THESIS

MULTI-SITE TRIAL OF WOODY PLANTS: 2006 PLANTING AND EVALUATION OF DIFFERENCES IN DROUGHT TOLERANCE OF THREE *AMELANCHIER* SPECIES

Submitted by

Eric Hammond

Department of Horticulture and Landscape Architecture

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2012

Master's Committee:

Advisor: James Klett

William Jacobi
Harrison Hughes

ABSTRACT

MULTI-SITE TRIAL OF WOODY PLANTS: 2006 PLANTING AND EVALUATION OF DIFFERENCES IN DROUGHT TOLERANCE OF THREE *AMELANCHIER* SPECIES

CHAPTER 1: MULTI-SITE WOODY PLANT EVALUATION IN COLORADO

A multi-site trial of several woody plants plant species and cultivars was conducted to determine their potential for landscape use in the state of Colorado. The trial was conducted with the input and cooperation for the Colorado Nursery Research and Education Foundation and Plant Select®. Data was collected from 2006-2010 at five sites with different soils, climates and cultural practices. Plants were evaluated based on size, growth, survival, aesthetics and heath. The taxa evaluated were: *Acer monspessulanum*, *Juniperus scopulorum* 'Woodward', *Larix decidua*, *Prunus serotina* (of central Texas providence), *Pyrus ussuriensis* 'Burgundy', *Quercus polymorpha* and, *Quercus × pauciloba.* Researchers recommend *Juniperus scopulorum* 'Woodward', *Prunus serotina* and, *Quercus × pauciloba* for widespread use in the state. *Quercus polymorpha* did not prove adapted to any of the sites and is not recommended. *Larix decidua and Pyrus ussuriensis* 'Burgundy' did not perform well at all sites and are only recommended for use in the state in some situations.

CHAPTER 2: EVALUATION OF DIFFERENCES IN DROUGHT TOLERANCE OF THREE *AMELANCHIER* SPECIES

In the summer and fall of 2010, research was conducted to evaluate the drought tolerance of *Amelanchier alnifolia*, *Amelanchier canadensis*, and *Amelanchier utahensis*. Potted plants of each species were subjected to three increasingly long periods without watering (dry downs) in a greenhouse. Predawn leaf water potential and soil volumetric water content (measured by time domain reflectometry) were measured for each plant and compared. The third dry down was allowed to continue until plants went dormant or died. Results show that in a greenhouse, potted, *Amelanchier utahensis* is more tolerant of low water conditions than the other species. The differences in drought tolerance between the *Amelanchier canadensis* and *Amelanchier alnifolia* are not as clear and may require more research to understand

TABLE OF CONTENTS

CHAPTER 1

MULTI-SITE WOODY PLANT EVALUATION IN COLORADO

Introduction

In 2002 Colorado State University's Department of Horticulture and Landscape Architecture, in conjunction with the Colorado Nursery and Greenhouse Association, the Colorado Nursery Research and Education Foundation and the Plant Select® program began a multi-site woody plant evaluation program. This project was undertaken to provide a systematic approach to gathering data on the performance of woody plants which are little used in the state. The specific goal was to determine if these woody plants were suitable for wider use in the variable climates and soils found in Colorado landscapes.

Plant material for the trial was selected with the aid of industry professionals. They were then established at multiple sites across the state. Test plants were evaluated based on: growth rates, quality of ornamental features, hardiness, susceptibility to diseases or pests, as well as, general performance in the variable soils and climates of the different sites. The first planting was made in the spring of 2002 and has been followed with seven subsequent plantings on nearly annual bases. This paper will focus on the evaluation of those plants established in the 2006 planting.

Literature Review

There are several other multi-site and single site trial programs similar to this program around the nation. However, they do not capture the diverse climatic conditions of Colorado. There is very little overlap between the species evaluated in those trials and the Colorado State University trials. The focus of this review will be on the methods of the other trials.

The University of Arkansas initiated a multi-site plant evaluation program in 1999. The program sought to evaluate plant performance across the state of Arkansas, identify plant material suitable for promotion through the Arkansas Select program and provide nurserymen with a source of plant material for propagation. Three sites were utilized. Site selection was based on USDA Plant Hardiness zones with one site in each of the three zones which are found in the state; zones 6, 7 and 8. A complete random design with four repetitions was used and plants were grouped by type; trees, shrubs and herbaceous perennials. Plants that traditionally need shade were planted in natural shade at the sites. The plants were irrigated with drip irrigation and where fertilized and mulched at planting. Growth data was collected yearly and used to calculate a growth index (πhr^2– where h is height and r is canopy radius) Plants remained in the trial for 5 years (14).

The Southern Extension and Research Activities/Information Exchange Group-27 was established in 1994 and conducted regional level evaluations of landscape plants including some woody plants. They distributed plants to 13 different sites managed by major land grant universities across the Sothern United States. Plants were evaluated on a scale of 1 to 10 for several factors including the following: damage from insect and diseases (based on severity), growth, flower, fruit, fall color, landscape potential, pest transmission potential and invasiveness potential. Initial bloom date was also recorded and plants were measured for both height and width (4).

Oklahoma Proven™ is a program established and managed by Oklahoma State University with input from other state agencies and the Oklahoma Botanical Garden and Arboretum Affiliate Gardens to evaluate and introduce plants suited to the conditions present in the state of Oklahoma. Both woody and herbaceous plants are evaluated in the trial. Plants are tested at 16 sites located throughout the state with the principle site at Oklahoma State University. Herbaceous plants are evaluated for a minimum of three years while woody plants are in trial for a minimum of 5 years (1).

Kansas State University has also conducted a multi-site evaluation of landscape trees to identify superior landscape plants for the Midwest. This trial was conducted at six Kansas Agricultural Experiment Stations and as of 1991 had evaluated forty taxa. A randomized block design with five replications was used with five new species or cultivars added annually beginning in 1986. Plants were fertilized annually and pruned as needed by the project's personnel. All other care was left to on-site personnel. Data was recorded in the spring on plant height, caliper, survival, foliage quality and overall quality. Plants material in the trial was evaluated for five years after which it was commonly moved to a permanent location at the research station. (8)

North Dakota State University undertook adaptation studies similar to those in Kansas and Arkansas. Their study sought to systematically evaluate species, cultivars and named varieties and new selections of woody plants in order to make recommendations about their use in the Northern Plains Region. Plants were tested at nine sites throughout the state. Data was collected on survival, vigor, growth, pest susceptibility, soil adaptability and landscape characteristics. Plants remained in the trial for a minimum of five years (19 and 20)

In Texas, the Coordinated Education and Marketing Assistance Program (CEMAP) evaluates ornamental plants across the state as a component of its Texas Superstar™ program. CEMAP is a joint venture between Texas A & M Agricultural Program, Steven A. Austin State University and members of the horticultural industry in the state. Its goal is to ensure consumers have access to the best plant material possible for conditions in Texas and to help the ornamental plant industry in the state become more profitable. To this end, they evaluate plant material at twenty-five sites thought-out Texas (15).

In 2006 the University of California at Davis began an intensive trialing process to identify native, low water use plants, suited for urban landscaping. From a list of potential plant material assembled from past experience, researchers selected ten potential taxa for trialing. Initially, twenty-four individuals of each taxon were planted in a randomized complete block design. Plants were given adequate water for one growing season then four different water treatments were applied. The six most promising species based on survival, growth, appearance and other observational factors were then advanced to a regional trial conducted at demonstration gardens distributed across the different climates found in California. They will be evaluated again at these sites on growth, survival and appearance (23).

In 1980, Auburn University started evaluating shade trees at the Alabama Agricultural Experiment Station, Piedmont Substation. The goal of their work was to provide a scientific basis for selection of shade trees for landscape use. From 1980 to 1985 two hundred and fifty taxa were selected and planted at the station. Nine individuals of each selection where planted in a randomized complete block design. No supplemental irrigation was applied. The plants where fertilized with a complete fertilizer at planting and have received annual applications of nitrogen since planting. Evaluation at the site is based on annual growth rate, survival and ascetics. In 2001, ninety five of the two hundred fifty taxa remained in the trial (33).

The National Arboretum conducts multi-site evaluations of woody plants in conjunction with cooperators as part of its plant breeding program. Based on their performance at the National Arboretum in Washington D.C. promising cultivars are made available to cooperators for further trialing. Interested cooperators then receive two or three plants of the cultivar for evaluation. Data is collected on disease and pest issues, growth rate, bloom, fruit timing and quality, as well as other ornamental features and a relative rating of commercial potential (22).

The North Central Regional Plant Introduction Station has conducted a long running and wide reaching evaluation program as part of its Introduction, Manipulation, Evaluation, Preservation, Cataloguing, and Utilization of Plant Germplasm project. Taxa for the trail were selected for many reasons including, but not limited to; potential performance at test sites based on the climate of native population, past experience with the taxon, ease of propagation and dissemination and trends in the nursery industry. A large and far spreading network of thirty- six national cooperators hosted the taxa they believed merited consideration at their individual sites. Not all taxa were evaluated at all sites. Plants were evaluated by the cooperators for ten years based on survival, growth and ascetics (29, 30, 31).

Many of the above programs are similar in structure to the Colorado State University trial. Similar data is collected in many of the trials and their goals are often similar. The common theme of this research is the need for a scientific and systematic approach to data regarding plant performance rather than simply observational data in order to make better recommendations for landscape plantings in varying climates and conditions.

Methods and Materials

Potential taxa for trialing were selected with input from the Colorado Green Industry, Plant Select® and Colorado State University personnel. A "Think Tank" of industry professionals and Colorado State University personnel compiled a list of potential species and named cultivars of woody plants based on experience with the plants. No specific criterion for recommending a plant was required other than the potential for success in Colorado landscapes. Plant Select® developed a list of potential woody plants based on twelve criteria they have used to evaluate a plant species or selection for possible introduction. These criteria include: 1) performance in a broad range of garden situations in the Rocky Mountain Region; 2) adaption to the Central Rocky Mountain Region's challenging climate; 3) uniqueness; 4) disease and insect resistance; 5) exceptional performance under low water conditions; 6) a long season of beauty in the garden; 7) noninvasiveness; 8) capability to be mass produced; 9) retail appeal and longevity in containers; 10) quantity currently available; 11) knowledge of basic propagation protocols and 12) Images available for publication. Plants from lists of potential plants were then selected for trialing if available.

The selected species were planted between early April and late May of 2005 at five different sites across the state. Two of the sites were at Colorado State University research stations while private cooperators hosted the other three sites. Plants were planted in a randomized block design with ten replications of each species at each site. The method of planting and the cultural practices were left to the discretion of the cooperators at the various sites. However, cooperators were asked to refrain from pruning the plants so that their natural growth habit could be observed

Sites-

Brighton, Colorado: Little Valley Whole Sale Nursery-

This site is located to the northeast of the city of Denver at 39.942379˚ N, 104.836261˚W and has an elevation of 1514 m. Test plants were planted in open furrows 1.8 m with 3.6 m between rows. The furrows were then immediately closed and irrigated. Flood irrigation with ditch water was used for all watering. Plants were irrigated according to need based on the nursery's field manager's discretion. Plants received periodic winter watering if no snow cover was present. Plant material was inspected on a near daily basis by the staff and managers. The soil on site is a clay loam with a pH of 7.3 (Appendix figure 1). Plants were fertilized once in 2010 with forty-five kg of nitrogen and ninety kg of sulfur per acre.

A weather station is located on site. Weather measurements were taken every ten minutes. The high temperature measurement at this site for the trial years was 40 °C (July 2006) while the low was -30.54 °C (January 2009). When compared to other sites, Brighton recorded the lowest temperature four out of five years while in 2009-2010 Fort Collins recorded the lowest temperature (Appendix Figure 1). The temperature data for May 2009 is missing due to issues with the weather station during this time. Average annual precipitation was 31.54 cm while the wettest year was 2009 with 40.46 cm and the driest was 2006 with 26.01 cm (Figure 1.1 and Figure 1.6, respectively). Plants appeared to have had aquate irrigation at this site durring the trial.

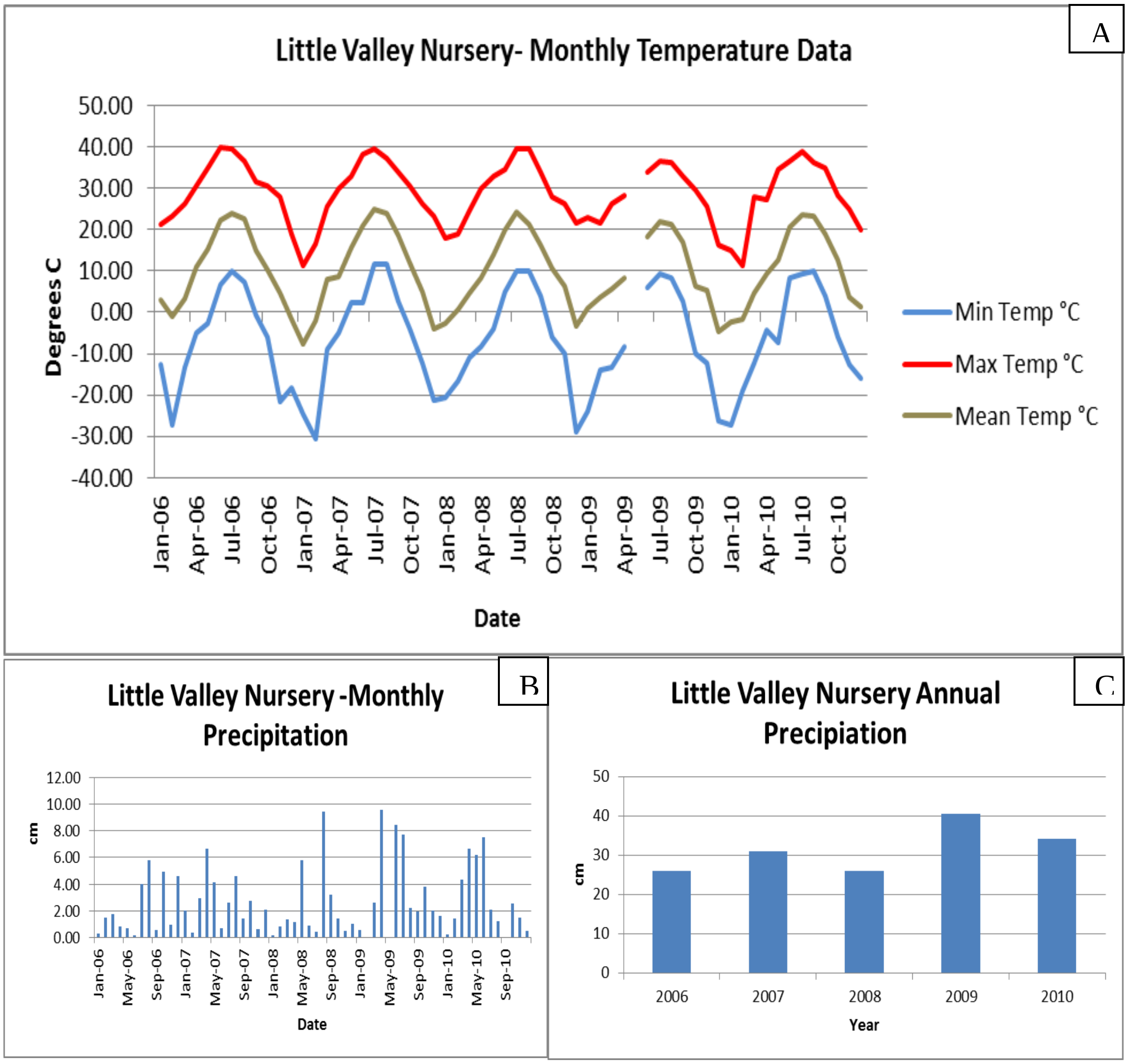


Figure 1.1 A-C: Monthly Temperature (A), Monthly Percipitaion (B) and Annual Precipiation (C) data for Little Vally Wholeale Nursery, Brighton, Colorado: January 2006 to October 2010. Weather station is located on site.

Calhan, Colorado: Harding's Nursery-

This site is located west of Colorado Springs in Calhan, Colorado (38.928935˚ N, 104.388313˚ W). This is the highest elevation test site at 1981 m. Test plants where planted in pre-augured holes spaced 1.8 m with 3 m between rows in a tilled field and watered immediately. An overhead sprinkler irrigation system used well water for irrigation. No winter watering was undertaken. Plants were irrigated according to need based on the nursery's field manager's discretion. Soils on site were sandy clay loam with a pH of 7.0. The nitrogen level in soils at this site was 2.8 ppm (Appendix Figure 1). This level of nitrogen is considered low enough to, in some situations, negatively affect woody plant growth (6). Green manure was applied to the surface of the field every other year. This site is located on a flat plain with no windbreaks. There was no onsite weather station to provide confirmation but cooperators have indicated that severe winds are common.

The nearest weather station to this site is located at the Colorado Springs Airport (38.49˚ N, 104.3893˚ W) which is approximately 48 km southeast of the site. This station took measurements every ten minutes. Weather at the airport likely varies from the trial site due to exposure and elevation (1,889 m). The high temperature measurement at the airport for the trial years was 37.2 °C (August 2008) while the low was -26.1 °C (December 2009). Average annual precipitation was 32.34 cm while the wettest year in 2009 had 39.92 cm of precipitation and the driest was 2010 with 23.82 cm (Figures 1.2 and 1.6, respectively). Due to the higher elevation of the trial site and its exposure to winds it seems likely that the conditions experienced by test plants in Calhan were more severe than the airport weather data indicates.

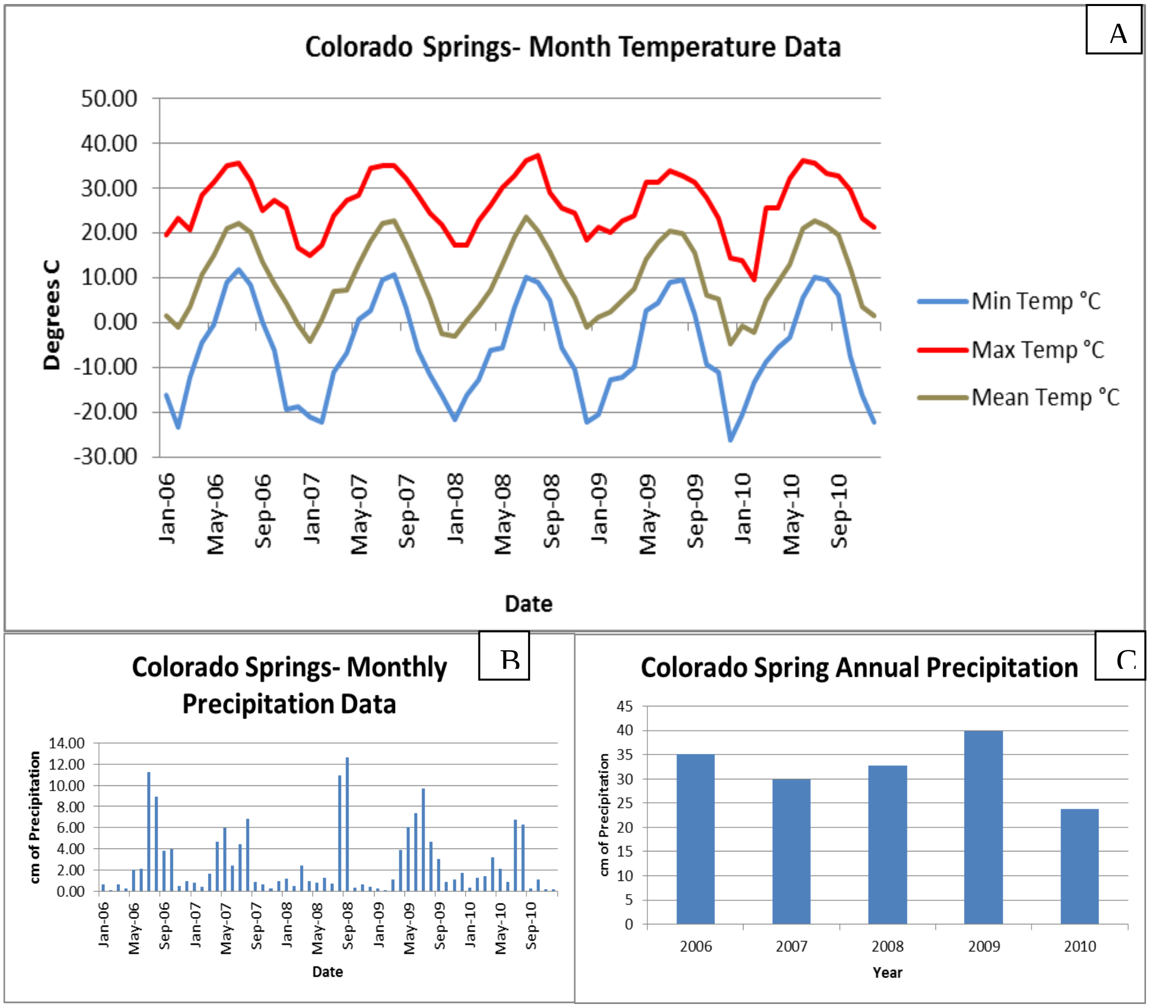


Figure 1.2 A-C: Monthly Temperature (A), Monthly Percipitaion (B) and Annual Precipiation (C) data for the Colorado Springs Airport, Colorado Springs, Colorado: January 2006 to October 2010.

Fort Collins, Colorado: The Colorado State University Horticultural Research Center-

This university research site is located on the eastern edge of Fort Collins (40.6138˚N, 104.9967˚ W) and has an elevation of 1524 m. Soils on site are clay with a pH of 8.0 (Appendix figure 1). Researchers and staff planted test plants in open furrows 1.8 m with 3 m between rows. The furrows were then immediately closed and irrigated. Furrow directed flood irrigation with well water was used for all watering. Irrigation scheduling and application was undertaken by the onsite manager. It seems likely the irrigation applied at this site was not adequate, particularly in the first three years of the trial. A sufficient quantity of water may not have reached the end of the furrow. Plants at the end of the furrow relative to the irrigation system were significantly smaller in many cases than those located at the start of the furrow system. Winter watering was not undertaken at this site during the trial. No additional fertilization was undertaken.

A weather station located at an adjacent university property was used to gather weather data. The station took measurements every ten minutes. The high temperature measurement at this station for the trial years was 39.59°C (June, 2006) while the low was -27.61°C (January, 2010). Average annual precipitation was 24.28 cm while the wettest year was in 2008 with 29.1 cm and the driest was 2006 with 12.36 cm (Figures 1.3 and 1.6). The nature of this site along with the noted irrigation issues meant that plants at this test site experienced more limited moisture conditions than most of the other test sites.

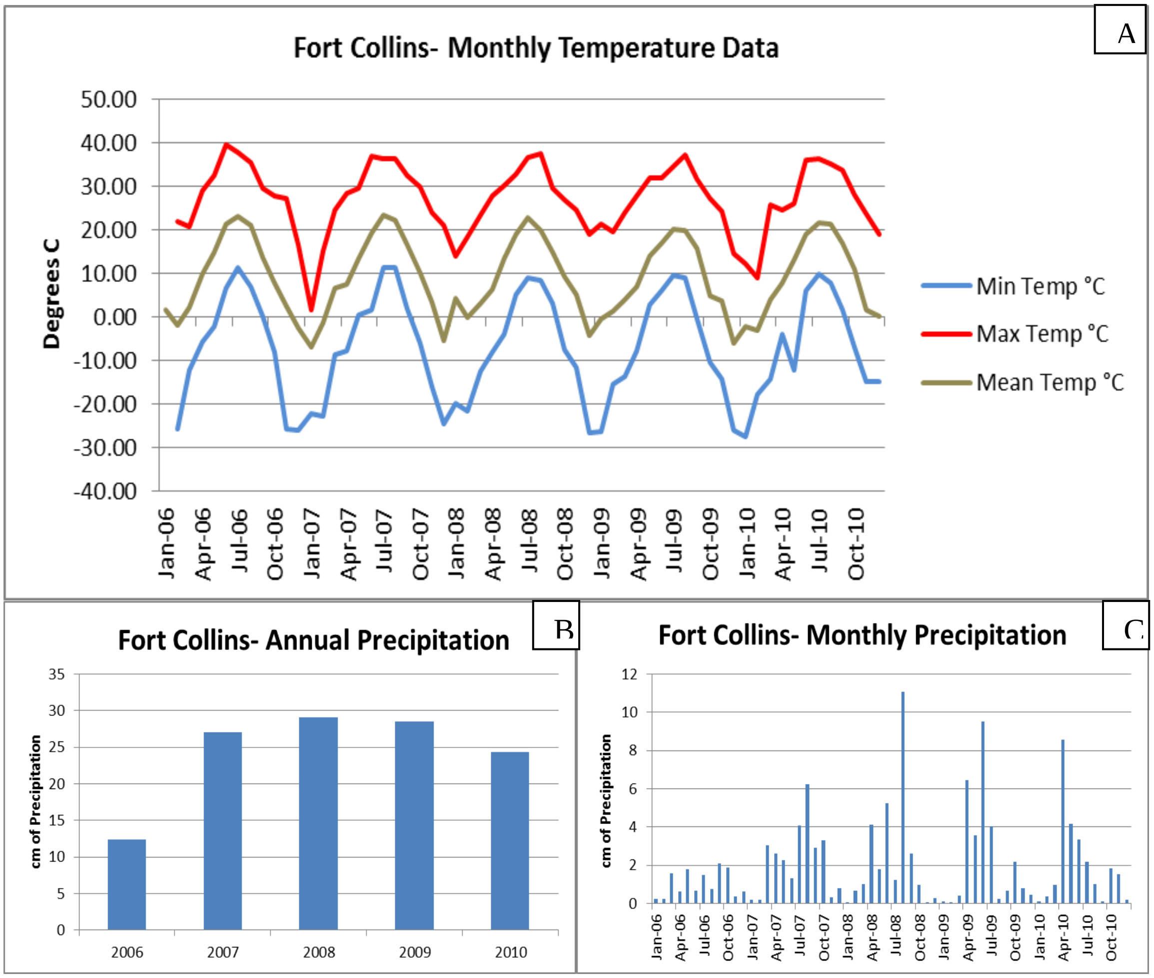


Figure 1.3 A-C: Monthly Temperature (A), Monthly Percipitaion (C) and Annual Precipiation (B) data for the Colorado State University Horticultural Research Center, Fort Collins, Colorado: January 2006 to October 2010. Weather station located on site.

Orchard Mesa, Colorado: The Colorado State University Western Slope Research Station-

This university run site is located on the western slope of the Central Rocky Mountains adjacent to the towns of Grand Junction and Orchard Mesa at (39.0453˚ N, 108.4680˚ W) at an elevation of 1475 m. Researchers and staff planted test plants in open furrows 1.8 m with 3 m between rows. The furrows were then immediately closed and flood irrigated. Further irrigation was accomplished with a micro-sprinkler irrigation system with water from the Colorado River. Water was applied at a rate of +20% of evapotranspiration.

Soils on the site are clay with a pH of 7.5 (Appendix figure 1). No supplemental fertilization was undertaken at this site.

A weather station is located on site and took measurements every ten minutes. The high temperature at the research station for the trial years was 40 °C (July, 2006) while the low was -25 °C (December, 2009). It should be noted that this low is extremely cold for this site with the next lowest temperature observed being -18.8°C (January of 2007). Average annual precipitation was 22.43 cm while the wettest year in 2010 had 27.94 cm and the driest was 2009 with 18.84cm (Figures 1.4 and 1.6). Plants appear to have received sufficient irrigation at this test site.

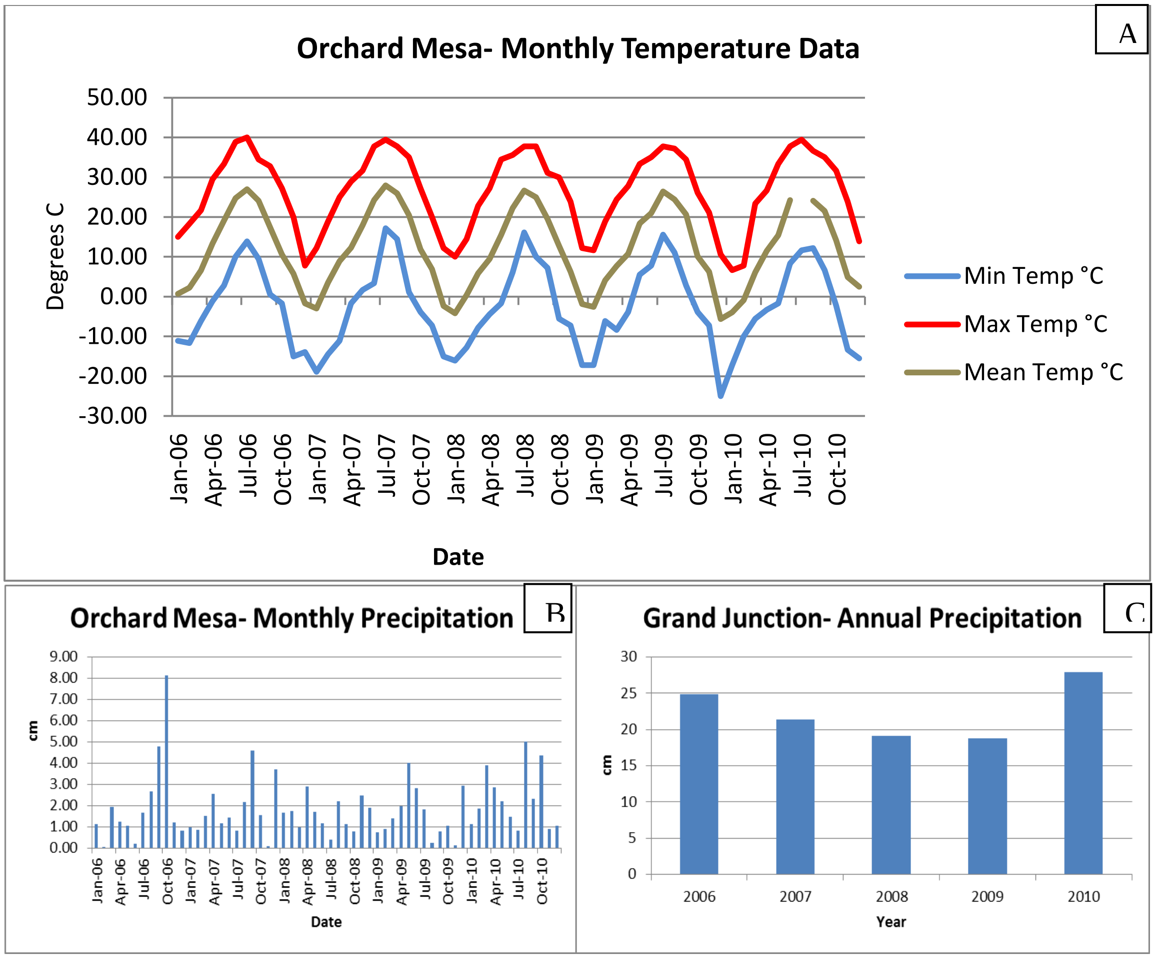


Figure 1.4 A-C: Monthly Temperature (A), Monthly Percipitaion (B) and Annual Precipitation (C) data for the Colorado State University Western Slope Research Station, Orchard Mesa, Colorado: January 2006 to October 2010. Weather station is located on site.

Hudson, Colorado: Boxelder Creek Nursery-

This site is located 6 km southeast of Hudson Colorado at 40.0134˚ N, 104.6070˚ W and has an elevation of 1539 m. Tests plants were planted in open furrows 1.8 m with 3 m between rows. The furrows were then immediately closed and irrigated. Both well and ditch water were used for flood irrigation depending on availability. Plants were irrigated weekly for the first growing season then according to need based on the nursery's field manager's discretion in later growing seasons. No additional fertilization was undertaken at this site. Soil at this site is clay with a pH of 7.8 (Appendix figure 1). The closest weather station is located in Greeley, Colorado approximately 48 km from the test site.

Weather at this station likely varies to some extent from the trial site due to differences in exposure and elevation.

The weather station took measurements every ten minutes. The high temperature measurement at the Greeley station for the trial years was 44.4 °C (July 2006) while the low was -27.2 °C (December 2009). Average annual precipitation was 41.95 cm while the wettest year was 2009 with 51.31 cm of precipitation and the driest was 2006 with 29.11cm (Figures 1.5 and 1.6).

In late May of 2010 this site experienced an extreme hail storm. The hail damaged all woody plant material at the site and subsequently forced the cooperator to destroy all remaining woody plants including the test plants. Data was collected from the plants before destruction on July 16th 2010. The data collected for 2010 was likely affected by the timing of its collection and the damage from the hail.

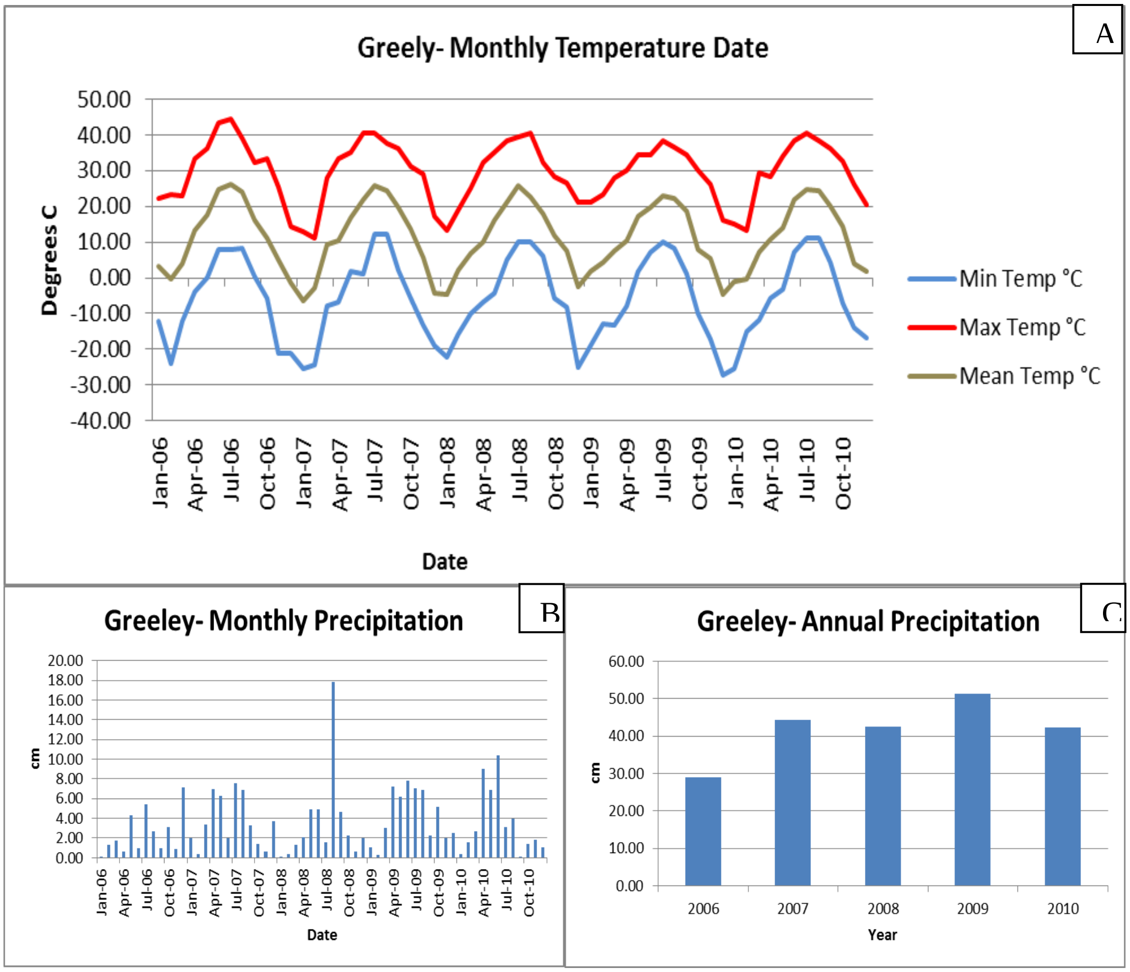


Figure 1.5 A-C: Monthly Temperature (A), Monthly Percipitaion (B) and Annual Precipitation (C) data for Greeley, Colorado: January 2006 to October 2010.

Table 1.1 Summery of extream temperartures mesurements and annual precipations for the five test sites from January 2006 to October 2010. Weather stations took measurements every ten minites.

	Minimum Temperature (°C)	**Maximum Temperature (°C)**	**Average Annual Precipitation (cm)**
Brighton	**-30.5**	**40.0**	**31.5**
Colorado Springs	**-26.1**	**37.2**	**32.3**
Fort Collins	**-27.6**	**39.5**	**24.2**
Orchard Mesa	**-25.0**	**40.0**	**22.4**
Greely	**-27.1**	**44.4**	**41.9**

Data Collection:

Growth data was collected at the end of each growing season at each site while other data was collected intermittently throughout the rest of the year. Growth data taken included:

plant height, width, caliper and growth increments for deciduous plants. Height and width but not caliper and growth increments were taken for conifers. Height was measured with a telescoping measure pole from the base of the plant to highest living point. Two width measurements were taken; one at the narrowest part of the plant and one at the widest. Caliper was measured fifteen cm from the ground and was not recorded on multi-stem plants. Two growth increments were taken from randomly selected branches. Other general performance data such as quality and timing of flowers, fall color, presence or absence of disease or insect issues and survival data was taken as needed throughout the year. Plants were minimally assessed for invasiveness. Researchers and cooperators watched for and reported other invasive seedlings tendencies.

The GLIMMIX procedure in SAS/STAT 9.2 (SAS Institute, Cary, NC, USA) was used to analyze the height, width, and caliper as well as growth interval data. The fixed effects for this data were the five individual sites, the five individual years, and the interaction of site by year. The random effect was the replication within each site. All values were logarithmically transformed for analysis. Pairwise differences between means were compared using a t-test with a level of significance $p<0.05$. Data was back transformed for graphing.

Soil samples were collected at each site with a soil probe. The probe was inserted and collected soil to a depth of 15 cm. Soil was taken from three random locations at each site. Weather data was collected from the closest possible weather station to each site

<u>Plant Material:</u>

***Prunus serotina* (Ehrh.) (Black Cherry)-**

Prunus serotina is a widely distributed species. Populations can be found as far north and east as New Brunswick and extend into Florida and Texas in the south with adjunct populations in Arizona, New Mexico and Mexico (16). The species is utilized in landscapes for its white flowers in the late spring, dark blue to black fruit and russet red fall color (2). The individuals evaluated in the trial were selected from the Edwards Plateau region of Texas. They are likely a selection of the recognized variety *eximia,* which is noted for its shorter height (~15 m when mature compared to the ~35 m seen in the more common eastern variety) and thicker leaves (15). This selection was introduced into the trial due to the potential combination of good cold hardiness and tolerance of alkaline soils. Individuals used in the trial were propagated from seed and were grow in number one containers before being transplanted to test sites.

***Acer monspessulanum* (L.) (Montpelier Maple)-**

A species native to the Mediterranean region of Europe and Africa, *Acer monspessulanum* is somewhat uncommon in North American landscapes. The species is noted for its dense habit, orange-red fall color and delicate three lobed leaves. The individuals were propagated from seed collected from a mature individual growing in Denver Colorado and were growing in number one containers at the time of planting (2).

***Juniperus scopulorum* 'Woodward' (Sarg.) (Woodward Rocky Mountain Juniper**)-

Rocky Mountain juniper is valued in landscapes as a reliably cold hardy (Zone 3) and drought tolerant conifer. It is oven used in windbreaks, shelterbelts, wildlife plantings, as well as, many other situations (2 and 25). *Juniperus scopulorum* 'Woodward' is a clone that was observed at the now closed United State Department of Agriculture Horticultural Research Station in Cheyenne, Wyoming. This plant was a selection originally made in Western Oklahoma for its narrow upright growth habit and strong apical dominance. Trial plants were vegetative propagated from rooted cuttings and were growing in four inch containers at the time they were transplanted to test sites.

***Larix decidua* (Mill.) (European Larch)-**

Larix decidua is a deciduous conifer native to many of the mountainous regions of Central and Eastern Europe which has become naturalized in the northeastern United States and Canada as well as the Great Lakes Region. It is noted for its fast growth rate, deciduous nature and need for moist soils (25). The species was selected for evaluation based on the several attractive individuals observed along Colorado's Front Range. Individuals used in the trial were grown from seed collected from an impressive individual in Fort Collin's City Park. They were growing in four inch (.75 l) containers at the time they were transplanted to test sites.

Pyrus ussuriensis 'Burgundy' (Maxim.) (Burgundy Ussurian Pear)-

Ussurian Pear and its many cultivars and clones are used in landscapes for the white flowers they develop in early spring, yellow to purple leaf color in the fall and their cold hardiness (Zone 3). However, individuals often exhibit features unattractive in landscapes such as thorns and susceptibility to fireblight (2). The selection 'Burgundy' was made by Fort Collins Wholesale Nursery for is deeper burgundy fall color, upright growth habit and low number of thorns. Trial plants were vegetative propagated. They were budded on to *Pyrus betulifolia* root stock. Plants were growing in four inch (.75 l) containers at the time they were transplanted to test sites.

***Quercus* × *pauciloba* (Rydb.) syn. *Quercus undulata* (Torr.)(Wavy-leaf Oak)-**

A native to the Southwestern United States this species is a semi-evergreen shrub (27). Features that merited its inclusion in the trial included drought tolerance, its tendency to hold green leaves late into the fall and dry brown leaves in the winter- which add winter texture to a landscape. Trial plants were grown from seed collected from Southwestern Colorado and were growing in four-quart containers at the time of planting.

***Quercus polymorpha* (Schltdl. & Cham.)(Monterrey or Mexican Live Oak)-**

Native to West Texas this evergreen species of oak is reported to have spreading habit and be resistant to oak wilt. Trial plants were grown from seed collected from native populations in West Texas and were growing in number one containers at the time of planting (13 and 25).

Results and Discussion

Acer monspessulanum-

Survival-

A. monspessulanum experienced some mortality during the first growing season of the trial and experienced further mortality throughout the trial. Overall, twelve percent (6 plants) died following transplant. However, all plants at the Orchard Mesa and Calhan sites survived transplant. One plant at both the Fort Collins and Hudson sites was lost due to transplant stress while four of the ten plants at Brighton were lost.

At the conclusion of the five-year trial, all of the plants located in Calhan were dead while all of those in Orchard Mesa survived. The other three sites had between 50% and 70% mortality (Fig 1.10). Considering that Orchard Mesa was by far the mildest site, recording a temperature of less than -19˚ C only once during the trial (-25˚C in December of 2009), it seems likely that the milder winters and good irrigation account for the lack of mortality at this site (Appendix figure 2).

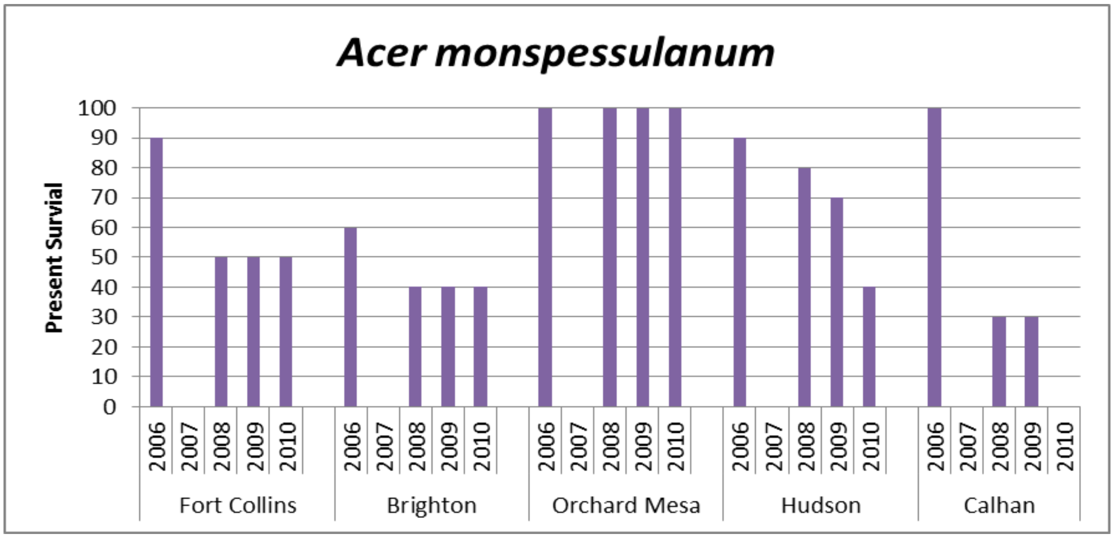


Figure 1.10 Survival Data for *Acer monspessulanum* at all five sites. Ten replications planted at all sites. No data was taken in 2007 at any site.

Growth-

Following the fifth year of the trial there was no significant difference in the mean widths of plants between sites. There was no significant change in the mean widths at any of the sites over that last three years of the trial. Height data showed a similar trend to width except for-. Orchard Mesa and Brighton test plants which were significantly taller than plants at other sites. Orchard Mesa was also the only site with a significant increase in the height after the first growing season (Fig. 1.11).

The lack of significant growth by trial plants can be attributed to yearly dieback during the winter followed by regrowth in the spring and summer. This was observed at all sites in all years of the trial. This cycle not only limited the size of the plants but also lead to the plants developing multiple stems which hindered the collection of caliper data.

Other observations-

The only ornamental feature that was observed was yellow-orange fall color on some plants. No flowers, fruits or insect or disease problems were observed on plants during the trial. Invasive tendencies were not observed, though plant did not set any seed during the trial.

Conclusion-

Based on the cycle of dieback and regrowth observed at all sites during this trial along with the lower mortally of plants at the site with the mildest winter it appears the *A. monspessulanum* is not winter hardy in most areas of Colorado.

Despite this, there are reasons to believe that this species may still have some potential for landscape use in the state. Larger plants of this species have proven winter hardy in the Denver metro area. Therefore, it is possible that plants gain some hardiness as they mature. It is also possible that a more cold hardy selection could be made and reproduced asexually.

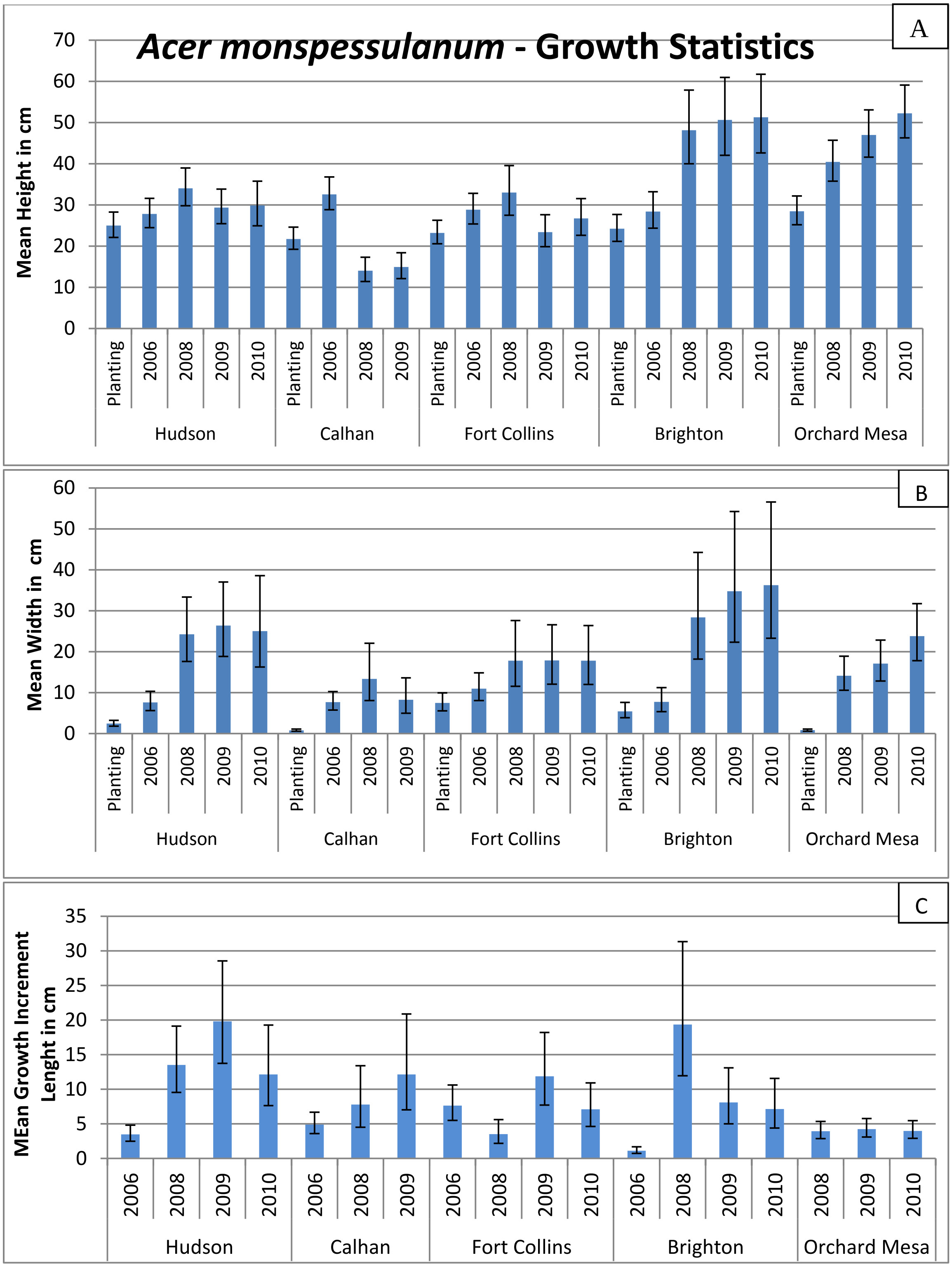


Figure 1.11A-C: Height (A), Width (B) and Growth Increment (C) data for *Acer monspessulanum* at all five sites. Ten replications were planted at all sites. Non-overlapping error bars indicates significant difference using Fishers least significant differences at $p < 0.05$. Data was transformed to log 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

***Juniperus scopulorum* 'Woodward'-**

Survival-

J. scopulorum 'Woodward' experienced low mortality during the trial with a few exceptions. All but one test plant survived the first growing season. Some mortality was observed later in Fort Collins and Calhan but not the other three sites. Between the end of the 2006 growing season and the end of the 2008 growing season, 40% of test plants were lost in Fort Collins and 30% in Calhan (Fig. 1.12). The dry open winters in Calhan and minimal water regime in Fort Collins likely contributed to the mortality at these sites (2).

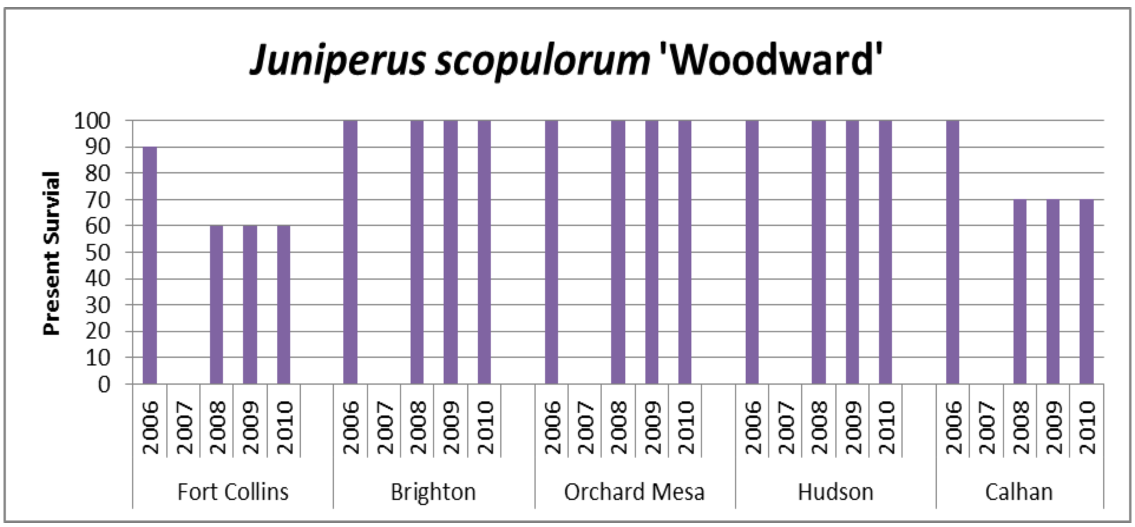


Figure 1.12 Survival Data for *Juniperus scopulorum* 'Woodward' at all five sites. Ten replications were planted at all sites. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season. No data was taken in 2007 at any site.

Growth-

The growth and habit of Woodward Rocky Mountain Juniper was remarkable consistent across most of the trial sites. Following the fifth year of the trial, plants were significantly taller at Orchard Mesa than any other site (nearly averaging nearly 130 cm in height). Plants at Calhan were significantly shorter than any other site besides Fort

Collins (averaging 73 cm and 85 cm respectively). The widths of the plants varied even less. The only significant difference in mean widths occurred at Calhan and Fort Collins where plants were significantly narrower than the other three sites (Fig 1.13). Once again, this is likely due to the challenging moisture conditions at these sites, which did not favor growth. The low level of nitrogen present in the soil in Calhan (2.8 ppm) could also have contributed to their smaller size (6).

The fact that plants were significantly taller at Orchard Mesa than Hudson and Brighton but not significantly wider is of particular interest. Though plants at Orchard Mesa gained extra height, they maintained the narrow habit observed at the other sites.

Other Observations-

Plants retained a light blue green color year round. The plants had a very upright habit with narrow branch angles and maintained a dominate central leader. Broken braches, presumed to be a result of snow loading, were observed on two plants at the Brighton site following the winter of 2008-2009. This was the only instance of such damage. No insect or disease damage or invasive tendencies were observed on this species.

Conclusion-

J. scopulorum ‘Woodward’ generally performed well in the trial and seems suited for wider use across Colorado. Plants maintained a narrow-upright growth habit as anticipated. Excluding the minor snow loading damage at the Brighton site, they were problem free. Some mortality, most likely related to winter water stress, was observed early in the trial. However, once plants were established they tolerated the dryer conditions.

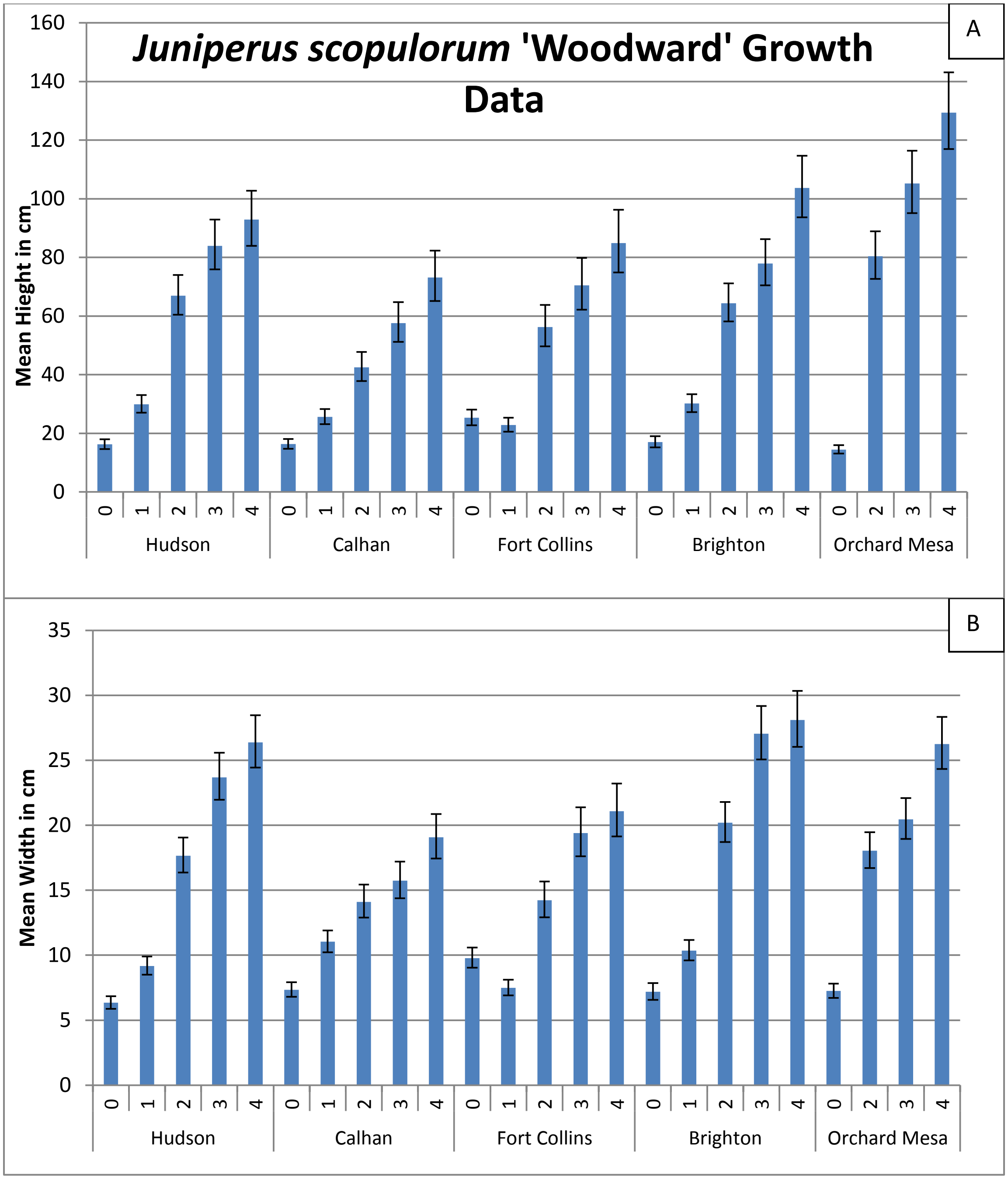


Figure 1.13 A-B: Height (A), Width (B) data for *Juniperus scopulorum* 'Woodward' at all five sites. Ten replications were planted at all sites. Non-overlapping error bars indicates significant difference using Fishers least significant differences at p<.05. Data was transformed to 1og 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

Larix decidua-

Survivability-

L. decidua experienced high mortality following transplanting with an overall mortality of 66% percent during the first growing season. Mortality was greatest at Orchard Mesa where no plants survived. At Brighton, Hudson and Calhan forty percent or less of plants survived the first season of the trial. Survivorship was greatest in Fort Collins where eighty percent of the plants remained alive after the first growing season (Fig 1.14). Differences in temperatures among the sites following planting may explain this. Fort Collins and Calhan had the lowest mean temperatures of any of the sites from May to August of 2006 (Appendix Figure 1.3b). These sites also had the lowest mortality (10% and 60% respectively). Orchard Mesa had the highest mean temperature of any site during this period and the highest mortality (100%). *Larix* is a genus noted for as common to bottom lands and swampy conditions (25). The warmer conditions in Orchard Mesa and Greely may have negatively affected establishment after transplant.

At the conclusion of the trial only one European Larch had survived at the Brighton, Hudson and Calhan sites while seven of the ten Fort Collins plants survived. No data was collected in 2007 so it cannot be determined exactly when the mortality observed between the end of the 2006 growing season and the end of the 2008 growing season occurred. Cold temperatures do not seem to be the cause. Depending on the site, either the winter of 2008-2009 or the winter of 2009-2010 had the lowest observed temperature (Appendix Figure 1.2). There was almost no mortality observed during those winters. Given the high mortality rate observed following transplant in 2006 it is possible that plants which survived may have been under stress which contributed to their failure to overwinter. As plants became established, no further mortality was observed (Fig 1.14). Test plants were sexually propagated. Therefore, it is also possible that the mortality observed could be a result of genetic differences in cold hardiness.

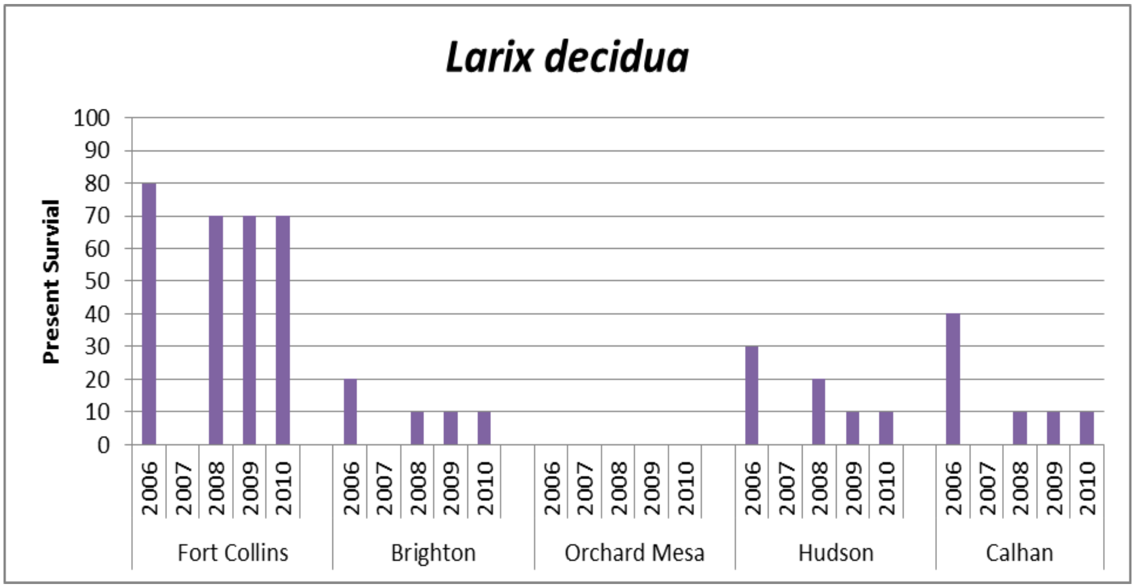


Figure 1.14 Survival Data for *Larix decidua* at all five sites. Ten replications were planted at all sites. No data was taken in 2007 at any site.

Growth-

The small number of plants that survived the first growing season makes comparing growth between sites difficult. At Fort Collins, where seven of the ten plants survived, there was significant growth during the trial. In terms of height there was also significant growth during each of the last three growing season of the trial. However, plants did not get significantly wider during the same period. There were almost no significant differences in growth increment length during the trial. However, the small surviving population along with missing data makes the data difficult to interpret. The non-significant decrease in height observed between 2008 and 2009 at the Hudson site is the result of the death of a taller replication (Fig. 1.15).

Other observations:

Needles of this species had a light green color and soft texture. As expected, they turned an orange-brown color and senesced in the fall. No insect or disease problems were observed on this species. Invasive tendencies were not observed at any of the sites.

Conclusion:

The most relevant data gained though this trial was the failure of the majority of the plants to successfully transplant from containers to the test sites. This indicated either that the species is difficult to transplant or that a different transplant procedure may be needed to have success.

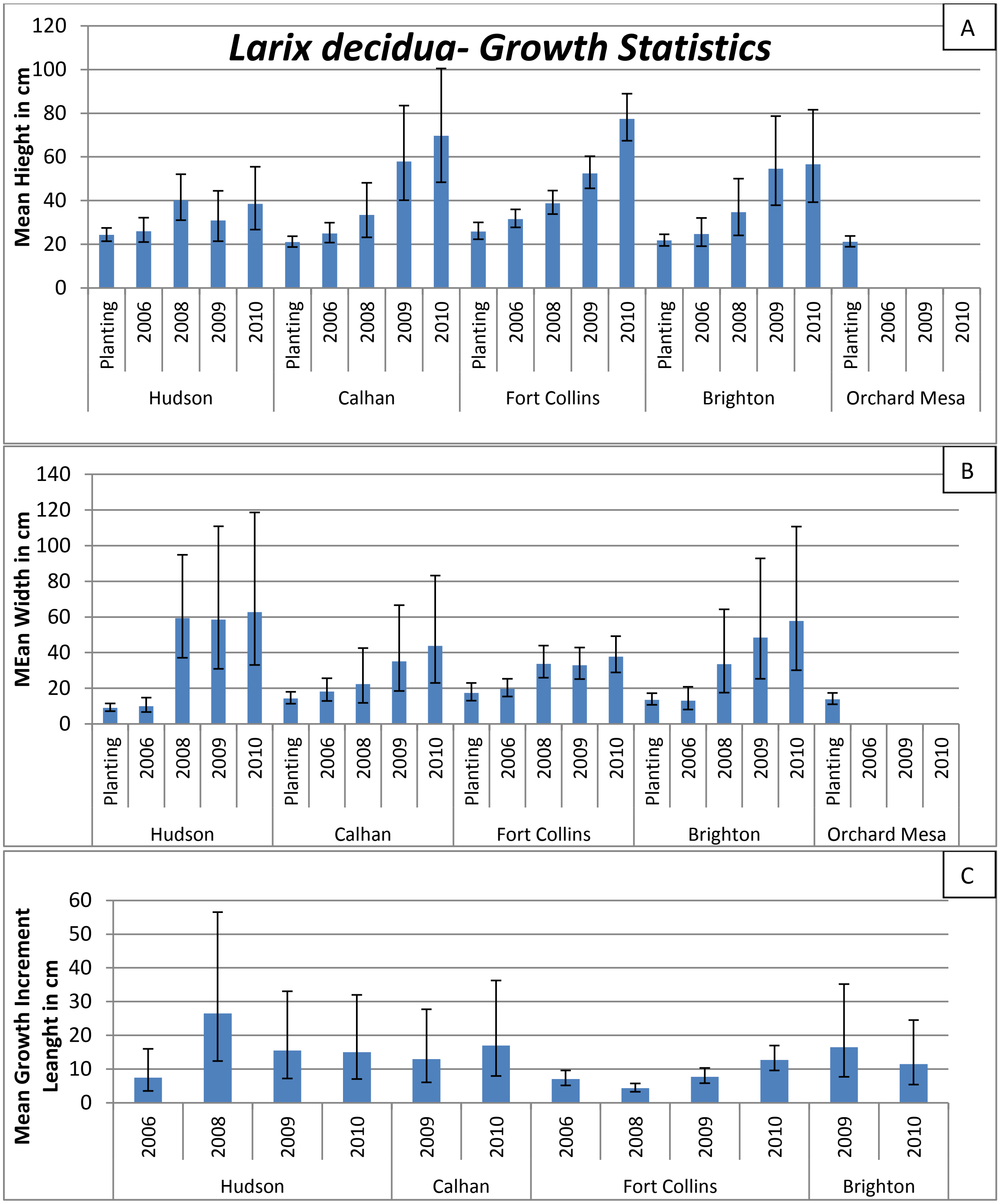


Figure 1.15 A-C Height (A), Width (B) and Growth Increment (C) data for *Larix decidua* at all five sites. Ten replications were planted at all sites. Non-overlapping error bars indicates significant difference using Fishers least significant differences at p<.05. Data was transformed to log 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

Prunus serotina-

Survival-

P. serotina transplanted well and had low mortality across all sites. All but one individual survived post-planting (through the 2006 growing season). All plants at the Brighton and Hudson sites survived the five-year trial. At Orchard Mesa, the only mortality observed was a result of transplant stress. Nine of ten plants survived at both the Fort Collins and Hudson sites (Fig. 1.16).

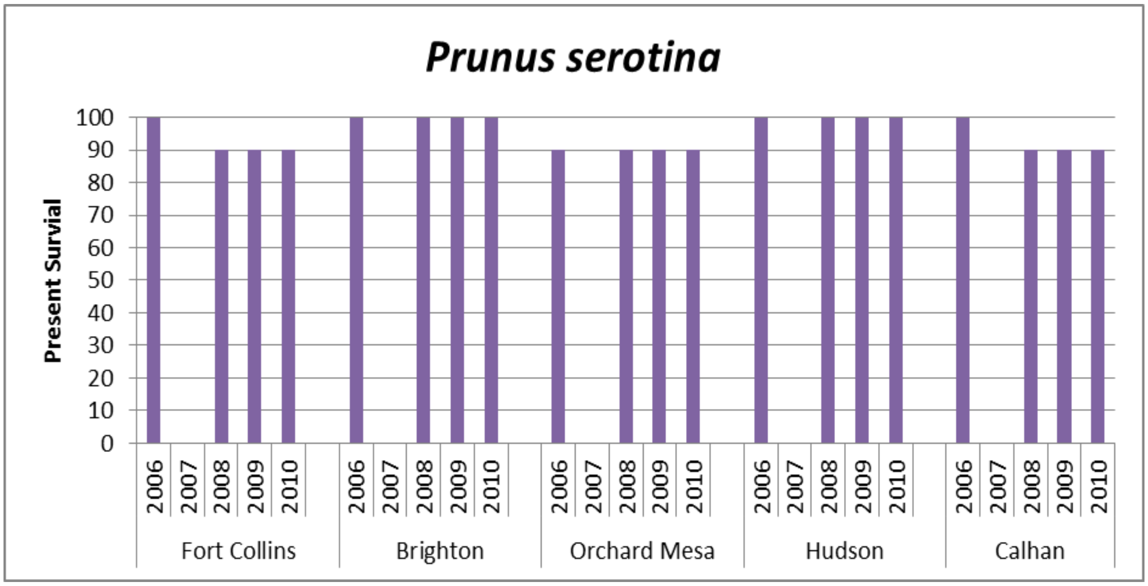


Figure 1.16 Survival Data for *Prunus serotina* at all five sites. Ten replications were planted at all sites. No data was taken in 2007 at any site.

Growth-

Plants had statistically significant growth at all sites but there were difference between in plant size following the trial. Following the final year of the trial, plants at the Brighton site averaged 182cm in height, which was significantly taller than that at all other sites but Orchard Mesa. Plants at Calhan were significantly shorter than at any other site. The only significant difference in mean widths between sites was at Calhan where plants were significantly narrower. Caliper was significantly larger at Brighton and Hudson than all other sites but there was no significant difference among the other sites (Fig. 1.17).

While there were some significant differences in height and caliper among the Brighton, Hudson and Orchard Mesa sites overall plants performed better at these locations than at the Calhan and Fort Collins sites. The smaller size was seen at the Fort Collins site which was likely a result of minimal irrigation and perhaps the high pH of the soil on site (6). In Calhan, a combination of factors likely contributed to low level of growth. Possible factors contributing to the low growth included the exposed nature of the site, ineffective overhead irrigation due to interference from wind, winter desiccation due to high winds, lack of irrigation in the winter and more sandy soils. Dieback was observed on plants at the Calhan site following each winter and during the winter of 2006-2007 all plants died to the ground. All plants recovered the following spring. Colder temperatures were observed at other sites that winter and cold damage was not observed at other sites. It is a reasonable assumption that the dry windy winters at the Calhan site resulted in dieback, which contributed to their reduced size.

Growth increments varied between year of the trial and site. Both the Fort Collins and Calhan sites had significantly smaller increments than other sites following the first growing season. This could indicate the plants at these sites were slower to establish (32). At both Brighton and Orchard Mesa, growth increments peaked in length after year three of the trial and were significantly shorter in subsequent years while other sites had increasing interval lengths throughout the trial. Brighton and Orchard Mesa were also the sites with significantly taller plants. Considering this data, it is possible that the plants at these sites are peaking in size. The sub-population they were propagated from is described as having a smaller mature size then to the main populated of the species (~15 meters) (16). Plants at Brighton and Orchard Mesa obtained this approximant height with means heights of 18.8m and 17.7m respectively.

Other Observations-

Ornamental features observed included attractive flowers, fruit and fall color. White flowers were observed on the plants in late May to early June at the four Front Range sites and early May at Orchard Mesa. Racemes of dark purple drupe fruits followed, developing in late July to early August. By the third growing season, plants were developing large quantities of fruit at all sites. Plants held their leaves late into the fall before developing a russet-red fall color. In Fort Collins, green healthy leaves were still observed on plants into the first week of November the last three years of the trial. This feature can add texture and color to a landscape late in the season. However, it also likely contributed to snow loading damage observed on some plants at the Fort Collins site after a November 2009 storm. Plants were still fully leafed at the time of the storm. No serious insect or disease issues were observed at any of the sites nor were any invasive tendencies observed.

Conclusion:

This selection of *P. serotina* has potential for more widespread use in landscapes across Colorado. Plants had high survival and significant growth in all the different climates and soil conditions in the trial. Test plants experienced no major pest or disease issues and had interesting ornamental features. The only concern raised during the trial is the potential for snow loading damage due to late senescence of leaves.

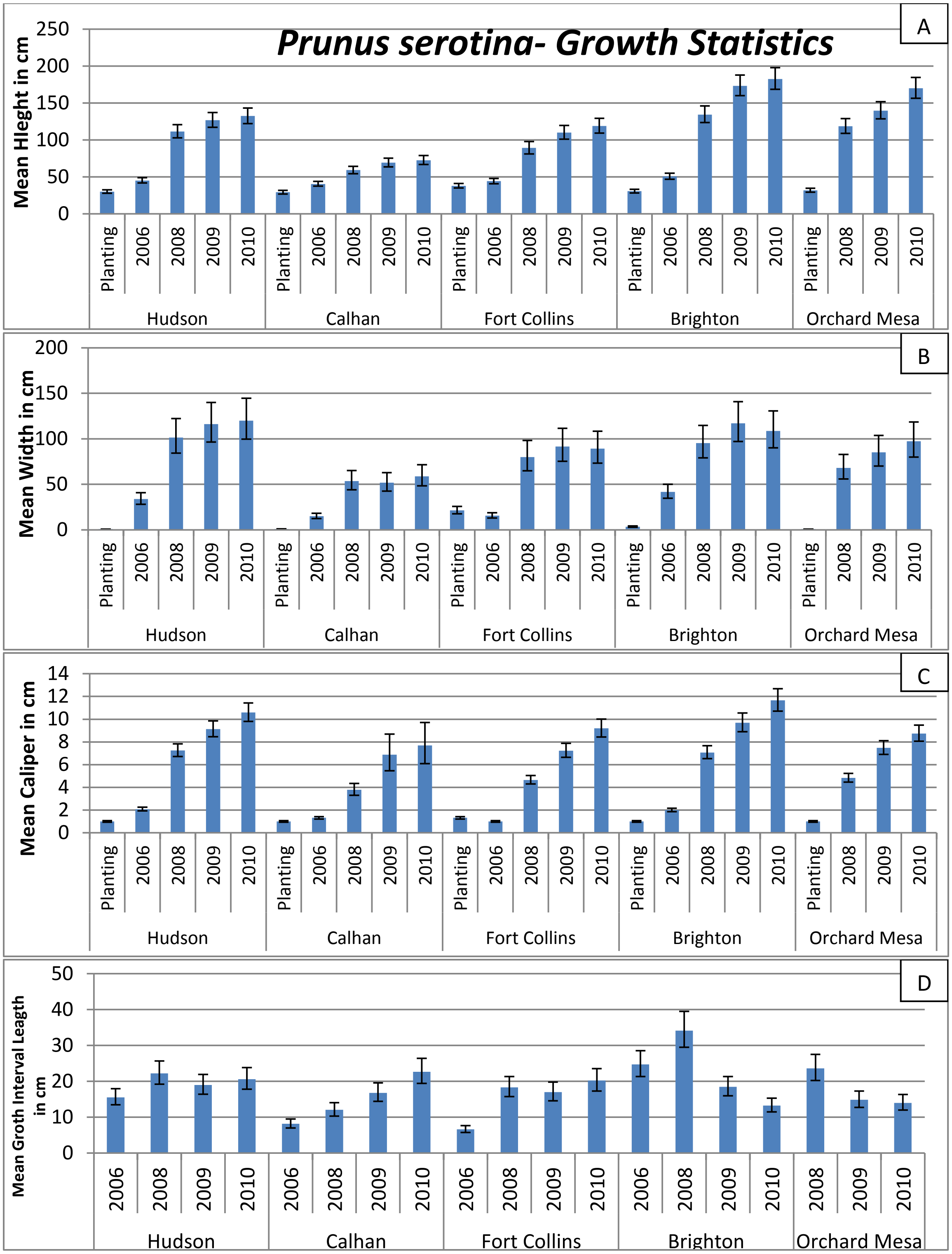


Figure 1.17 A-D Height (A), Width (B), Caliper (C) and Growth Increment (D) data for *Prunus serotina* at all five sites. Ten replications planted at all sites. Non-overlapping error errors bars indicates significant difference using Fishers least significant differences at p<.05. Data was transformed to 1og 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

***Pyrus ussuriensis* 'Burgundy'-**

Survival-

Mortally rates for *P. ussuriensis* 'Burgundy' varied between sites. All plants survived the first growing season at Brighton, Orchard Mesa and Calhan. However, some mortality occurred in Hudson (20%) and more mortality occurred in Fort Collins (40%). Further mortality would occur at all sites except Orchard Mesa where all plants survived. Survival rates at other sites varied between 30% in Fort Collins to 80% in Calhan and Brighton (Fig 1.18).

The low survival rates in Fort Collins can be attributed to fireblight and rodent damage at the base of the trees. Mortality at other sites was low and occurred during the winters. Given the generally good survival rates at Calhan, the most exposed site, and Brighton the, coldest site (Appendix Figure 1.2), it seems likely that other factors besides low temperatures or desiccation of tissues were responsible. Such factors could have included stress-induced form fireblight, which was observed on some of the Fort Collins plants prior to their death.

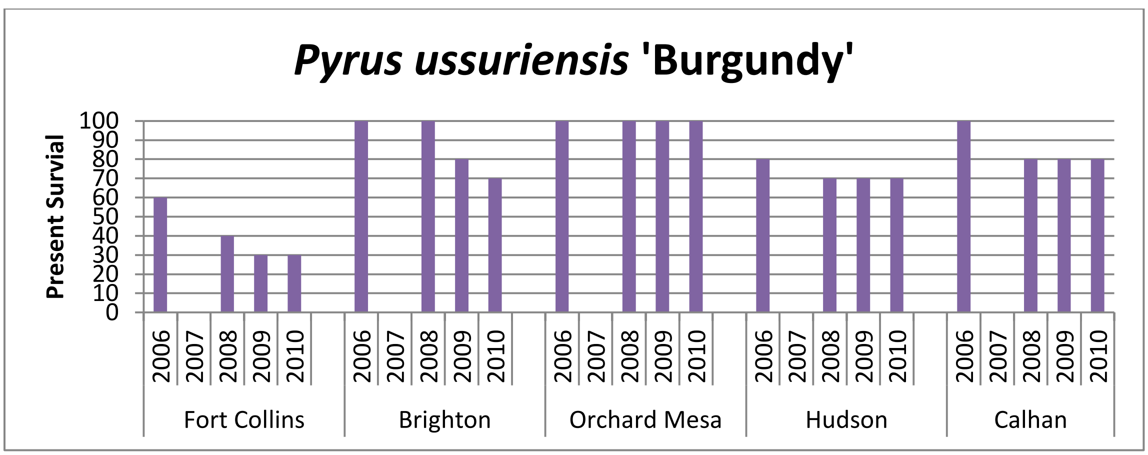


Figure 1.18 Survival Data for *Pyrus ussuriensis* 'Burgundy' at all five sites. Ten replications planted at all sites. No data was taken in 2007 at any site.

Growth-

Following the final year of the trial, there were significant differences in height but not width or caliper between sites. Plants were significantly taller in Brighton, Hudson and Orchard Mesa than in Fort Collins and Calhan. This is likely due to the harsher cultural conditions at these sites. In Fort Collins the irrigation schedule was insufficient. The Calhan site is every exposed. Neither site received irrigation during the winter. These two sites also had the highest incidence of fireblight, which contributed to their shorter heights and reduced vigor. No significant differences in plant widths existed between sites at the conclusion of the trial. This supports the idea that this selection has a consistent upright growth habit with more vertical growth than horizontal. This is further supported by the lack of significant differences between mean widths within sites between the end of the fourth and fifth growing seasons at any of the sites (Fig 1.19).

Data collected on mean growth increments lengths speak to the potential impact of the more difficult cultural conditions and high incidence of fireblight at the Fort Collins and Calhan sites. There was no significant increase in the mean growth increments length at these sites over the course of the trial. Whereas, at the Brighton and Hudson sites growth increments were significantly longer in the later growing seasons than the first (Fig 1.19). This could be due to failure of the plants at the Fort Collins and Calhan sites to become well-established (32). Presumably, this was due to the harsher cultural and environmental conditions at these sites and greater presence of disease. The growth increments on plants in Orchard Mesa also failed to increase significantly during the trial. However, this could be related to the vigorous nature of the understock at this site which threatened to outgrow the grafted clone during the final three years of the trial.

Other Observations-

Plants exhibited ornamental features similar to other selections of *P. ussuriensis*. However, the fall color of this clone was consistently a deep purple opposed to the yellow to purple often seen on other selections. The habit of the plants was upright and narrow. Despite narrow branch angles no snow loading damage was observed at any site during the trial. Spines were observed on some plants. They occurred on the branches and were sparse. This could be an undesirable feature. No invasive tendencies were observed on this species at any of the trial sites.

The *Pyrus betulafolia* understock used was very vigorous at the Orchard Mesa site. During some growing seasons, the sucker growth from the below the graft union almost out grew the grafted clone. The understock was also visible on a several plants in Brighton but was not as vigorous. This understock is common and not noted as having notable issues with suckering (24).

At the Fort Collins and Calhan sites, every plant was affected with bacterial fireblight at some point during the trial. Single infected individuals were also observed at Hudson and Brighton. At Fort Collins trial plants were located near a large population of Crabapples (*Malus sp*.). The genus *Malus* is a potential host for fireblight. This could account for the greater prevalence of fireblight on the test plants in Fort Collins. The high rate of infection at Calhan may have been the result of the overhead irrigation used at that site. Water splashing off the crowns of infected plants can help spread the bacteria (11). Rodent damage was also present on all the Fort Collins plants.

Conclusion-

This clone of Ussurian Pear has potential for landscapes due to its improved fall color and narrow upright habit. Plants overwintered well at the most exposed site in the trial indicating adaptability and hardiness. However, the presence of fireblight on many of the plants was a concern. The presence of spines and aggressive understock were also concerns.

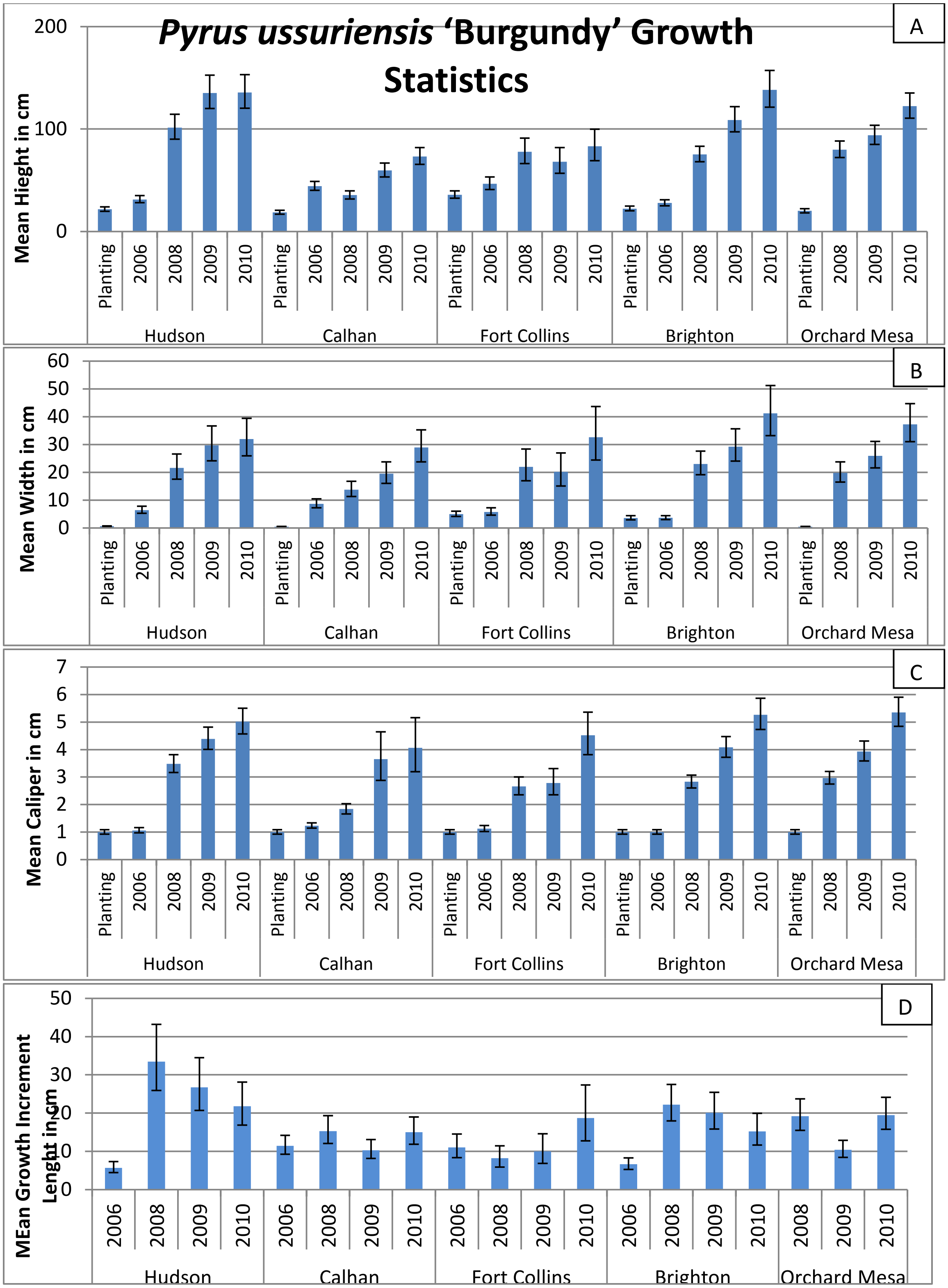


Figure 1.19 A-D Height (A) , Width (B), Caliper (C) and Growth Increment (D) data for *Pyrus ussuriensis 'Burgundy'* at all five sites. Ten replications were planted at all sites. Non-overlapping error bars indicates significant difference using Fishers least significant differences at p<.05. Data was transformed to 1og 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

Quercus polymorpha-

Survival-

Q.polymorpha transplanted well, however, none of the plants at any of the sites survived the first winter of the trial (Fig 1.20). Orchard Mesa experienced the mildest winter of any of the trial sites in 2006 with a low temperature of -18°C. Therefore, this species does not possess the hardiness to survive a winter of this severity.

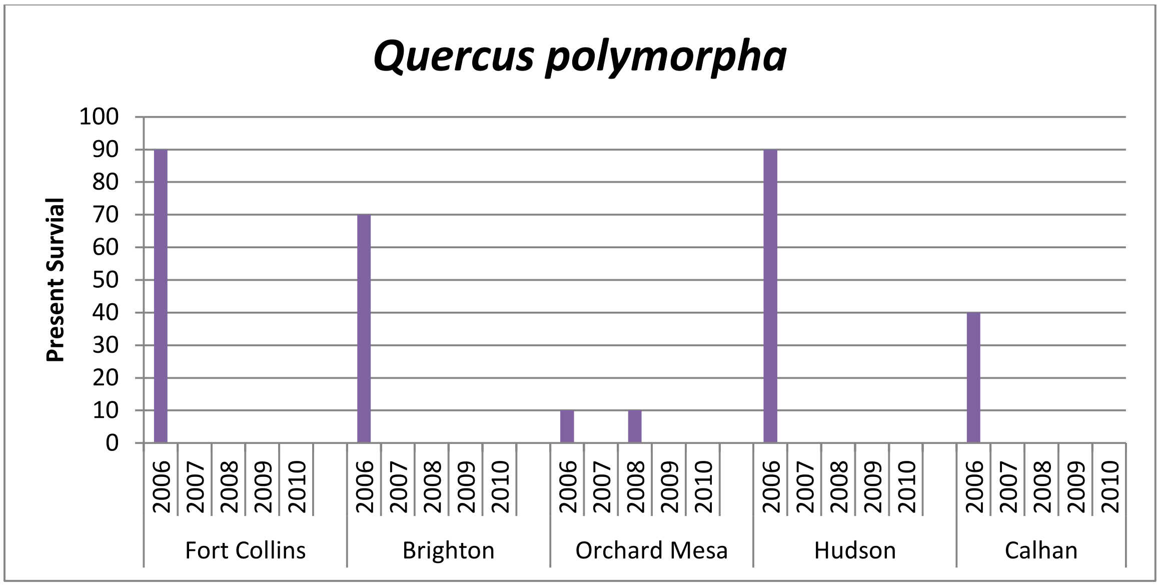


Figure 1.20 Survival Data for *Quercus polymorpha* at all five sites. Ten replications were planted at all sites. No data was taken in 2007 at any site.

Conclusion-

The Western Slope region of Colorado is the mildest region of the state (Appendix Figure 1.4). This species of oak lacked enough hardiness to survive in this region (Orchard Mesa). Based on this, *Q.polymorpha* is not suited for landscape use in Colorado due to lack of cold hardiness.

***Quercus* × *pauciloba* syn. *Quercus undulata* -**

Survival-

Quercus × *pauciloba* experienced some mortality during the first growing season of the trial but very little in subsequent years. Mortality rate following the first growing season ranged from 30% at Brighton, Hudson and Orchard Mesa to 10% at Fort Collins. Following the first growing season the only other mortality occurred at the Calhan site where four plants died between the winter of 2006-2007 and the end of the 2008 growing season (Fig 1.21). Temperatures over this period were not particularly extreme when compared to other sites (Appendix Figure 1.2). This site is the most exposed trial site. The semi-evergreen nature of this species would be a disadvantage under such conditions. It maintained green leaves late into the fall season in a windy exposed site without additional watering. This exposes the plants to additional risk of desiccation, especially non-established and recently transplanted plants (2). This is a likely explanation for the observed mortality in Calhan.

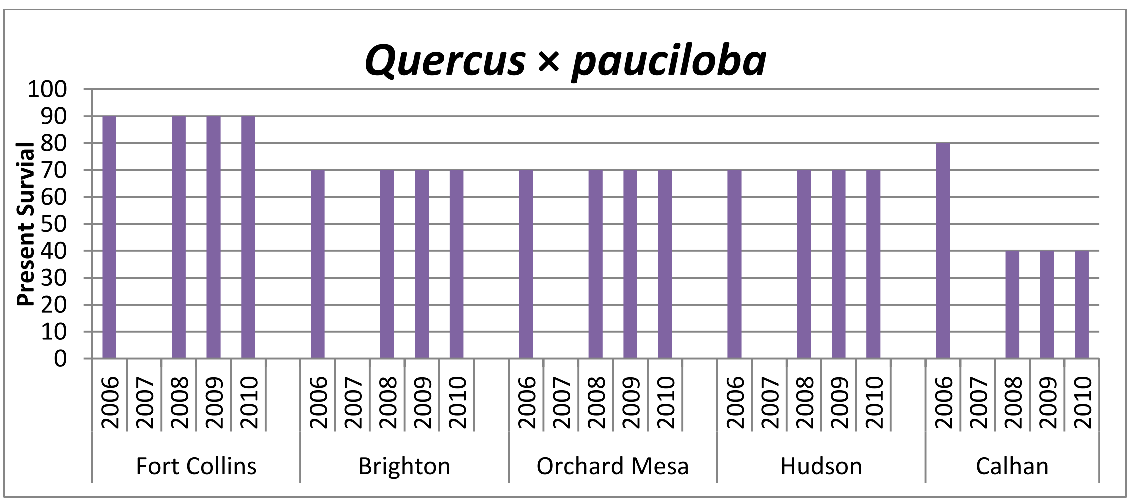


Figure 1.21 Survival Data for *Quercus x pauciloba at* all five sites. Ten replications were planted at all sites. No data was taken in 2007 at any site.

Growth-

Quercus × *pauciloba* experienced statistically significant and consistent growth during the trial. Plants in Brighton and Hudson were significantly taller than plants in Calhan but there were no other statistical differences in height or width among sites at the conclusion of the trial. There were also no significant differences in the length of growth increments between the sites or between years over the last three growing seasons of the trial. This species exhibited a shrubby and often multi-stemmed habit so no caliper data was taken.

Other comments-

Many plants held green leaves into the early winter or showed juvenility, holding brown leaves all winter. The extent to which these features manifested varied among individual plants within the sites. There was also a variation in size and the shape and texture of the lobes of the leaves among individual plants. This is not a surprise as these plants were sexually propagated. No invasive tendencies were observed at any of the sites; however, plants did not set seed during the trial.

Conclusion-

Quercus × *pauciloba* is well suited for use in a variety of sites in Colorado. Plants performed well at all sites excluding Calhan where it appeared plants needed to become established to withstand an exposed winter without supplemental irrigation. However, even at this site all plants which were alive after the second winter survived the rest of the trial. The plant preformed just as well in Fort Collins under more difficult moisture conditions as they did in the milder climate and longer growing season at Orchard Mesa and the colder winters at Brighton (Appendix Figure 1.2).

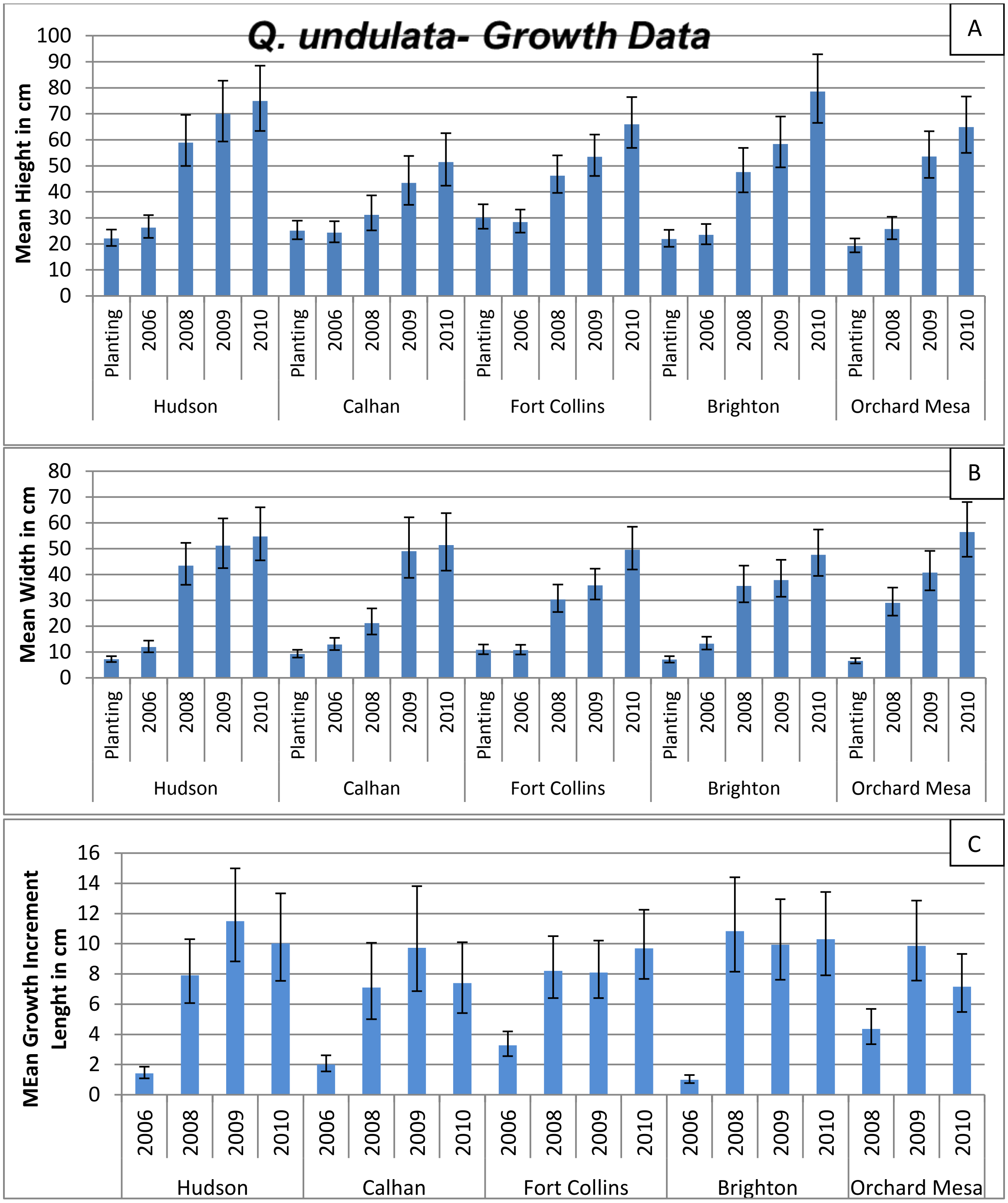


Figure 1.22 A-D Height (A), Width (B) and Growth Increment (C) data for *Quercus* × *pauciloba* at all five sites. Ten replications were planted at all sites. Non-overlapping error bars indicates significant difference using Fishers least significant differences at p<.05. Data was transformed to 1og 10 then back transformed for graphing. No data was taken in 2007 at any site or at Orchard Mesa following the 2006 growing season.

WORKS CITED

1) Anella, L. B., Maronek, D. M., and Schnelle, M. A. July, 2001. Oklahoma Proven: A Plant Evaluation and Marketing Program. HortTechnology 11 (3): 381-384.

2) Cox, R. A. and Klett, J. E. 2005. Evergreen Trees (Colorado State University Extension Fact Sheet). Accessed August 10, 2011. http://www.ext.colostate.edu/pubs/Garden/07403.html

3) Dirr, Michael A. 1998. Manual of Woody Landscape Plants. Stipes Publishing L.L.C., Champaign, Illinois.

4) Dunwell, W. C., Fare, D., Arnold, M. A., Tilt, K., Knox, G., Witte, W., Knight, P., Pooler, M., Klingeman, W., Niemiera, A., Rutter, J., Yeager, T., Ranney, T., Beesonm, R., Lindstrom, J., Bush, E., Owings, A. and Schnelle, M. July 2001. Plant Evaluation Program for Nursery Crops and Landscape Systems by the Southern Extension and Research Activities/Information Exchange Group- 27. HortTechnology 11 (3): 373-375.

6) Follett, R. H. and Soltanpour, P. N. 1999. Soil Test Explanation (Colorado State University Extension Fact Sheet). Accessed August 11, 2011. http://mining.state.co.us/TechnicalBulletins/SoilTestExp

7) Harris, R. W., Leiser, A. T., Neel, P. L., Long, D., Stice, N. W. and Maire, R. G. Trunk Development of Young Trees. California Agriculture. April, 1973. 7-9.

8) Hensley, D. L., Wiest, S., C., Long, C. E., Pair, J. C. and Gibbons, III, F. D. Sept., 1991. Evaluation of Ten Landscape Trees for the Midwest. J. Environ. Hort 9 (3): 149-155.

9) Herman, D. E. 1998. Selection, Evaluation and Introduction of Hardy Woody Plants for the Northern Plains. Accessed May 30, 2010. http://www.reeis.usda.gov/web/crisprojectpages/177898.html

10) Johnson, G., Gillman, J., Pellett, H., Giblin, C., Hanson, D., and Weicherding, P. 2003. Nicollet Island brownfield study. University of Minnesota Urban Natural Resources. Accessed May 30, 2010. http://www.myminnesotawoods.umn.edu/2009/01/nicollet-island-brownfield-study

11) Koski, R. D. and Jacobi W. R. 2009. Diseases Fire Blight (Colorado State University Extension fact Sheet). Accessed August 11, 2011. http://www.ext.colostate.edu/pubs/garden/02907.html

12) Krahn, A. 2009. Prairie T.R.U.S.T. Project. Accessed June 10, 2010. http://www.prairietrees.ca/prairie.htm.

13) Lady Bird Johnson Wildflower Center at The University of Texas at Austin. 2007. Native Plant Data Base: *Quercus polymorpha*. Accessed June 26, 2011. http://www.wildflower.org/plants/result.php?id_plant=QUPO2

14) Lindstrom, J. T., Robbins, J. A., Klingaman, G. A., Starr, S., and Carson, J. Sept, 2001. The University of Arkansas Plant Evaluation Program; HortTechnology 11(3) 362-364.

15) Mackay, W. A., Arnold, M. A., Davis, T. D., Grant, G. G., George, S.W., Larry, S. A., Lineberger, D. R. and Parsons, J. M. July 2001. Texas Superstar and the Coordinated Assistance Program (CEMAP): How We Operate. HortTechnology 11(3): 389-391.

16) Marquis, David A. *Prunus serotina* Ehrh. Black Cherry. . Russell, B. M., and Honkala, B. H. Silvics of North America: 1. Conifers; 2. Hardwoods. Accessed June 8, 2011. http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/prunus/serotina.htm

17) Nesom, G. United States Department of Agriculture Natural Resources Conservations Service. 2004. Plant Guide: *Prunus serotina* Ehrh. Accessed June 8, 2011. http://plants.usda.gov/plantguide/pdf/pg_prse2.pdf

18) North Dakota State University, Dickinson Research Extension Center. 1995. Field Evaluation Planting: Technical Report; Field Evaluation of Woody Plant Materials. Accessed 30 May, 2010. http://www.ag.ndsu.nodak.edu/dickinso /research/1995/hort95d.htm.

19) North Dakota State University, Dickinson Research Extension Center. 1995. Species-Site Adaptation Study of Woody Plants for North Dakota. Accessed 15 August, 2010. http://www.ag.ndsu.nodak.edu/dickinso/research/1995/hort95e.htm

20) Pair, J. C. METRIA. KSU Horticulture Research Center Ornamentals Testing Program. Accessed June 10, 2010. http://www.ces.ncsu.edu/fletcher/programs/nursery/metria/metria7/m75.pdf.

21) Plant Select®. About Plant Select®. Accessed June 9, 2010. http://www.plantselect.org/about.php.

22) Poole, M. R. July 2001.Plant Breeding at the U.S. National Arboretum: Selection, Evaluation, and Release of New Cultivars. HortTechnology 11 (3): 365-367.

23) Reid, S. K. and Oki, L. R. July, 2008. Field trials identify more native plants suited to urban landscaping. California Agriculture 62(3):97-104.

24) Stebbins, R. 1995. Choosing Pear Rootstocks for the Pacific Northwest (Pacific Northwest Extension).
Assessed January 11, 2012.
http://icecubetopper.com/pdfs/docs/pac_nw/pac_nw_choosing_pear_rootstock.pdf

25) Stevens, M. United States Department of Agriculture Natural Resources Conservations Service. 2008. Plant Guide: Rocky Mountain Juniper *Juniperus scopulorum* Sarg. Accessed June 20, 2011.
http://plants.usda.gov/plantguide/pdf/cs_jusc2.pdf

25) Sullivan, J. United States Department of Agriculture Forest Service. 1994. Fire Effect Information Database: *Larix decidua*. Accessed June 29, 2011.
http://www.fs.fed.us/database/feis/plants/tree/lardec/all.html#INTRODUCTORY

26) United States Department of Agriculture Natural Resources Conservations Service. PLANTS Profile for *Quercus polymorpha*. Accessed June 26, 2011.
http://plants.usda.gov/java/profile?symbol=QUPO2

27) Utah State University Cooperative Extension. Wavyleaf Oak. Accessed September 16, 2011.
http://forestry.usu.edu/htm/treeid/oaks/wavyleaf-oak

28) Warren, K. (J. Frank Schmidt Nursery). Unpublished correspondence. January 20, 2011.

29) Widrlechner, M. P. METRIA. NC-7 Regional Ornamental Trials: Evaluation of New Woody Plants. Accessed May 30, 2010.
www.ces.ncsu.edu/fletcher/programs/nursery/metria/metria07/m77.pdf.

30) Widrlechner, M. P., Hasselkus, E. R., Herman, D. E., Iles, J. K., Pair, J. C., Paparozzi, E. T., Schutzki, R. E., and Wildung, D. K. Dec. 1992. Performance of Landscape Plants from Yugoslavia in the North Central United States. Environmental Horticulture. 10(4):192-198.

31) Widrlechner, M. P., Hebel, J. B., Herman, D. E., Iles, J. K., Kling, G. J., Ovrom, A. P., Pair, J. C., Paparozzi, E. T., Poppe, S. R., Nance, R., Schutzki, R. E., Tubesing, C. and Wildung, D. K. March 1998. Performance of Landscape Plants from Northern Japan in the North Central United States. Environmental Horticulture. 16(1):27-32

32) Whiting D. and O'Meara. Diagnosing Tree disorders (Colorado State University Extension Fact Sheet). Accessed August 11, 2011.
http://www.ext.colostate.edu/mg/gardennotes/102.html

33) Williams, D. J., Gilliam, C.H., Keever, G. J. and Owen J. T. July 2001. The Auburn University Shade Tree Evaluation: Its Roots and Fruit. HortTechnology 11 (3): 358-361.

CHAPTER 2

EVALUATION OF DIFFERENCES IN DROUGHT TOLERANCE OF THREE *AMELANCHIER* SPECIES

Introduction

Various species of the genus *Amelanchier* are increasingly being used as landscape plants along the Front Range region of Colorado. There are several reasons for this increase in use. Many species of the genus have attractive ornamental features in multiple seasons. White flowers develop on many species in mid-to-late spring. Attractive and edible red fruit, which often darkens to blue, follows the flowers in mid-summer. Many species also have an attractive orange to red fall foliage color. In addition to these attractive ornamental features, the genus is often purported to be low water use or xeric. However, there are many species, hybrids and named selections of the genus and, not all of these have all of these positive features. (3). Flower, fruit and fall foliage color can be evaluated visually but water needs are more difficult to evaluate.

Plant drought tolerance mechanisms fall into two general groups: dehydration tolerance and dehydration avoidance (8, 12). Dehydration tolerance represents any adaption that allows plants to maintain functions under low moisture conditions. Dehydration avoidance allows plants to avoid or reduce the stress of low moisture conditions (waxy leaves, stomatal closure, leaf abscission and large root systems are some examples of such adaptions). Our research study sought to evaluate the overall drought tolerance, including both dehydration tolerance and avoidance, of three different species of *Amelanchier*. Three Amelanchier species were utilized in this experiment: *A. canadensis* (Medik.), *A. alnifolia* (Nutt.) and *A. utahnsis* (Koehne). Containerized plants were evaluated during three separate periods of dry down induced water stress during the fall of 2010 in a greenhouse setting. Soil moisture content and pre-dawn leaf water potential were collected over the course of the dry down periods.

Materials and Methods

<u>Plant Material-</u>

A. alnifolia is a shrub or small tree which may reach seven meters in height and has a variable growth habit. It is native to much of Canada and the Western United States (Appendix figure 2.1). It is primarily found growing in woodland interfaces and riparian zones and is often present in disturbed areas. White flowers may be present on plants from April to June depending on the site with fruiting following on mature plants in June to August. (10)

A. canadensis is also observed in nature as a small tree or large shrub which can reach eight meters in height and often forms clumps. It is native to the Eastern United States and Canada (Appendix figure 2.2). It is common in mesic soils such as forested wetlands and fresh water tidal marshes (1). Some sources list it as being tolerant of drier conditions (4) but most agree it prefers moist, well-drained soils (4, 9). Flowers develop on this species in the early spring before the plant leafs out and fruit set follows turning from green to red to dark blue (9).

A. utahensis is a slightly smaller species with a mature height of two to four meters. It is native to the higher elevations (1500 m-2750 m) of the Western United States (Appendix Figure 2.3). It is found growing on both rocky slopes and streambeds. However, it is noted as being intolerant of high water tables and poorly drained soils. The ranges of *A. utahensis* and *A. alnifolia* overlap and they are sometimes observed growing together. However, *A. utahensis* generally is seen on drier sites. Flowers on this species are white with five petals and occur in May with dark blue fruit that can persist longer than on other species of *Amelanchier* (7).

Ten plants of these three species where acquired from a local wholesale grower (Little Valley Wholesale Nursery, located in Brighton, Colorado). All plants were produced by rooting cuttings. Healthy plants, similar in size within a given species were selected. There were some plant size differences between species. The plants were container grown and were growing outdoors in number five containers (13.59 l) when they were acquired in late June, 2010. Plants were growing in a soilless media consisting of composted chicken manure, bark sphagnum peat moss and perlite. They were moved to a greenhouse at the Plant Environmental Research Center on the Colorado State University Campus. Plants were allowed to acclimate to the greenhouse for two weeks before experimental treatments were applied.

<u>Methods-</u>

In late June of 2010 ten plants of each species were arranged in a complete random design in three rows of ten on a single greenhouse bench. Two plants of each species were then randomly designated as controls. Plants were fertilized with a slow release complete fertilizer (Osmocote® 14-14-14 at a rate of 32 grams/sq. m., which was the medium label rate). At the end of this period, plants were watered until the growth media was draining freely from the containers and then the first dry down period was begun.

During these dry periods test plants received no water while control plants were watered every other day until the soil in the containers was draining freely. In total, three dry down periods were undertaken between June and November of 2010. No supplemental lighting was given to the plants and the average day and night time temperatures were 27.1°C and 22.4°C respectively. Plants were re-watered and allowed to recover for at least one week between dry downs. During the dry down periods, data on predawn leaf water potential and percent soil moisture content were collected.

Predawn leaf water potential was measured on two leaves per plant using a pressure chamber, (PMS Instrument Company Model 1000; Albany, Oregon). This method has been shown to be reasonably accurate when compared to other methods and instruments for determining leaf water potential such as a thermocouple psychrometer (2). It has also been shown to accurately assess internal plant water status, which is commonly interpreted as a measure of stress (13).

Water potentials were gathered at two and then four day intervals. However, it became apparent plants would survive longer than anticipated and could run out of leaves for leaf potential measurements . Therefore, during the third dry down period data was gathered at four day intervals for all plants for the first 20 days of the dry down. Then data was collected from plants at irregular intervals based on the number of leaves remaining for potential measurement. Though these intermediate data points were gathered irregularly, all plants had data taken as near as possible to the time they died or went dormant.

Soil moisture content was measured with a model MLX2 Theta Probe (Delta T Devices, Cambridge England). This instrument reported volumetric soil moisture content as a percentage based on Time-domain reflectometer. When collecting data two measurements were taken from each container, one from the south facing side and one from the north. Soil moisture data was taken directly preceding each collection of predawn leaf water potentials.

The dry down treatments were conducted in the summer and fall of 2010. The first and second treatments lasted nine days (July tenth to July nineteenth) and nineteen days (July twenty-fourth to August ninth) respectively. These initial dry downs were undertaken to allow researchers to become comfortable with the instruments and provide an idea of rate at which stress would increase in response to low water condition. Therefore, the data from these first two dry down are of limited use in evaluating the drought tolerance of the test species and are presented as Appendix Figures 2.4 and 2.5

Near the end second dry period all replications of A. *alnifolia* and *A. canadensis* become afflicted with spider mites (*A. utahensi*s was not noticeably affected). In an effort to mitigate the spider mite infestation the foliage of all test plants (including *A. utahensis*) was sprayed with a forceful stream of water at the conclusion of the second dry down period. Plants were also given a longer recovery period of twenty-one days between the second and third dry period. The spider mite issue seemed to be alleviated by these measures. There were no signs of new spider mite feeding during the two week recovery period. During this recovery period, some replications of *A. alnifolia* and *A. canadensis* also had flushes of new vegetative growth increasing their overall size.

The third and final dry down period began on August twenty-ninth. The third dry down was allowed to continue either until a plant lost all its leaves, effectively going dormant, or until no fleshy leaves remained on the plant. In no case was the last remaining leaf on a plant sampled. Either plants dropped their last leaves or they desiccated on the plants leaving none that could be sampled.

When a plant no longer had any leaves to sample it was classed as either dormant or dead. A plant was considered dormant if it still had living tissue above ground. Tissue was considered living if it was green and moist. A plant was considered dead if it had no living tissue above ground.

Due to inconsistency among test plants, both in terms of growth during the trial (and thus size) and spider mite infestations, comparing data among species at specific dates during the dry downs was problematic. Analysis of the data primarily focused on average maximum predawn leaf water potential for each species and the average minimum volumetric soil water content for a species. For nearly all plants these values were observed on the last day of the third dry down period. This approach minimized the effect of plant size as it does not consider the rate of water use but only the extreme level of stress and minimum level of moisture the plant endured. The effect of the spider mite infestation on these factors was uncertain.

The GLIMMIX procedure in SAS/STAT 9.2 (SAS Institute, Cary, NC, USA) was used to analyze the leaf water potential and soil water content data. Pairwise differences between species means were compared using a t-test with Tukey-Kramer’s adjustment for multiple comparisons. The “proc freq” procedure in SAS was used to analyze differences in the number of plants of each species that died after the third dry down period.

Results and Discussion-

<u>Final Predawn leaf water potential-</u>

There was no significant difference among the average predawn leaf water potential at the end of the third dry down period among species. Average potentials for control plants were significantly higher than plants subjected to dry down (figure 2.1). The average potentials for the controls at the conclusion of the trial were -.4 Mpa, -.44 Mpa and -.52 Mpa for *A. alnifolia, A. canadensis* and *A. utahensis* respectively. Among test plants, *A. utahensis* recorded the lowest average potential with -6.21 Mpa, *A. canadensis* was second lowest with an average of -5.36 Mpa and *A. alnifolia* had the highest average with -5.11 Mpa. While none of the differences among these values were significant, several factors may have influenced these results.

The pressure chamber utilized to take the measurements only measured up to seven Mpa. During the third dry down, one test plant of A. *alnifolia* and three of *A. utahensis* were still not extruding sap at this level of pressure. This indicates that the final negative pressure in the vascular tissue was less than -7 Mpa. To be conservative these measurements where averaged as -7 Mpa. However, the real value, though unknown, was more negative. The decision to perform multiple dry downs may also have affected results. While recovering from the stress of the first dry down *A. canadensis* and *A. alnifolia* became infested with spider mites. The extra stress that this presumably added might have affected their tolerance to low water conditions.

It should be noted that the final water potential observed was not always the lowest for a given individual. Two individuals of *A. alnifolia* had a decrease in potential in the final measurement. However, analysis of the average highest potentials observed among species also showed no significant differences (Appendix Table 2.1).

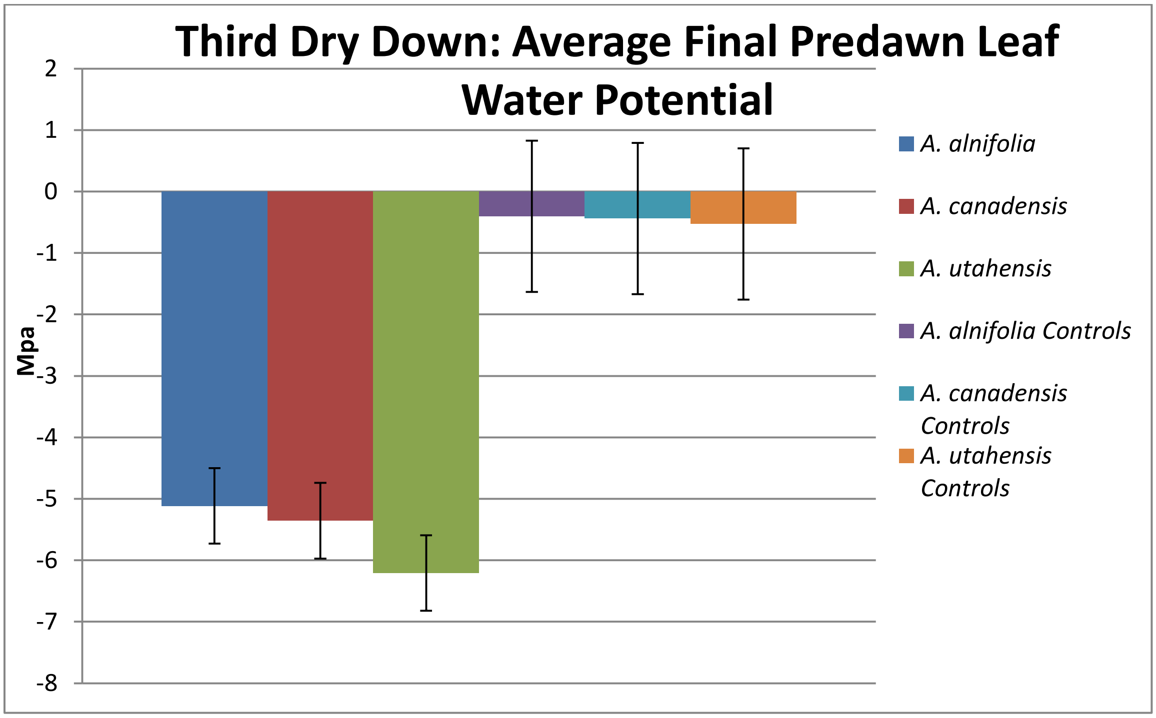


Figure 2.1- Average final predawn leaf water potential during third dry down in Mpa for three greenhouse grown Amelanchier species. All species had 8 repetitions put under drought stress and two controls. Error bars are equal to +/- 1.4 of the standard error of the species means. Non-overlapping error bars indicate a significant difference equivalent to a t-test with 0.05 level of significance (p=0.05).

<u>Final Soil Water Content-</u>

The final soil volumetric soil water content was significantly less for *A. utahensis* than *A. alnifolia*. However, there were no other significant differences among species averages at the end of the dry down. The species averages for control plants were significantly higher than the species average for plants subjected to dry down (Figure 2.2). These results show that *A. utahensis* was able to tolerate lower water conditions and was able to extract more of the water in the soil than *A. alnifolia*.

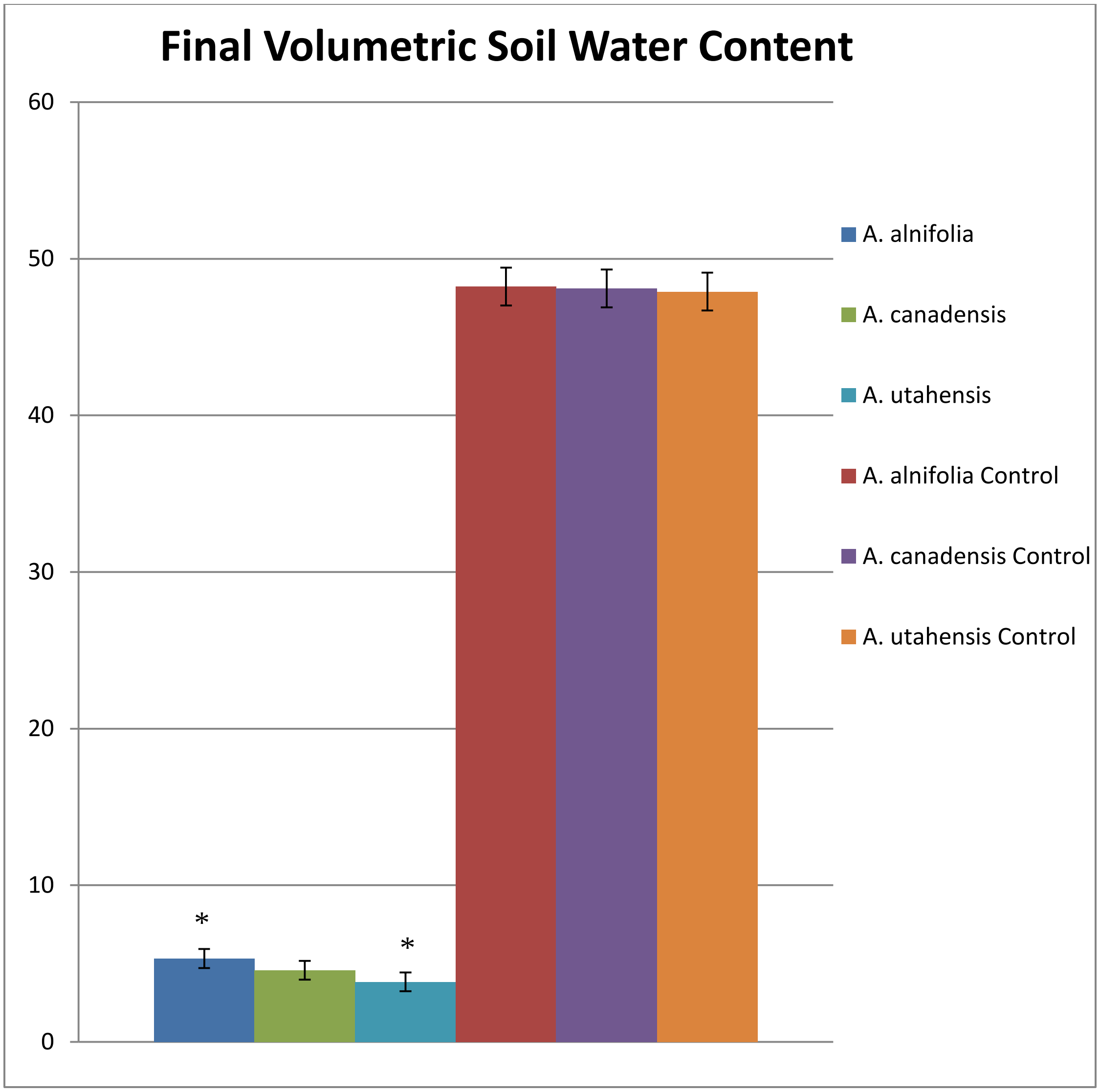


Figure 2.2- Average final volumetric soil water content during third dry down for both experiential plants and controls of all species as measured with Theta Probe (a Time domain reflectivity device). All species had 10 repetitions, two of which were controls. Error bars are equal to +/- 1.4 of the standard error of the species means. Non-overlapping error bars indicate a significant difference equivalent to a t-test with 0.05 level of significance (p=0.05). (* Note: *A. alnifolia* is significantly different from *A. utahensis* p=.02)

Survival-

During the final dry down, plants were considered active in the experiment and had data collected from them until they went dormant or died. Individuals of *A. utahensis* were, on average, active for significantly longer than *A. canadensis* (33.9 days versus 25.7). This was the only significant difference in length of active period (Figure 2.3).

Although test plants were of a similar size when they were acquired, individuals of *A. canadensis* and *A. alnifolia* grew at different rates while recovering between dry downs. They were thus larger going into the final dry down. It is possible that larger size lead to increase water demand. This makes the number of active days difficult to compare.

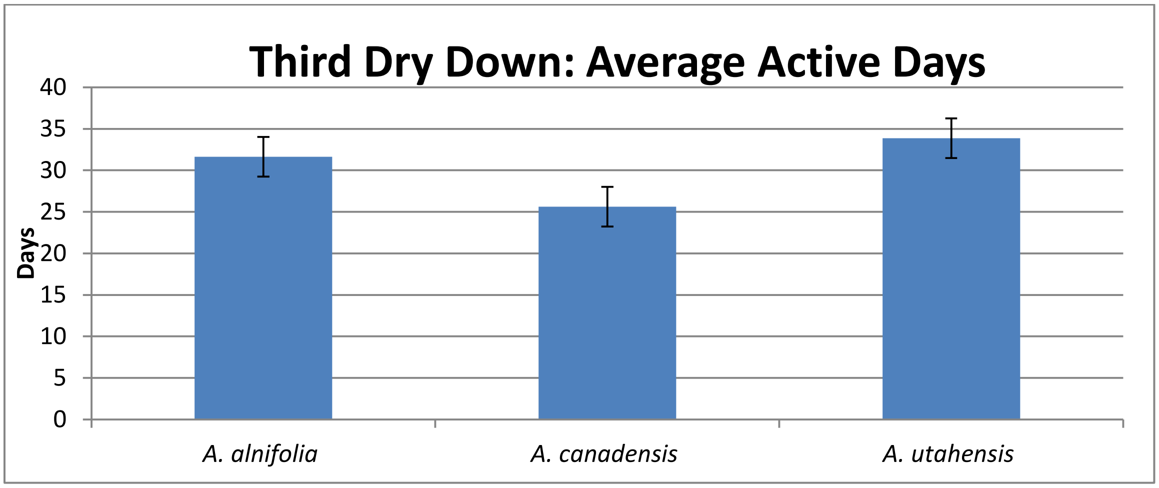


Figure 2.3- Average number of days test plants remained active during the third and final dry down. Plants were considered active if they still had succulent leaves. Error bars are equal to +/- 1.4 of the standard error of the species means. Non-overlapping error bars indicate a significant difference equivalent to a t-test with 0.05 level of significance (p=0.05).

It may be more useful to look at differences in the condition of plants between species when they became inactive. Some of the plants appeared to die while others went dormant. Individuals of *A. canadensis* all died to the soil line because of the water stress imposed by the dry down. They had no green tissue above the soil line. *A. alnifolia* exhibited a more mixed result with five individuals losing all their leaves but maintaining green tissues above ground and three individuals dying to the soil line. Although they lost all of their leaves, all individuals of *A. utahensis* had living tissue on the above ground portion of the plant at the conclusion of the trial (Table 2.1). The frequency of dead and dormant plants was significantly different when comparing any two species (Appendix Table 2.2).

Table 2.1- Percentage of plants for the three species tested which were dead or dormant following the third dry down. Plants were considered dead if all their tissues above the soil line had desiccated. If there was still living tissue above the soil line, they were classed as dormant. None of the plants were overwintered to determine survival.

	Species	*A. alnifolia*	*A. canadensis*	*A. utahensis*
State of Plants at the conclusion of 3rd dry down	Dead	37.5	100	0
	Dormant	62.5	0	100

Conclusion

Based on these results *A. utahensis* may be more tolerant of dehydration than *A. alnifolia* but otherwise no other significant differences in tolerance were observed. There were no significant differences in maximum predawn leaf water potential observed in this experiment. However, the difference between *A. utahensis* and *A. alnifolia* may have been significant if a pressure chamber with a higher maximum pressure had been available. The p-value for the comparison between the two using the conservative measurements for *A. utahensis* was .09. *A. utahensis* was also able to extract significantly more water from the soil than *A. alnifolia*. So, in terms of pure dehydration tolerance, *A. utahensis* appears to be more tolerant than *A. alnifolia*. However, this experiment showed no differences between *A. canadensis* and *A. utahensis* or *A. canadensis* and *A. alnifolia* in terms of dehydration tolerance.

In terms of drought avoidance it appears there may be differences among species, though more testing is needed to confirm this. Both *A. alnifolia* and *A. utahensis* kept moist green leaves longer than *A. canadensis*. These two species also had significantly more plants go dormant as compared to dying from the stress induced by the third dry down. Taken together these results might indicate a high level of drought tolerance through avoidance of dehydration (as compared to tolerance of dehydration) in *A. alnifolia* and *A. utahensis*. This is especially probable for A. *utahensis*, which suffered no mortality due to the stress of the final dry down period.

In terms of overall drought tolerance, it would appear that A. utahensis has a higher tolerance than the other two species. The difference in tolerance between *A. alnifolia* and *A. canadensis* is less significant and would depend on the type of drought. It appears both might be tolerant of and respond similarly to short periods of drought as they both tolerated similar levels of dehydration. However, over a prolonged drought, *A. alnifolia* might fare better as is shown in a higher potential for drought avoidance. Field trials in landscape settings would better assess the nature and extent of these species' drought avoidance abilities.

WORKS CITED

1) Campbel1, S. C. University of Maine Department of Biological Science. 2010. *Amelanchier canadensis var. canadensis* . Accessed January 10, 2012. http://sbe.umaine.edu/amelanchier/?page_id=151.

2) Boyer J. S. August 1966. Leaf Water Potentials Measured with a Pressure Chamber. Plant Physiology 42: 133-137.

3) Dirr, M. A. 1998. **Manual of Woody Landscape Plants**. Stipes Publishing L.L.C., Champaign, Illinois.

4) Evans, E. North Carolina State University Department of Horticulture. Plant Fact Sheet: *Amelanchier canadensis*. Accessed January 10, 2012. http://www.ces.ncsu.edu/depts/hort/consumer/factsheets/trees-new/amelanchier_canadensis.html.

5) John, T. K. United States Department of Agriculture Natural Resources Conservations Service. Plants Profile *Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem. Saskatoon serviceberry. Accessed January 10, 2012. http://plants.usda.gov/java/profile?symbol=AMAL2.

6) John T. K. United States Department of Agriculture Natural Resources Conservations Service. Plants Profile *Amelanchier canadensis* (L.) Medik. Canadian serviceberry. Accessed January 10, 2012. http://plants.usda.gov/java/profile?symbol=AMCA4.

7) John T. K. United States Department of Agriculture Natural Resources Conservations Service. Plants Profile *Amelanchier utahensis* Koehne Utah serviceberry. Accessed January 10, 2012. http://plants.usda.gov/java/profile?symbol=AMUT.

8) Kramer. J. and Boyer, J. 1995. **Water Relations of Plants and Soils, 2nd edition**. Academic Press, San Diego, California.

9) Missouri Botanical Garden. *Amelanchier canadensis*. Accessed January 10, 2012. http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/j290/amelanchier-canadensis.aspx.

10) Nesom, G. United States Department of Agriculture Natural Resources Conservations Service. 2006. Plant Guide: Saskatoon *Amelanchier alnifolia*. Accessed January 10, 2012. http://plants.usda.gov/plantguide/pdf/pg_amal2.pdf.

11) Noller, G. United States Department of Agriculture Natural Resources Conservations Service. 2006. Plant Guide: Utah Serviceberry *Amelanchier utahensis* (Koehne). Accessed January 10, 2012. http://plants.usda.gov/plantguide/pdf/pg_amut.pdf.

12) Pallardy, S. and Rhoads, J. Drought effects on leaf abscission and Leaf Production in Populus Clones. 11th Central Hardwood Forest Conference. Columbia, MO. U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station. 1997.

13) Richard H.,Waring, R. and Cleary, B. March 1967. Plant Stress Evaluation by Pressure Bomb. Science 155: 1248+1253-1254.

APPENDIX I

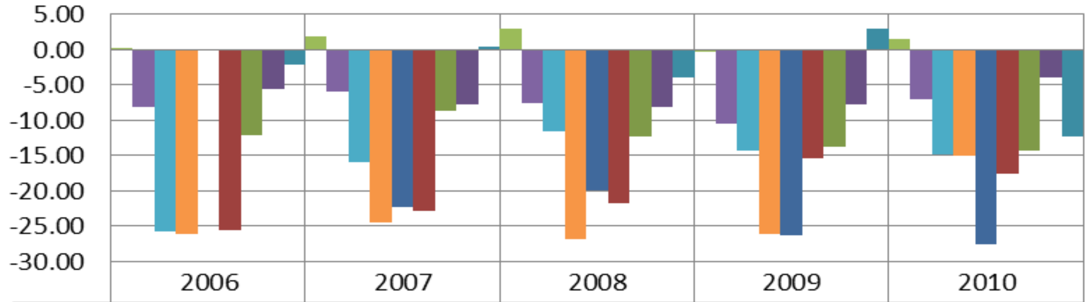
Appendix I

Site	pH	EC (mmhos/ cm)	Lime Estimate	Organisc Matter (%)	NO3-N (ppm)	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Texture
Brightion	7.3	1	Meduim	2.9	17.4	16.5	332	1.6	7.8	2	1.8	Clay loam
Calhan	7	0.03	Low	1.1	2.8	11.2	241	0.7	8	4.2	3.9	Sand clay loam
Fort Collins	8	0.9	High	2.8	33.5	7.1	403	3.1	6.5	7.5	4.4	Clay
Grand Junction	7.5	0.6	Very High	4	16.8	8.1	166	1.9	5	1	2.9	Clay
Hudson	7.3	0.5	Medium	1.6	20.9	4.3	215	0.4	5.3	9.4	2.7	Clay

Appendix Figure 1.1: Soil Data for Brighton, Calhan, Fort Collins, Hudson and Orchard Mesa. This data was collecting in the fall of 2010.

A

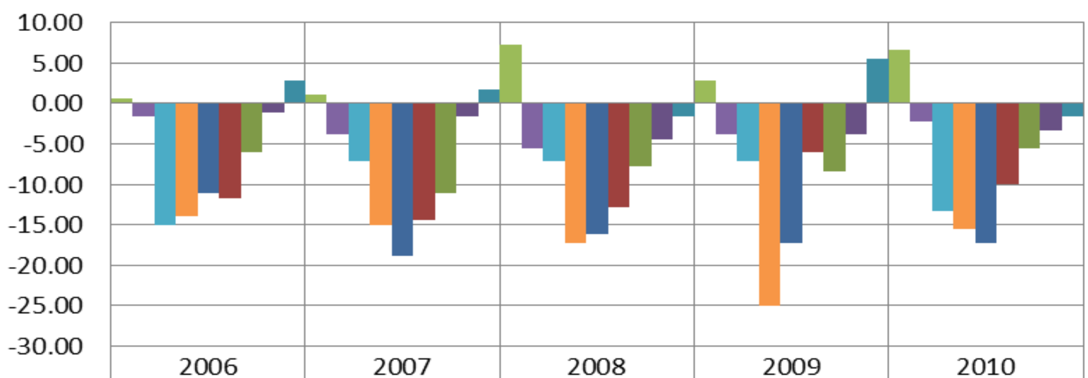
Fort Collins- Minimum Temperatures



	2006	2007	2008	2009	2010
SEPT	0.13	1.81	2.94	-0.40	1.50
OCT	-8.16	-5.99	-7.62	-10.50	-7.07
NOV	-25.72	-15.99	-11.53	-14.36	-14.86
DEC	-26.11	-24.44	-26.76	-26.11	-15.00
JAN		-22.22	-20.00	-26.26	-27.61
FEB	-25.66	-22.89	-21.67	-15.44	-17.66
MAR	-12.15	-8.67	-12.39	-13.83	-14.33
APR	-5.67	-7.70	-8.06	-7.78	-3.89
MAY	-2.16	0.44	-3.89	2.86	-12.22

B

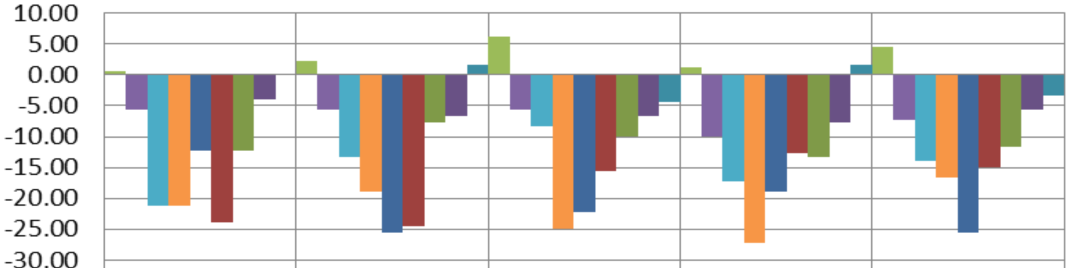
Orchard Mesa- Minimum Temperatures



	2006	2007	2008	2009	2010
SEPT	0.56	1.11	7.22	2.78	6.67
OCT	-1.67	-3.89	-5.56	-3.89	-2.22
NOV	-15.00	-7.22	-7.22	-7.22	-13.33
DEC	-13.89	-15.00	-17.22	-25.00	-15.56
JAN	-11.11	-18.89	-16.11	-17.22	-17.22
FEB	-11.67	-14.44	-12.78	-6.11	-10.00
MAR	-6.11	-11.11	-7.78	-8.33	-5.56
APR	-1.11	-1.67	-4.44	-3.89	-3.33
MAY	2.78	1.67	-1.67	5.56	-1.67

C

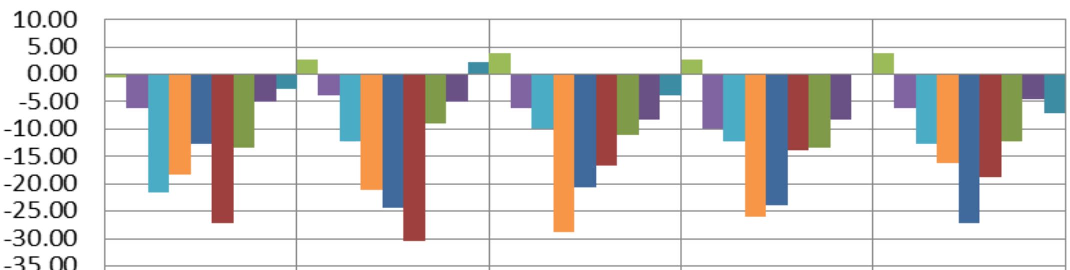
Greeley- Minimum Temperatures



	2006	2007	2008	2009	2010
SEPT	0.56	2.22	6.11	1.11	4.44
OCT	-5.56	-5.56	-5.56	-10.00	-7.22
NOV	-21.11	-13.33	-8.33	-17.22	-13.89
DEC	-21.11	-18.89	-25.00	-27.22	-16.67
JAN	-12.22	-25.56	-22.22	-18.89	-25.56
FEB	-23.89	-24.44	-15.56	-12.78	-15.00
MAR	-12.22	-7.78	-10.00	-13.33	-11.67
APR	-3.89	-6.67	-6.67	-7.78	-5.56
MAY	0.00	1.67	-4.44	1.67	-3.33

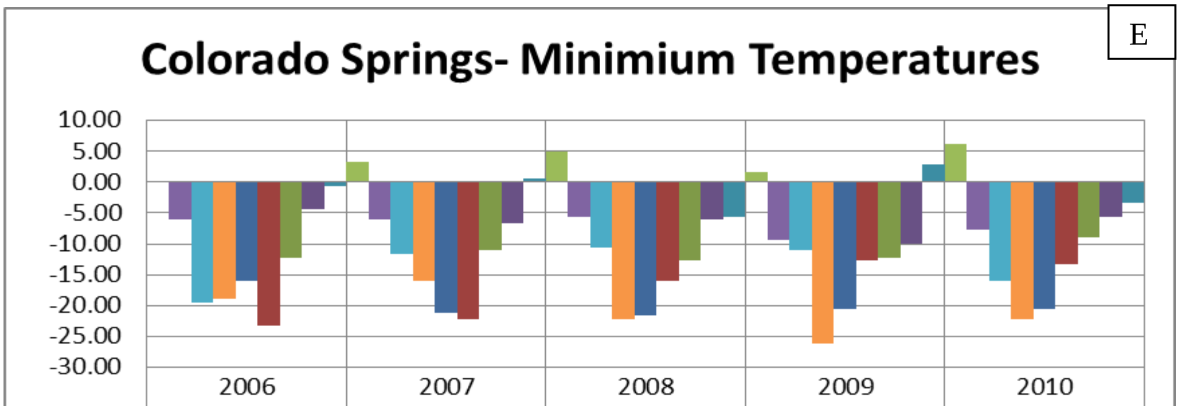
D

Brighton- Minimum Temperatures



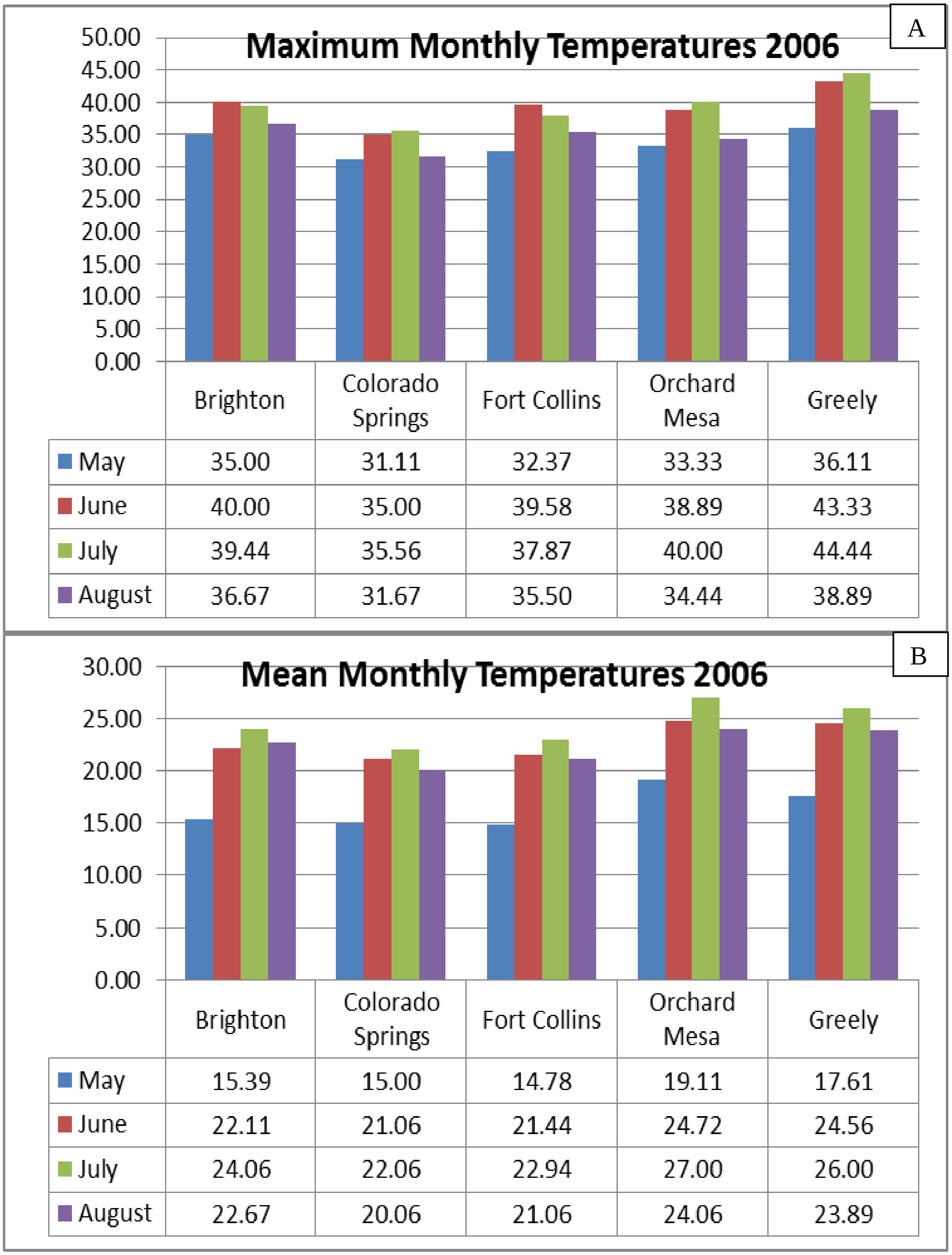
	2006	2007	2008	2009	2010
SEPT	-0.56	2.78	3.89	2.78	3.89
OCT	-6.11	-3.89	-6.11	-10.00	-6.11
NOV	-21.67	-12.22	-10.00	-12.22	-12.78
DEC	-18.33	-21.11	-28.89	-26.11	-16.11
JAN	-12.78	-24.44	-20.56	-23.89	-27.22
FEB	-27.22	-30.56	-16.67	-13.89	-18.89
MAR	-13.33	-8.89	-11.11	-13.33	-12.22
APR	-5.00	-5.00	-8.33	-8.33	-4.44
MAY	-2.78	2.22	-3.89		-7.22

E



	2006	2007	2008	2009	2010
SEPT	0.00	3.33	5.00	1.67	6.11
OCT	-6.11	-6.11	-5.56	-9.44	-7.78
NOV	-19.44	-11.67	-10.56	-11.11	-16.11
DEC	-18.89	-16.11	-22.22	-26.11	-22.22
JAN	-16.11	-21.11	-21.67	-20.56	-20.56
FEB	-23.33	-22.22	-16.11	-12.78	-13.33
MAR	-12.22	-11.11	-12.78	-12.22	-8.89
APR	-4.44	-6.67	-6.11	-10.00	-5.56
MAY	-0.56	0.56	-5.56	2.78	-3.33

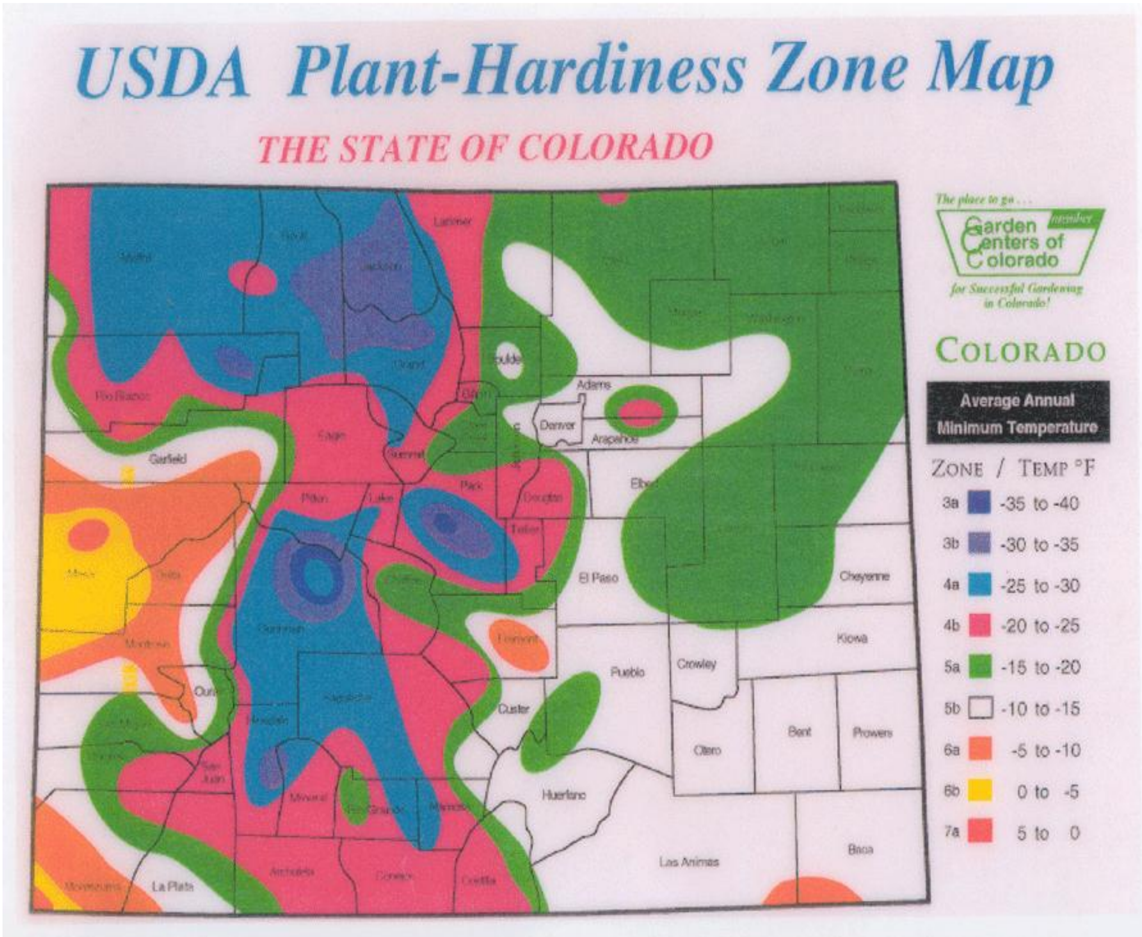
Appendix Figure 1.2 A-E: Extreme Low Temperatures measurements in degrees Celsius from September to May from 2001 to 2006 at Fort Collins (A), Orchard Mesa (B), Greely (C), Brighton (D) and Colorado Springs (E). Weather stations took measurement every ten minutes



	Brighton	Colorado Springs	Fort Collins	Orchard Mesa	Greely
May	35.00	31.11	32.37	33.33	36.11
June	40.00	35.00	39.58	38.89	43.33
July	39.44	35.56	37.87	40.00	44.44
August	36.67	31.67	35.50	34.44	38.89

	Brighton	Colorado Springs	Fort Collins	Orchard Mesa	Greely
May	15.39	15.00	14.78	19.11	17.61
June	22.11	21.06	21.44	24.72	24.56
July	24.06	22.06	22.94	27.00	26.00
August	22.67	20.06	21.06	24.06	23.89

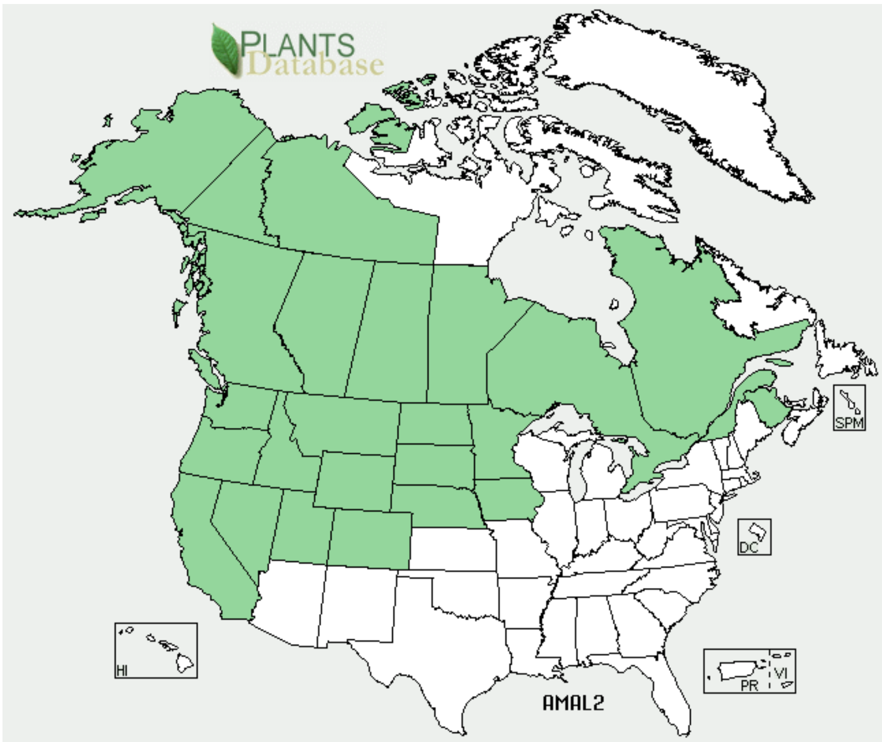
Appendix Figure 1.3 A and 1.3 B- Monthly maximum (A) and Monthly mean (B) Temperatures for Brighton, Colorado Springs, Fort Collins, Orchard Mesa and Greely during the months of May- August for 2006. Weather stations took measurements every ten minutes.



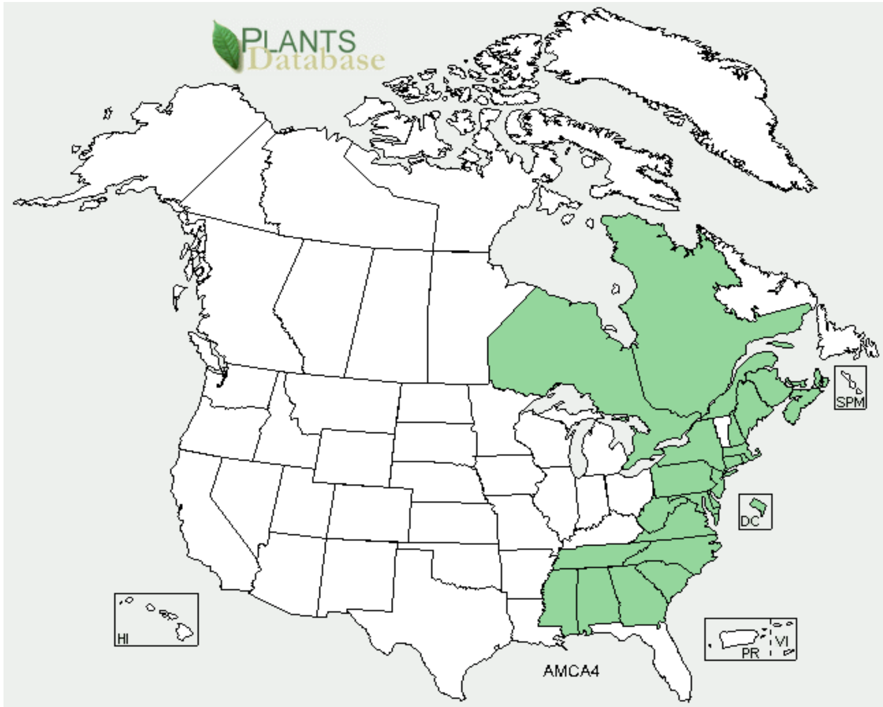
Appendix Figure 1.4: USDA Pant-Hardiness Zone Map for the State of Colorado.

APPENDIX II

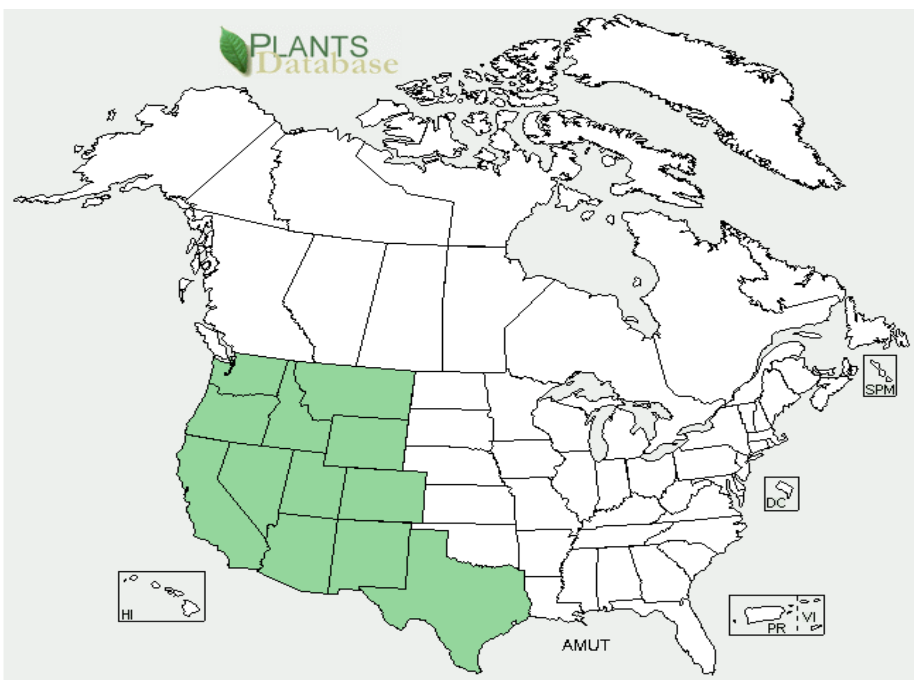
Appendix II



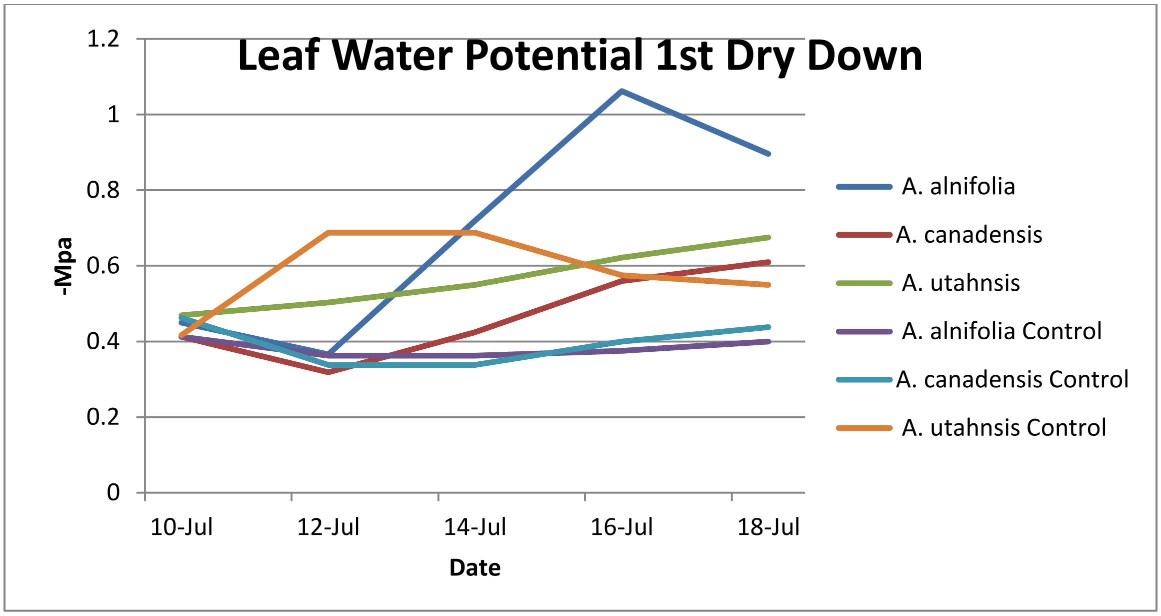
Appendix Figure 2.1- North American Range of *Amelanchier alnifolia* illustrated in green (5).



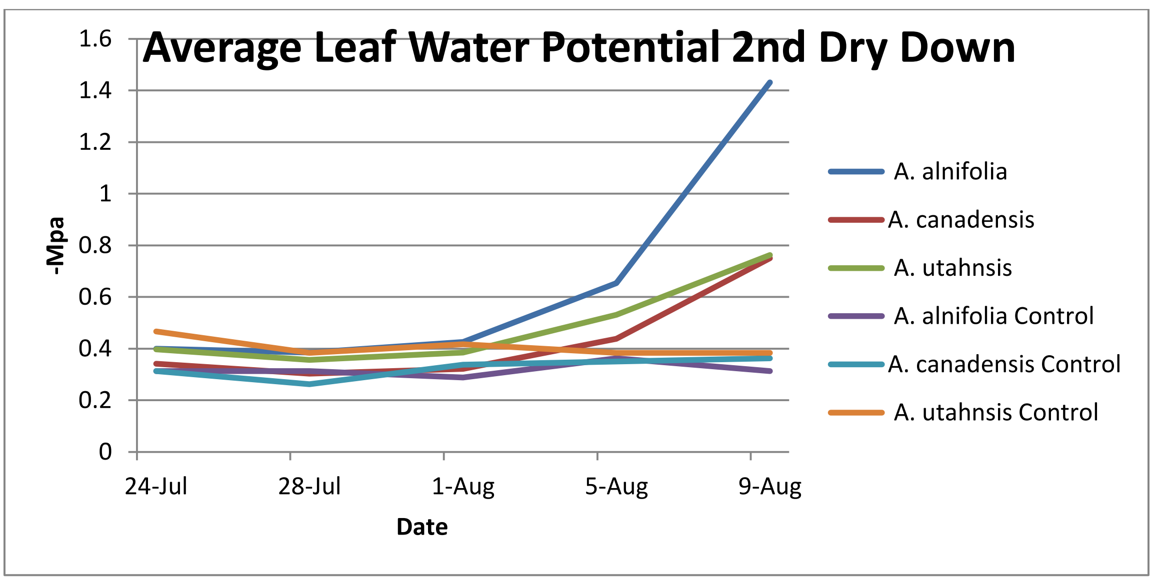
Appendix Figure 2.2- North American Range of *Amelanchier canadensis* illustrated in green (6).



Appendix Figure 2.3- North American Range of *Amelanchier utahensis* illustrated in green (7).



Appendix Figure 2.4- Average Leaf water potential in -Mpa during the first dry down. Data was taken every second day from July 10th 2011 to July 18th 2011 and is presented as average of all measurement for plants of a species from a given day.



Appendix Figure 2.5- Average Leaf water potential in -Mpa during the second dry down. Data was taken every fourth day from July 24th 2011 to August 9th 2011 and is presented as average of all measurement for plants of a species from a given day.

Appendix Table 2.1- Average minimum predawn leaf Water potential and comparison of difference between species during third dry down in -Mpa. All species had 10 repetitions, two of which were controls. Key: *A*= *A. alnifolia*, AC= *A. alnifolia* control plant, C= *A. canadensis*, CC= *A. canadensis* control plants, U= *A. utahensis* and UC= A. utahensis control plants.

treat Least Squares Means

treat	Estimate	Standard Error	DF	t Value	Pr > |t|
A	5.11563	.43952	24	11.64	<.0001
AC	.40000	87903	24	0.46	0.6532
C	5.35625	4.3952	24	12.19	<.0001
CC	.43750	8.7903	24	0.50	0.6232
U	6,20625	4.3952	24	14.12	<.0001
UC	,52500	8.7903	24	0.60	0.5559

Differences of treat Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

treat	_treat	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
A	AC	4.71562	9.8279	24	4.80	<.0001	0.0009
A	C	-.24063	6.2157	24	-0.39	0.7021	0.9987
A	CC	4.67812	9.8279	24	4.76	<.0001	0.0010
A	U	-1.09063	6.2157	24	-1.75	0.0921	0.5115
A	UC	4.59062	9.8279	24	4.67	<.0001	0.0012
AC	C	-4.95625	9.8279	24	-5.04	<.0001	0.0005
AC	CC	-.03750	12.4314	24	-0.03	0.9762	1.0000
AC	U	-5.80625	9.8279	24	-5.91	<.0001	<.0001
AC	UC	-.12500	12.4314	24	-0.10	0.9207	1.0000
C	CC	4.91875	9.8279	24	5.00	<.0001	0.0005
C	U	-.85000	6.2157	24	-1.37	0.1841	0.7451
C	UC	4.83125	9.8279	24	4.92	<.0001	0.0007
CC	U	-5.76875	9.8279	24	-5.87	<.0001	<.0001
CC	UC	-.08750	12.4314	24	-0.07	0.9445	1.0000
U	UC	5.68125	9.8279	24	5.78	<.0001	<.0001

Appendix Table 2.2- Caparison between species of the proportion of plants which were dead at the conclusion of the third dry down. There were eight repetitions of each species. A value of .05 or less indicates a significant difference in the proportion of plants which died using the Chi-squared method.

COMPARISON	p value
A to C	0.07
A to U	0.05
C to U	0.0001