THESIS

WOODY PLANT EVALUATION IN COLORADO

Submitted by

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ABSTRACT

PART 1: EVALUATION OF COLD HARDINESS OF *CUPRESSUS ARIZONICA* 'COOKE PEAK'

A trial was conducted to assess the cold hardiness of twig and foliage samples of *Cupressus arizonica* 'Cooke Peak', trees grown from seed with a high elevation provenance. Samples were collected monthly over a three month period, November, December, and January, during the winter of 2005-2006 from three Colorado field sites. Individual samples were dissected into four subsets, and chilled to three target temperatures in an artificial freezing chamber at Colorado State University, Fort Collins, Colorado. Each month's samples were prepared and chilled within one week of collection. One subset was held as a control, while the others were chilled to -10 °C, -20 °C, and -30 °C. One set of subsamples was removed from the freezing chamber at each of the three target temperatures. Samples were held at room temperature for one week to allow visual damage to develop. Two evaluators assessed visual damage symptoms in the cambium and on the foliage and assigned scores based on the percent of damage. Results indicate that this tree is hardy to -20 °C, with visual damage increasing as temperatures approach -30 °C.

PART 2: MULTI-SITE WOODY PLANT EVALUATION IN COLORADO

A multi-site evaluation of five woody plant taxa was conducted at five sites in Colorado with differing soil and weather conditions and cultural management practices. This project is a partnership with Plant Select ®, a Colorado non-profit corporation that makes plant recommendations and introductions. Data was collected for five years, 2002-2006, beginning at planting. Plants were evaluated based on rates of survival, and increases in caliper, canopy width, and height. Information regarding ornamental features and pest infestations was also recorded to assist Plant Select ® in determining if plants warranted introduction or recommendation for widespread use in the State. Plants included in the trial were *Cotoneaster ignavus* 'Szechuan Fire,' *Cupressus arizonica* 'Cooke Peak,' *Fraxinus americana* 'Jeffnor,' *Fraxinus* x 'Northern Gem,' and *Tilia mongolica* x *Tilia cordata* 'Harvest Gold.' Statistical analyses of growth measures showed significant differences between plants of the same taxon at different sites. While all plants adapted to Colorado growing condition, researchers felt that only *Tilia mongolica* x *Tilia cordata* 'Harvest Gold' should be recommended for widespread use.

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EVALUATION OF COLD HARDINESS OF *CUPRESSUS ARIZONICA* ‘COOKE PEAK’

CHAPTER 1:

EVALUATION OF COLD HARDINESS OF CUPRESSUS ARIZONICA ‘COOKE PEAK’

Introduction

In partnership with the local nursery industry, Colorado State University initiated a multi-site woody plant evaluation project in 2002. One species included in the initial planting for this program was *Cupressus arizonica* Greene, Arizona cypress. Arizona cypress, *Cupressus arizonica* ‘Cooke Peak’, is a coniferous tree reaching up to 25 meters in height. The bark is furrowed, and branches spread horizontally, giving the tree a broadly conical shape. The glaucous green foliage is scale-like and acuminate, usually 2mm in length with a resin gland on the dorsal side. The cones are globose, 2-3 cm in size, and a dark red or brown at maturity. They are composed of 6-8 scales. Its native range extends from New Mexico and Arizona, in the United States, reaching into the states of Northwestern Mexico (6). There is debate about the taxonomy of this species, with some authors placing several varieties into the single species, *C. arizonica* Greene, and some distinguishing these varieties as separate species based on morphological differences.

While Arizona cypress has generated interest among growers in Colorado in the past, there are concerns regarding its cold-hardiness. This tree is considered hardy in USDA hardiness zones 7-9. Mean low temperatures for zone 7a are -15.0 ^{o} C to -17.7 ^{o} C (3). Much of Colorado’s population lives in USDA zones 5a and 5b. Mean minimum temperatures for these two USDA zones are as follows: zone 5a, -28.8 º C; and zone 5b, -26.1 º C. Zone 4b minimum temperatures fall between -28.9º C and -31.6 º C. The parent population for the trees evaluated in this research, named for the site of collection of its seed, grows near the summit of Cooke Peak, New Mexico, at an elevation of 2563 m on north side of the mountain. The goal of this research was to estimate the USDA hardiness zone of *Cupressus arizonica* 'Cooke Peak', a selection grown from seeds whose provenance is from a high elevation.

Researchers evaluated cold hardiness using a freezing chamber. This method provided consistent test conditions and allowed rapid assessment of damage with a large set of samples (2). Damage was assessed by measuring electrolyte leakage or chlorophyll fluorescence, as well as by visually scoring damage to samples. Commonly used visual rating intervals are either 1-3, or 1-10. In the former, ratings identify no damage, some visible injury symptoms, and finally, total browning of the sample. Using a scale of 1-10, visible damage includes examination for foliar and cambial discoloration**.** While there have been questions regarding consistency of results between artificial freezing and actual field results, research demonstrates that artificial freezing can provide reliable predictions of field performance (1, 4).

Methods and Materials

Foliage samples were harvested during the first week in three successive months, November, and December, 2005, and January, 2006 from three different sites in Colorado. Sampling dates were approximately at four week intervals. The trees had been transplanted from #5 containers into the fields in the spring of 2002. At the time of sampling, trees ranged in height from 2.3-4.5 m. Cold sensitivity of plant tissues from different positions of the plant was evaluated by taking samples from lower, middle, and top one-thirds of each plant, on both north and south sides.

Three trees at each site were randomly selected to include in this research. The same trees were used throughout the course of this study. After harvesting, samples were labeled and placed in plastic bags, stored in coolers to maintain a temperature under 4° C and delivered to Colorado State University in Fort Collins. Shoots were cut into segments 4 to 7 cm in length. Each was wrapped in moist paper toweling (4), labeled, and placed in individual plastic bags with an identifying tag for each target temperature. One grouping was labeled and kept as a control set. All samples were held in an unlit cooler on the Colorado State University campus at 10° C until processed for testing. For each month's evaluation, all samples, except the control group, from the three sites were frozen at one time. Testing was conducted 5 to 7 days after harvest.

The cold-hardiness of Arizona Cypress "Cooke Peak" (*Cupressus arizonica* 'Cooke Peak') was evaluated by using artificial freezing conducted in a Watlow Series 942 freezing chamber. After freezing, samples were examined and the extent of damage was scored using visual assessment by two evaluators. Evaluators rated tissue samples using a range of 1 (no damage) to 10 (total foliar and cambial damage). Samples were evaluated after being chilled to three target temperatures: -10° C, -20° C, and -30° C.

Samples from all sites were placed in the freezing chamber, and the temperature was lowered to -2° C and held at that temperature for one hour. This regimen reflected the local temperatures for the time of the study which, relating laboratory results to actual field hardiness for this region. The temperature was lowered over a 5 hr period to -10° C, and held there for one hour. At that point the chamber was opened and those samples labeled for that target temperature were removed and stored at room temperature. Subsequently, the temperature was lowered to -20° C over the next 5 hrs, and held at that temperature for 1 hr. The next set of samples was removed. The temperature was then lowered to -30° C over a 5 hr period and that temperature was maintained for 1 hr. The samples were left in the chamber at -30° C. With the samples still inside, the temperature was raised to 0° C in one-half hour. The final samples were left at 0° C for another one-half hour, after which the chamber switched off, and the temperature inside was allowed to reach room temperature. Control and frozen samples were held together at room temperature for a 1 week interval before evaluation (4) to allow progression of visual damage.

Scoring for visual damage symptoms was performed by two evaluators. Evaluators examined samples by checking for changes in color, with undamaged samples retaining a green color, and dry texture. Damaged samples showed varying extent of browning coloration, and water-soaked texture. In evaluating cambial damage, evaluators scraped the bark to examine browning of the tissue under the bark. They quantified their estimates of damage in 10 per cent increments. Higher scores indicate greater estimates of visual damage to foliage and cambium. The scores assigned by the evaluators were analyzed statistically using the SAS system GLIMMIX procedure. Ratings were analyzed in order to appraise differences in visual damage symptoms based on the effect of the position of samples collected from trees, as well as for differences in overall hardiness between sites. Confidence level of 95% was used for this analysis.

Temperature data for two of the test locations, Brighton, Colorado, and Grand Junction, Colorado, was collected on-site. For the third site, Calhan, Colorado, the closest official weather station is located at the Colorado Springs airport, approximately 48.3 kilometers distance. Weather data was collected for the months of October, November, and December, 2005, and January, 2006. There was a trend of decreasing temperatures as the sampling period progressed (Fig. 1a-c). All three locations experienced their coldest temperatures of the sampling period during two episodes of lower than normal temperatures in mid December, 2005. At all sites, snow cover was minimal to non-existent. Grand Junction typically experiences warmer temperatures throughout the year and a longer growing season. The Brighton site lies approximately 322 km east of the Grand Junction test plot, and 137 km north of the Calhan location. All sites are located in nursery fields, with differing irrigation methods. The nursery at the Brighton location utilized furrow irrigation; the nursery at Grand Junction used a micro-sprinkler irrigation system; and at the Calhan location, implemented overhead irrigation.

Results and Discussion

In Dec. 2005, the Brighton site experienced abnormally cold temperatures. This nursery suffered cold temperatures two different periods. The daily minimum temperatures at the Brighton site fell below -10° C from December 4 - December 10, with temperatures for three of these dates, Dec. 7, 8, and 9, falling below -20° C. The second cold interval occurred from Dec. 15 –Dec. 20. During this period, the lowest temperature recorded was -16° C. These were the lowest temperatures recorded during the sampling period (Fig. 1.1a).

At the Grand Junction site, temperatures in the field fell below -10° C twice during the study period. The first was an extended period running from Dec. 5– Dec. 11. The lowest temperature during this period was -13° C. The second episode of low temperatures extended from Dec. 14 through Dec. 17. The lowest temperature during this period was -16° C. Following these weather events, temperatures moderated and minimum daily temperatures remained above -6° C for the remainder of the experiment (Fig. 1.1b).

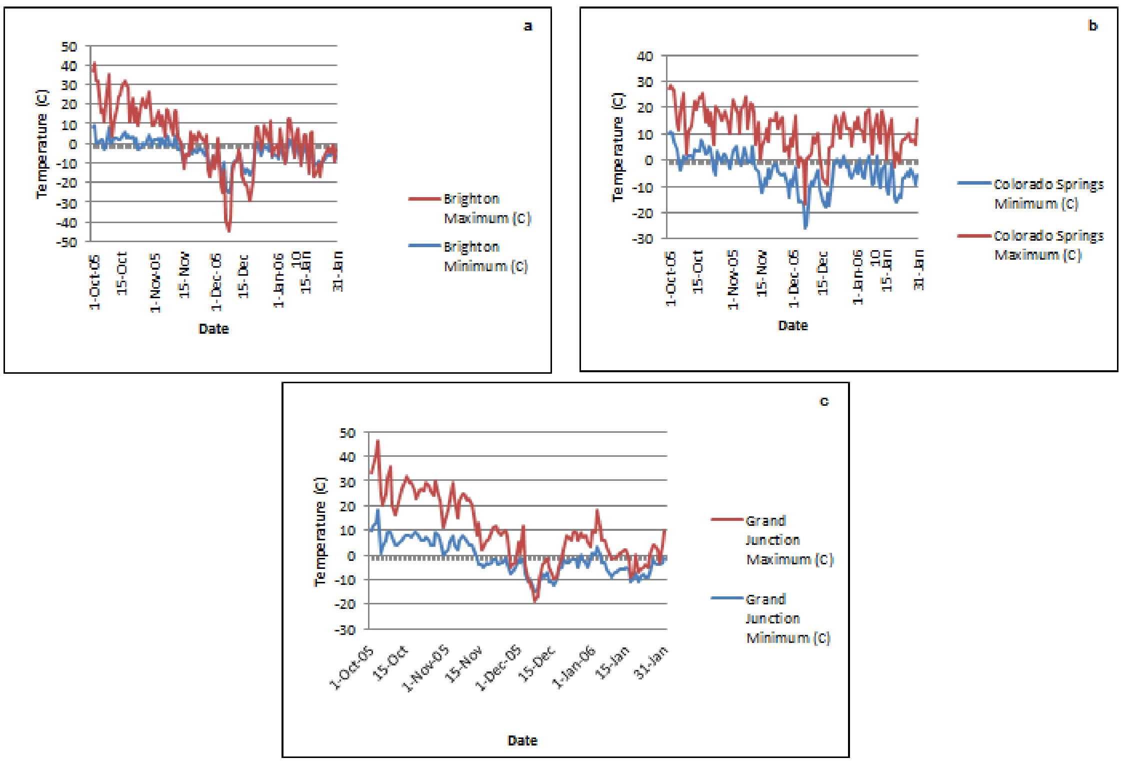

Figure 1.1 a-c: Monthly Maximum and Minimum Temperatures at Brighton (a), Colorado Springs, for Calhan test site (b), and Grand Junction (c) for the study period October, 2005-January, 2006.

The coldest temperatures for the Calhan site, recorded from Colorado Springs, were also recorded in two intervals lasting several days (Fig. 1.1c). Recorded low temperatures remained below -10° C for the dates Dec. 4 – Dec. 8, and for two of these dates, the low temperatures were below -20° C. Previously, on Dec. 2, the high temperature reported was 15° C. This site experienced a second extended period of low temperatures between Dec. 14 and 19. Once again, low temperatures remained below -

10° C, with three dates experiencing low temperatures below -15° C. The lowest recorded reading for this period was -18° C. Again, temperatures moderated after these episodes, with the recorded low temperatures remaining above -10° C.

There was no statistical difference in injury among cuttings collected from different positions or aspects on the plants. These results are not shown.

We found an increasing level of cold hardiness in the nursery fields as the winter season progressed. At all sites, damage ratings for the November samples were higher than for samples collected and analyzed in December and January. December sampling occurred before the onset of extreme cold temperatures. Analysis of individual sites, as well as for all sites combined, revealed that samples collected in Nov., 2005 showed the most severe injury when subjected to -30° C (Fig. 1.2a-d). Overall, the mean damage score was above 8, with the Grand Junction site showing a mean above 9 (Fig. 1.2c). The Calhan site, with the harshest climatic conditions, had a mean score of around 7 (Fig. 1.2b). Temperatures at the Calhan site were slightly lower during the month of October, placing plants into the first stage of cold hardiness. A review of the analysis of the November samples shows that at both Brighton and Calhan, there was significantly more damage noted at -30° C than at -10° C or -20° C. Grand Junction samples were the only set in the November evaluation that had differences in the amount of damage among the three test temperatures (Fig 1.2c). Again, this is probably a reflection of the climatic conditions at the test site. The cooler October temperatures would have encouraged plants to begin to harden off, temperatures in Grand Junction may not have been cool enough to initiate this response.

At both the Grand Junction and Brighton sites, November damage was greater than that shown in December evaluations. Damage scores for target temperatures decreased for samples from two sites, indicating less damage (Figs. 1.2a, c). The greatest

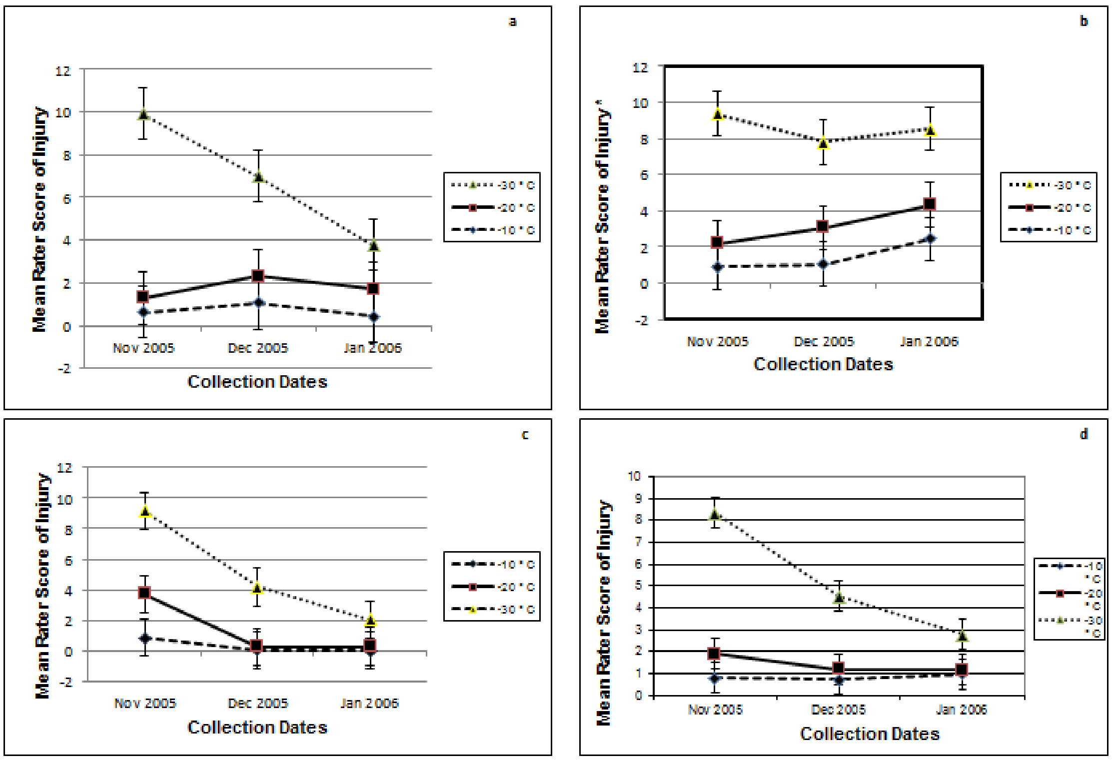

Figure 1.2a-d: Mean Rater Response for Chilling Injury for Samples from Brighton (a), Calhan (b), Grand Junction (c), and combined sites; n=161; Error Bars at ½ SE indicate Fisher's least significant difference at p<0.05.

difference in visual rating showed in damage scores for the -30° C chilling. Samples from these two sites chilled to -10° C and -20° C showed no difference in the extent of injury(Figs. 1.2a,c). Samples from the Calhan site chilled to-30° C showed greater injury than those chilled to -10° C. Results for the -20° C samples were not different from either of the above mentioned ones. For samples from all sites (Fig. 1.2 d), the amount of damage did not differ between the -10° C and the -20° C analysis. The samples chilled to -30° C were more damaged at this temperature than at the two warmer temperatures.

The samples collected on the last sampling date, Jan. 2006, had low scores indicating an increase in cold hardiness. At all sites, as well as in the overall comparison, the damage scores were not different among the three test temperatures (Fig. 1.2d). Visual damage scores for samples chilled to -20° C actually showed higher results between December and January. Collection timing may account for this, since the December sampling occurred before the extremely low temperatures. These temperatures may have inflicted damage before plants had developed full cold hardiness.

Conclusions:

The cultivar *Cupressus arizonica* , 'Cooke Peak', was evaluated to determine if the cultivar's cold hardiness makes it suitable for production in Colorado nurseries and useful in Colorado landscapes. No other seed sources or cultivars were evaluated. This species' native range lies in USDA hardiness zones 7-9, while much of Colorado lies in zones 5a and 5b. This research indicates that at temperatures approaching -20° C, Arizona cypress 'Cooke Peak' can be considered reliably hardy, showing minimal damage due to cold temperatures normally experienced throughout those areas in Colorado in which this tree might be used. As temperatures approach -30° C, damage will increase, especially in late fall or early winter, when the plant may not have reached full cold hardiness. Since this plant is seedling-propagated, there can be significant differences in hardiness between individual specimens due to differing genetics between individuals. While this plant can be used in many areas of Colorado, more research should be conducted to develop a cultivar hardy to -30° C for more widespread use in Colorado.

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PART 2

MULTI-SITE WOODY PLANT EVALUATION IN COLORADO

CHAPTER 2:

MULTI-SITE WOODY PLANT EVALUATION IN COLORADO

Introduction

Colorado State University Department of Horticulture and Landscape Architecture cooperates with nursery and landscape industries in Colorado by conducting research concerning the installation and maintenance practices of woody plants, educating landscape professionals about these practices, and evaluating the suitability of new woody and herbaceous plants for use in Colorado landscapes. In 2001, Colorado State University, Plant Select ®, and local private nurseries jointly initiated a woody plant evaluation program. A goal of this program was to evaluate woody plant taxa currently unused or underused in Colorado for future use. This information allows for recommendations to be made to nurseries interested in growing these taxa, and for landscapers to use these recommended plants in their most appropriate sites. Industry professionals suggest new plant material for trial based on aesthetics, ornamental features exhibited extending over multiple months, current use in the local landscapes, and adaptability to local environments. Final evaluations are based on growth performance, aesthetics, susceptibility to pests, adaptability to Colorado's soils and weather extremes, and survival. There are five sites currently participating in the program geographically distributed across the state, reflecting a variety of soils, temperatures, cultural management regimes, and water quality. The first planting was established in the spring of 2002.

Literature Review

Colorado is not unique in seeking to institute a woody plant evaluation program. Reasons for implementing and maintaining such a program include the following: 1) educational opportunities for students as future professionals; 2) providing locally accurate information for commercial and residential consumers regarding hardiness, adaptability, and pests; 3) supporting regional producers of plant material; 4) evaluating particular ornamental traits of plants in current use in the horticultural market; 5) selecting enhanced ornamental features; and, 6) evaluating invasiveness of potential new introductions.   This literature review of evaluation programs shows variations in their characteristics. The purposes, audience, number of sites used, length of time of trials, cultural practices, and the structure at each site and other characteristics vary from program to program depending on regional and local needs. Many of these projects utilize a partnership of public sector and private resources. For some evaluation programs, plant development is key, and the plant evaluation is the final step in breeding programs.

The Kansas State University Horticulture Research Center in Wichita, KS, evaluates taxa for both the local nursery industry and the urban residential landscape user. This program emphasizes field testing for environmental stresses of heat, drought, and winter hardiness, as well as a plant's adaptability to landscape use. Information is provided to horticultural industry groups (12). In an evaluation of ten landscape trees, this program conducted research at six Kansas Agricultural Experiment Stations throughout the state. Plants were selected on the basis of their commercial availability, likelihood of environmental tolerance, and potential landscape use. Personnel at the cooperating sites assumed responsibility for care and maintenance with the exception of fertilization and pruning. Five replications of each taxon were planted at each site, spaced 3.1 m apart. Plants were evaluated for four years for survival, height and stem diameter. Researchers also made subjective ratings of foliage and overall quality. Survival, and height or stem diameter data were also recorded (5).

Researchers from the USDA National Arboretum introduction program direct cooperating university and private sector nurseries in evaluating 2-3 plants each year. Plants are evaluated for 3-10 years, depending on genus. USDA performs the initial selection and evaluation, and relies on its cooperators to test plants under different environments and production regimes. Data is collected on disease susceptibility, pest incidence, growth rate, and ornamental features. Comments from the cooperators regarding commercial potential are also collected (14).

Oklahoma Proven, is a plant recommendation program which was initiated in 1999 by the Department of Horticulture and Landscape Architecture at the Oklahoma State University. Members of its advisory committee include industry representatives, staff from state agencies, and the Oklahoma Botanical Garden and Arboretum Affiliate Gardens. It seeks to provide local consumers with plant material about which they can feel confident of success. Oklahoma Proven promotes plants felt to be suitable for statewide use. The program seeks to assure these plants are readily available before being promoted. This program enlists 16 affiliate sites as potential test plots. To ensure statewide evaluation, plants are tested in at least one site in each of three climatically unique regions of the state. Woody plants are evaluated for a minimum of 5 years (1).

In California, there is an emphasis for testing native plants, especially those requiring low inputs of water and nutrients. The emphasis on water utilization has resulted in a project using 24 replications of each taxon, randomized within plots representing a variety of water regimes. This research is being conducted at one site. This study calculated performance based on a "growth index," using a formula of [H +(l +w/2)/2], where H = height, and l and w = canopy width taken at 90°angles to each other. Ornamental features and pest issues were also noted. This program evaluates plants on a monthly basis (15).

In Minnesota, the University of Minnesota's Nicollet Island Brownfield study evaluates trees twice annually at a single location. Caliper measurements are taken 15 cm above the soil line in the autumn at the end of the growing season. Condition ratings are completed in the late spring or early summer to include overwintering data. These trees are evaluated over a three year period. They are mulched and watered four times during the first season. No supplemental maintenance is given after the first season. Fifteen taxa were included with a total of 186 individual plants in the study (7).

The North Central Regional Plant Introduction Station, established in 1948, conducts extensive woody plant evaluations around the country. This program is part of the USDA Agriculture Research Service. The intent of this program is to expand the range of useful plants in the nursery trade throughout the North Central United States (17). This region has a wide variety of growing conditions. The emphasis has been on collection of data over a long period of time from a broad range of sites to create detailed evaluations of plant performance. Cooperators use their own cultural management techniques, and prepare performance reports one, five, and ten years after planting. Plants from Japan and the former Yugoslavia have been included in the trial. Numbers of replications range from 3-20 plants (17, 18).

In North Dakota, the woody plant evaluation project seeks to "enhance the inventory of superior, hardy woody plants for the Northern Plains." This project does not limit its efforts to evaluating native material, but also examines introduced and foreign woody plants for shelter and landscape uses (6). At the Dickinson, ND, site of this study, plantings are not randomized. Trees are planted in blocks consisting of a single row with a minimum of five plants of each taxon to facilitate ease of evaluation. Conifers are in a single block, with shrubs and small trees, medium sized trees, and tall trees located in their respective blocks. Trees are planted ten feet apart and rows are 20 feet apart. No fertilizers or herbicides are used, although repellent chemicals are used to discourage rodent damage to trunks and browsing damage by larger animals (10). Evaluators record planting date, survival, vigor, canopy width, height, cold hardiness, animal and insect damage, disease symptoms, and unusual and outstanding features of each plant. This project not only selects and evaluates woody plants, but also introduces them to the landscape industry. Its focus is less consumer-oriented, seeking to "disseminate research information to scientific, commercial, and public sectors."

Another North Dakota State University Agriculture Experiment Station project identifies monoculture planting as an issue in that state "where the inventory of adapted woody species is very limited." This project utilizes seven sites, four NDSU research centers, and three urban forestry program locations. The number of replications per plant at each site varies according to propagation technique for each plant, i.e., clonal vs. seed propagated. Data is collected annually and will include vigor, height, crown width, hardiness, pest susceptibility, soil adaptability, and landscape characteristics. In addition, weather and climatic data will be correlated with overall plant performance (11).

The University of Arkansas Statewide Plant Evaluation Program was established in 1999. The three sites are located in the following three USDA hardiness zones: 6b, 7a, and 8a. The stated policy of this program lists two criteria for including woody plants: 1) adaptability of broadleaf evergreens across USDA zones 6, 7, and 8; and 2) including underutilized evergreen or deciduous plants or plants with a specific landscape purpose. Herbaceous plants are also evaluated in this program (9).

In Canada, the Western Nursery Growers Group instituted a trial program using 5 replications of trees at 4 sites for a 5 year period (8). Replications were not randomized. This program contracts a program administrator to perform evaluations, while nursery staff plant and maintain the plant material. The primary focus of this trial is evaluating cold hardiness, but other characteristics such as height, width, caliper, vigour, flowering and pest resistance are also noted. Special challenges in this project include the remote and distant locations, USDA zones 2 and 3, and travel, since a round trip distance to visit all four sites is 3600 km. Evaluations are conducted in June of each year to assess general performance and winter injury. Cooperating sites treat the trial trees as part of their regular nursery stock production, using the same cultural practices, and delaying pruning until after each year’s June evaluation. This date allows assessment of prior year’s growth and dieback (3).

In this research, Colorado State University combines efforts with Plant Select® and various individuals and businesses in the local nursery industry to evaluate plants for the Colorado landscape. The intention is to diversify the palette of available plants for the burgeoning local population. It also supports the local nursery industry by identifying plants which can be grown for use both locally and outside the state. For inclusion in the Plant Select® promotion program, plants are evaluated based on the following criteria: 1) Performance in a broad range of garden situations in the Rocky Mountain region; 2) Adaptation 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 and number of current propagators; 11) Knowledge of basic propagation protocols; and 12) Images available for publication (13). This multi-site plant evaluation seeks to assist Plant Select ® in identifying woody plants to include in its promotion efforts.

Methods and Materials—Multi-site Woody Plant Evaluation

Plant Select ® is a cooperative program of local nursery professionals, plant brokers, Colorado State University and Denver Botanic Gardens. This program seeks to support the local green industry in their production and marketing efforts. Greenhouse operations, landscape firms, and retail garden centers participate. Members of this group established a woody plant subcommittee to plan an ongoing, regional, long term plant evaluation. The project described in this study used 5 test sites. Three sites were located at private sector nurseries along the Colorado Eastern Front Range. Operators of these nurseries volunteered their sites to participate in the project. Two sites were located on

Colorado State University Research Station property. One of the Research stations, the Western Colorado Research Center at Orchard Mesa, was located adjacent to Grand Junction in western Colorado. This site provided a location with different soils, water quality, and climatic conditions to test plants.

Brighton: Little Valley Wholesale Nursery hosted the Brighton test site. This site lies approximately 322 kilometers east of the Grand Junction test plot, and is located on the north side of the Denver metropolitan area at an elevation of 1514 m. Coordinates are 40.032, -104.837. Test plants were planted into a furrow by staff at the nursery, filled, and immediately watered to settle the soil. Plants were furrow irrigated with untreated ditch water. At this site, plants were planted six feet apart, with rows 12 feet apart. Irrigation occurred based on the availability of irrigation water, and a hand test of soil moisture by nursery staff. The 'feel and appearance method' is one technique used to monitor soil moisture conditions. While this method is not as precise as instrument-based measurements, an experienced evaluator can estimate soil moisture accurately within five per cent (4). Charts are available to help estimate soil moisture based on observing soil texture, ability to form a ribbon with the sample, firmness and surface roughness, loose soil particles, soil color, soil and water staining on fingers, water glistening on the soil sample's surface. Field managers and crews inspected plant material frequently, almost on a daily basis. The Brighton weather station, 3SE, was located at the nursery. Soil at this site consists of clay loam, with pH tested at 7.8 (Appendix figure 2.1)

Figure 2.1: 2005 Photo of trial at Little Valley Wholesale Nursery, Brighton

Calhan: Located approximately 40 km east of Colorado Springs, Harding's Nursery had the highest elevation of all the sites in this study, at 1981 m. Soils at this 24.3 ha nursery were composed of sandy clay loam soil, with a pH of 7.0 (Appendix Figure 2.1). The fields at this site were irrigated overhead with untreated water pumped from a well at the site. Plants for the trial were augured into the soil. Rows were 10 feet apart and plants were spaced 6 feet apart within rows. Irrigation was supplied based on staff inspections of plants, soil moisture, and weather reports. Coordinates for this site are 39.9402, -104.3893. There was no weather station on this site. For this study, weather data from the Colorado Springs airport weather station was used. Coordinates are 38° 49' N. latitude, -104° 43' W. longitude. The airport lies 48.3 kilometers southeast of the actual test plot location. The elevation at the weather station is 1856 meters.

Fort Collins: The Colorado State University Horticultural Research Center is located on the east edge of the City of Fort Collins, 55 miles north of the Denver metropolitan area. Coordinates are 40.6138, -104.9967. Elevation at this site is 1524 m. The clay soil at this location has a pH of 7.9. Plants were furrow-irrigated with water pumped from a well on the site. The field manager scheduled and performed irrigation. The weather station used was adjacent to the site on another University research facility, Agricultural Research, Development, and Education Center (ARDEC). Researchers and staff planted the trial selections in a furrow, then filled with native soil and watered immediately after planting. The soil at this site is clay (Appendix Figure 2.1).

Grand Junction: The Colorado State University Western Slope Research Station is located adjacent to Grand Junction on Orchard Mesa at 1475 m elevation. The weather station used at Grand Junction site, 6ESE, was on the property. Coordinates are 39.0453, -108.4680. Irrigation water comes from the Colorado River and was untreated. Plants in this study were planted into a furrow by local staff and researchers and flood-irrigated twice at planting. After settling the soil with water, Research Station staff installed a micro-spray irrigation system. Irrigation water came from the Colorado River. The amount of supplemental irrigation water equalled ET + 20%. Soils here are clay with a pH of 7.5 (Appendix Figure 2.1). Grand Junction typically experiences warmer temperatures throughout the year and a longer growing season than the other test sites (Appendix Figure 2.2). Plants were spaced 7 feet apart within rows and rows are 12 feet apart.

Hudson: Green Acres Nursery, now Box Elder Creek Nursery, is located approximately 25 km northeast of Denver, 6 km southeast of Hudson, Colorado, at an elevation of 1539 m. The coordinates are 40.0134, -104.6070**.** Soils at the Hudson site are clay, with a pH of 7.8 (Appendix Figure 2.1). Nursery staff planted the test plants into a furrow, then filled with existing soil, and watered immediately after planting. Irrigation water for this site came from wells located on the site and from irrigation ditches. No weather station is located on the site; weather data from Greeley, Colorado was used for this study. This weather station is located approximately 30 miles from the Hudson test site. Rows were spaced 3.3 m apart, with 2.1 m between each plant in the row. Trees were watered weekly for the first season and monitored during subsequent seasons. Trees in the ground for two or more years were watered monthly. Field managers conducted weekly inspections of plant material.

Three soil samples were collected at each nursery. A soil probe was forced into the soil to a depth of 15 cm. Samples were collected between trees at the end of replications 2, 5, and 7, and analyzed at the Colorado State University Soils Laboratory.

Plant material was planted as field conditions allowed, beginning in mid April, 2002, with the last planting at Grand Junction occurring in the last week of May, 2002. Following planting, each cooperating site used its own cultural management techniques to maintain the plant material. Researchers asked that no pruning be done to allow plants to show their natural form.

Trees were measured for height, caliper, canopy width, and annual growth increments of branches. Initial measurements were taken at planting. Subsequent measurements were taken during dormancy after the end of each growing season from 2002-2006. Caliper was measured 15 cm above the soil line. Canopies were measured from two directions, parallel with the planting row, perpendicular to the row. Branch growth increments were measured at each data collection from three randomly selected branches. Measurements were initially collected in U. S. standard units and later converted to metric units. In addition, observations were recorded regarding overall condition of plants, insect and pest issues, and aesthetics.

Woody plants used for this research were planted in the spring of 2002 and included *Cotoneaster ignavus* E. Wolf ‘Szechuan Fire’ (Szechuan Fire cotoneaster), *Cupressus arizonica* Greene ‘Cooke Peak’ (Cooke Peak Arizona cypress), *Fraxinus americana* L. ‘Jeffnor’ (Northern Gem ash), *Fraxinus x* ‘Northern Blaze’ (Northern Blaze ash) and *Tilia mongolica* Maxim. X *Tilia cordata* Mill ‘Harvest Gold’ (Harvest Gold linden).

Cotoneaster ignavus E. Wolf ‘Szechuan Fire’ (Szechuan Fire cotoneaster) is a deciduous shrub approximately 1.8 to 2.5 m in height, spreading between 1.5 and 2 m. It produces white flowers bloom in May and followed by dark red fruit. Leaves are pubescent, giving them a bluish hue. Nurserymen selected this plant from the former USDA Experimental Station, Cheyenne, Wyoming, where it had been tested for many years without irrigation or maintenance.

A conifer chosen for this trial was *Cupressus arizonica* Greene 'Cooke Peak' (Cooke Peak Arizona cypress). This tree is seed propagated. Seeds were collected from Cooke Peak, New Mexico. It has green to silvery blue foliage and exfoliating bark. Mature height is 15-22 m, with a width of 6-9 m. These trees were planted from # 5 (12.87 l) containers, and ranged between 2.3 and 4.5 m in height.

Fraxinus americana L. 'Jeffnor' (Northern Blaze ash) is a male clone selected at Jeffries Nursery, Manitoba, Canada. Mature height of 14-15 m, and spread of 9-10 m can be expected. The foliage is green, with a yellow fall color. The nursery rates hardiness as USDA Zone 3. This plant was selected because of its cold hardiness, interesting chocolate brown color of its new twig growth, dark green summer foliage, and yellow-orange fall foliage color.

Fraxinus x 'Northern Gem' is a hybrid of *F. mandshurica* Rupr. (Manchurian ash) x *F. nigra* Marsh. (Black ash). This tree was selected and introduced Jeffries Nurseries, Manitoba, Canada. It will reach a height of 12-15 m, and a spread of 9-10 m. This hybrid was selected for this trial because it is rated hardy to USDA Zone 3.

Jeffries Nurseries in Manitoba, Canada, also selected and introduced Harvest Gold® linden. It is an open pollinated hybrid of *Tilia cordata* Mill and *Tilia mongolica* Maxim. Harvest Gold® linden has a moderate growth rate with a mature height greater than 13 m. As a young tree, it is fairly upright, and becomes rounded with age. No serious disease or pest problems have been reported, but gypsy moth caterpillars and

Japanese beetles will sometimes feed on the foliage. The leaves are resistant to mites and fungal leaf spot.

Harvest Gold® linden has better cold hardiness and better fall color (usually yellow) than many of the other lindens currently available. Jeffries Nurseries reports flowers and seeds are produced in smaller amounts than most other lindens.

Researchers processed data to compare growth performance of plants in the study using a repeated measures analysis of variance. The GLIMMIX procedure in SAS/STAT 9.2 (SAS Institute, Cary, NC, USA) was used. Proc GLIMMIX incorporates statistical models with data that contains correlations or nonconstant variability and where the response is not necessarily normally distributed. The procedure used a generalized linear mixed model to fit fixed and random effects. For this study, the fixed effects 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. Year was the repeated measures effect. The numbers of surviving replications shown in sections discussing each taxon (Figures 2.3a, 2.4a, 2.5a, 2.6a and 2.7a) provided values used for n. Caliper and canopy width measurements were skewed. For analysis, these data were transformed logarithmically to normalize residuals and to make the residuals independent of the means. Pairwise differences between means were compared using a t-test with a level of significance $p<0.05$.

Results and Discussion

***Cotoneaster ignavus* 'Szechuan Fire'**

At all five sites, this plant showed an ability to Adapt to varying environments and cultural

Figure 2.2: 2005 photo of *Cotoneaster ignavus* 'Szechuan Fire' at Grand Junction

management regimes. All plants survived at three sites, while one plant died at Hudson, with two losses at Fort Collins (Fig 2.3a). During the study, the only insect infestation witnessed were pear slugs (*Caliroa cerasi*). No formal counts of populations or evaluations of damage were made.   No disease infections were observed at any of the sites. At all sites, the plants fruited heavily. Plants at all sites maintained healthy green leaf color, with no symptoms of mineral deficiency or heat stress. All plants in this study demonstrated an open, arching growth habit. At each site, growth increased steadily as the study progressed with both canopy and height increasing in a step-wise fashion (Fig 2.3 b, c).

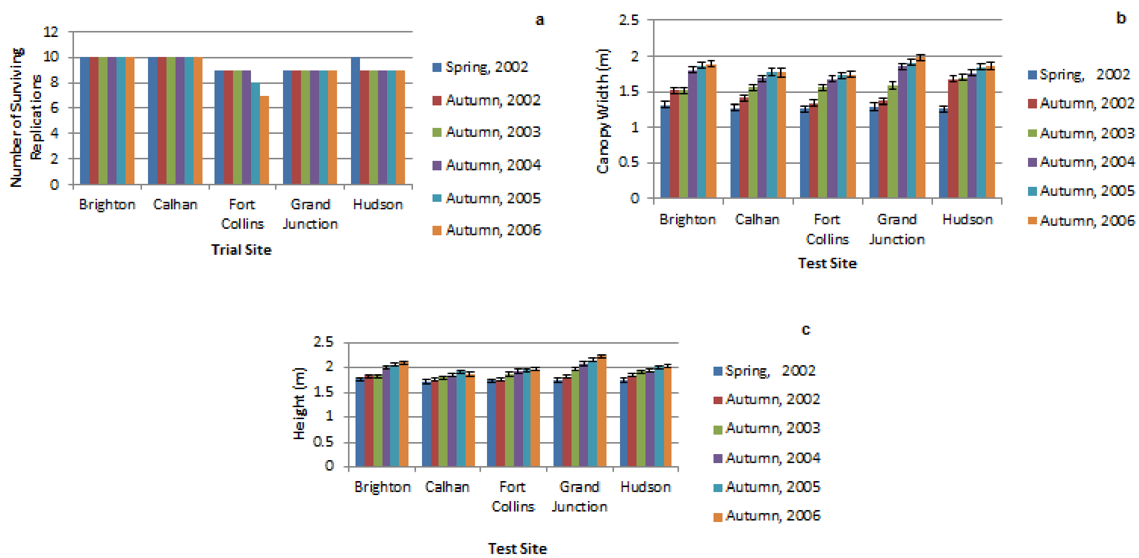

Figure 2.3 a-c: Survival, Canopy Width, and Height Data for *Cotoneaster ignavus* 'Szechuan Fire' 2002-2006 at 5 Trial Sites; 9 replications planted at Fort Collins and Grand Junction; numbers of survivors in graph a serve as n values; statistics tested using Fisher's LSD between means; if error bars at ±½ LSD do not overlap, it indicates the means are different since they exceed Fisher's LSD at $p<0.05$; Canopy Width and Height Data transformed to log 10.

At Brighton, both height and canopy width increased during 2002, the initial growing season. There was no change in 2003 in either height or canopy spread. Both mean height and canopy increased from 2003 size during 2004 but not in 2005 or 2006.

The same is true for mean canopy width. The change in canopy width between 2004 and 2006 was significant.

At Calhan, both mean canopy width and height increased between the Spring, 2002 planting and the Fall 2002 data collection (Fig 2.3 b-c). During 2003, height increased, but not canopy spread. In 2004, both height and canopy increased. For the remainder of the study, 2005 and 2006, height did not increase, while mean canopy width did not increase between consecutive years although the change between 2004 and 2006 was significant.

A similar pattern held true at the Fort Collins site. Growth proceeded in a step-wise fashion for both mean height and canopy measurements. Those specimens planted at this site started the study with significantly wider mean canopies than three of the other sites, but this difference disappeared by the end of the five year study period. The 2002 growing season resulted in significant increases in both height and canopy widths, as did growth in 2003. After this, growth for both height and canopy slowed, with no differences between consecutive years, but a significant increase between 2003 and the final data collection in the Fall of 2006. A possible explanation lies in the weather conditions for the 2003 season. While temperatures were generally consistent throughout the study period (App. Fig 2.5a), a review of precipitation data (App Fig 2.5b) shows a higher level of naturally-occurring moisture during the early months of 2003.

At Grand Junction, the *Cotoneaster ignavus* ‘Szechuan Fire’ began the study as significantly taller plants than those planted at other sites. They also showed greater mean width than all other sites except the Fort Collins location. Increases in canopy were noted at all data collections here, except for the final one during the Fall of 2006. For height, there was growth during 2002, the first season after planting, and during the 2005 season. The remaining data collections did not show changes in mean height.

Growth at the Hudson site progressed steadily for both height and canopy measurements. The most dramatic increase in mean canopy width occurred during 2002, with barely significant differences occurring during subsequent growing seasons. Meteorological data was not collected at the site, therefore there is a possibility that there was more precipitation on the site than that recorded at the Greeley weather station. In addition, cultural practices for this site include more frequent watering during the first growing season. This also may have contributed to larger growth increments. The change between the Fall, 2005 and Fall, 2006 height was not significant. For height, mean measurements showed differences during the first and second growing seasons (Fig 2.3c). Growth slowed during the middle portion of the study period, with an increase noted during the 2006 growing season. The growth during the last season may be attributed to warmer temperatures at this site during 2006 (Appendix Fig 2.7a). In addition higher levels of precipitation in late 2005 and early 2006 (App. Fig. 2.7b) may have contributed to greater than normal soil moisture at the beginning of the growing season.

Data collected at the beginning of this study showed differences in mean height and canopy measurements between sites. The plants at the Fort Collins and Grand Junction sites were taller than those at other sites, with wider canopies. Plants at Hudson and Brighton were smaller in both height and canopy. In spite of these differences the plants at Brighton and Hudson performed the best, and at the end of this study, these were among the tallest plants with the widest mean canopy in this study. The differences disappeared over time. The Grand Junction site's environment includes a longer growing season (Appendix Figure 2.2), lighter soil texture, a higher content of organic matter in the soil, and pH closer to neutral(Appendix Figure 2.1). While these conditions suggest greater opportunities for plant growth, the height data and canopy data was the same as in Brighton and Hudson . One possible explanation is that growth increments may have been longer at Grand Junction, and the heavier mass of individual stems weighed them down, showing an increase in canopy width in proportion to the heights of plants at this site.

***Cupressus arizonica* 'Cooke Peak'**   The survival data for *Cupressus arizonica* 'Cooke Peak' (Fig 2.4a) showed mixed results. Only the Grand Junction site showed one hundred per cent survival for the five year period of the study. Calhan experienced the highest rate of mortality(Fig. 2.5a) At all sites, mean heights and canopy widths were the same at the beginning of the study (Fig. 2.5 b, c) the study. (Fig 2.5 b,c). These results changed by the end of the trial period.

Figure 2.4 *Cupressus arizonica* 'Cooke Peak' at Grand Junction, 2005

At Brighton, all then trees survived through the 2004 growing season. One plant died by fall 2005, and two more in 2006. Canopy size increased between spring and fall 2002 (Fig 2.5b), and also during the 2004 growing season, with no significant change after that. Plant heights increased during the first season, followed by no change during 2003. There was also an increase in 2004. Height increases in each of the following years was not significant (Fig 2.5c).

At the Calhan site, only four plants survived to 2006 (Fig 2.5a). Canopy size increased during the years 2002, 2003, and 2004. There was no change in mean canopy in the 2005 and 2006 growing seasons; however, there was increased mortality in these years. The mean height increases were slight, with no difference in annual mean height data between consecutive years' data collections. The mean heights at the end of the study were not significantly different from the measurements taken at the beginning of the study period.

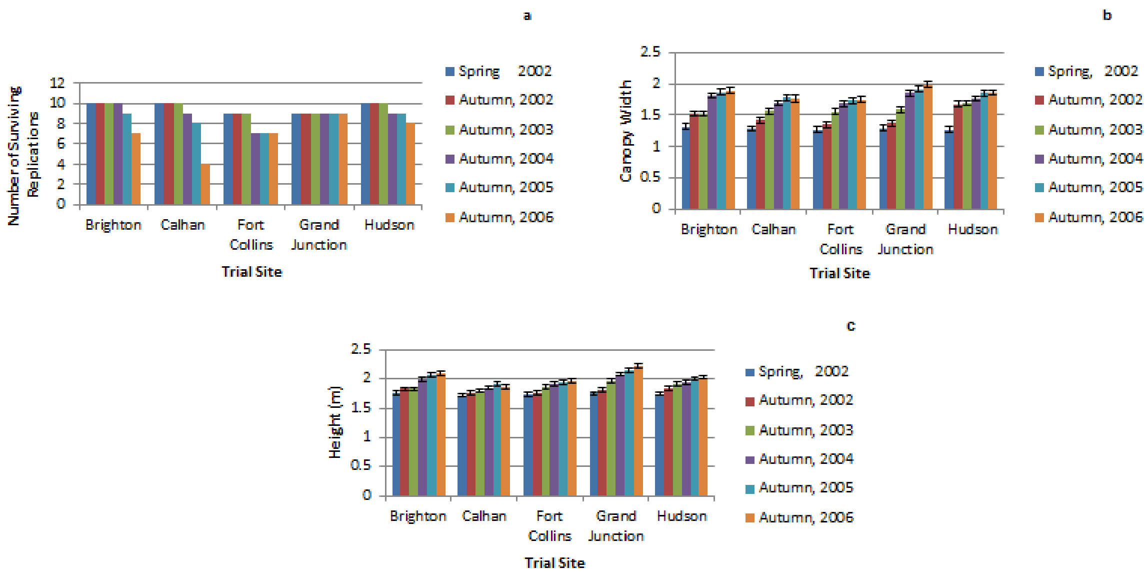

Figure 2.5 a-c: Survival, Canopy, and Height Data for *Cupressus arizonica* 'Cooke Peak' 2002-2006 at 5 Trial Sites; 9 replications planted at Fort Collins and Grand Junction; numbers of survivors in graph a serve as n values; statistics tested using Fisher's LSD between means; if error bars at ± 1/2 LSD do not overlap, it indicates the means are different since they exceed Fisher's LSD at $p<0.05$; Canopy Width and Height Data transformed to log 10.

Plants at the Fort Collins test site also suffered mortality. All nine trees there survived until the Fall 2003 while two replications died before the next data collection (Fig 2.5 a). There was no change in height or canopy during 2002 (Fig 2.5 b, c). In 2003, both height and canopy width increased. The Fall 2004 data collection showed an increase in mean canopy width, but not in height. After that, there were no changes in height or canopy until the end of the study.

At the Grand Junction test site, neither canopy nor height increased in 2002. In 2003, both measures increased over 2002 sizes and in 2004 only height was greater than in 2003. After Fall 2004, canopy size and plant height did not increase over 2004 size.

As in Calhan, all plants at the Hudson site survived until November, 2003 and one died by Fall of 2004. An additional tree died after the Fall 2005 site visit. Eight trees survived until the end of the study (Fig 2.5 a). After planting in Spring, 2002, both mean canopy width and mean height increased. Canopy width did not increase during the 2003 season. For 2004, there was no change in either mean width or height at Hudson when compared to the size of the plants at the end of the 2003 growing season. While slightly larger than 2003 plant size, the Fall, 2005 data collection showed no significant change in mean height and canopy. Annual growth did not result in larger mean canopy or height of plants between 2005 and 2006.

Interestingly, *Cupressus arizonica* 'Cooke Peak' showed some size differences that may be attributed to local climates. The higher mortality observed at some locations may be a result of winter low temperature damage. Other work conducted in conjunction with this study evaluated the cold tolerance of this plant. The winter of 2005-06 brought two episodes of extreme cold temperatures (Appendix Figure 2.3-2.7). Survival data (Figure 2.5 a) shows additional mortality during this period.

The trees at the Grand Junction site were taller than those at other sites. This difference began to show quickly. The Fall, 2003 data collection showed that the mean height at Grand Junction was greater than all other sites, with the differences being significant in comparison with all except Hudson. By Fall, 2004, the mean height at Grand Junction was greater than at any of the other four test sites and this difference continued throughout the study period. Canopy widths were also greater than at other sites, but this difference was not significant between Grand Junction and Brighton. A longer growing season, soil conditions, and cultural management are all factors that may contribute to these differences.

***Fraxinus americana* 'Jeffnor'**

Figure 2.6: 2004 photo of fall leaf color and twig color of *Fraxinus americana* 'Jeffnor' at Fort Collins

Fraxinus americana 'Jeffnor,' Northern Blaze American ash, performed well at all sites.

All trees survived at all sites throughout the five year test period (Fig 2.7a). Most of the trees were planted as unbranched whips. Some had slight lateral growth the time of planting. For most trees, there is no canopy width recorded for the initial data collection.

At Brighton, height did not change significantly between the Spring, 2002 planting date andthe end of the 2003 growing season. There were significant increases in height in 2004, 2005, and 2006 (Fig 2.7d). Trunk caliper measurements showed an increase during the season following planting, with no change the following season, 2003 (Fig 2.7b). As in height measurements, mean caliper increased significantly in 2004, 2005, and 2006 (Fig 2.7). The Fall, 2003 data shows that the trees had developed canopies by that time, even though unbranched at planting. As with height and trunk caliper, any change in mean canopy width was not significant during 2003. In both 2004 and 2005 there were significant increases in canopy width at this site, but not in 2006 (Fig 2.7c). A possible explanation for this is that this site experienced extremely low temperatures during the winter of 2005-2006 (App. Fig.2.7a). There may have been some slowing of growth due to damage from these temperatures.

Growth rates were slow at Calhan. All growth measurements were significantly lower at this site, particularly during the final three years of the study period. For mean height, there was no significant change between consecutive years (Fig 2.7d). Trunk caliper measurements showed increases in mean caliper during all growing seasons

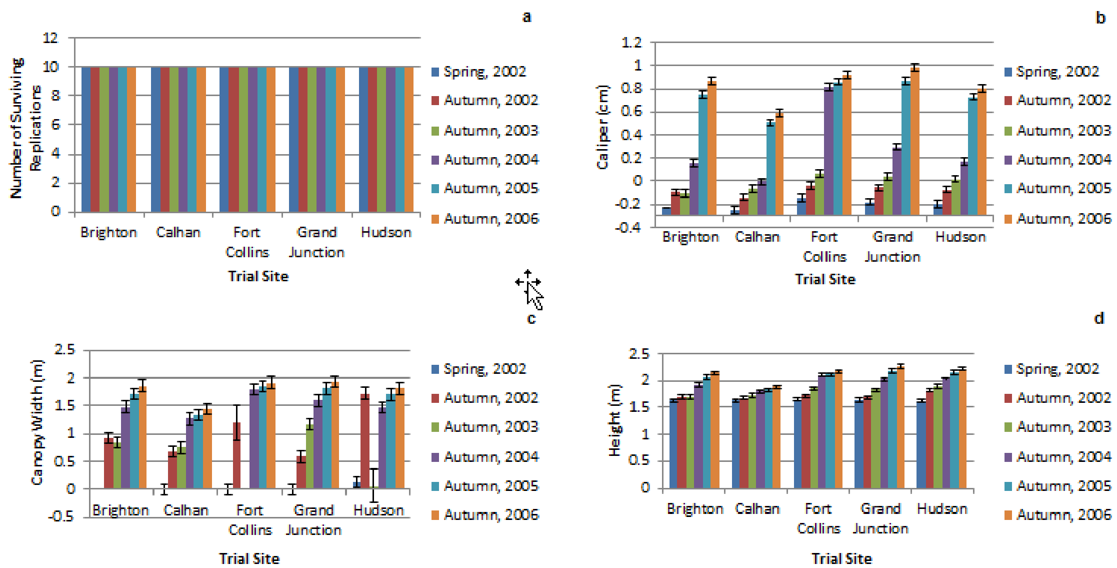

Figure 2.7 a-d: Survival (a), Caliper (b), Canopy Width (c), and Height Data for *Fraxinus americana* 'Jeffnor' 2002-2006 at 5 trial sites; numbers of survivors in graph a serve as n values; statistics tested using Fisher's LSD between means; if error bars at ± 1/2 LSD do not overlap, it indicates the means are different since they exceed Fisher's LSD at $p<0.05$; Caliper, Canopy Width, and Height data transformed to log 10.

except 2004 (Fig 2.7b). Moderate summer temperatures and higher spring and summer precipitation may explain this increase (App. Figs 2.7 b, c). Mean canopy widths also changed slowly, with a significant increase in mean width found only in the Fall, 2004 data collection (Fig 2.7c). As with caliper, weather conditions for that season may have contributed to this increase. A comparison of results at the end of the study period shows that these trees were significantly smaller at this site in all measurements than at the other four test sites. Observations of weed management practices may have played a large role in this slow rate of growth.

Growth of *Fraxinus americana* 'Jeffnor'at the Fort Collins site progressed steadily throughout the course of the trial. As at the other sites, survival was 100% (Fig 2.7a). While mean height did not increase in 2002, the year of planting, it increased significantly in both 2003 and 2004, and then slowed during 2005 and 2006 (Fig 2.7d). Mean trunk caliper also increased in 2002, 2003, and 2004 (Fig 2.7b). Like the height, caliper growth slowed in 2005 and 2006. There were increases in mean canopy width in 2002 and 2003, but changes were insignificant in the final three years (Fig 2.7c). At this site, infestations of lilac-ash borer (*Podosesia syringae syringae* (Harris)) were more severe than at other sites. This infestation and irrigation practices may have played a role in differences between growing seasons. The trees seemed to tolerate this pest, since data indicates that caliper, canopy, and height were acceptable compared to those recorded at other sites (Fig 2.7b-d).

These trees performed well in Grand Junction. They were planted in late May, 2002. While height did not show a significant increase in 2002, increases were significant for the remainder of the four years (Fig 2.7d). Caliper measurements showed size increases yearly at each data collection (Fig 2.7b). Mean canopy width also increased between data collections, except for the final growing season of this research, 2006 (Fig 2.7c).

At the Hudson location, mean growth measures increased steadily throughout the course of the study. While height increased during the initial growing season, there was no change in 2003. In both 2004 and 2005, increases were significant, but the height did not increase significantly in 2006. This reflects similar performance at the other sites, at which growth, while not always significantly different, continued steadily throughout the study (Fig 2.7d). At each yearly data collection, there were increases in caliper except for 2006 (Fig 2.7b). The same held true for mean canopy width. While changes were significant, in 2003, maintenance crews pruned the lateral growth on the trees, almost to the trunk. Statistical analysis shows this decrease in mean canopy width due to heavy pruning in the Fall, 2003 (Fig. 2.7b).

At all sites, *F. americana* 'Jeffnor' showed steady growth in all measurements. A comparison of height shows that at the end of the study, the mean height of the trees was greatest at Grand Junction. The difference was significant in comparison to trees at all other sites except Calhan. At the beginning of the study, there was no difference between mean height among the five sites. As time progressed, differences for each measurement were apparent at all sites (Fig 2.7 b-d). While height increased at a gradual and step-wise pace, changes in caliper were often more dramatic. *F. americana* 'Jeffnor' showed attractive ornamental features, with chocolate brown stem color on new growth, and deep green summer leaf color. Fall color was yellow-orange.   At the Fort Collins test site, trees were infested with lilac-ash borer (*Podosesia syringae syringae* (Harris)). While damage was visible, there was little dieback, and trees were vigorous enough to withstand the stress. Ornamental features noted included dark green leaves with a rusty orange to yellow fall color. Branches and twigs were wider in diameter, and retained a chocolate color for the first two years of growth.

F. americana 'Jeffnor' was also tested from 1997-2003 in the fields at J. F. Schmidt Nursery. In its first year, it produced a whip reaching over 2 m. in height.

Upper branches tended to be long and leggy, while lower branches were weak. This habit gave the canopy an unbalanced appearance. Older trees became tall and upright. This nursery felt the fall color, yellowish-brown, was poor. Because of the fall coloration and poor branch structure, nursery personnel decided not to produce this cultivar (15).

Fraxinus x 'Northern Gem'

Three of the five test sites showed one hundred per cent survival of ten replications of *Fraxinus* x 'Northern Gem.' At Calhan, there was one loss in 2002, and one in 2004. In 2005, one died at Fort Collins (Fig 2.9a).

Figure 2.8: 2005, leaves of *Fraxinus* x 'Northern Gem' (l) and *Fraxinus americana* 'Jeffnor' (r), Brighton.

Trees at Brighton did not show changes in height in 2002 or 2003. In 2004, and 2005, mean height increased significantly. There was no significant difference in height between 2005 and 2006 (Fig 2.9d). Mean trunk caliper measurements did not increase until the 2004 growing season, but then increased dramatically in both 2004 and 2005. Height growth then slowed in 2006 (Fig 2.9d).

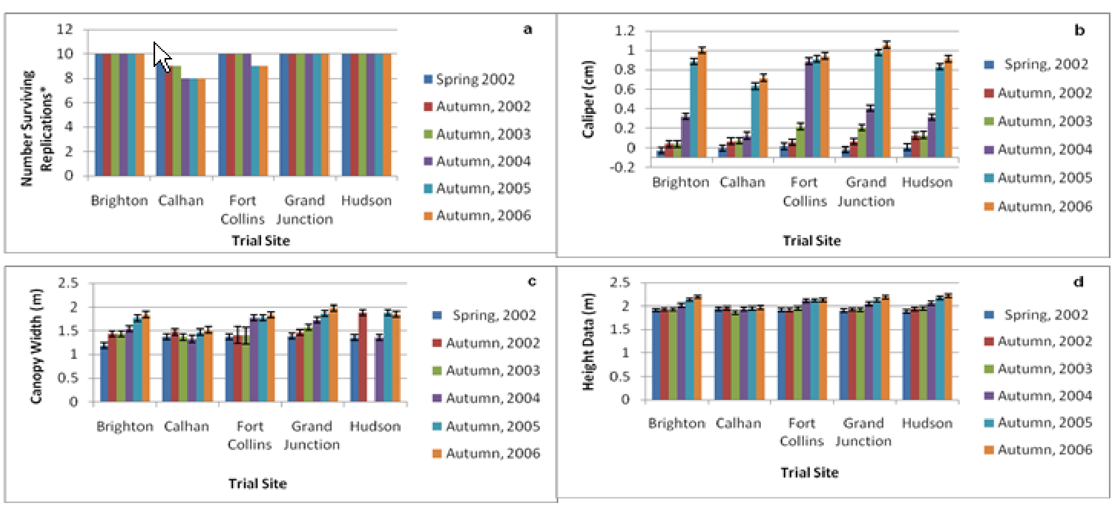

Figure 2.9 a-d: Survival, Caliper, Canopy Width, and Height Data for *Fraxinus* x 'Northern Gem' 2002-2006 at 5 Trial Sites; numbers of survivors in graph a serve as n values; statistics tested using Fisher's LSD between means; if error bars at ½ LSD do not overlap, it indicates the means are different since they exceed Fisher's LSD at $p<0.05$; Caliper, Canopy Width, and Height data transformed to log10.

Canopy width increased during the first season, but after the Fall of 2002 data collection, there was no change until 2005. There was no significant change between 2005 and 2006 for mean canopy width.

At Calhan, Fraxinus x 'Northern Gem' showed a survival rate of 80% over the course of this five year study (Fig 2.9a). There was no change in height for *Fraxinus* x 'Northern Gem' during the course of the trial (Fig 2.9d). There were fluctuations in mean height, but no significant changes. Mean caliper remained the same from the date of planting until the end of 2003. While caliper expanded in 2004, which showed an increase over data collected at planting, there was no difference between 2003 and 2004 mean calipers. There was a dramatic increase in 2005, and a smaller increase in 2006 (Fig 2.9b). Results from the analysis of mean canopy width reflect a similar trend to height changes. There was no difference in mean canopy width between the date of planting and the final data collection (Fig 2.9c). At the end of the trial, caliper, canopy width, and height were significantly lower at this location (Fig 2.9b-d). Possible explanations include cultural practices and severe weather conditions, including frigid temperatures (App Fig 2.9b) and hail events.

Results at the Fort Collins site show a consistent trend among all three measurements. There was no change in height in these trees between the planting date in the Spring of 2002 and the end of the 2003 growing season. In 2004, there was a growth spurt, but after that time, the mean height of trees at this site did not change. Mean trunk caliper and mean canopy width showed similar results, with increases in 2004. After 2004, there was no increase in size in caliper or canopy width. This tree also experienced infestations of Lilac-ash borer (*Podosesia syringae syringae* (Harris)). *Fraxinus* x

‘Northern Gem’ seemed more attractive to the pest than *Fraxinus americana* ‘Jeffnor.’ Damage was more extensive, yet this tree also appeared to tolerate the injury.

Trees at Grand Junction showed a steady increase in height, with one large change in 2005. One possible explanation is that the there was more precipitation in the spring of 2004 than in some other years (Appendix Figure 2.6b). While there was no change between 2002 and 2003, beginning in 2004, height progressively increased. While there is no difference between 2004 and 2005, and between 2005 height and 2006, the 2006 mean height is greater than 2004. Mean trunk caliper showed a more step-wise progression, with increases in each growing season. There were large increases in 2004 and 2005. Mean canopy width also showed increases throughout the study, although only significant in 2004 and 2005. As with height, the occurrence of precipitation during the winter and early portions of the growing season in these two years may have contributed to these significant changes.

At Hudson, mean height increased at a rate similar to Grand Junction. There was no change until 2004. 2005 showed another increase, while the change between 2005 and 2006 was not significant (Fig 2.9d). Mean caliper increased during the 2002 growing season, and again in 2004, 2005, and 2006, with a large increase in 2005 (Fig 2.9c). Canopy width showed a large increase during the initial season of planting. As with *F. americana* ‘Northern Blaze,’ and *Tilia mongolica* ‘Harvest Gold’, workers at this site reduced the canopies of these trees prior to the Fall of 2003 data collection (Fig 2.9d). Growth resumed the following season, and by the end of 2006, mean canopy width was second only to Grand Junction.

Fraxinus x 'Northern Gem' proved to be a vigorous tree. At all sites, after the second growing season, there were large increments of caliper growth. Heavy pruning of the canopy did not seem to slow this tree's growth over a long term. In this trial, this tree attracted lilac-ash borer (*Podosesia syringae syringae* (Harris)), particularly at the Fort Collins location. Borers favored this cultivar over the American species in the trial, even when planted beside each other. While there was more dieback due to borer damage, trees still remained vigorous. The fall color was yellow.

In 1999-2006, J. F. Schmidt Nursery placed conducted a field evaluation of *Fraxinus* x Northern Gem. This nursery chose not to produce this tree in its fields due to slow growth as a 1 year old tree, low branching and dull fall color. In this trial, the tree grew into a rounded and compact tree, but its slow growth as a 1 year old tree resulted in low branching on mature specimens (15).

***Tilia mongolica* x *Tilia cordata* 'Harvest Gold'** *Tilia mongolica* x *Tilia cordata* 'Harvest Gold', 'Harvest Gold' Mongolian linden demonstrated high rates of survival at four of five sites (Fig 2.11a).At the Brighton site, there was a single loss of a tree following planting. Weatherdata (Appendix Figure 2.3a) showed severe low temperatures during the winter of 2005-2006 . No significant hail events were reported during the first growing season and mean heights did not change at this location (Fig 2.11 d). However, both mean trunk caliper and canopy width showed increases during this period (Fig 2.11 b,c).

Figure 2.10: *Tilia mongolica* x *Tilia cordata* 'Harvest Gold' (2006, Grand Junction)

During 2003, height and trunk caliper remained the same, but canopy width showed a decrease in size. Since most of these specimens were initially planted as unbranched whips, some new shoots on these plants during the first season may have died during the winter of 2002-2003. This may be the result of a combination of cold temperatures and low precipitation. Brighton temperature data (App Fig 2.3a) shows that for January, 2003, temperatures were warmer than the preceding two months, and that February, 2003, was colder. In addition, precipitation for January was lower than other years (App Fig 2.3b). This combination of unusual weather factors occurring during the establishment period of the trees may have resulted in damage to the buds on the lateral branches. Possibly, with few branches to measure at this stage of the plants' life, shorter lateral branches may have been randomly chosen in Fall, 2003 than in previous data collections. An additional tree died between the fall 2003 and 2004 data collections. From 2004 through 2006, all measurements showed annual increases. In 2004, all three measurements showed significant increases. Mean caliper increased in 2005, while canopy and height were not significantly different. In the last growing season, growth slowed, and measurements showed no significant differences in mean growth rates at the Brighton site (Fig. 2.11 a-c).

At the Calhan location, measurements of growth and survival for this taxon lagged behind the other four sites (Fig 2.11 a-d). The numbers of surviving replications steadily declined each year after planting. At the conclusion of the study, only one replication remained alive. Over the course of the trial, the mean height did not change until the final year. During 2002, there were no changes in height or caliper, but mean

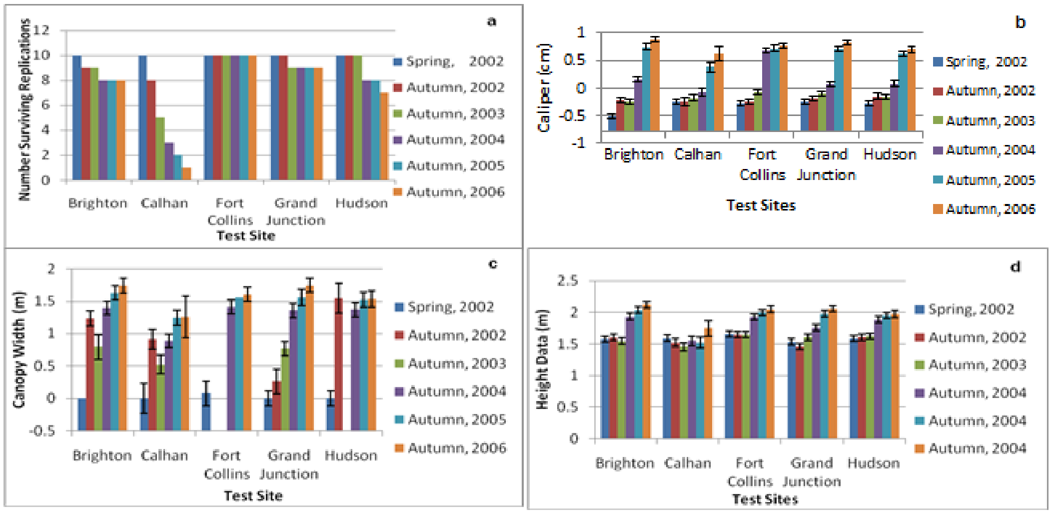

Figure 2.11 a-d: Survival, Caliper, Canopy Width, and Height Data for *Tilia mongolica* x *Tilia cordata* 'Harvest Gold' 2002-2006 at 5 Trial Sites; numbers of survivors in graph a serve as n values; statistics tested using Fisher's LSD between means; if error bars at ± 1/2 LSD do not overlap, it indicates the means are different since they exceed Fisher's LSD at $p<0.05$; Caliper and Canopy Data transformed to log 10.

canopy width (Fig. 2.11c) increased. There were also no changes in height or caliper in 2003, while canopy width decreased. Weather data showed that the length of the frost free growing season was shorter this year (2003) than in other years of the study (App Fig 2.7). In contrast, 2004 had the longest frost-free period for this site during the study. The plants showed no increase in height or caliper in 2004, but canopy width increased. A storm with large hail was recorded at this site in 2004. In 2005, both caliper and canopy increased in size, while height showed no change. In the final year of data collection, 2006, the single remaining tree at this site showed an increase in height and caliper, but not in canopy width. Overall, performance in all measures for this plant at this site lagged behind performance at the other locations. Rodent damage and weed control techniques could have contributed to poor results at the Calhan test site.

In Fort Collins, all ten replications of *Tilia mongolica* x *Tilia cordata* 'Harvest Gold' survived the five years of the study (Fig 2.11a). It was the only site where all ten replications survived the five years of the study. In 2002, only canopy increased between planting and the fall data collection. Both mean caliper and mean canopy width increased in 2003, while mean height did not change significantly. In 2004, height and caliper changed significantly, while canopy did not. Caliper also increased in both 2005 and 2006, while height and canopy width did not.

At the Grand Junction trial site, weather data showed the longest frost-free season in each of the years of the study of all test sites (App Fig 2.2). Over the course of the trial, only one ‘Harvest Gold’ linden died. This occurred between the Fall of 2002 and the Fall of 2003 data collections. During the initial season, none of the growth parameters of interest showed change (Fig 2.11b-d). In 2003 and 2004, height, caliper, and canopy width showed significant growth increases each season. The 2005 data collection showed large growth increments both in height and caliper, while canopy width showed no change. Trunk caliper was the only measurement to show change in 2006.

At Hudson, in 2002, *Tilia mongolica* x *Tilia cordata* ‘Harvest Gold’ height did not change at the end of the first growing season, but both caliper and canopy widths increased. In 2003, there were no changes, except that researchers were unable to collect canopy width because crews had severely pruned the trees. In 2004, both height and caliper increased, while canopy width did not show a significant change over the measurement taken before pruning. Caliper was the only measurement showing change in 2005, while none of the growth measurements changed significantly in 2006.

Three of the five test sites showed similarities in growth rates for ‘Harvest Gold’ Mongolian linden. At Brighton, Fort Collins, and Hudson, mean height measurements remained insignificant until the end of the third growing season. Then, they showed significant increases. At Grand Junction, there was a consistent increase in heights over the five year study period. However, the longer growing season did not result in a significant difference in final height, caliper or canopy width for this tree when compared to Brighton and Fort Collins test sites. Mean caliper measurements were similar between Grand Junction and Hudson, but the data showed a difference. With canopy width and height, no significant difference resulted. Perhaps the severe pruning during the second growing season at the Hudson site caused the tree to devote resources to replacing leaf area through height and canopy growth, slowing caliper increases. The data collected at the Calhan site showed a significantly lower mean final height, while caliper and canopy width cannot be considered different than the other sites. The small sample size at the end of the study makes this result inconclusive.

Comments recorded at all sites at data collection indicated that this tree was pest-free during the trial and maintained good leaf color and texture at four of the five sites. Flowers were fragrant, but seemed less abundant than other *Tilia* species and cultivars. Less leaf scorch was observed on this tree at several sites following extreme summer heat. In the absence of pruning, it maintained a good growth habit. The plant's description cites exfoliating bark and golden-yellow buds for winter interest. These appeared minimal during the plant's early growth stage, with the bark flaking rather than exfoliating. The buds, while bright, did not appear brilliant. No signs of winter damage such as trunk cracking or significant branch dieback were observed at any of the test sites.

In testing at J. F. Schmidt Nursery, this hybrid produced excellent growth as a 1 year tree, reaching almost 2 m in height. Specimens were very well branched at two and three years of age, with strong caliper and excellent pyramidal structure. Nursery staff felt that *T. mongolica* x *T. cordata* 'Harvest Gold' grew significantly faster than *T. cordata* 'Greenspire.' Summer foliage in this trial was was glossy dark green, and this tree provided bright and clean golden yellow color. Because of these features, J. F. Schmidt Nursery began producing this tree (15).

Conclusions:

Results of this study show that *Cotoneaster ignavus* 'Szechuan Fire' is a plant that can adapt to various climates and soil conditions throughout Colorado. It produces white flowers in late spring, followed by abundant purple fruit. The plant has matte green to blue-green leaves in the summer with yellow fall color. Under cultivation, it has an open growth habit, making it less suitable as a hedge or screen planting. While being adaptable and relatively pest-free, its ornamental characteristics do not justify its inclusion in the Plant Select® program.

Cupressus arizonica 'Cooke Peak' has generated interest in the Colorado nursery and landscape sectors. Throughout Colorado it has performed satisfactorily at most sites and under varying environmental and cultural conditions; however more research needs to be done to develop clones and cultivars that are reliably cold hardy for the Eastern Front Range of Colorado. The mature size for the species (height 15-22 m; width 6-9 m) would overwhelm most modern Colorado residential landscapes. New cultivars also need to possess a smaller mature size. In addition, research on harvesting and transplanting protocols needs to be completed before this tree can be recommended for widespread use in Colorado.

Fraxinus americana 'Jeffnor' proved to be a vigorous tree with many interesting ornamental features, including young shoot color, dark green summer foliage, and yellow-orange fall color. It was less susceptible to lilac-ash borer (*Podosesia syringae syringae* (Harris)), a common pest of *Fraxinus* spp. in Colorado. With the threat of Emerald ash borer approaching from the Eastern United States, this tree should not be grown extensively and efforts should be directed to encouraging taxonomic diversity and pest resistant species and cultivars.

Even without the threat of Emerald ash borer mentioned above, observations and results from this trial lead to a conclusion to not recommend *Fraxinus* x 'Northern Gem' for use in Colorado landscapes. While this trial resulted in vigorous tree growth even while infested with lilac-ash borer, its lack of outstanding ornamental features discourages a recommendation for widespread use in Colorado.

Tilia mongolica x *Tilia cordata* 'Harvest Gold' is a strong candidate for recommendation for planting in Colorado. At one of the more difficult sites, Fort Collins, all trees survived. Even though height and canopy width increased slowly during the first two years, the cultivar grew well in the last 4 years. Resistance to leaf scorch due to heat and its good growth habit in the absence of pruning support more widespread planting in Colorado.

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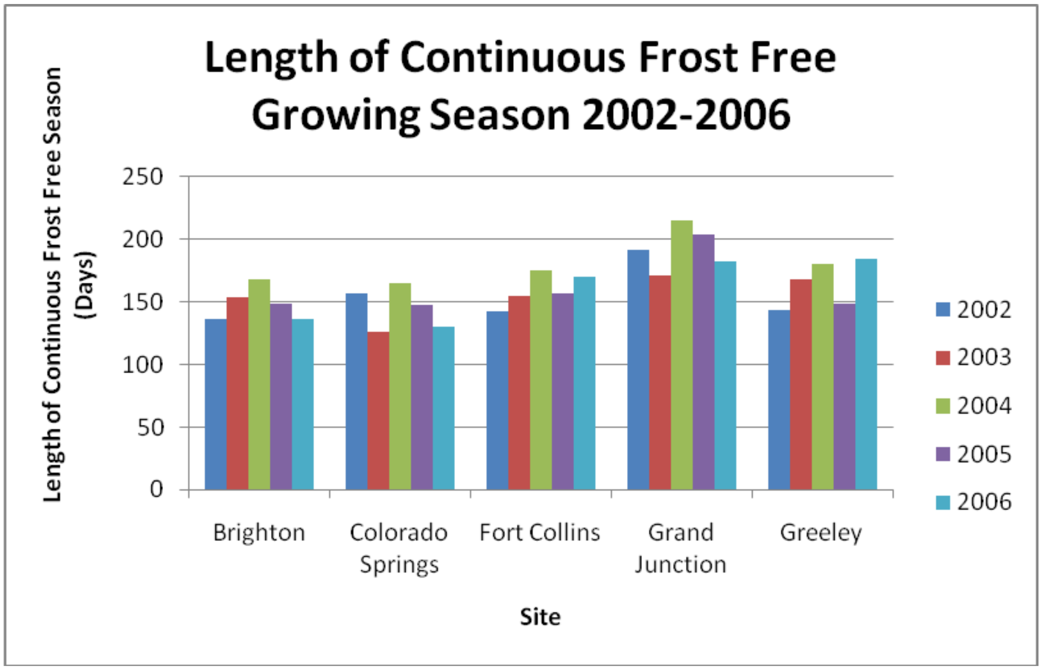
APPENDICES FOR PART 2

APPENDIX I



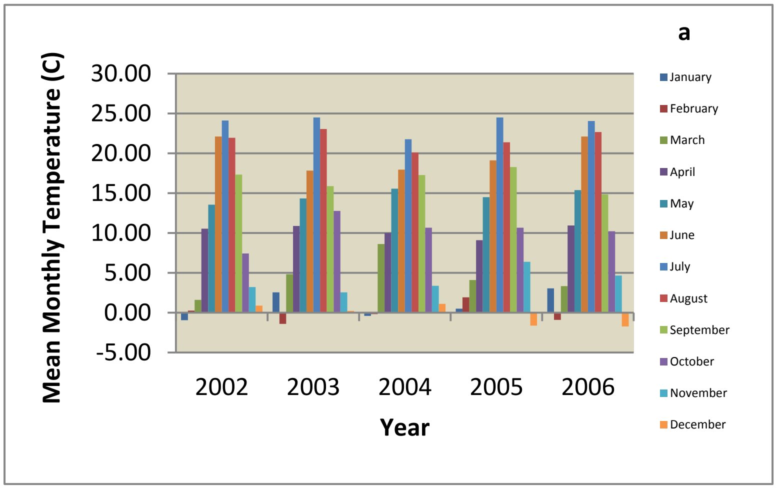
Appendix Figure 2.1: Length of Continuous Frost Free Growing Season at 5 Trial Sites 2002-2006.

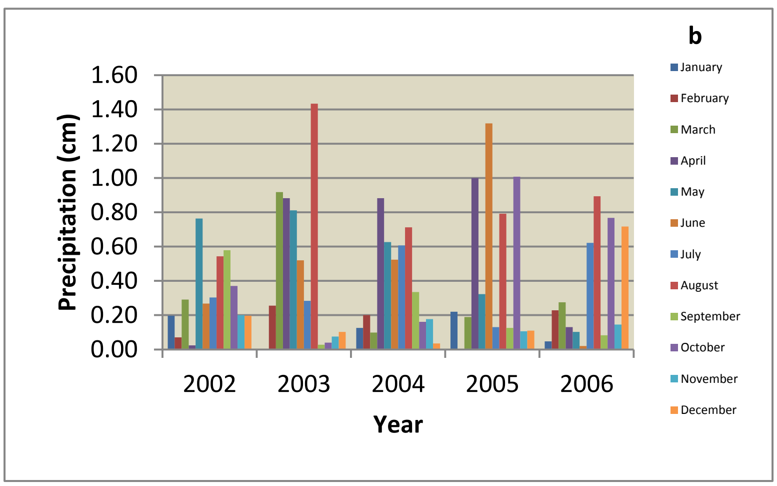
APPENDIX II

Trial Site	pH	EC (mmhos/cm)	Lime Estimate	Organic Matter (%)	NO3-N (ppm)	P (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Texture Estimate
Brighton	7.8	1.0	Medium	2.7	7.4	16.5	332	1.6	7.8	2.0	1.8	Clay loam
Calhan	7.0	0.3	Low	1.1	2.8	11.2	241	0.7	8.0	4.2	3.9	Sandy Clay loam
Fort Collins	7.9	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	4.0	10.8	8.1	166	1.9	5.0	1.0	2.9	Clay
Hudson	7.8	0.5	Medium	1.6	20.9	4.3	215	0.4	5.2	94.0	2.7	Clay

Appendix 2.2 Soil Test Results for 5 Trial Sites

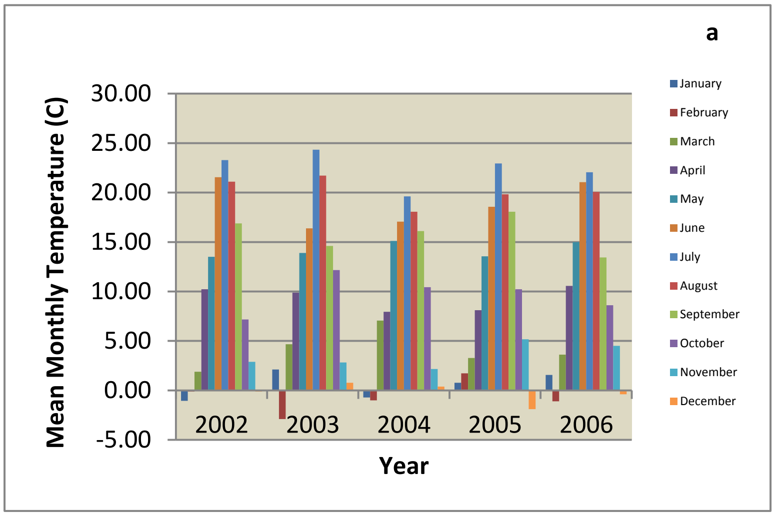
APPENDIX III

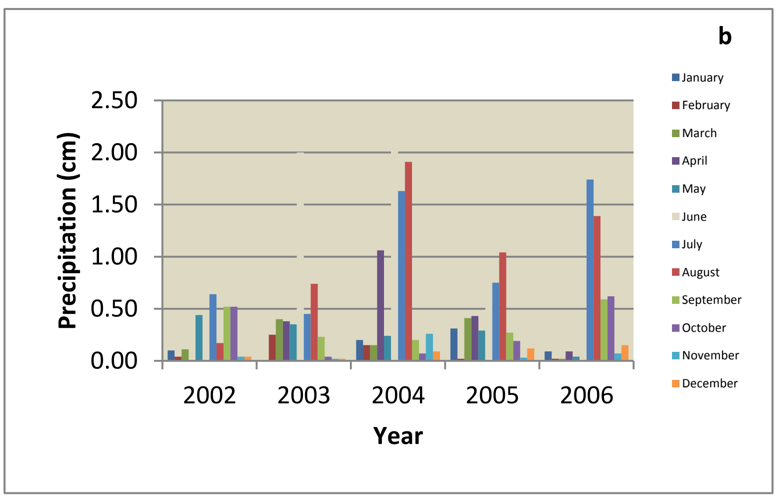




Appendix Figure 2.3 a-b: Monthly Mean Temperature(a) and Precipitation (b) Data for Test Site at Brighton Test Site 2002-2006

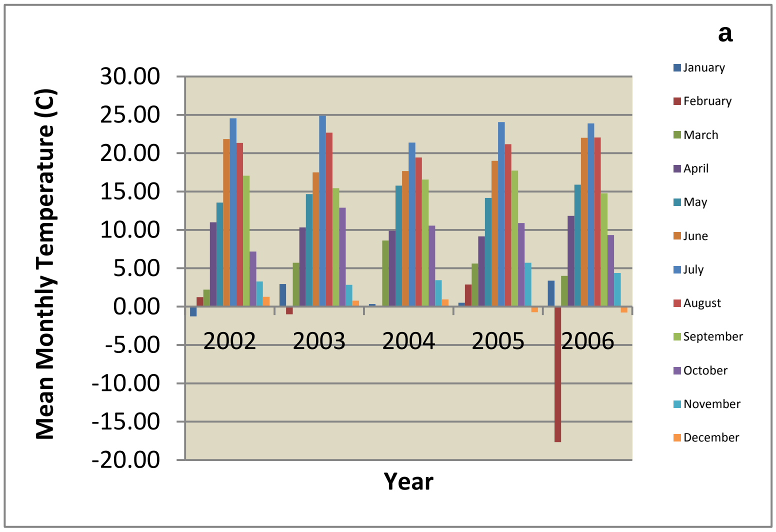
APPENDIX IV

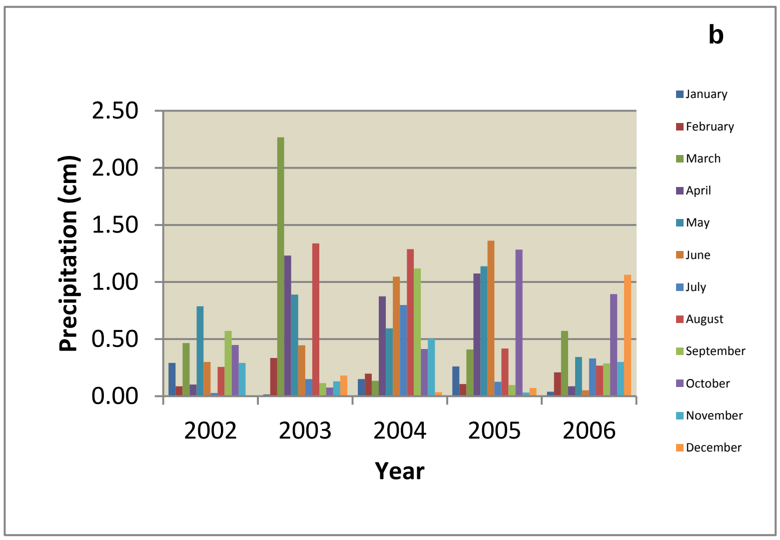




Appendix Figure 2.4 a-b: Monthly Mean Temperature (a) and Precipitation (b) Data for Colorado Springs for Calhan Test Site 2002-2006.

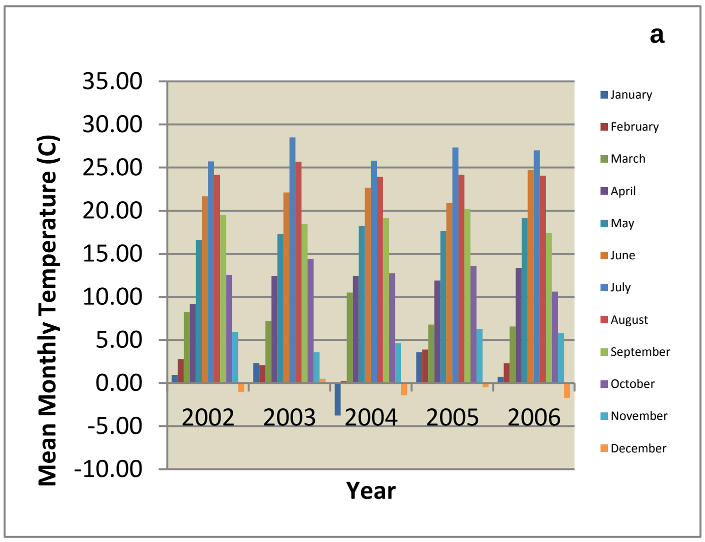
APPENDIX V

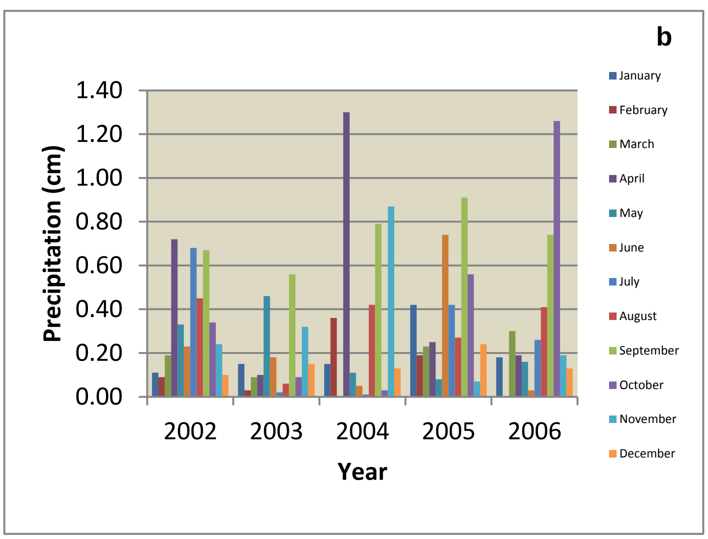




Appendix Figure 2.5: Monthly Mean Temperature (a) and Precipitation (b) Data for Fort Collins Test Site 2002-2006.

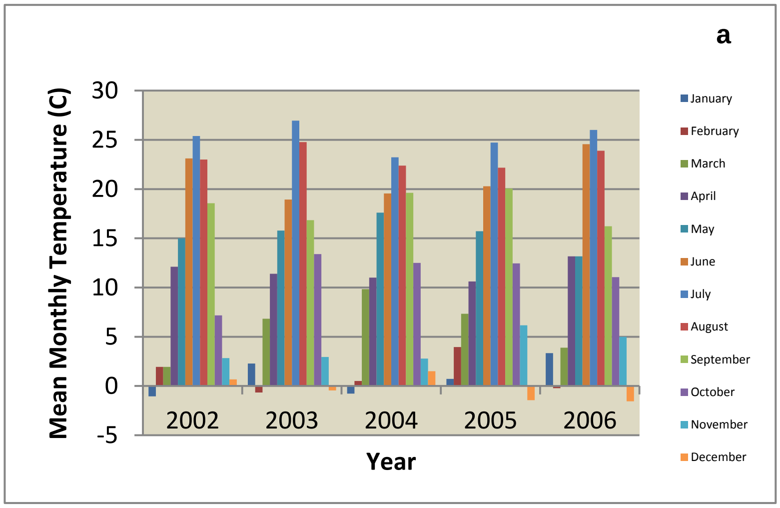
APPENDIX VI

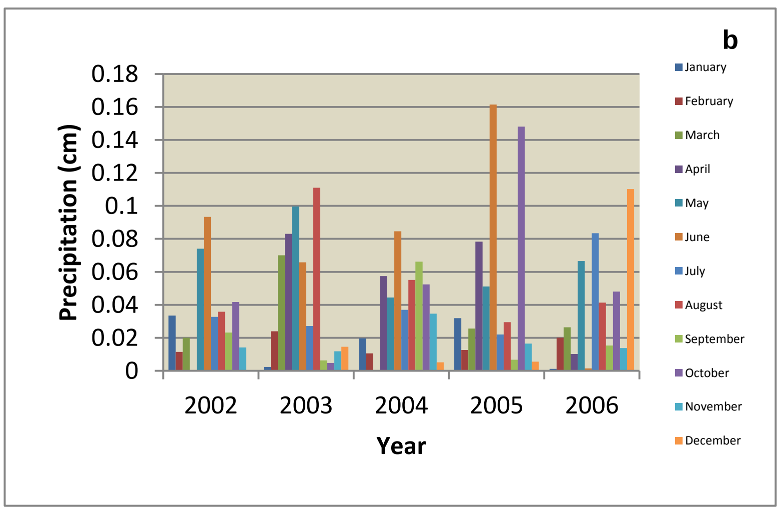




Appendix Figure 2.6: Monthly Mean Temperature (a) and Precipitation (b) Data for Grand Junction Test Site 2002-2006.

APPENDIX VII





Appendix Figure 2.7: Monthly Mean Temperature (a) and Precipitation (b) Data for Hudson Test Site 2002-2006 taken at Greeley weather station