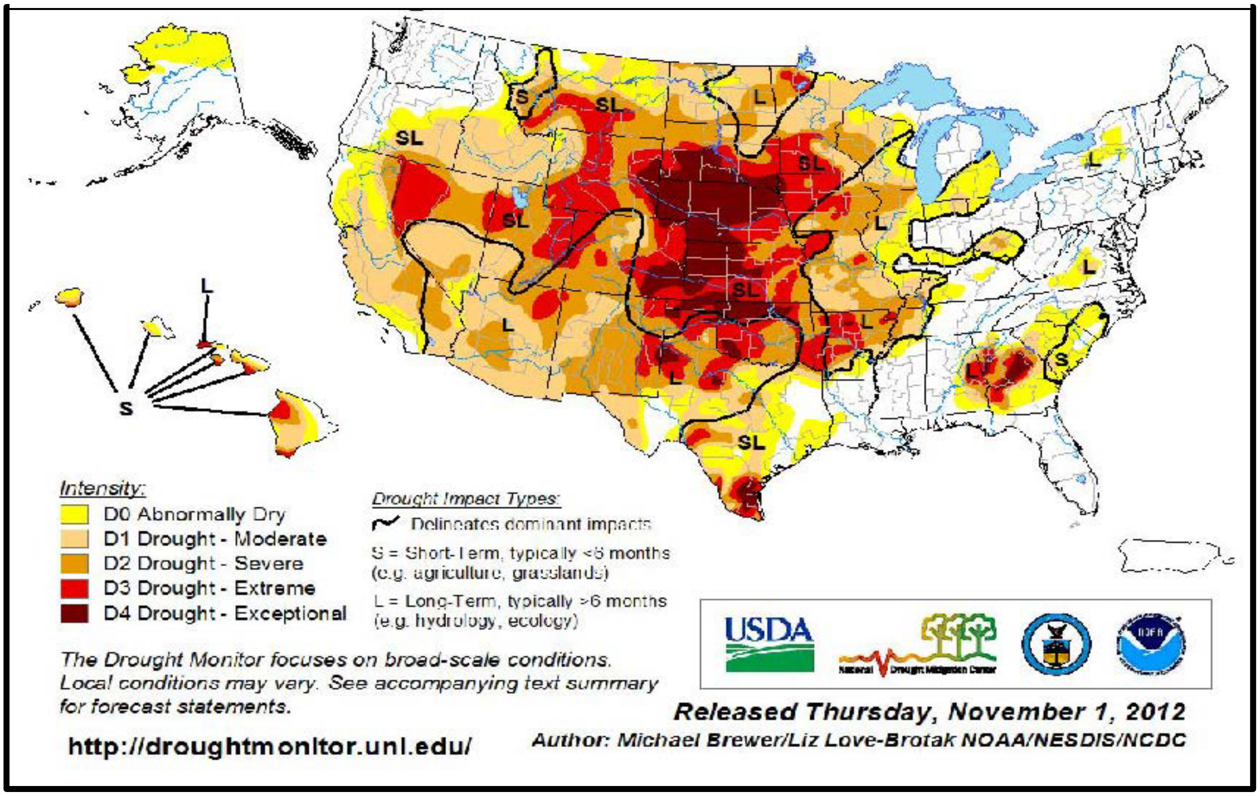


Figure 2.2 Average annual precipitation gradients (in) for the state of Kansas (United States) during the period of 1981-2010.

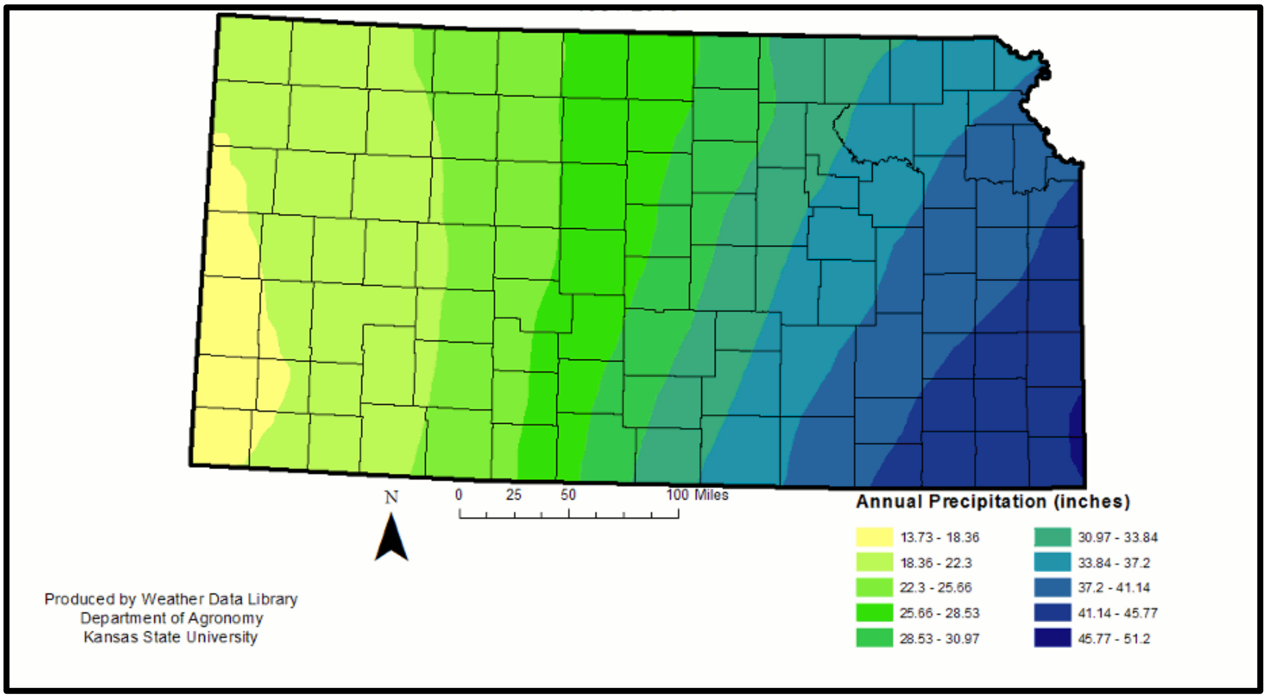
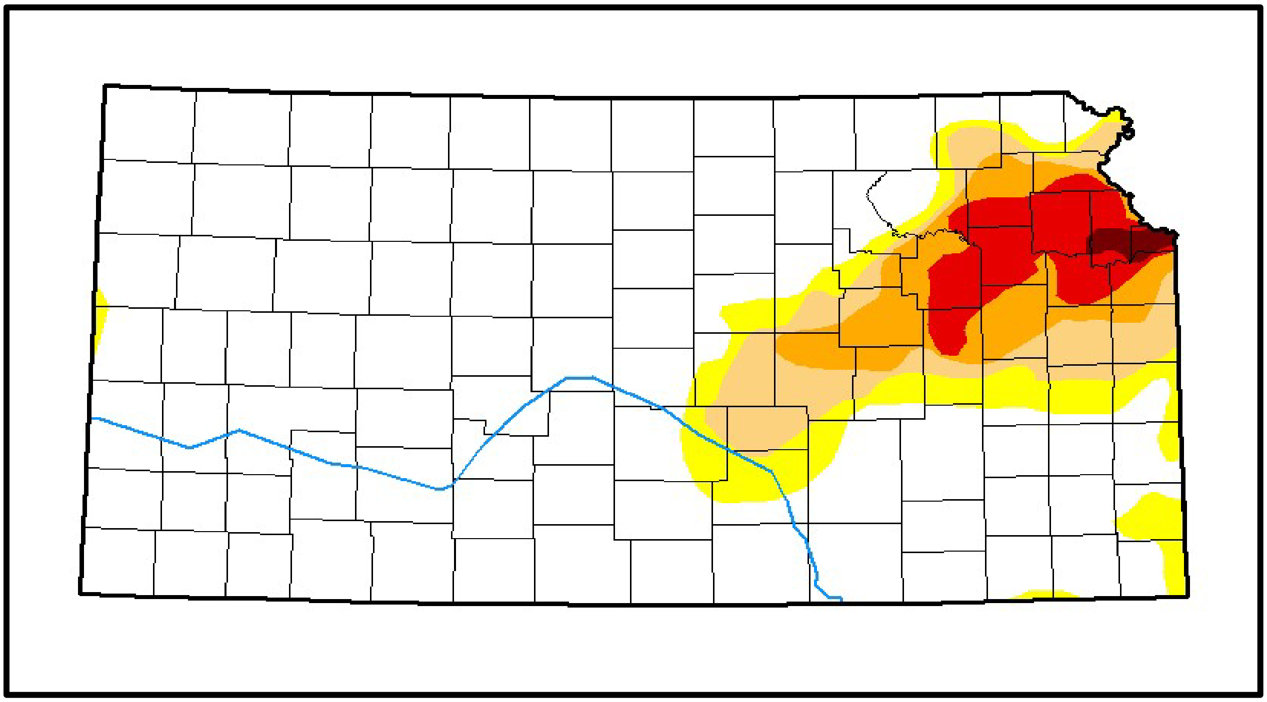


Figure 2.3 Kansas drought severity conditions September 11, 2018 following several days of daily precipitation.



Courtesy http://droughtmonitor.unl.edu/

Table 2.1 Selected *Viburnum* species and corresponding treatment percent container capacity (CC) determined by pre-dawn water potentials using a Scholander pressure bomb chamber in the Kansas State University Throckmorton Plant Sciences Center greenhouse complex (Manhattan, KS).

Common name	Latin name	Moderate Drought[Z] % CC	Severe Drought[Y] % CC
Arrowwood Viburnum	*V. dentatum* ‘Chicago Lustre’	75%	68%
Smooth Witherod	*V. nudum* ‘Winterthur’	75%	68%
Lantanaphyllum Viburnum	*V.* x *rhytidophylloides*	72%	66%
Laurustinus	*V. tinus* ‘Robustum’	68%	60%
American Cranberrybush	*V. trilobum* ‘Compactum’	65%	60%
Awabuki Viburnum	*V. awabuki* ‘Chindo’	70%	63%

[Z] Moderate drought was determined when signs of wilt was observed

[Y] Severe drought was determined when plants reached -15 bar using a Scholander pressure chamber

Table 2.2 Initial height (Ht), shoot dry weight (SDW), root dry weight (RDW), and growth index (GI) of *Viburnum trilobum* 'Compactum', *Viburnum dentatum* 'Chicago Lustre', *Viburnum nudum* 'Winterthur', *Viburnum rhytidophylloides* 'Alleghany', *Viburnum tinus* 'Robustum', and *Viburnum awabuki* 'Chindo' at treatment initiation.

	V. trilobum 'Compactum'	*V. dentatum* 'Chicago Lustre'	*V. nudum* 'Winterthur'	*V. x rhytidophylloides* 'Alleghany'	*V. tinus* 'Robustum'	*V. awabuki* 'Chindo'
Ht (cm)	31.6	98.8	83.6	45.4	43.6	43.8
SDW (g)	11.04	101.64	122	31.94	17.08	88.46
RDW (g)	10.04	38.32	69.86	13.28	4.2	23.44
GI^Z	24.53	102	96.53	39.46	31.93	66.86

^{Z}(plant height+maximum plant width+perpendicular plant width)÷ 3 in cm

n=5

Table 2.3 Growth parameters of *Viburnum trilobum* 'Compactum' following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	18.2**a^{Y}	19.8a	11.2b
Shoot weight (g)	17.6**a	15.2a	11.8b
Growth Index^{z}	29.7*a	23.7a	18.5b
P_{net} (mmol CO^2•m^{-2}•s^{-1})	2.4^{NS}	.	.
S/R ratio	2.1**b	1.8b	2.7a

^{NS}, **, * Not significant, significant at $P \leq 0.01$, or significant at $P \leq 0.05$

^{Z}(Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

^{Y}Means followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

Table 2.4 Growth parameters of *Viburnum dentatum* 'Chicago Lustre' following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences Center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	159.2**a^{Y}	60.0b	23.8c
Shoot weight (g)	138.8**a	85.4b	74.4b
Growth Index^{Z}	129.7**a	86.7b	82.9b
P_{net} (mmol CO^2•m^{-2}•s^{-1})	2.1^{NS}	3.8	2.8
S/R ratio	0.9**b	1.5b	3.7a

^{NS}, **, * Not significant, significant at $P\leq 0.01$, or significant at $P\leq 0.05$

^{Z}(Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

^{Y}Means followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

Table 2.5 Growth parameters of *Viburnum nudum* 'Winterthur' following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences Center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	286.0** a[Y]	100.0b	37.4c
Shoot weight (g)	235.0** a	125.6b	52.6c
Growth Index[Z]	114.8** a	90.5b	72.6c
P_{net} ($mmolCO^2 \cdot m^{-2} \cdot s^{-1}$)	9.0[NS]	9.3	6.7
S/R ratio	0.9* b	1.3a	1.5a

[NS], [**], [*] Not significant, significant at *P≤0.01*, or significant at *P*≤0.05

[Z](Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

[Y]Means followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

Table 2.6 Growth parameters of *Viburnum* x *rhytidophylloides* 'Alleghany' following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	8.8^{NSY}	8.0	8.8
Shoot weight (g)	21.8^{NS}	18.2	24.8
Growth Index^{Z}	40.7^{NS}	34.7	40.1
P_{net} ($mmolCO^2 \cdot m^{-2} \cdot s^{-1}$)	$.^{NS}$	1.8	1.1
S/R ratio	2.8^{NS}	2.8	2.9

^{NS}, **, * Not significant, significant at $P \leq 0.01$, or significant at $P \leq 0.05$

^{Z}(Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

^{Y}Means followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

Table 2.7 Growth parameters of *Viburnum tinus* 'Robustum' (southern ecotype sp.) following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	30.4^{NS}	15.2	11.8
Shoot weight (g)	$106.6^{*}a^{Y}$	62.2b	54.0b
Growth Index^{Z}	$65.1^{*}a$	56.7b	56.3b
P_{net} (mmol CO^2•m^{-2}•s^{-1})	$7.0^{*}a$	2.8b	.
S/R ratio	4.1^{NS}	4.5	4.7

^{NS}, **, * Not significant, significant at *P≤0.01*, or significant at *P*≤0.05

^{Z}(Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

^{Y}Means followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

Table 2.8 Growth parameters of *Viburnum awabuki* 'Chindo' following the treatment of plants to moderate and severe drought in the Kansas State University Throckmorton Plant Sciences center greenhouse complex (Manhattan, KS).

	Well Watered	Moderate Drought	Severe Drought
Root weight (g)	107.2**a[Y]	67.0b	39.4c
Shoot weight (g)	224.8**a	118.2b	106.6b
Growth Index[Z]	92.1**a	77.9b	75.3b
P_{net} ($mmolCO^2 \bullet m^{-2} \bullet s^{-1}$)	8.4**a	3.5b	3.8b
S/R ratio	2.1**b	1.8b	2.7a

NS, **, * Not significant, significant at *P≤0.01*, or significant at *P*≤0.05

Z(Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

YMeans followed by a different letter within a species and within a row are significantly different based on Fisher's Protected LSD (α = 0.05), n=5

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Chapter 3 - Heat affects physiology and leaf greenness of selected *Viburnum* spp.

Abstract

The Great Plains can be a challenging environment for ornamental landscape plants. The area can be prone to periods of high temperatures. *Viburnum* plants were potted into 2-gal (6.3 L) containers during the summer of 2012. Drought studies were conducted within a controlled greenhouse environment (Manhattan, KS) during June 2013 and April 2014, respectively. Plants acclimated in a greenhouse maintained at 25C/18C (77F/64F; day/night) for 28 days and were watered as needed until treatments were initiated. Heat trials were conducted within a controlled greenhouse environment (Manhattan, KS) April 2014. *Viburnum dentatum, V. nudum*, and *V. tinus* were then exposed to high temperatures in a greenhouse maintained at 38C /25C (100/77F) day/night for 28 days and were watered as needed prior to photosynthetic measurements. Plants then had photosynthetic rates measured at increasing temperatures from 20C to 45C in 5C increments. Whole plant responses to increased day/night temperatures during acclimation prior to temperature curve measurements resulted in growth of all species slowing compared to control plants. SPAD decreased in plants exposed to high temperatures. All acclimated plants exhibited increased temperature optimum for P_{net} with a less severe rate of increase and decline when compared to control. These species can withstand high temperatures and effectively maintain growth and photosynthesis to sustain life making them a candidate for filed trials in Kansas.

Introduction

Homeownership rates have begun to climb after a 12-year decline ending in 2016 (United States (U.S.) Census Bureau, 2018). In the third quarter of 2018, homeownership rates were 64.3%, with a national average vacancy rate dipping down to 1.6% (U.S. Census Bureau, 2018). The Midwest U.S. had the highest home ownership rates across the US, 69.0% (U.S. Census Bureau, 2018). Median asking prices of homes continue to climb out of the recent housing slump that bottomed out in 2013, currently the median asking price is $206,400 United States dollars (Figure 3.1; U.S. Census Bureau, 2018). Well-planned and maintained landscaping is a contributing factor effecting home values positively by adding to curb appeal and has the largest return of any home improvement project (Hall and Hodges, 2011). Curb appeal is defined as the combined quality of the home exterior quality and the landscape appearance including the maintenance (Elam and Stigrall, 2012). Landscape appearance and maintenance can increase home values between 5% and 20% (Behe, et al., 2005; Elam & Stigrall, 2012). A well-planned landscape can also decrease utility bills through reducing the need for heating and cooling by providing shading and wind reduction (Akbari et al., 2001; Heisler, 1986; Maco et al., 2002; McPherson, 1993). Other benefits of landscape include dust abatement, noise reduction, and a visual barrier, creating a sense of privacy within busy urban areas (Brandle, et al., 2000). Landscapes are also a sanctuary for wildlife and insects.

The world climate has seen an increase in carbon dioxide (CO_2) and a shift toward a warmer climate (Shen et al., 2011; Pan et al., 2015). Review of climate data has shown the rate for mean high temperature range from 0.19C to 0.25C increase per decade over a 50 year and 30-year period, respectively (Papalexiou et al., 2018). Kansas, specifically, has had temperature extremes ranging from -40C (-40F) in 1905 to 49.4C (121F) in 1936 (Kansas State University, 2018). In 2018, temperatures have ranged from a high of 40.5C (105F) to a low of -29.4C (-21F) within the state. With the mean temperature continuing to increase and periods of extreme heat becoming more frequent while lasting several days to weeks, it is important to find landscape plants that can withstand the rigors of today's environment and while being aesthetically pleasing.

Temperature stress can elicit a host of responses within a plant. Many plants cannot survive temperatures greater than 45C (113F) for longer than a few minutes as this can cause considerable damage to the photosynthetic light harvesting apparatus (Taiz and Zeiger, 2006). Extreme elevated temperature may cause plants to lose membrane stability allowing cell contents to aggregate with heavy metals and other compounds that have leaked from vacuoles (Berry and Bjorkman, 1980; Bjorkman et al. 1980). Heat stress will cause proteins to unfold or become misfolded which may aggregate together forming Heat shock granules and can cause considerable damage and even cell death when the cells ability to remove these aggregates is hampered (Planas-Marquès et al., 2016; Nakajima and Suzuki, 2013). Elevated temperatures [>35C (95F)] can cause Ribulose bisphosphate carboxylase/oxygenase (rubisco) activity to decrease which reduces the amount of carbon fixed by photosynthesis (Crafts-Brandner and Law, 2000). A decrease in photosynthesis as well as an increase in respiration from the elevated temperatures effectively starves the plant and can cause the plant to cannibalize itself to create energy. This results in senescing leaves and a reduction in overall plant growth. Heat stress has also been shown to induce several heat shock protein's (HSP's). Although the role of HSP's is not clearly understood, most agree that they play a role in membrane stabilization and cell protection. Protection occurs by maintaining the fluidity of cells by stopping the denaturing of proteins and assisting in the refolding of proteins that have been damaged by elevated temperatures. Research has shown that HSP's are induced at the induction of high temperatures within 3 to 5 minutes and can last several hours after elevated temperatures subside (Sachs and Ho, 1986). An improved thermotolerance has also been shown to occur when a plant is subjected to a heat shock (>40C) for a brief period and then returned to a more optimum temperature (Queitsch et al., 2000). Queitsch (2000) showed that plants subjected to a heat shock treatment were able to maintain a higher rate of photosynthesis at higher temperatures over control plants. A plant's ability to acclimate and maintain photosynthesis under high temperatures by maintaining membrane stability and protecting the light harvesting mechanism is crucial to its ability to survive.

A quick greenhouse-based assay using temperature curves can assist with selecting plants that will withstand the rigors of our climate and become candidates for longer field trials prior to putting into wholesale plant production. *Viburnum* was chosen because of its wide breadth of aesthetic characteristics and it is widely produced. The purpose of this physiological adaptability trial is to find *Viburnum* species that can tolerate increasing heat and acclimate by increasing the optimum temperature for photosynthesis while maintaining growth and to test the assay for use as a tool to quickly identify plants that can tolerate environmental stresses and be advanced to field trials.

Materials and Methods

On 3 May 2012, 20 plants each of 6 *Viburnum* spp. (Table 3.1) rooted liners (192 mL; (4x8 propagation liner inserts, Landmark Plastics, Akron, OH) had containers removed and potted to 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA). (Spring Meadow Nursery, Grand Haven, MI) filled with an amended pine bark: Eastern redcedar:sand (2:2:1, v/v/v). Eastern redcedar (*Juniperus virginiana* L.) is a native conifer species with a native range in the Eastern half of the U.S. It has become a pest to native grasslands in the Great Plains due to its aggressiveness and the ease with which it proliferates from seed (Briggs et al., 2002). Studies to verify its suitability as a substrate media showed that non-native pine bark can be supplemented using this resource (Starr et al., 2012). Rooted liners were produced in 192 mL (4x8 propagation liner inserts, Landmark Plastics, Akron, OH) containers that were removed and planted to 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA). Media consisted of pine bark: Eastern redcedar : sand (2:2:1, v/v/v) amended with 1.2 $kg \cdot m^{-3}$ (2.0 $lbs \cdot yd^{-3}$) micronutrient package (Micromax®, Scotts, Marysville, OH) and 9.5 $kg \cdot m^{-3}$ (16 $lbs \cdot yd^{-3}$) controlled release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH). Eastern redcedar was ground to a particle size of 9.5 mm (3/8 in.) using a hammermill (Model 30HMBL, C.S. Bell Co., Tiffin, OH). Plants were grown under partial shade (50%) for the remainder of the growing season at the Kansas State University John C. Pair Horticultural Research Center (Haysville, KS). Plants were overwintered in an unheated hoop house covered in white polyurethane plastic and vented with fans when inside temperatures reached 10C (50F). On 15 June 2012 *V. awabuki* 'Chindo' and *V. tinus* 'Robustum' were propagated from apical softwood cuttings (Classic Viburnums, Upland, NE). Fully rooted liners were transplanted into 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA) containing the previously mentioned media on 15 August 2012. *V. awabuki* and *V. tinus* are southern ecotype *Viburnum* species (≥ USDA hardiness zone 7) and consequently were grown out within the greenhouses at the Throckmorton Plant Sciences Center, Kansas State University (Manhattan, KS). Plants were grown under natural photoperiod and irradiance with greenhouse temperatures maintained at 25C/18C (77F/64F; day/night) and watered as needed. Plants were monitored weekly for pests and if found, were controlled with appropriate chemicals, horticultural oils, or cultural controls. *Tetranychus urticae* (spider mites) were found during the stress trial and water was used to knock them off the leaves when possible. On 13 June 2013 plants grown in the cold-frame were moved into a glass greenhouse at Throckmorton Plant Sciences Center, Kansas State University (Manhattan, KS), and allowed to acclimate for 4 w. Plants were grown under natural photoperiod and irradiance and watered as needed to avoid moisture stress. Greenhouse temperatures were set to 25C/18C (77F/64F; day/night). Prior to treatment initiation, five plants of each species were selected at random for fluorescence measurements and destructive harvest.

Growth data was collected which included: height (H), width(W), shoot dry weight (SDW), and root dry weight (RDW). Growth Index (GI) was calculated as (plant height + maximum plant width + perpendicular plant width) ÷3. SPAD chlorophyll meter (model SPAD 502, Spectrum Technologies, Aurora, IL) was used to take measurements on five fully expanded leaves to get an indicator of leaf greenness. Photosynthetic capacity (P_{net}) of each plant was measured using a Li-Cor (Li-Cor, Lincoln, NE)) infrared gas analyzer and a climate-controlled cuvette. Cuvette environmental parameters were set to achieve 400 $\mu L \cdot L^{-1}$ CO_2, 2000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (PAR), and leaf temperature near ambient outside air temperature (25C/77F). Following data collection, plants were destructively harvested, where roots were separated from the shoots at the soil line and washed free of substrate. Roots and shoots were then placed in a forced air-drying oven (model SC-400, The Grieve Co., Round Lake, IL) at 65C (149F), dried to a constant weight, and subsequently weighed.

On 22 July 2013, temperatures within the greenhouse were raised to a minimum 38C /25C (100/77F) day/night to expose plants to high temperatures. Plants were allowed to acclimate for 28 days. During this period plants were irrigated as needed to eliminate drought stress. Measurements commenced following the high heat exposure period to capture the plants' photosynthetic response to temperature extremes.

After the high heat exposure period growth and physiological data identical to the initial measurements were taken. Similar to the method of Ranney and Ruter (1997), potential photosynthetic capacity (P_{net}) was determined by measuring photosynthesis during increasing leaf temperature under saturating CO_2 (2000 $\mu L \bullet L^{-1}$) and saturating photosynthetically active radiation (*PAR*; 2000 $\mu mol \bullet m^{-2} \bullet s^{-1}$) with a CIRAS-1 (PP Systems, Haverhill, MA) infrared gas analyzer and a climate-controlled cuvette. A recently matured terminal leaf was placed in the controlled atmosphere cuvette at 20C (68F) and allowed 20 min for carbon assimilation to stabilize before the first reading was taken. The temperature was then raised in 5 degree increments from 20C (68F) to 45C (113F) with a reading taken at each incremental raise after a 20 min acclimation period. Following data collection, plants were destructively harvested and dried as previously described. The 2013 plant trial had damage from *Tetranychus urticae* (spider mites) potentially impacting the data, therefore the trial was repeated May 2014 using species that were performing well in the field trial. The species selected for the repeated trial were *V. dentatum, V. nudum,* and *V. tinus*. The experimental design and protocol were followed as described with only data from the 2014 trial presented.

The experimental design was a randomized complete block design with five single plant replicates. Temperature response was set up as a split plot with the whole plot being greenhouse temperature and the split being leaf temperature. Data were subjected to ANOVA and means separated using Tukeys Studentized T test $P \leq 0.05$ (SAS v. 9.2, SAS Institute Inc., Cary, NC). No statistical comparisons were made between species.

Results and Discussion

Initial trial plants (2013) were detrimentally affected during heat exposure by an infestation of *Tetranychus urticae* (spider mites) resulting in several of the deciduous species dropping leaves or severe yellowing. Data was inconclusive and could not be attributed to the treatment (data not shown). A second, identical trial was conducted on two species that were thriving in the field trial and a southern ecotype (*V. tinus*) during the period of 2014 April/May, which data is presented herein.

Whole plant responses to increased day/night temperatures during heat exposure prior to photosynthesis measurements resulted in growth of all species slowing compared to control greenhouse temperatures. *Viburnum nudum* exhibited the most response to heat by reducing both RDW (1.82 g) and SDW (5.44 g) as well as overall size as measured by GI (30.2) for exposed plants (Table 3.2). Even with reduced growth the shoot/root ratio (S/R) was not affected, indicating the plant was able to maintain a similar but slower growth rate as control plants. SPAD, a measure of leaf greenness, was reduced which may have led to a decreased P_{net} as exhibited in the temperature curve slopes. Control plants had a 60% difference over heat exposed plants in rate of assimilation even though temperature optimum (T_{opt}) per the quadratic equation was 32.5C (90.5F) and 41.8C (107.2F), respectively (Fig. 3.2). The apparent adaptation to heat and the ability to maintain carbon assimilation after being exposed to high heat is indicative of this species and its native range, which is along the Eastern coast of the United States, West to Kentucky from Georgia to Eastern Texas, with a USDA hardiness zone rating of 5-9 it has been known to survive -29C (-20F) in Illinois (Dirr, 2008). Its native habitat has an acidic soil, boggy, humid area but has strong ability to adapt to drought (Pool et al., 2019).

Viburnum dentatum exhibited similar responses as *V. nudum* with reduced biomass accumulation in both RDW (1.96 g) and SDW (6.88 g) for heat exposed plants, yet GI (36.47) was no different than control plants resulting in plants that were similar in size but less dense (Table 3.2). Shoot/Root ratio decreased from control to heat exposed, indicating an increase in root production. SPAD (model SPAD 502, Spectrum Technologies, Aurora, IL) was not affected. *Viburnum dentatum* heat curves showed a greater increase of P_{net} rate for control plants where exposed plants increased at a lesser rate. Temperature optimum for control and heat exposed plants were 40.5C (104.9F) and 49.2C (120.6F), respectively (Fig. 3.3).

Viburnum tinus biomass accumulation was not affected by heat exposure. Growth, however, was significantly reduced during heat exposure resulting in smaller overall plants (Table 3.2). This adaptive characteristic has been demonstrated in a previous study where *V. tinus* reduced overall size and downregulated photosynthetic capacity (Fini et al., 2010). The species is native to the Mediterranean region of Southern Europe where many shrub species exhibit the same capabilities to endure periods of high heat, irradiance, and drought (Tattini et al., 2006; Fini etal., 2010). Heat curves exhibit this pattern of downregulation where control plants had a higher rate of P_{net} and then declined as temperatures became suboptimal (Fig. 3.4). Whereas, heat exposed plants, had a lower P_{net} rate of increase, and overall downregulation, with no severe decline (Fig. 3.4). Temperature optimum for control plants was 63.3C (145F) due to its linear regression line whereas, control was 38.5C (101.3F). The optimum for control plants is not a realistic number as most plants cannot survive and thrive above 45C (113F; Yamori et al., 2014).

Conclusions

With an increase in temperature, plants will begin to increase respiration rates and downregulate the state of Rubisco (Salvucci and Crafts-Brandner, 2004; Atkin and Tjoelker, 2003). The temperature at which respiration is optimized is just below 45C (113F). Plants will acclimate respiration, such that plants acclimated at high temperature will have a lower respiration rate at a common high temperature where photosynthesis is optimized (Atkin et al., 2005, Yamori et al., 2005). Many plants are able to increase production of heat shock proteins (HSP), as well as heat-stable rubisco activase, to protect the integrity of membranes thus protecting the integrity of the photosynthetic apparatus (Yamori et al., 2014).

Viburnum dentatum and *V. nudum* were able to increase T_{opt} above control plants indicating that these species were able to acclimate to increased temperature. Plants were smaller, as they reduced growth during the heat exposure period, even though water was not limiting. With the increase in T_{opt} and reduced yet sustained growth *V. nudum* and *V. dentatum* may be species that can withstand rigors of the Great Plains. *Viburnum tinus* did not decrease size, but placed resources into root production as evidenced in the reduction in S/R. The species also was able to maintain a steady increase in P_{net} for the heat exposed plants whereas the control plants increased to optimum and then declined rapidly. *Viburnum tinus* with its slowed growth and steady increase of P_{net} with no decline at higher temperatures after heat exposure may help it to survive in the Great Plains. A potentially limiting complication with *V. tinus* is that cold hardiness is rated to zone 9 and may not be adapted to the region and further studies should be done to determine its ability to survive in USDA cold hardiness zone 5. With this study, the recommendation for the use of *V. dentatum* and *V. nudum* is warranted and the technique is a viable option as a quick assay to determine a plants suitability to warmer regions of the Great Plains.

Tables and Figures

Table 3.1 Selected *Viburnum* spp. in a heat acclimation and increasing temperature photosynthesis adaptation study at Throckmorton Plant Sciences Center (Manhattan, KS)

Common name	Scientific name
Awabuki Viburnum	*V. awabuki* 'Chindo'
Smooth Witherod	*V. nudum* 'Winterthur'[z]
Arrowwood Viburnum	*V. dentatum* 'Chicago Lustre'[z]
Laurustinus	*V. tinus* 'Robustum'[z]
American Cranberrybush Viburnum	*V. trilobum* 'Compactum'
Lantanaphyllum Viburnum	*V.* x *rhytidophylloides* 'Alleghany'

[Z] Plants used in the repeated trial May 2014

Table 3.2 Root dry weight (R_{dw}), shoot dry weight (S_{dw}), SPAD, growth index (GI), and shoot-to-root ratio (S/R ratio) of *Viburnum nudum* 'Winterthur', *Viburnum dentatum* 'Chicago Lustre', and *Viburnum tinus* 'Robustum' following exposure to heat (38C) in a controlled atmosphere greenhouse at Throckmorton Plant Sciences Center (Manhattan, KS).

	Viburnum nudum 'Winterthur'		*Viburnum dentatum* 'Chicago Lustre'		*Viburnum tinus* 'Robustum'	
	Control	Acclimated	Control	Acclimated	Control	Acclimated
R_{dw} (g)	4.66^{**}a	1.82b	4.18^{**}a	1.96b	17.86^{NS}	11.76
S_{dw} (g)	10.94^{**}a	5.44b	11.7^{**}a	6.88b	54.92^{NS}	37.84
SPAD^z	45.34^{**}a	37.34b	37.28^{NS}	35.5	55.14^{NS}	54.52
GI^y	41.00^{**}a	30.2b	45.07^{NS}	36.47	53.93^{**}a	42.27b
S/R ratio^x	0.42^{NS}	0.32	0.37^{*}a	0.25b	0.31^{NS}	0.29b

^{NS}, **, * Not significant, significant at $P \le 0.01$, or significant at $P \le 0.05$

Means followed by a different letter within a species and within a row are significantly different based on Tukey's Studentized Range test (α = 0.05), n=5

^{z} Measure of leaf greenness 1 -100

^{y} (Plant Height + Plant Width + Perpendicular Plant Width) ÷3 in cm

^{x} Shoot dry weight ÷ Root dry weight

Figure 3.1 Median asking price for homes that were vacant and for sale for the periods of 1995-2018 in the continental United States

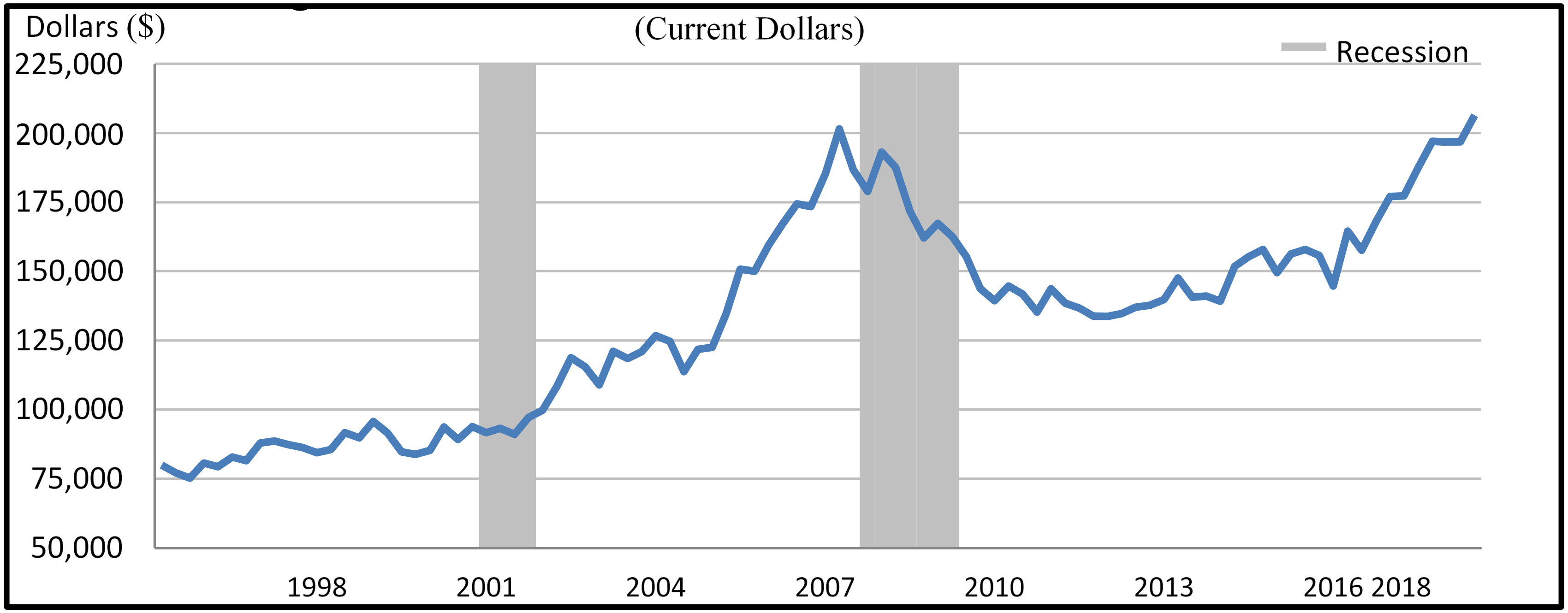


Figure 3.2 Potential photosynthetic capacity (Pnet, µmol CO2·m-2·s-1) of *Viburnum nudum* 'Winterthur' exposed at 38/30C (solid line) and 25/18C (dashed line) (Day/Night), y = -0.0248x2 + 2.0759x - 22.397, r^2 = 0.99 and y = -0.0541x2 + 3.9001x - 44.052, r^2 = 0.92 in a controlled atmosphere greenhouse at Kansas State University Greenhouse Complex (Manhattan, KS) during increasing temperature at 1500 µL·L^{-1} CO_2 and 2000 µmol·m^{-2}·s^{-1} *PAR*, n=5.

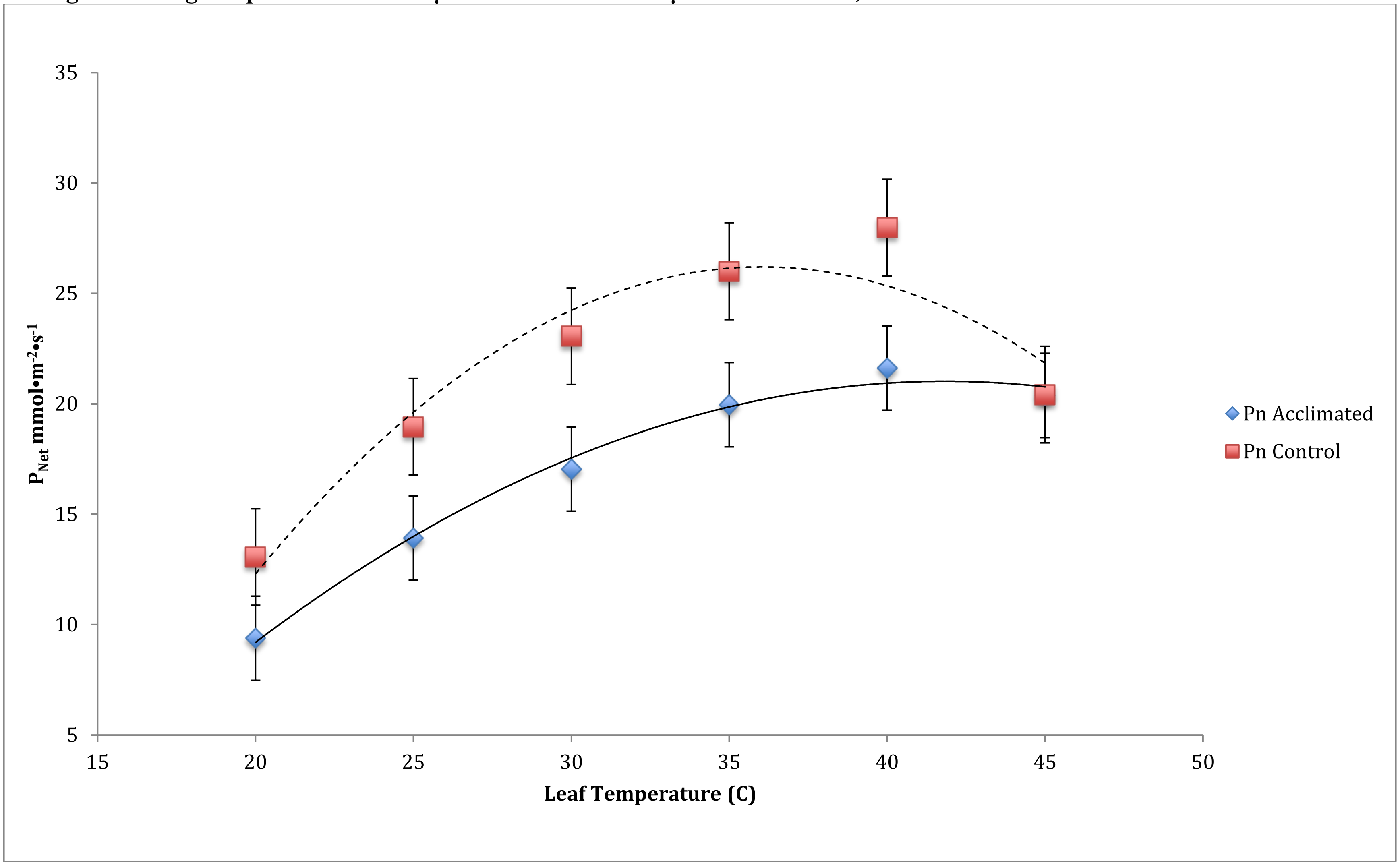


Figure 3.3 Potential photosynthetic capacity (Pnet, µmol CO2·m-2·s-1) under increasing leaf temperature of *Viburnum dentatum* 'Chicago Lustre' exposed at 38/30C (solid line) and 25/18C (dashed line) (Day/Night), $y = -0.0208x^2 + 1.9699x - 22.511$, $r^2 = 0.99$ and $y = -0.0421x^2 + 3.2372x - 37.747$, $r^2 = 0.90$, respectively, during increasing temperature at 1500 $\mu L \cdot L^{-1}$ CO_2 and 2000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ *PAR*, n=5.

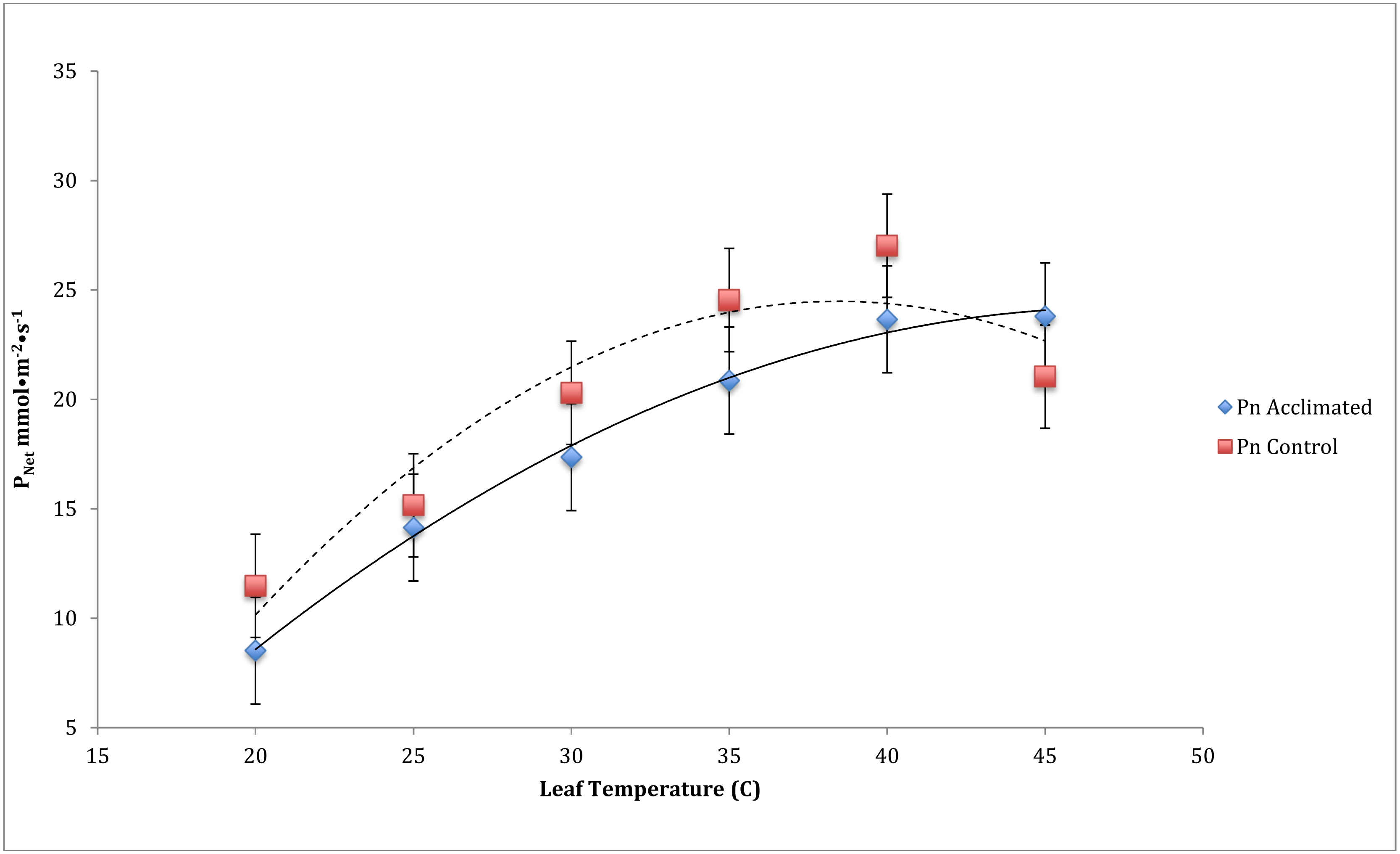
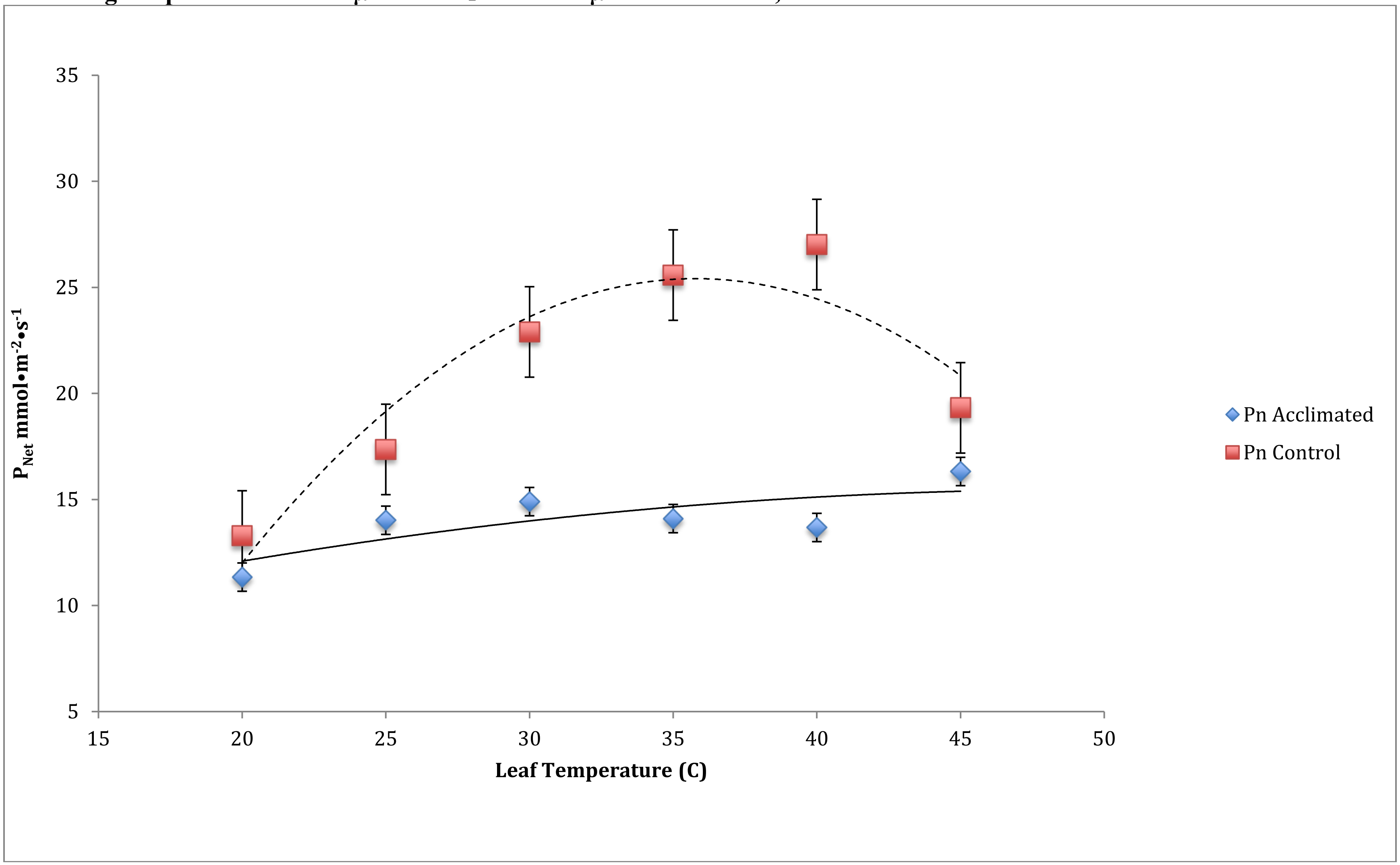


Figure 3.4 Potential photosynthetic capacity (Pnet, µmol CO2·m-2·s-1) of *Viburnum tinus* 'Robustum' exposed at 38/30C (solid line) and 25/18C (dashed line) (Day/Night), $y = -0.0039x^2 + 0.3826x + 5.9809$, $r^2 = 0.60$ and $y = -0.0538x^2 + 3.8496x - 43.468$, $r^2 = 0.89$, in a controlled atmosphere greenhouse at Kansas State University greenhouse complex (Manhattan, KS) during increasing temperature at 1500 $\mu L \cdot L^{-1}$ CO_2 and 2000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ *PAR*, n=5.



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Chapter 4 - Survival and growth of select *Viburnum* spp. across three cold hardiness zones in Kansas

Abstract

United States Department of Agriculture (USDA) cold hardiness zones have shifted within the last decade resulting in areas of Kansas having potentially more options for landscape plants due to being warmer on average, than in the past. Field trials have been used to evaluate a plants ability to survive in new climates but can be difficult and expensive to conduct. This trial was conducted to evaluate the ability of 19 distinct *Viburnum* spp. to be evaluated across three USDA hardiness zones in Kansas. Seven sites were chosen across the state to capture not only the variability in temperature but also precipitation. *Viburnum dentatum*, *V. nudum*, *V. opulus*, and *V.* x *rhytidophylloides* are plants that can survive the rigors of Kansas or other areas with similar climates. *Viburnum opulus* was able to maintain 100% survival across all sites with significant differences in final growth indices. *Viburnum carlesii*, *V. sargentii*, *V. trilobum*, and *V. carlcephalum*, are all candidates to be used on sites that have adequate moisture or ability to irrigate and some amount of shade and protection. *Viburnum* x *burkwoodii* only had one plant survive in Salina, KS and would not be recommended based on this trial.

Introduction

United States Department of Agriculture (USDA) plant hardiness zones have recently been updated (2012) for the first time since 1990, indicating warmer temperature trends in Northern regions (Heller, 2012). With the change in hardiness zones and a seemingly warmer and drier climate for the region, a concerted effort to identify ornamental landscape plants that will withstand the rigors of the Great Plains region of the U.S. is necessary. These plants should transplant easily, be drought tolerant, and withstand high and low temperature extremes that commonly occur throughout the region as well as high soil pH, alkaline water, high sustained winds, and pest pressure.

Along with the ability to adapt to varying climates, plants must be aesthetically pleasing or useful within an ornamental landscape setting. Sometimes plants that are well adapted to severe drought or heat conditions are not aesthetically pleasing to homeowners and landscapers. Homeowners are looking for plants that are low-input, low maintenance, and have aesthetically pleasing traits across all seasons. Low-input plants are plants that require little or no supplemental water or fertilizer after establishment. Low-maintenance plants require little pruning, fertilization, or pesticides. These plants tend to grow slower with a compact habit thus reducing the need for maintenance to keep them at the desired shape and size. Aesthetically-pleasing plants are, for all intents and purposes, plants that “look good.” Flowering time, color, and abundance are important characteristics to be accepted for use within a landscape. With abundant flowering comes, with most plants, abundant fruit set. Fruits make for sometimes-interesting color displays that can range across many colors of the visible spectrum and sometimes are in combinations within one infructescence. The fruit are also attractants to wildlife and can draw them into the home landscape. Fruit can also be edible and be used by the homeowner. Season of interest can vary with fruit, as some fruits will only stay on the plant a few weeks while others may last through the winter, adding a color contrast to the winter landscape.

Homeowners and landscape contractors often must rely on anecdotal advice for plants that survive and thrive in their area due to lack of research on establishment for their desired plants. Otherwise, they rely upon research and ratings from resources that may not be an exact fit for their region or microclimate. Consumers then must rely on trial and error to select plants for their landscape which can be costly and time consuming. Universities, industry, and botanical gardens often have research available on plant varieties for landscapes and have found the best method for making recommendations is by using field trials over a several year period (2 to 5 yrs) in native soils (Lindstrom et al., 2001; Jones and Cregg, 2006). Plant trials in the U.S. began in the late 1800's as a means to compare American seed-produced plants with other competitive lines from Europe (Nau, 2007). The premise of a plant trial is based upon the idea of comparison. Trials are used to generate research-based comparisons between species or cultivars to observe growth habit, flowering, fruiting, vigor, pest problems or lack thereof, color, environmental stress tolerance, exposure, and survivability. Trial sites are set up to identify superior selections or cultivars when compared to "industry standard" plants. Trials can also be used to evaluate anecdotal plant selections for regional retailers to ensure research-based evidence for use of selected plants. If multiple sites are available, as well as resources to effectively manage multiple sites, then a state- or region-wide trial would provide information that could be used to make region-wide recommendations for selected plants. Consumers then will have confidence in recommended plants if they are within those geographic regions.

When conducting region-wide trials, many challenges may arise. Weather will vary across a region, where one area may be extremely dry, other areas may have too much rainfall. Variability in weather is why multiple sites and years are necessary to make recommendations for a region. Widrlechner (1998) identified interactions between moisture index, mean January temperature and mean July temperature that predicted survivability of ornamental landscape plants from Japan across sites in the North Central U.S. Greater than 70% of the variability between sites was due to these three variables with the greatest effect contributed to the moisture index. Greatest percent survival for ornamental landscape plants in Widrlechner's trial was seen in sites with the wettest and warmest climates. Trials also require adequate space, available water, funding, and collaborators that will care for plants using best management practices set forth by the researcher. Even with all the above requirements being met, plants may still fail for unknown reasons. Multiple sites and replication within those sites, allows for anomalies to be accounted for so that recommendations can be made for the region. Researchers, with all the complications of conducting field trials, have investigated ways to trial plants in controlled settings to overcome the challenges of field studies (Adkins, et al., 2002, Dirr and Lindstrom Jr., 1990, Garcia-Navarro, et al., 2004, Sakai, et al., 1986).

Kansas has had temperature extremes ranging from -40C (-40F) in 1905 to 49.4C (121F) in 1936 (Kansas State University (KSU), 2018). In 2018, temperatures ranged from a high of 40.5C (105F) to a low of -29.4C (-21F) within the state. Summer can also be accompanied by several weeks reaching 38C (100F) or hotter. Precipitation in the state follows a North to South gradient line with a slight tilt to Southwest to Northeast gradient as you move East across the state. Southeast portions of that state receive on average 114.3 cm (45in) to 45.72 cm (18 in) in the Southwest (Figure 1.3).

Viburnum L. are one of the most widely grown genus of landscape plants according to a recent Census of Horticulture Specialties (USDA, 2014). Nine hundred forty-one producers sold 2.1 million *Viburnum* in 2014, grossing $21.9 million in revenue (USDA, 2014) The species is known for its adaptability to sometimes-harsh environments. It has been on many recommended plant lists as a plant tolerant of environmental stresses including urban settings due to its adaptability, much of which is anecdotal (Flint, 1985). The sum of flowering, attractive foliage, and sometimes radiant fruit makes *Viburnum* a high quality choice to trial.

With the wide variability in precipitation and temperatures across Kansas, a multisite state-wide trial was implemented to evaluate plants that can be recommended across the state. The popularity of *Viburnum* and number of available varieties that are both aesthetically pleasing and adaptable to environmental stress make it a great choice for landscapes and a great choice for this state-wide study. The purpose of this study is to evaluate select *Viburnum* spp. across the state of Kansas to determine suitability for recommendation to consumers, landscape contractors, and wholesale plant growers as well as to compare field study results to physiological adaptation studies on drought and heat within a greenhouse.

Materials and Methods

On 3 May 2012, 64 plants each of 19 *Viburnum* spp. (Table 4.1) rooted liners (Spring Meadow Nursery, Grand Haven, MI; Classic Viburnums, Upland, NE) were produced by the supplier in 192 mL (4x8 propagation liner inserts, Landmark Plastics, Akron, OH) containers that were removed and planted to 6.0 L (1.6 gal) containers (Classic 600, Nursery Supply Inc., Chambersburg, PA; Table 4.1). Eastern redcedar (*Juniperus virginiana* L.) is a conifer species with a native range in the Eastern half of the United States. It has become a pest to native grasslands in the Great Plains due to its aggressiveness and the ease that it proliferates from seed (Briggs et al., 2002). It is suitable as an alternative media to reduce the need for non-native pine bark while using local resource (Starr et al., 2012). The media was amended with 1.2 $kg \cdot m^{-3}$ (2.0 $lbs \cdot yd^{-3}$) micronutrient package (Micromax®, Scotts, Marysville, OH) and 9.5 $kg \cdot m^{-3}$ (16 $lbs \cdot yd^{-3}$) controlled release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH). Eastern redcedar was ground to a particle size of 9.5 mm (3/8 in.) using a hammermill (Model 30HMBL, C.S. Bell Co.,Tiffin, OH). Plants were grown under partial shade (50%) for the remainder of the growing season at the Kansas State University (KSU) John C. Pair Horticultural Research Center (Haysville, KS). Plants were overwintered in an unheated hoop house covered in white polyurethane plastic and vented with fans when inside temperatures reached 10C (50F).

Field trial sites were chosen based on availability of space, volunteers, and geographic locations across Kansas. The sites were as follows, KSU Northwest Research Center (Colby, KS), Saline County demonstration garden (Salina, KS), KSU Tuttle Creek Forestry Research Center (Manhattan, KS), Olathe Horticulture Research and Extension Station (Olathe, KS), Parsons Arboretum (Parsons, KS), KSU John C. Pair Horticulture Research Center (Haysville, KS), and Prairie Wind Aquatics (Garden City, KS) (Table 4.2). Planting time that is recommended by King and Nance (2012) as most successful, is Fall. On 14 September 2012 fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and planted at the KSU John C. Pair Horticulture Research Center (37.520102, -97.314379) in Haysville, KS (United States Department of Agriculture (USDA) hardiness zone 6b). On 27 September 2012, fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and transported to the Parsons Arboretum (37.329319, -95.267172) in Parsons, KS (USDA hardiness zone 6b). Plots had previously been treated with Glyphosate Plus (Quali-Pro, Pasadena, TX), a non-selective herbicide, and cultivated to remove weeds and *Cynodon dactylon* (Bermuda grass). Plants were planted in plots and watered to settle the native soil. All plots were top-dressed with controlled-release fertilizer (Osmocote® 18N-2.6P-9.9K, Scotts, Marysville, OH) applied at a rate of 5.4 kg·100 m^{-2} (11 lbs · 1000 ft^{-2}). Pre-emergent herbicide (Snapshot® 2.5 TG, Dow AgroSciences, Indianapolis, IN) was applied post-plant at a rate of 2.08 kg·100 m^{-2} (4.6 lbs·1000 ft^{-2}). Local mulch from forestry operations was installed to retain moisture and to suppress weeds. On 4 October 2012 fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and transported to the Colby, KS and Garden City, sites, respectively. Plants were planted at the KSU Northwest Research Extension Center (39.393811, -101.063004) in Colby, KS (USDA hardiness zone 5b) on 5 October 2012 and at Prairie Wind Aquatics (37.991178, -100.887544) in Garden City, KS (USDA hardiness zone 6a) on 6 October 2012. Sites were cultivated and cleared of weeds prior to planting. On 12 October 2012 fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and transported to the Saline County demonstration garden (38.832013, -97.600023) in Salina, KS (USDA hardiness zone 6a). On 19 October 2012, fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and transported to the KSU Tuttle Creek Forestry Research Center (39.249071, -96.573143) in Manhattan, KS (USDA hardiness zone 6a). On 26 October 2012, fully rooted 6.0 L (1.6 gal) containers of each species were selected for uniformity and transported to the Kansas State Research and Extension Center- Olathe (38.883864, -94.992697) in Olathe, KS (USDA hardiness zone 6a). Growth data was collected at all sites to include height and width. A chlorophyll meter, SPAD 502 Plus (Spectrum Technologies Aurora, IL), was used to measure leaf chlorophyll content on three recently expanded leaves throughout the plant canopy. All sites, excluding Parsons, had a weather station (Spectrum Technologies Inc., WatchDog 1450, Aurora, IL) installed with a radiation shield to measure temperature, relative humidity, and soil moisture within the plots. Parsons had a weather station data logger (Spectrum Technologies Inc., Watch Dog Model 2700, Aurora, IL) installed to collect weather (temperature, relative humidity) and soil moisture data.

The experimental design was a randomized complete block design with three single plant replicates at each site. Growth and SPAD data were subjected to ANOVA and means separation using Waller–Duncan K-ratio t test at α = 0.05. No statistical comparisons were made between species.

Results and Discussion

Viburnum nudum, *V. opulus*, and *V. x rhytidophylloides* outperformed (greater than 80% survival) all other species, with *V. dentatum* nearly in range (78%; Table 4.3). *Viburnum opulus* was able to maintain 100% survival across all sites with significant differences in final growth indices between all sites where Salina, Manhattan, and Haysville were similar in final growth indices and also had the greatest growth (Table 4.9). *Viburnum opulus* plants at Olathe and Parsons were similar to all except Salina and Colby with Salina having the greatest growth (206% increase) and Colby having the least growth (0% increase; Table 4.9). The species is known to be a vigorous grower, especially in wet sites (Dirr, 2007). *Viburnum nudum* and *V.* x *rhytidophylloides* both maintained 83% survival (Table 4.3). *Viburnum nudum* exhibited significant differences in final growth indices and leaf chlorophyll content with Olathe having the largest plants and lowest leaf chlorophyll content (Table 4.8). Salina, Manhattan, and Parsons were similar to both Olathe and Haysville for growth while leaf chlorophyll content was similar to each other but not Haysville or Olathe (Table 4.8). Haysville resulted in the smallest plants and the greatest leaf chlorophyll content (Table 4.8). *Viburnum* x *rhytidophylloides* had the greatest growth in Salina and Parsons and the least in Manhattan and Olathe, while there were no differences in leaf chlorophyll content (Table 4.22). This lack of growth for *V.* x *rhytidophylloides* is not typical for the species which is known for its rapid and robust growth rate (Dirr, 2007). *Viburnum nudum* is a native to the Eastern and Southern part of the United States (U.S.) and is most often found in wetland type areas (Dirr, 2007). In this study it performed best at Olathe and had an increase in growth index of 150% and was similar to

Parsons, where the site received the most rainfall in 2013, even though it only had a 49% increase in growth index (51 in; Table 4.2). *Viburnum dentatum* had no significant differences across all sites for growth indices or leaf chlorophyll content (Table 4.5). Growth indices increased on average 180% with the greatest in Salina (300%) and the least in Parsons (70%; Table 4.5). The species is known to demonstrate colonizing growth habit and is a rapid grower that can withstand most any site from North to South across the U.S. (Dirr, 2007). In this trial, *V. dentatum* only had losses in Haysville and Colby. These failures could be due to weed pressure at Haysville and lack of moisture and supplemental irrigation in Colby as well as extreme temperatures with Colby reaching -16.4F(-26.8C) and exceeding 110F(43.6C) at both sites (Table 4.2).

Viburnum carlesii, *V. sargentii*, *V. trilobum*, and *V.* x *carlcephalum* all had survival rates exceeding 60% which should garner interest and another study on these species (Table 4.3). *Viburnum carlesii*, *V. trilobum*, and *V.* x *carlcephalum*, performed best in Salina where Extension Master Gardener volunteers helped maintain the site which was in partial shade the majority of the day but also performed equally well in Parsons (Tables 4.4; 4.16; 4.19). Leaf chlorophyll content of the aforementioned species had no significant differences except for *V. trilobum*. Salina also had at or above normal precipitation during the study making the need for supplemental irrigation less crucial compared to other sites (Table 4.2). The site also never experienced temperatures below 0F (-17.7C) but experience several days above 100F (37.7C) with temperature maximum reaching 108F (42.2C, Table 4.2). *Viburnum sargentii* had consistent growth increases across Manhattan, Parsons, and Haysville, but were not significantly different, all which are in the Eastern half of Kansas and received more precipitation (Table 4.14). *Viburnum* x *juddii* and *V.* x *pragense* survival were at 55% with no plants surviving in Haysville and only two surviving for *V.* x *juddii* in Colby (Table 4.3). *Viburnum* x *pragense* exhibited the most growth in Salina (340% increase) and Parsons (124% increase), both areas with part shade during the day, while *V.* x *juddii* performed best in Manhattan (208% increase) but was not significantly different than Salina (103% increase; Tables 4.20, 4.21). Leaf chlorophyll content was not significantly different between all sites.

Viburnum sieboldii followed closely behind the previously mentioned species with an overall survival rate of 50% with 100% survival in Salina, Parsons, and Haysville (Table 4.3). Growth index was not significantly different across sites and resulted in growth increases of 120%, 190% and 226% for Parsons, Haysville, and Salina where it survived but leaf chlorophyll content was greatest in Haysville and Parsons (Table 4.15).These species with 50% - 80% should not be disregarded completely due to the ability to survive and thrive at sites where they have part shade, adequate moisture, or a combination of both. These site characteristics can aid less hardy plants in their ability to adapt to sometimes harsh sites (Hastwell and Facelli, 2003; Lindstrom et al. 2001).

Viburnum dilatatum, *V. farreri*, *V. plicatum*, *V. plicatum tomentosum*, *V. rhytidophyllum*, *V. rufidulum*, *V.* x *bodnantense*, and *V.* x *burkwoodii* all had survival rates less than 45% (Table 4.3). These species should be used with caution in climates similar to Kansas. Even though they did not survive across all sites at least one plant from every species was able to survive in Parsons except *V.* x *burkwoodii*, where only one plant survived in Salina (Table 4.3). The survival of these plants can partially be attributed to the available moisture in 2013 (51 in) with a volumetric water content percent average (VWC%) of 37%, as water is one of the most limiting factors when it comes to landscape plant establishment (Gilman et al. 1998, Table 4.2).

Site characteristics and cooperator consistency in maintenance of the site was crucial to plant survival in this study as can be seen in the overall survival by site (Table 4.3). Garden City was removed from the study due to several limitations. The site was open and exposed to land where herbicide had been applied during study establishment, and drift damage was observed. The site also did not receive adequate supplemental irrigation during times of no precipitation. Planting time was also an issue in Colby and Garden City, with a large temperature swing at time of planting possibly shocking trial plants going into Winter, which could have led to winterkill and plants not establishing well the following Spring (Hormay, 1943). Colby survival rates were low, with only 15% of the plants surviving two seasons. Irrigation was not adequate at the site as evidenced by moisture readings taken during the study showing volumetric water content percent average VWC% of 12% (Table 4.2). This lack of irrigation in a site with only 21 inches of precipitation during a growing season could have put plants in a deficit they could not overcome (Table 4.2). Haysville also had complications with site maintenance. The site had previously been covered in *Cynodon dactylon* (Bermuda grass) and was sprayed with glyphosate prior to establishment and then tilled into the plots with large clumps raked out. *Cynodon dactylon* is a very aggressive spreader and regenerates from rhizomes. It often takes several applications of spraying with a non-selective herbicide to completely eradicate. This led to the plots being overrun with grass and competing with trial shrubs for nutrients and water. The site also had a minimum temperature of -5.0F (-20.5C) and a maximum temperature of 110.6F (43.6C) which can be very stressful on plants (Table 4.2). Overall survival in Haysville was 31% (Table 4.3). Olathe and Manhattan had overall survival at 50%, these sites had complications with mechanical damage and wildlife browsing as well as irrigation lapses due to equipment breaks and maintenance. These irrigation lapses led to sporadic periods of wet and dry and average VWC% of 26.6% and 45.9% for Olathe and Parsons, respectively (Table 4.2). This led to weed encroachment on the sites and stress due to inoperable irrigation. Many sites had data removed due to only one plant surviving which did not allow for analysis on growth and leaf chlorophyll content.

Salina and Parsons were the most successful sites which can be attributed to several factors. At these sites volunteers were consistent and diligent in their care of the plots. Plots were kept clean of weeds, watered consistently, and observed several times throughout the growing season. Salina and Parsons had the best overall survival with rates of 76% and 87%, respectively (Table 4.2). In general, Salina also had some of the largest gains in growth indices and maintained the only *V.* x *burkwoodii* that survived the statewide trial (Table 4.3). Salina was a site that was either part shade or full shade for most of the day and trees on the South side of the plot that protected the site from drying summer winds. Research has shown that plants may grow better when protected from intense sunlight (Wilson et al., 2014). There also was a creek within 30 ft resulting likely resulting in higher humidity helping with water loss during times of drought. Parsons also had periods of shade throughout the day and a creek nearby that could contribute to soil moisture stability. The Parsons site only had 6 plants senesce with most of them exhibiting increases in growth except *V. dilatatum*. *Viburnum dilatatum* either did not survive or decreased in size over the study, most likely from dieback, winterkill, and mechanical damage.

Conclusions

Evidence in this study can lead us to recommend that *V. dentatum*, *V. nudum*, *V. opulus*, and *V.* x *rhytidophylloides* are plants that can survive the rigors of Kansas or other areas with similar climates. They exhibited large gains in size in all sites except Colby. *Viburnum carlesii*, *V. sargentii*, *V. trilobum*, and *V. carlcephalum*, are all candidates to be used on sites that have adequate moisture or ability to irrigate and some amount of shade and protection. *Viburnum sieboldii*, *V.* x *juddii*, and *V.* x *pragense* fall into that category of use with caution and on a site that is protected, shaded, and irrigated. *Viburnum dilatatum, V. farreri, V. plicatum, V. plicatum tomentosum, V. rhytidophyllum, V. rufidulum, V.* x *bodnantense, and V.* x *burkwoodii* are species that should be used with extreme caution if the goal is survival and growth as these species did not perform well in the current study. Poor growth of *V. rufidulum* was not expected as it is a native to the region.

Weather during this study was also a challenge. The study was installed during a period where Kansas was experiencing extreme drought with a portion of the state being declared disaster areas due to the drought. This drought may have contributed to the failure to establish of many of the plants. Precipitation in 2013 was at or above average for all sites except Colby and Olathe and for 2014 precipitation was below average for all sites (Table 4.2). The lack of precipitation would require supplemental irrigation to aid in establishment and further growth and survival. The sites that had the greatest survival had the most precipitation with Parsons receiving 86 in and Salina 65 in (Table 4.2).

It is critical to have volunteers who are vested in the project and want to see it succeed so that proper care is performed, sites are kept free of weeds, watered consistently when needed, and monitored for damage or other issues. With proper care a greater number of plants may have survived and resulted in more recommendations for *Viburnum* as landscape plants. Trials have limitations such as travel expenses, time, dedicated volunteers to manage the sites, available space, and overall cost of materials, making them a challenge to conduct. Robust dataloggers are also recommended. These sites without having constant supervision experienced lapses in data due to batteries dying and sensor cables being cut or chewed through by animals. This study was able to provide supporting evidence for the use of several species which also correlated well with the quick assay studies in the greenhouse, where *V. dentatum* and *V. nudum* both performed well and survived at most sites. Replication of these techniques should be conducted to verify with field survival data that the quick assay techniques are a viable way to identify plants to use in field studies prior to expending resources required to conduct such studies.

Tables and Figures

Table 4.1 Selected *Viburnum* spp. planted in Fall 2012 for a two season (2013-2014) field establishment study at Kansas State University (KSU) Northwest Research Center (Colby, KS), Saline County demonstration garden (Salina, KS), KSU Tuttle Creek Forestry Research Center (Manhattan, KS), KSU Olathe Horticulture Research and Extension Station (Olathe, KS) Prairie Wind Aquatics (Garden City, KS), KSU John C. Pair Horticulture Research Center (Haysville, KS), and the Parsons Arboretum (Parsons, KS) representing three United States Department of Agriculture (USDA) cold hardiness zones in Kansas.[z]

Scientific name	Common name	Leaf Morphology
V. carlesii 'Diana'[w]	Koreanspice Viburnum	Deciduous, dull green pubescent
V. dentatum 'Chicago	Arrowwood Viburnum	Deciduous, glossy green
V. dilatatum 'Michael	Linden Viburnum	Deciduous, lustrous green
V. farreri[x]	Fragrant Viburnum	Deciduous, glossy green pubescent
V. nudum 'Winterthur'[w]	Smooth Witherod	Deciduous, glossy green
V. opulus 'Roseum'[w]	European Cranberrybush	Deciduous, glossy green pubescent veins, lobed leaf
V. plicatum 'Popcorn'[w]	Japanese Snowball	Deciduous, glossy green pubescent veins
V. plicatum var.	Doublefile Viburnum	Deciduous, glossy green pubescent veins
V. rhytidophyllum 'Cree'[w]	Leatherleaf Viburnum	Semi-evergreen, deep green, pubescent, wrinkly and thick
V. rufidulum[x]	Rusty Blackhaw	Deciduous, lustrous green
V. sargentii 'Onondaga'[w]	Sargent Viburnum	Deciduous, dull green, sparsely pubescent on underside, lobed leaf
V. sieboldii 'Wavecrest'[x]	Siebold Viburnum	Deciduous, glossy green, pubescent veins, thick
V. trilobum 'Compactum'[w]	American Cranberrybush	Deciduous, dark green, lobed leaf
V. x *bodnantense* 'Dawn'[xy]	Fragrant Viburnum	Deciduous, dark green
V. x *burkwoodii* 'Conoy'[w]	Burkwood Viburnum	Evergreen, deep green, pubescent, thick
V. x *carlcephalum*	Fragrant Viburnum	Deciduous, glossy green, pubescent below
V. x *juddii*[w]	Judd Viburnum	Deciduous, dull green pubescent
V. x *pragense* 'Decker'[w]	Prague Viburnum	Semi-evergreen, deep green, pubescent,
V. x *rhytidophylloides*[w] 'Alleghany'	Lantanaphyllum Viburnum	Evergreen, deep green, pubescent, thick

[Z] Garden City was removed as a site due to complications

[Y] Was not planted in Manhattan, KS site

[x] Provided by Classic Viburnum

[W] Provided by Spring Meadows Nursery

Table 4.2 Site descriptions, challenges and overall survival of *Viburnum* spp. trials at Kansas State University (KSU) Northwest Research Center (Colby, KS), Saline County demonstration garden (Salina, KS), KSU Tuttle Creek Forestry Research Center (Manhattan, KS), KSU Olathe Horticulture Research and Extension Station (Olathe, KS) Prairie Wind Aquatics (Garden City, KS), KSU John C. Pair Horticulture Research Center (Haysville, KS), and the Parsons Arboretum (Parsons, KS)

Location Hardiness Zone	Site Description	Challenges	Overall Survival
Colby Cold Hardiness Zone 5b	• Northwestern region of Kansas agricultural research station • Windbreaks on North, West, and South sides within 100 ft of plots • Average precipitation, 21 in, 2013 (14.5 in) and 2014 (17.9 in) were below average • Min/Max Temperature -16.4F (-26.8C,2012)/112.2F (44.5C, 2014) • Soil classification: Keith silt loam, 0-1 percent slope	• Fall planting recommended but cold snap occurred with snow at planting • Watering was not adequate as evidenced by soil moisture data •Average Volumetric water content percent (VWC)_12%	15%
Salina Cold Hardiness Zone 6a	• Located at a local KSU Extension Master Gardener display garden within 30 ft of a creek • Trees on South side within 10 ft of plots provided shade much of the day • Average precipitation 31 in, 2013 (36 in) and 2014 (29 in) were above and below normal, respectively • Min/Max Temperature 12.5F (-10.8C, 2013)/108F (42.2C, 2014) • Soil classification: McCook silt loam, rarely flooded	• Volunteer support from Kansas Extension Master Gardeners was consistent from planting through maintenance • Some animal damage • VWC_37.9%	76%
Manhattan Cold Hardiness Zone 6a	• Forestry research station located near Tuttle reservoir river ponds in Northeastern Kansas • Protected on all sides by trees within 300 ft, providing no shade • Average precipitation 33 in, 2013 (33 in) and 2014 (29 in) were at or slightly below normal • Min/Max Temperature -6.1F (-21.2C, 2013)/106.6F (41.4C, 2014) • Soil classification: Eudora silt loam, rarely flooded	• Deer browsing was noted, and deer fence added • String trimmer hit plants once • VWC_45.9%	51%
Olathe Cold Hardiness Zone 6a	• Located at a horticulture research station in Northeast Kansas • Windbreaks were South and West of plots providing no shade • Plots were terraced North to South • Average precipitation 40 in, 2013 (36 in) and 2014 (35 in) were below normal • Min/Max Temperature -10.0F (-23.3C, 2014)/101.0F (38.3C, 2013) • Soil classification: Oska-Martin silty clay loam, 4-8 percent slope	• Maintenance did not manage weed pressure well • Watering was not monitored as evidenced by soil moisture readings • VWC_26.6%	49%
Parsons Cold Hardiness Zone 6b	• Located at a local arboretum where *Cynodon dactylon* (Bermuda grass) was sprayed out and tilled in • Some shading during afternoon from established shade trees • Creek was within 100 ft • Average precipitation 43 in, 2013 (51 in) and 2014 (35 in) were above and below normal, respectively • Min/Max Temperature -12.9F (-24.9C, 2014)/119.5 (48.6C, 2014) • Soil classification: Lanton silt loam, 0-2 percent slope, occasionally flooded	• Some periods of short-term flooding • Volunteer support from Kansas Extension Master Gardeners was consistent from planting through maintenance • VWC_37%	87%
Haysville Cold Hardiness Zone 6b	• Horticulture research station in Southcentral Kansas • Plots were located in area with full sun, windbreaks on South and East sides within 100 ft • *Cynodon dactylon* (Bermuda grass) was sprayed prior to tilling • Average precipitation 33 in, 2013 (41 in) and 2014 (26 in) were above and below normal, respectively • Min/Max Temperature -5.0F (-20.5C, 2014)/110.6 (43.6C, 2013) • Soil classification: Canadian-Waldeck fine sandy loams, rarely flooded	• Weed pressure was severe from *Cynodon dactylon* (Bermuda Grass) • Plot maintenance was not consistent • VWC_ No data	31%
Garden City Cold Hardiness Zone 6a	• Back Acreage of Prairie Wind Aquatics • No windbreaks or shading • Average precipitation 20 in, 2013 (17.8 in) and 2014 (21.9 in) were near normal • Min/Max Temperature 11.55F (-11.4C, 2013)/ 100.7F (38.2C, 2013) Data only from 2013 • Soil classification: Bridgeport clay loam, rarely flooded	• Fall planting recommended but cold snap occurred with snow at planting • Rabbit damage was severe • Herbicide drift contributed to failure • VWC_27.3% (Only 2013)	0% Site was abandoned

Table 4.3 Nineteen *Viburnum* spp. percent survival across six sites, Kansas State University (KSU) Northwest Research Center (Colby, KS), Saline County demonstration garden (Salina, KS), KSU Tuttle Creek Forestry Research Center (Manhattan, KS), KSU Olathe Horticulture Research and Extension Station (Olathe, KS) Prairie Wind Aquatics (Garden City, KS), KSU John C. Pair Horticulture Research Center (Haysville, KS), and the Parsons Arboretum (Parsons, KS) after two growing seasons (2013-2014), n=3.

	Location						
Species	Olathe	Manhattan	Salina	Colby	Haysville	Parsons	Overall[Z]
V. carlesii 'Diana'	33%	100%	100%	0%	66%	100%	67%
V. dentatum 'Chicago Lustre'	100%	100%	100%	0%	66%	100%	78%
V. dilatatum 'Michael Dodge'	0%	33%	33%	0%	0%	66%	22%
V. farreri	0%	0%	0%	0%	0%	100%	33%
V. nudum 'Winterthur'	100%	100%	100%	0%	100%	100%	83%
V. opulus 'Roseum'	100%	100%	100%	100%	100%	100%	100%
V. plicatum 'Popcorn'	100%	0%	66%	0%	0%	100%	44%
V. plicatum tomentosum 'Shasta'	100%	0%	66%	0%	0%	100%	44%
V. rhytidophyllum 'Cree'	0%	0%	100%	0%	0%	100%	33%
V. rufidulum	0%	0%	33%	0%	0%	100%	33%
V. sargentii 'Onondaga'	66%	66%	0%	33%	100%	100%	61%
V. sieboldii 'Wavecrest'	0%	0%	100%	0%	100%	100%	50%
V. trilobum 'Compactum'	66%	100%	100%	33%	0%	100%	67%
V. x bodnantense 'Dawn'	0%	0%	*	0%	0%	100%	28%
V. x burkwoodii 'Conoy'	0%	0%	33%	0%	0%	0%	6%
V. x carlcephalum 'Cayuga'	66%	66%	100%	0%	33%	100%	61%
V. x juddii	33%	100%	100%	66%	0%	33%	55%
V. x pragense 'Decker'	66%	100%	100%	0%	0%	66%	55%
V. x rhytidophylloides 'Alleghany'	66%	100%	100%	66%	66%	100%	83%
Overall[Y]	49%	51%	76%	15%	31%	87%	51%[X]

* Species was not planted at this site
[Z] Species overall survival, n=18
[Y] Site overall survival across all species, n= 57
[X] Study overall survival across all sites and all species, n= 342

Table 4.4 Physiological effects of geographic location on growth of *Viburnum carlesii* 'Diana' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^{z}				SPAD value^{y}			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	34.0^{ns}	---	---	---	43.0^{ns}	---	---	---
Salina (Central)	19.8	75.0ab^{x}	81.9^{ns}	119.6a	32.4	70.2ab	45.5^{ns}	49.7^{ns}
Manhattan (Northeast)	---	67.3ab	81.2	102.2ab	---	72.1ab	47.4	72.4
Olathe (East Central)	---	---	---	---	---	---	---	---
Parsons (Southeast)	59.0	86.0a	99.2	126.8a	59.0	71.9ab	42.9	67.4
Haysville (South Central)	46.3	65.6ab	72.2	111.2ab	44.4	74.4a	45.2	75.9
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measure in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.5 Physiological effects of geographic location on growth of *Viburnum dentatum* 'Chicago Lustre' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^z Spring 2013	Growth index^z Fall 2013	Growth index^z Spring 2014	Growth index^z Fall 2014	SPAD value^y Spring 2013	SPAD value^y Fall 2013	SPAD value^y Spring 2014	SPAD value^y Fall 2014
Colby (Northwest)	34.6b^x	---	---	---	36.2b	---	---	---
Salina (Central)	35.3b	108.6a	110.2^ns	140.9^ns	32.7b	35.0^ns	32.9a	39.8^ns
Manhattan (Northeast)	56.2ab	85.4ab	88.6	101.7	43.4b	39.2	33.2a	36.9
Olathe (East Central)	36.0ab	67.1b	75.7	100.7	39.5b	37.2	25.9b	38.9
Parsons (Southeast)	67.5a	76.0b	77.8	114.6	67.4a	38.8	35.0a	40.9
Haysville (South Central)	---	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^z Growth index = (height + width1 + width2) / 3 measured in cm.

^y Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^x Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^ns Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.6 Physiological effects of geographic location on growth of *Viburnum dilatatum* 'Michael Dodge' planted in Fall 2012 at six locations across Kansas (n=3).

	Growth index^{z}				SPAD value^{y}			
Location	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	50.7^{ns}	---	---	---	31.4^{ns}	---	---	---
Salina (Central)	43.3	41.7b^{x}	39.0^{ns}	66.7^{ns}	37.7	54.2^{ns}	29.4^{ns}	41.6b
Manhattan (Northeast)	60.2	27.7b	11.5	15.3	41.0	47.5	43.4	49.2ab
Olathe (East Central)	---	---	---	---	---	---	---	---
Parsons (Southeast)	35.9	51.8a	33	38.3	35.9	48.5	42.4	51.4a
Haysville (South Central)	39.6	---	---	---	39.4	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.7 Physiological effects of geographic location on growth of *Viburnum farreri* planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^{z}				SPAD value^{y}			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	---	---	---	---	---	---	---	---
Salina (Central)	---	---	---	---	---	---	---	---
Manhattan (Northeast)	---	---	---	---	---	---	---	---
Olathe (East Central)	21.2^{ns}	---	---	---	30.7^{ns}	---	---	---
Parsons (Southeast)	40.0	40.1	47.1	63.0	39.8	58.9	56.5	---
Haysville (South Central)	---	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.8 Physiological effects of geographic location on growth of *Viburnum nudum* 'Winterthur' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	36.3[ns]	---	---	---	57.1a	---	---	---
Salina (Central)	56.5	65.3a[x]	61.3bc	84.1ab	33.7b	57.1a	44.1[ns]	47.4b
Manhattan (Northeast)	37.0	69.2a	68.5ab	82.5ab	41.8ab	40.1b	37.1	46.1a
Olathe (East Central)	38.7	71.8a	80.1a	96.9a	46.8ab	46.1ab	40.6	40.7c
Parsons (Southeast)	45.7	66.1a	66.8ab	79.1ab	45.7ab	52.4ab	43.3	46.3b
Haysville (South Central)	24.7	50.6b	46.2c	56.7b	34.7ab	47.8ab	41.7	54.3a
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.9 Physiological effects of geographic location on growth of *Viburnum opulus* 'Roseum' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^{z}				SPAD value^{y}			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	51.9^{ns}	55.6^{ns}	53.1b^{x}	52.0c	41.5ab	39.9cd	36.9ab	35.0b
Salina (Central)	39.1	64.3	83.1a	119.9a	41.4ab	57.2a	33.8b	47.1a
Manhattan (Northeast)	28.7	54.9	76.6a	104.1ab	26.7b	35.9d	36.1ab	49.6a
Olathe (East Central)	---	52.0	63.0ab	82.8b	---	52.5ab	33.2b	43.3ab
Parsons (Southeast)	51.8	63.4	74.4ab	95.2b	51.8a	46.0bc	38.9a	50.0a
Haysville (South Central)	38.8	62.4	66.8ab	99.1ab	33.0ab	46.9bc	36.9ab	49.6a
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.10 Physiological effects of geographic location on growth of *Viburnum plicatum* 'Popcorn' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^{z}				SPAD value^{y}			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	---	---	---	---	---	---	---	---
Salina (Central)	42.0^{ns}	76.5^{ns}	73.3^{ns}	100.8^{ns}	38.0^{ns}	38.8^{ns}	44.4a^{x}	39.9b
Manhattan (Northeast)	---	---	---	---	43.8	---	---	---
Olathe (East Central)	---	76.9	83.0	110.5	52.6	41.4	34.6b	54.2a
Parsons (Southeast)	44.0^{ns}	93.4	100.0	120.3	44.0	39.6	41.9a	48.8ab
Haysville (South Central)	23.5^{ns}	---	---	---	53.4	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.11 Physiological effects of geographic location on growth of *Viburnum plicatum var tomentosum* 'Shasta' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^z				SPAD value^y			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	48.7ab^x	---	---	---	32.5b	---	---	---
Salina (Central)	64.5a	99.8a	101.2a	117.7b	32.6b	35.0^{ns}	41.3a	42.2b
Manhattan (Northeast)	45.0ab	---	---	---	41.6ab	---	---	---
Olathe (East Central)	50.2ab	71.7b	79.9b	105.2b	51.2ab	37.2	31.7b	48.0ab
Parsons (Southeast)	63.6a	95.9a	102.4a	135.8a	63.6a	38.8	40.5a	53.6a
Haysville (South Central)	22.3b	---	---	---	43.0ab	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.12 Physiological effects of geographic location on growth of *Viburnum rhytidophyllum* 'Cree' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	33.8[ns]	---	---	---	43.0[ns]	---	---	---
Salina (Central)	30.0	50.4[ns]	45.4[ns]	57.1[ns]	47.6	67.3[ns]	60.0[ns]	64.8[ns]
Manhattan (Northeast)	27.7	---	---	---	34.7	---	---	---
Olathe (East Central)	32.5	---	---	---	29.1	---	---	---
Parsons (Southeast)	38.4	48.7	43.8	59.0	38.5	77.7[ns]	57.9	70.1
Haysville (South Central)	32.3	---	---	---	53.5	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.13 Physiological effects of geographic location on growth of *Viburnum rufidulum* planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^z				SPAD value^y			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	36.2^ns	---	---	---	42.6^ns	---	---	---
Salina (Central)	27.7	---	---	---	39.1	---	---	---
Manhattan (Northeast)	39.9	---	---	---	39.1	---	---	---
Olathe (East Central)	34.0	---	---	---	43.6	---	---	---
Parsons (Southeast)	32.3	58.8	75.9	104.3	32.3	57.5	37.3	56.0
Haysville (South Central)	---	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

^z Growth index = (height + width1 + width2) / 3 measured in cm.

^y Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^x Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^ns Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.14 Physiological effects of geographic location on growth of *Viburnum sargentii* 'Onondaga' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	---	---	---	---	---	---	---	---
Salina (Central)	39.9[ns]	---	---	---	41.0[ns]	---	---	---
Manhattan (Northeast)	35	37.5[ns]	62.7a[x]	77.7[ns]	34.9	29.2[ns]	34.9[ns]	53.9[ns]
Olathe (East Central)	---	---	---	---	---	---	---	---
Parsons (Southeast)	35.3	33.8	50.8ab	60.0	35.3	49.0	38.1	54.8
Haysville (South Central)	26.8	28.7	33.9b	50.6	47.6	55.8	32.7	54.9
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.15 Physiological effects of geographic location on growth of *Viburnum sieboldii* 'Wavecrest' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	36.6[ns]	---	---	---	38.5[ns]	---	---	---
Salina (Central)	35	78.4ab[x]	82.3b	114.2[ns]	29.7	55.5[ns]	40.1[ns]	41.8b
Manhattan (Northeast)	---	---	---	---	---	---	---	---
Olathe (East Central)	35.8	---	---	---	36.1	---	---	---
Parsons (Southeast)	62.2	83.7[a]	99.6a	137.1	62.2	59.3	43.9	57.9a
Haysville (South Central)	42.5	69.3[b]	74.9b	123.0	41.9	60.8	39.4	61.2a
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.16 Physiological effects of geographic location on growth of *Viburnum trilobum* 'Compactum' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	39.3 [ns]	---	---	---	34.4[ns]	---	---	---
Salina (Central)	24	37.1a[x]	44.9ab	62.0a	27.4	48.6a	31.8[ns]	46.8a
Manhattan (Northeast)	44.1	21.1b	49.2ab	57.2ab	41.3	17.4b	28.9	32.3bc
Olathe (East Central)	40.7	16.8b	27.3b	25.0b	32.2	24.5b	28.7	29.6c
Parsons (Southeast)	30.9	33.6a	51.1a	61.8a	30.9	22.1b	29.8	37.9b
Haysville (South Central)	---	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.17 Physiological effects of geographic location on growth of *Viburnum* x *bodnantense* 'Dawn' planted in Fall 2012 at six locations across Kansas (n=3).

	Growth index[z]				SPAD value[y]			
Location	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	16.2b[x]	---	---	---	---	---	---	---
Salina (Central)	---	69.5[ns]	68.2[ns]	107.5[ns]	---	45.1[ns]	39.5[ns]	39.2[ns]
Manhattan (Northeast)	---	---	---	---	---	---	---	---
Olathe (East Central)	17.3b	---	---	---	---	---	---	---
Parsons (Southeast)	82.4a	103.2	89.0	118.7	82.4[ns]	51.1	40.9	53.8
Haysville (South Central)	16.8b	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.18 Physiological effects of geographic location on growth of *Viburnum* x *burkwoodii* 'Conoy' planted in Fall 2012 at six locations across Kansas (n=3).

	Growth index[z]				SPAD value[y]			
Location	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	30.3[ns]	---	---	---	---	---	---	---
Salina (Central)	---	---	---	---	---	---	---	---
Manhattan (Northeast)	20.7	---	---	---	33.0[ns]	---	---	---
Olathe (East Central)	---	---	---	---	---	---	---	---
Parsons (Southeast)	---	---	---	---	---	---	---	---
Haysville (South Central)	---	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.19 Physiological effects of geographic location on growth of *Viburnum* x *carlcephalum* 'Cayuga' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index^z				SPAD value^y			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	62.3a^x	---	---	---	43.9^{ns}	---	---	---
Salina (Central)	41.5ab	66.9^{ns}	72.0a	86.6a	45.5	67.1^{ns}	53.6^{ns}	63.1^{ns}
Manhattan (Northeast)	41.8ab	47.5	62.5ab	70.8ab	48.0	64.3	48.8	76.4
Olathe (East Central)	36.2ab	50.0	66.0ab	70.3b	47.0	60.0	45.8	62.5
Parsons (Southeast)	42.4ab	52.9	63.8ab	81.2a	42.4	64.5	50.5	71.0
Haysville (South Central)	25.0b	48.3	43.3b	45.3b	47.0	64.8	56.4	60.8
Garden City (Southwest)	---	---	---	---	---	---	---	---

^{z}Growth index = (height + width1 + width2) / 3 measured in cm.

^{y}Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

^{x}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

^{ns}Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.20 Physiological effects of geographic location on growth of *Viburnum* x *juddii* planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	29.4[ns]	40.0[ns]	47.0[ns]	50.2b[x]	52.8[ns]	74.3a	44.7[ns]	57.5[ns]
Salina (Central)	40.5	54.0	60.9	82.5ab	51.5	60.6b	47.4	51.5
Manhattan (Northeast)	27.3	49.3	66.1	84.3a	43.1	57.1b	44	62.4
Olathe (East Central)	---	---	---	---	---	---	---	---
Parsons (Southeast)	---	---	---	---	---	---	---	---
Haysville (South Central)	31.7	---	---	---	49.9	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.21 Physiological effects of geographic location on growth of *Viburnum* x *pragense* 'Decker' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	---	---	---	---	---	---	---	---
Salina (Central)	27.6[ns]	83.1ab[x]	96.1[ns]	121.4a	48.5abc	67.3b	57.0[ns]	68.5[ns]
Manhattan (Northeast)	---	68.1bc	51.6	78.7b	31.0c	74.3ab	53.8	63.8
Olathe (East Central)	30.3	52.5c	46.0	57.8b	57.7a	69.3b	50.4	74.7
Parsons (Southeast)	54.1	100.7a	96.1	121.7a	54.1ab	79.6a	57.4	79.0
Haysville (South Central)	49.5	---	---	---	38.1bc	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α =0.05 (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Table 4.22 Physiological effects of geographic location on growth of *Viburnum* x *rhytidophylloides* 'Alleghany' planted in Fall 2012 at six locations across Kansas (n=3).

Location	Growth index[z]				SPAD value[y]			
	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Spring 2013	Fall 2013	Spring 2014	Fall 2014
Colby (Northwest)	---	---	---	---	---	---	---	---
Salina (Central)	27.6[ns]	83.1ab[x]	96.1[ns]	121.4a	---	67.3b	57.0[ns]	68.5[ns]
Manhattan (Northeast)	---	68.1bc	51.6	78.7b	---	74.3ab	53.8	63.8
Olathe (East Central)	30.3	52.5c	46.0	57.8b	---	69.3b	50.4	74.7
Parsons (Southeast)	54.1	100.7a	96.1	121.7a	39.8	79.6a	57.4	79.0
Haysville (South Central)	49.5	---	---	---	---	---	---	---
Garden City (Southwest)	---	---	---	---	---	---	---	---

[z]Growth index = (height + width1 + width2) / 3 measured in cm.

[y]Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ; average of 3 leaves per plant).

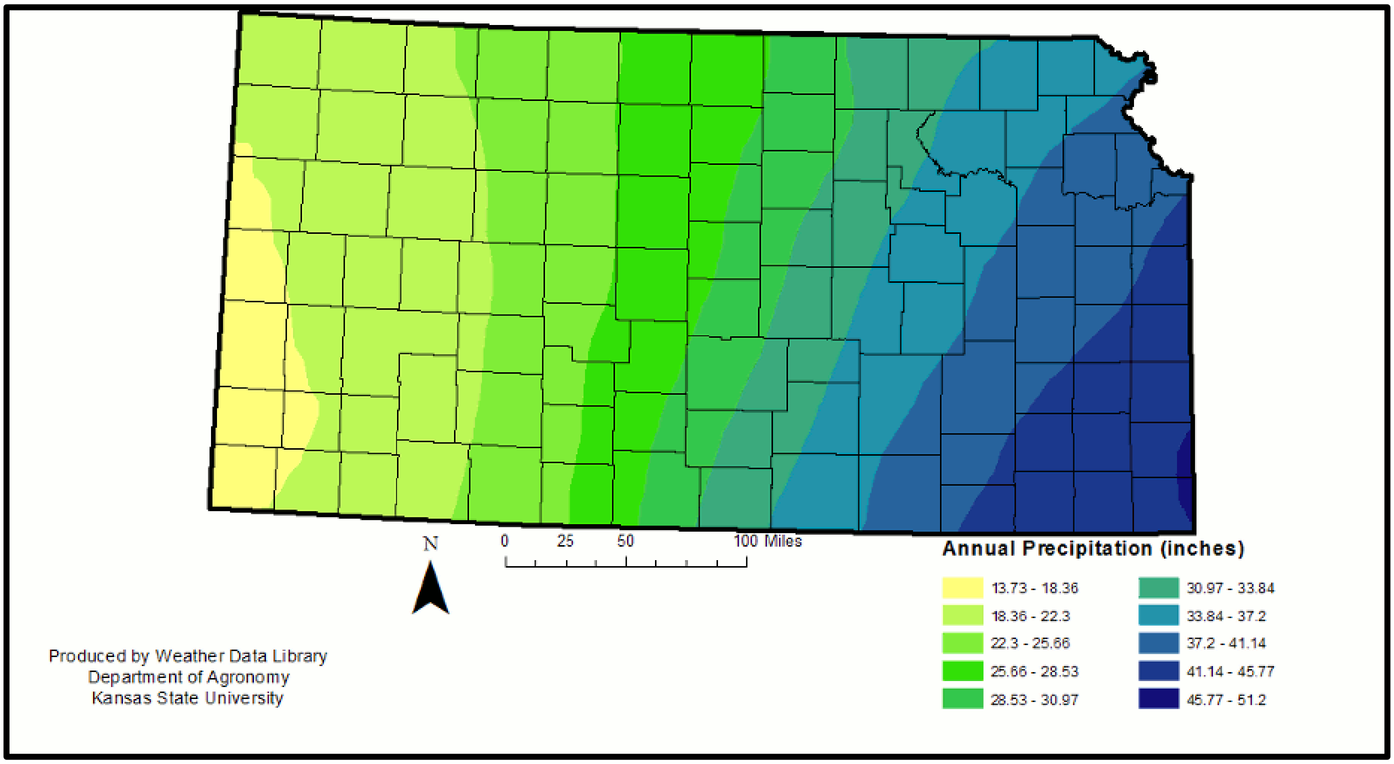
[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[ns]Means not significantly different.

--- Data point dropped due to less than 2 plants survived

Figure 4.1 Red balloons indicate seven replicated trial sites, Kansas State University (KSU) Northwest Research Center (Colby, KS), Saline County demonstration garden (Salina, KS), KSU Tuttle Creek Forestry Research Center (Manhattan, KS), KSU Olathe Horticulture Research and Extension Station (Olathe, KS) Prairie Wind Aquatics (Garden City, KS), KSU John C. Pair Horticulture Research Center (Haysville, KS), and the Parsons Arboretum (Parsons, KS) (3 reps of each species) for an establishment study on 19 *Viburnum* spp. planted in the fall of 2012 for a two season (2013-2014) establishment trial. Blue balloons indicate Extension agent cooperator sites (non-replicated sites--each agent received one plant of each species to record observational data).

Figure 4.2 Kansas normal mean annual precipitation (in) during the period of 1981-2010.



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Chapter 5 - Summary

The purpose of this research was two-fold, discover *Viburnum* spp. that can survive in the Great Plains and evaluate the validity of greenhouse drought and heat tolerance data to recommend plants for field trial. Viburnum was chosen because it is a widely available, popular shrub species, with enough variability in species characteristics to examine environmental stress adaptability in an effort to develop an assay for future plant evaluations. We conducted a short-term recurring drought study on 6 *Viburnum* spp., a heat acclimation and tolerance trial on three *Viburnum* spp., and a field trial on 19 *Viburnum* spp.

Viburnum awabuki, *V. dentatum*, *V. nudum*, *V. tinus*, *V. trilobum*, and *V. x rhytidophylloides* were subjected to short-term recurring drought in a controlled atmosphere greenhouse at Throckmorton Plant Sciences Center (Manhattan, KS). Treatments were well watered (WW; 90% container capacity [CC]), moderate drought (MD; based on signs of wilt) and severe drought (SD). Severe drought was determined by Scholander pressure chamber. Plants were measured for pre-dawn water potential and when plants reached -1.5 megapascal, container capacity was measured and classified as severe drought. *Viburnum dentatum*, *V. nudum*, and *V. trilobum* are species that have potential to be recommended as drought-tolerant species able to withstand the rigors of the Great Plains, specifically Kansas. With the three being deciduous, their ability to shed leaves, go dormant and then recover once moisture returns is to their advantage. *Viburnum tinus* and *V. x rhytidophylloides* exhibited significant challenges when managing drought and overwatering. *Viburnum awabuki* exhibited the most promise to be used in the Great Plains but it is a Southern ecotype selection that will have difficulty acclimating to the cold winter temperatures of the region. Further studies on the ability of *V. awabuki* to survive the cold temperatures of the region would be of interest. To recommend *V. x rhytidophylloides* further studies are needed paying close attention to well-watered treatment plants to ensure that the root system is not subjected to flooding conditions causing root damage prior to drought treatment.

The heat study was conducted at the Throckmorton Plant Sciences Center (Manhattan, KS), where plants were acclimated at 38C/25C (100F/77F) day/night within a controlled atmosphere greenhouse for 28 days. The plants chosen were *V. dentatum*, *V. nudum*, and *V. tinus*. Heat acclimation resulted in smaller plants yet *V. tinus* did not reduce biomass accumulation whereas *V. dentatum* and *V. nudum* reduced biomass. *Viburnum* dentatum and *V. nudum* both increased temperature optimum (T_{opt}) for net photosynthetic rate (P_{net}) following acclimation to high temperature. *Viburnum tinus* exhibited high P_{net} values for control and acclimated plants. With the reduced growth yet increased photosynthesis, these plants acclimated to heat by reducing size and adjusting T_{opt} to be able to maintain growth during periods of high heat. This characteristic is crucial to surviving in sites that experience prolonged periods of high day/night temperatures. The increased photosynthetic capacity afforded *Viburnum nudum* and *V. dentatum* the ability to continue increasing in size and biomass even during periods of high stress.

Field trials were conducted across the state of Kansas to account for variability in site across the state. Plants were grown out from liners at the John C. Pair Horticulture in Haysville, KS and then planted at seven sites across Kansas; Colby, Salina, Manhattan, Olathe, Parsons, Haysville, and Garden City. Planting time that is recommended by many Universities as most successful is Fall (King and Nance, 2012). Plants were installed during Fall of 2012. At planting in Colby and Garden City temperatures switched rapidly which may have resulted in shock to the plants. These two sites both had significantly more losses and resulted in the Garden City site being omitted. Garden City also had limitations due to rabbit browsing and pesticide drift.

Eastern and Southern sites had better survival and growth. Sites that provided shade (Salina and Parsons had greater than 75% survival). These sites had volunteers who were invested in the outcome of the study and paid careful attention to the site. Manhattan, Olathe, and Haysville had significant weed pressure and a survival of 51% or less. Colby had less than average precipitation during the study, resulting in 31% survival. The trials were a success in identifying several species of *Viburnum* which could be evaluated in the field trial for overall survival and adaptation to sites of varying characteristics. *Viburnum nudum, V. dentatum, V. trilobum, V. sieboldii,* and *V. tinus* all performed well in the drought study. From these studies, a field trial of *V. dentatum*, *V. nudum*, and *V. trilobum* can be recommended to evaluate the survival of the species over several years to account for the variability in the Great Plains climate and the many environmental stresses that can be encountered.

Limitations

Field trials are time consuming, expensive and labor intensive. If volunteers are not invested and interested in the project, it will not be as successful as possible. Weed encroachment was a problem at several sites. Parsons, even with the weed pressure from *Cynodon dactylon* (Bermuda grass), was still able to have a survival rate of 87% showing that volunteer participation in weed control may have been helpful. In contrast Haysville and Manhattan had weed pressure and volunteer participation was not adequate to keep weed levels at an acceptable tolerance and percent survival was 31% and 51%, respectively.

The greenhouse studies on drought and heat tolerance were a team effort with many late nights to collect data. Without the team in place to help to collect the data, one researcher could not have conducted these trials without sacrificing all regard for personal and family time. Pests were a problem for the deciduous species and caused *Viburnum dentatum* and *V. trilobum* to shed leaves throughout the heat and drought studies. Water was used to knock them off the leaves, but a severe infestation caused considerable leaf drop, making photosynthetic measurements impossible on *Viburnum trilobum*. Length of time exposed to heat also was crucial and proved to affect the rate of photosynthesis. The 28-day acclimation would be considered a chronic stress resulting in considerable damage and down regulation of photosynthesis. If conducting this trial a heat shock exposure of 24 hours would illicit a response toward acclimation.

Future work

Future studies of the best performing species in all studies should include cold tolerance studies. The field studies did have cold conditions but a study to find low temperatures that can be tolerated and not reduce overall aesthetic qualities and growth. Additional field trials when conducted should be sure to have clear expectation and guidelines for care. Volunteer participation should be vetted to ensure cooperation from the Extension Master Gardeners or others by gathering their input on what plants are of interest and how they are willing to participate in the study because without their support these kinds of studies cannot be conducted successfully. This support is crucial to ensuring the trials are run effectively and in a manner that is economical in times when research dollars are limited. The assays we performed were successful in identifying plants that performed well under drought and high heat conditions and those species also survived well in the field study. These types of assays can be recommended as a means to identify plants that are suited to a trial geography that already have been identified as environmental stress tolerant prior to investing the time and money into conducting a long-term field trial. Sites should be as condensed as possible and still cover all hardiness zones and precipitation gradients in the geographical area. This will capture the variability in precipitation and temperatures that can be experienced across distinct geographical regions.

Chapter 6 -

Combined References

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Appendix A -

Viburnum sieboldii 'Wavecrest' May 2013 located at the Parsons Arboretum (Parsons, KS).

Viburnum x pragense 'Decker' October 2013 at the Salina Master Gardener Display Garden (Salina, KS).

Viburnum nudum 'Winterthur' November 2012 located at the Parsons Arboretum (Parsons, KS).

Viburnum rhytidophyllum 'Cree' November 2012 located at the Parsons Arboretum (Parsons, KS).

Viburnum dentatum 'Chicago Lustre' November 2012 located at the Parsons Arboretum (Parsons, KS).

Viburnum plicatum ‘Popcorn’ November 2012 located at the Parsons Arboretum (Parsons, KS).

Viburnum carlesii ‘Diana’ October 2013 located at the John C. Pair Horticulture Center (Haysville, KS).

Viburnum x rhytidophylloides 'Alleghany' October 2013 located at the John C. Pair Horticulture Center (Haysville, KS).

Viburnum sargentii ‘Onondaga’ October 2013 located at the John C. Pair Horticulture Center (Haysville, KS).

Viburnum x carlcephalum ‘Cayuga’ May 2013 located at the John C. Pair Horticulture Center (Haysville, KS).

Viburnum trilobum 'Compactum' May 2013 located at the John C. Pair Horticulture Center (Haysville, KS).

Viburnum x juddii May 2013 at the Salina Master Gardener Display Garden (Salina, KS).

Viburnum rufidulum May 2013 at the Salina Master Gardener Display Garden (Salina, KS).

Viburnum dilatatum 'Michael Dodge' May 2013 at the Salina Master Gardener Display Garden (Salina, KS).

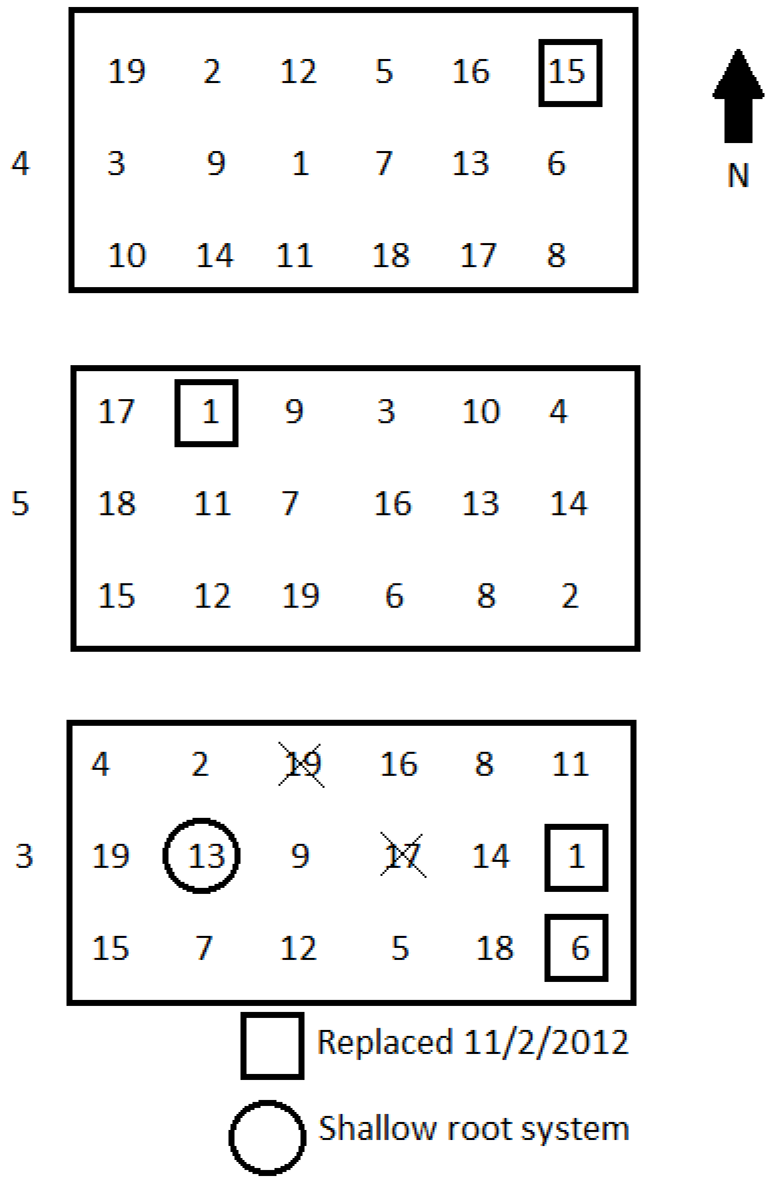
Viburnum x bodnantense ‘Dawn’ May 2013 at the Salina Master Gardener Display Garden (Salina, KS).

Viburnum x burkwoodii ‘Conoy’ May 2013 at the Salina Master Gardener Display Garden (Salina, KS).

Viburnum farreri November 2012 located at the Parsons Arboretum (Parsons, KS).

Viburnum plicatum f. tomentosum ‘Shasta’ November 2012 located at the Parsons Arboretum (Parsons, KS).

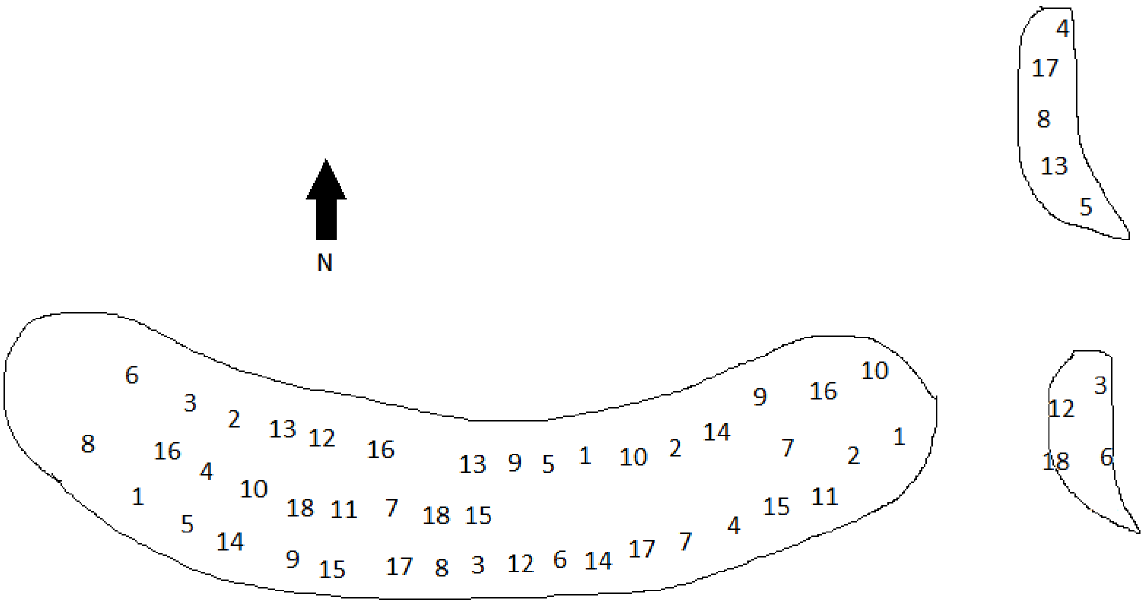
Manhattan planting plan



Plant Number Key

1. V. x bodnantense 'Dawn'
2. V. burkwoodii 'Conoy'
3. V. carlcephalum 'Cayuga'
4. V. carlesii 'Diana'
5. V. dentatum 'Chicago Lustre'
6. V. dilatum 'Michael Dodge'
7. V. juddi
8. V. nudum 'Winterthur'
9. V. opulus 'Roseum'
10. V. plicatum 'Popcorn'
11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Salina planting plan



Plant Number Key

1. V. x bodnantense 'Dawn'
2. V. burkwoodii 'Conoy'
3. V. carlcephalum 'Cayuga'
4. V. carlesii 'Diana'
5. V. dentatum 'Chicago Lustre'
6. V. dilatum 'Michael Dodge'
7. V. juddi
8. V. nudum 'Winterthur'
9. V. opulus 'Roseum'
10. V. plicatum 'Popcorn'
11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Garden City planting plan

N

9	1	17
6	16	2
10	12	3
13	8	5
11	15	7
4	14	18

5	10	4
16	6	12
17	3	11
9	18	2
7	8	1
14	15	13

14	16	12
9	5	15
10	13	1
2	4	17
3	18	6
8	7	11

Plant Number Key

1. V. x bodnantense 'Dawn'
2. V. burkwoodii 'Conoy'
3. V. carlcephalum 'Cayuga'
4. V. carlesii 'Diana'
5. V. dentatum 'Chicago Lustre'
6. V. dilatum 'Michael Dodge'
7. V. juddi
8. V. nudum 'Winterthur'
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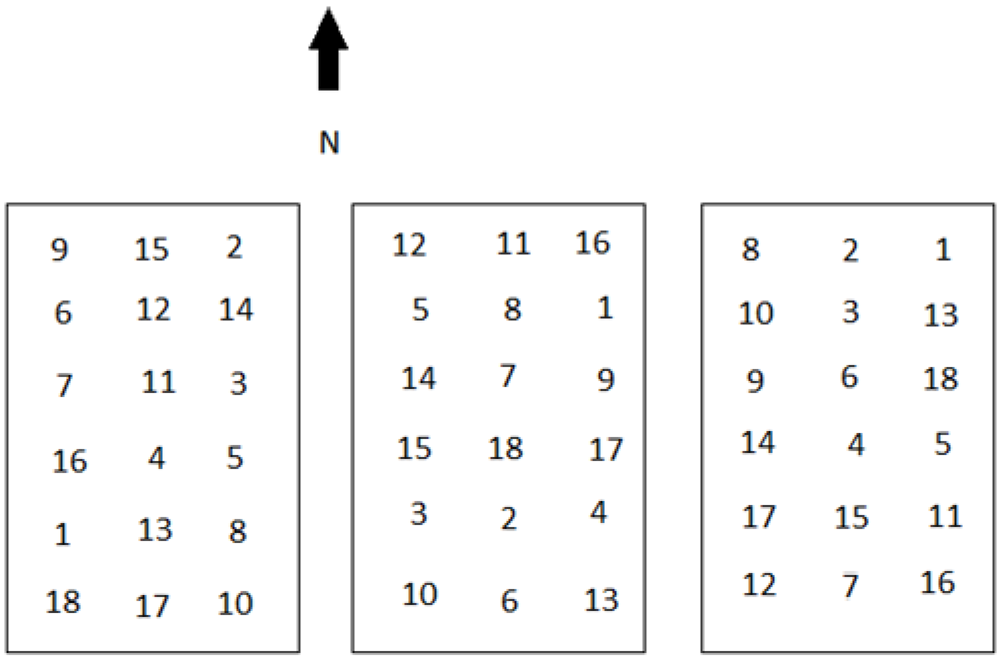
11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Colby planting plan



Plant Number Key

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2. V. burkwoodii 'Conoy'
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11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Olathe planting plan

← N

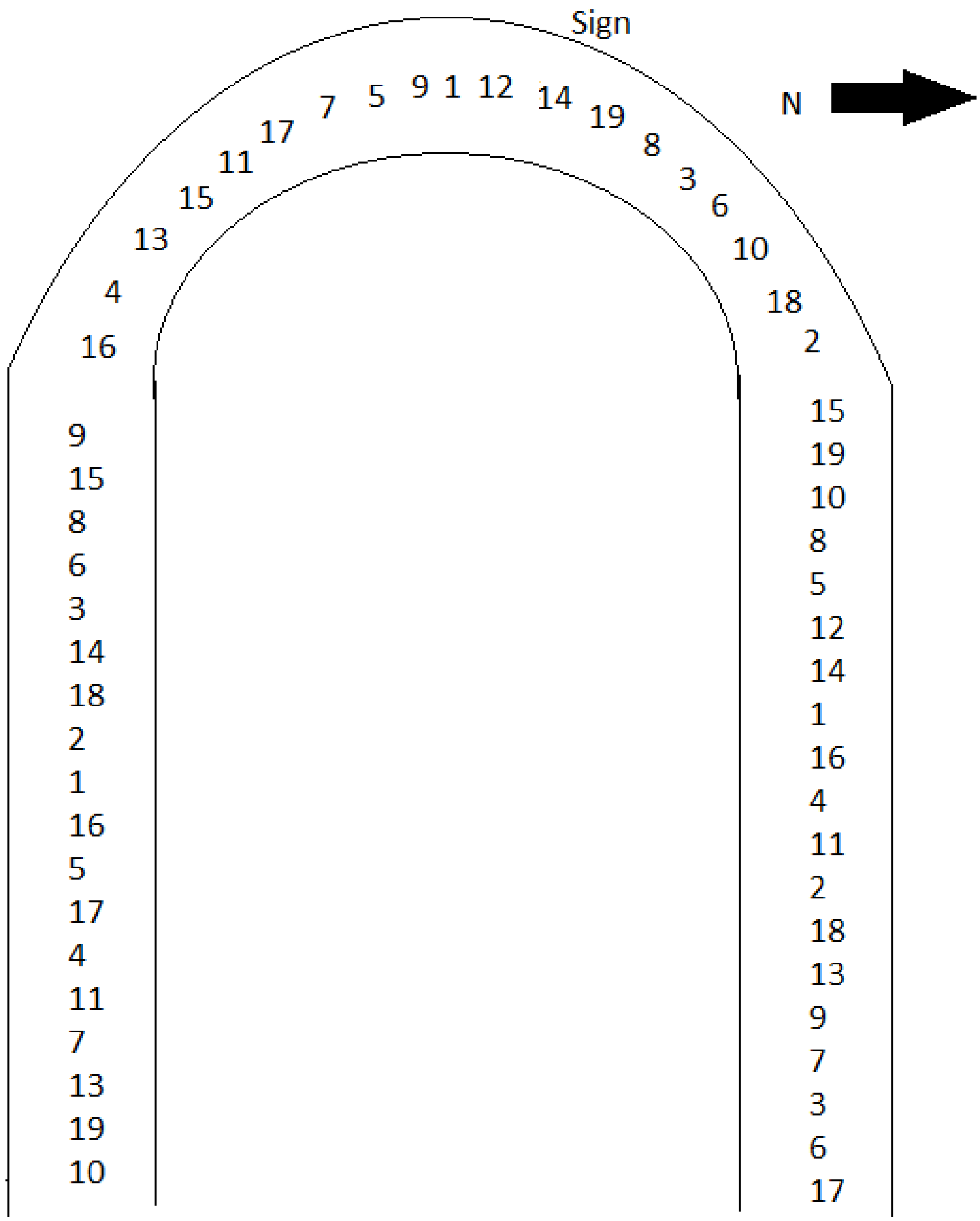
1	2	3
12	3	5
9	11	18
11	1	4
5	18	10
15	4	3
13	9	9
8	2	12
4	7	16
2	12	2
6	8	13
18	10	8
14	16	15
1	14	1
16	6	14
7	5	11
10	15	6
3	13	7

Walkway

Plant Number Key

1. V. x bodnantense 'Dawn'
2. V. burkwoodii 'Conoy'
3. V. carlcephalum 'Cayuga'
4. V. carlesii 'Diana'
5. V. dentatum 'Chicago Lustre'
6. V. dilatum 'Michael Dodge'
7. V. juddi
8. V. nudum 'Winterthur'
9. V. opulus 'Roseum'
10. V. plicatum 'Popcorn'
11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Parsons planting plan



Plant Number Key

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12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. rufidulum
16. V. sargentii 'Onondaga'
17. V. sieboldii 'Wavecrest'
18. V. trilobum 'Compactum'
19. V. farreri

Haysville planting plan

N →

1	5	10	2	16	3	14	4	1
7	14	4	6	12	11	3	7	10
18	2	16	13	9	1	17	5	6
3	12	13	8	15	14	11	16	9
17	15	9	18	7	5	12	18	13
6	11	8	17	10	4	8	2	15

Plant Number Key

1. V. x bodnantense 'Dawn'
2. V. burkwoodii 'Conoy'
3. V. carlcephalum 'Cayuga'
4. V. carlesii 'Diana'
5. V. dentatum 'Chicago Lustre'
6. V. dilatum 'Michael Dodge'
7. V. juddi
8. V. nudum 'Winterthur'
9. V. opulus 'Roseum'
10. V. plicatum 'Popcorn'
11. V. plicatum tomentosum 'Shasta'
12. V. pragense 'Decker'
13. V. rhytidophylloides 'Alleghany
14. V. rhytidophyllum 'Cree'
15. V. sargentii 'Onondaga'
16. V. sieboldii 'Wavecrest'
17. V. trilobum 'Compactum'
18. V. farreri