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Adaptability of Tree Species as Windbreaks for Urban Farms in the U.S. Intermountain West

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Abstract: Windbreaks or shelterbelts are a management tool to protect crops from damaging horizontal wind flow, and may provide a useful buffer between farmland and urbanized areas by reducing pesticide drift, dust, and noise associated with farming activities. Plant selection for windbreaks in the Intermountain West can be difficult as high elevation coupled with extreme temperatures, high pH soils, and limited access to water are common. This study assessed eight tree species for suitability as a windbreak in the Intermountain West, with a particular focus on initial establishment and use at the urban–agriculture interface. Species were assessed for mortality, size, canopy density, insect and disease issues, and initial cost. Measurements of shadow characteristics were used as a novel approach to compare canopy density and porosity. Standard poplar (*Populus x canadensis*) and 'Theves' columnar poplar (*Populus nigra* 'Afghanica') were the most effective at rapid establishment, but species with more moderate growth rates, such as aspen, juniper, and hackberry, may provide lower long-term maintenance costs for the environmental conditions found in the Intermountain West.

Keywords: windbreak; tree selection; water wise trees; intermountain west; canopy density; ceptometry; alkaline soil tolerance

1. Introduction

Windbreaks or shelterbelts are a management tool commonly employed in crop production. A primary purpose of a windbreak is to protect the crop from damage, by reducing horizontal wind speed through interrupted air flow. In addition to protecting the crop from direct wind damage, the wind break may provide a favorable microenvironment, can reduce wind erosion, and improve retention of snow and soil moisture [1,2]. Other benefits include protecting livestock, providing wildlife habitat and enhancing the agricultural landscape [3]. The crop protection benefits of windbreaks can be variable and may differ among crop species, year, and weather [1]. Detrimental effects can result from root competition between the windbreak and the crop, reduced space for the crop, and crop shading when the windbreak is excessively tall [4].

Windbreaks can be established using perennial or annual species, including trees, shrubs and grasses, or could be constructed with wooden fencing or other materials. The ability of a windbreak to provide protection is related to characteristics such as height, width, shape, and internal structure [3]. The internal characteristics affect porosity, which is a function of canopy density [5] and affects air movement and cold air drainage. Effective windbreaks typically have an average porosity of

35%–40% [6]. The porosity of deciduous windbreaks changes with crop growth stage from dormancy to the completion of shoot elongation. Deciduous trees are able to reduce pesticide drift by 70% early in the season and up to 90% when the canopy is fully developed [7].

In the case of perennial crops such as orchards and vineyards, seasonal changes in porosity from a deciduous windbreak could have potential benefits. In high elevation valleys, radiative freeze conditions can cause pooling of cold air that damages developing flower buds/blossoms. A porous windbreak in the early spring allows for cold air drainage that reduces the risk of radiative freeze damage. However, less porous winter windbreaks can result in better winter survival of twigs and buds, in addition to the protection of developing fruit in the summer [8,9]. In the case of cane berry crops such as raspberry and blackberry, desiccating winter winds are a major cause of floricane shoot and bud mortality [10]. Where these conditions are prevalent and spring air drainage is less critical, evergreen shrubs and trees could be beneficial [7].

Economic considerations of using windbreaks include initial establishment costs and the cost of long-term maintenance. Factors that affect establishment costs include ease of propagation and rapid growth rates. Long-term maintenance costs would be affected by the ability of the species to survive in harsh environmental conditions. Maintenance costs also include the need for pruning, including cutting and disposing of unwanted growth [11]. Species requiring more frequent pruning labor would be much less efficient. In arid regions, drought tolerance and irrigation needs should also be considered. Studies have shown that windbreaks are able to prolong water availability, by capturing drifting snow and slowing snow melt to provide localized water availability [12].

Fruit- and vegetable-producing regions in the Intermountain West are experiencing rapid population growth resulting in urban encroachment [13]. One possible benefit of windbreaks would be to improve relations between farms and residential neighbors by reducing pesticide drift, capturing dust, and reducing noise associated with farming activities, and providing privacy. However, the windbreak characteristics desired for small acreage operations at the urban interface may differ dramatically from characteristics suited to rural agronomic situations. For the urban interface, an optimum windbreak would be one that maximizes wind, dust and noise reduction while minimizing the occupied space as well as the shading of crop-growing areas. Growing conditions in the Intermountain West can be challenging, with relatively cold winters, hot dry summers and alkaline soils.

The objective of this research was to initially screen potential windbreak species that would be adapted to a high-elevation arid environment and form a suitable buffer between residential areas and urban/suburban agricultural fields. Here we report on initial survival, establishment and canopy characteristics at the end of the establishment phase.

2. Materials and Methods

An experimental planting of windbreak species was established in 2013 at the Utah State University Agriculture Experiment Station's Kaysville Research Farm in Kaysville, Utah (41°01′16° N latitude, 1328 m elevation, 165 freeze-free days, 55.8 cm annual precipitation). Eight species were selected for the trial: a seedless hybrid poplar with a standard growth habit (*Populus x canadensis*), 'Theves' columnar poplar (*Poplus nigra* 'Afghanica'), 'Taylor' juniper (*Juniperus virginiana* 'Taylor'), columnar Swedish Aspen (*Populus tremula* 'Erecta'), Skinny Genes® Oak (*Quercus robur* x *alba* 'Skinny Genes'), 'Prairie Sentinel' Hackberry (*Celtis occidentalis* 'JFS-KSU1'), 'Frans Fontaine' Hornbeam (*Carpinus betulus* 'Frans Fontaine'), and Leyland Cypress (Cupressus x leylandii) [14]. Most of these were selected for a narrow growth habit and are deciduous to provide seasonal changes in porosity. However, one evergreen and one wide-growth habit species were also included for comparison.

With the exception of the standard poplar, all trees were obtained from a commercial nursery in 26 L pots. Standard poplar trees were propagated from softwood cuttings taken from a windbreak planting in Eastern Idaho that was established in approximately 1982. Cuttings were rooted in 3.8 L pots at the Utah State University Research Greenhouse in Logan, UT, USA.

Plants were established in three replicate plots, arranged in a randomized block design with blocking by location. Tree spacing was varied by species based on predicted final tree size, and tree numbers per plot were varied to target plot length of 12.2 m. For several species with limited tree number, the final plot length was 9.8 m (Table 1). Plots were established along a farm border, and oriented in an NE to SW row orientation.

Table 1. Plot size (plant number and plot length) of windbreak species included in a trial at the Utah State University (USU) Kaysville Research Farm in Kaysville, UT, USA. Plant spacing was varied to accommodate the expected size of the species at maturity. Plant number was varied to reach a target plot length. Each species was included in three replicate plots arranged in a randomized block design.

	Plants/Plot	Plot Length (m)	Plant Spacing (m)
Standard poplar	4	12.2	3.0
Columnar poplar	8	12.2	1.5
Juniper	8	9.8	1.2
Aspen	8	9.8	1.2
Oak	8	12.2	1.5
Hackberry	8	12.2	1.5
Hornbeam	8	12.2	1.5
Cypress	6	12.8	2.1

Soil at the site was a Kidman fine sandy loam with 0% to 1% slopes, and a native pH of 7.5. Irrigation water was applied through a drip system (Rain Bird Xeri-bug emitter) with a rate of 7.6 L per hour per emitter with a single emitter placed at each tree. After initial establishment, trees were watered for 8 h per day over three consecutive days at one-month intervals, with a total of 182 L per month per tree. No fertilizers were applied during the course of the study. Pruning was limited to removal of dead or diseased branches, and was conducted annually prior to spring budbreak. Tree height and spread were also measured during dormancy after the annual growing season.

On 25 June 2019, canopy density was determined by measuring light interception using a trailer-mounted ceptometer. The ceptometer consists of light sensor bars (SQ-311, Apogee Instruments, Logan, UT, USA) mounted on a boom, and linked to a data logger (CR-1000, Campbell Scientific, Logan, UT, USA), that is also equipped with a GPS receiver. The data sampling rate and ceptometer ground speed were calibrated to provide measurements at 15 cm intervals, and the individual light sensors are spaced at 10 cm along the bars resulting in a light sampling grid of 10 × 15 cm. These light measurements were interpolated to 0.25 × 0.25 m cells and compared to a reference light meter placed in full sun to determine percent light interception by the windbreak. Light interception measurements of each plot were made at 10:00 and 10:30 a.m. The measured area was determined by shade angle and shade casting length corresponding to the bottom 3 m of tree canopy [15]. For example, at 10:00 a.m., a 275° bearing with 3.22 m measured area width was used to define the area shaded by the windbreak. For 10:30 a.m., the bearing was 281° and the measured area width was 2.65 m. This ceptometry approach has been used to characterize two-dimensional canopies associated with high-density fruit orchards [16]. The resulting determination of canopy density has also been shown to be related to spray droplet drift through a planar canopy [17].

In the statistical analysis of tree height, width and space fill, measurements were log transformed before analysis. Transformed data showed unequal variance among treatments, with juniper showing less variance than the other species. Data were analyzed using generalized linear mixed-model with replication as random factor, and species as fixed factor, and residuals modeled with non-constant variances for juniper and non-juniper species. Pairwise comparisons of the estimates were made as needed and were adjusted for multiplicity using Tukey–Kramer's method. All analyses were performed using PROC GLIMMIX of SAS/STAT (version 15.1, SAS Institute Inc., Cary, NC, USA). Significance level is specified at 0.05 level.

3. Results

Results from the analyzed data were broken down into specific criteria that contribute to windbreak effectiveness. Factors included mortality, height, width, canopy density, insect, and disease issues and relative cost. Trees that showed success in multiple aspects were considered successful for windbreak selections.

3.1. Mortality

Leyland Cypress had 100% mortality in the first winter (Table 2). Hornbeam had significant winter kill in the first winter, with 100% mortality by the end of the second winter (data not shown). Leyland Cypress plots were replanted after the first winter, and winter killed again the second winter. The oak and aspen plots had some mortality over the five years, with an average of 96% and 79% survival, respectively. Both of these showed annual winter dieback and damage from deer rubbing and browsing, which may have contributed to the eventual tree mortality. Deer damage was not as readily apparent on the other species in the study. The area is subjected to occasional high winds. Some wind damage was noted in the larger weak-wooded species such as the standard and columnar poplar, but none of this resulted in tree loss.

Table 2. Survival and cost of trees. Survival of windbreak trees is shown for one (2014) and five (2018) years after planting. Cost (USD) of a single tree grown in a standard 18.9 L (#5) container, shown per tree and per linear foot. Pricing obtained from local and internet nurseries. Trees such as Standard poplar and Columnar poplar have high survival rates and are relatively inexpensive.

	Survival (%)		**Tree Purchase Cost**	
	2014	**2018**	**US$/Tree (19 L Pot)**	**US$/Meter (Cur. Density)**
Standard poplar	100%	100%	$28	$9
Columnar poplar	100%	100%	$35	$22
Juniper	100%	100%	$60	$49
Aspen	88%	79%	$60	$49
Oak	100%	96%	$100	$66
Hackberry	100%	100%	$130	$85
Hornbeam	71%	0%	$75	$49
Cypress	0%	0%	$100	$47

3.2. Height

Windbreak height influences efficacy of crop protection as well as dust and chemical drift inhibition. The area protected from wind is typically 10 to 15 times the windbreak height [18]. The optimum height for dust, pesticide and noise buffering is less clear. For small acreage situations, excessively tall windbreaks may result in undesirable shading of the crop. Average tree height after five years varied among species, with the tallest trees being columnar and standard poplar at 5.71 and 5.68 m tall, respectively (Figure 1). The fast growth rate of the two poplar types was expected. Juniper, aspen, and hackberry grew at a moderate rate and produced trees that averaged 2.96, 2.92, and 2.76 m in height, respectively. Oak grew to an average height of 1.21 m. Oak species in general tend to be slow growing, and it was expected that these would not result in a tall windbreak within the short establishment period reported here. However, oak growth was also limited by repeated deer and winter injury as described above.

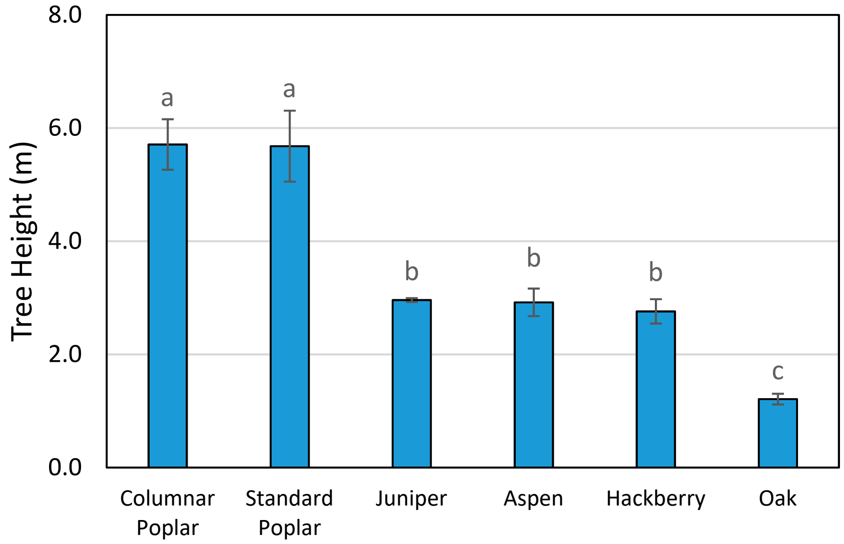

Figure 1. Average height of species compared for windbreaks. Vertical bars indicate standard error, and letters indicate difference at $p < 0.05$. Columnar poplar and standard poplar showed the greatest height gain from 2014 to 2018, with average heights of 5.71 and 5.68 m, respectively. Oak had the least height gain, with an average height of 1.21 m.

3.3. Width

Standard poplar growth habit resulted in the widest trees at 1.95 m (Figure 2), followed by columnar poplar at 0.91 m. Oak and hackberry produced the narrowest tree canopies of 0.46 and 0.43 m wide, respectively. The initial in-plot tree spacings were selected based on projected final tree size which was obtained by consulting with local arborists and recommendations in nursery catalogues. Figure 2 also shows space fill (%) or the width of the canopy as a function of tree spacing. Space fill was highest in standard poplar (64.0%), followed by columnar poplar (59.5%), juniper (49.3%) and aspen (46.4%). The lowest space fill was found with oak (29.8%) and hackberry (28.2%). The relatively low level of space fill was partly the result of less than optimal growth and repeated injury (oak and aspen), but also due to incorrect assumptions of final tree size when determining initial plant spacing (Table 1).

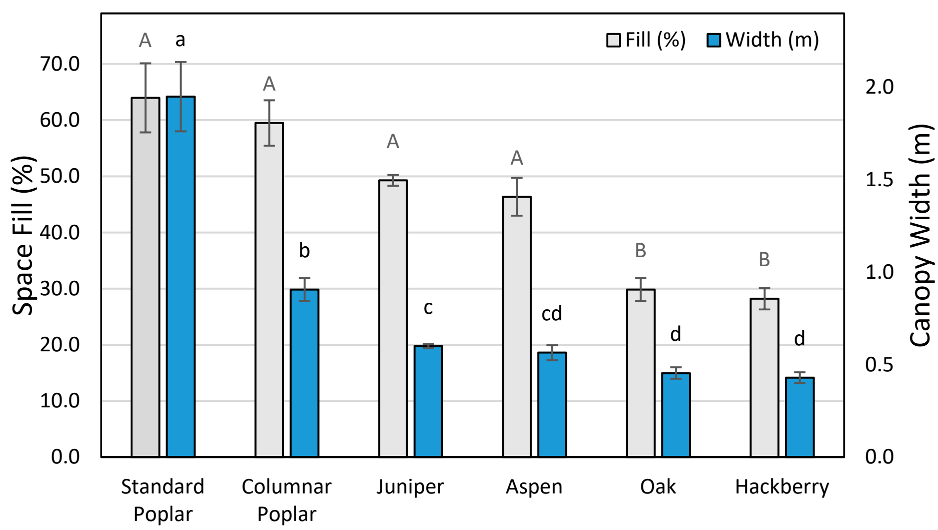

Figure 2. The average width and space of candidate windbreak species. Space fill (%) is shown on the left, and average tree width is shown on the right. Standard poplar showed the greatest ability to produce horizontal growth and the greatest percentage of space filled. Hackberry and oak both showed the least amount of horizontal growth and ability to fill the allotted space.

3.4. Canopy Density

The overall canopy density across the plot was highest for the columnar poplar, followed by the standard poplar (Table 3, Figure 3). Juniper trees have the highest internal canopy density, but the overall plot density was lower, as the trees had only filled 49% of their allotted space. By comparison, the standard poplar had a more porous canopy, with 64% of the space filled, but 52% of light intercepted in the first 3 m of canopy.

Table 3. Canopy density of windbreaks as determined by light interception. Values are the percent of light intercepted by the canopy, with measured area based on sun angle (shadow length).

	Light Interception (%)	
Columnar poplar	52.0	a
Standard poplar	41.9	b
Aspen	27.1	c
Juniper	24.3	cd
Hackberry	21.1	d
Oak	10.7	e

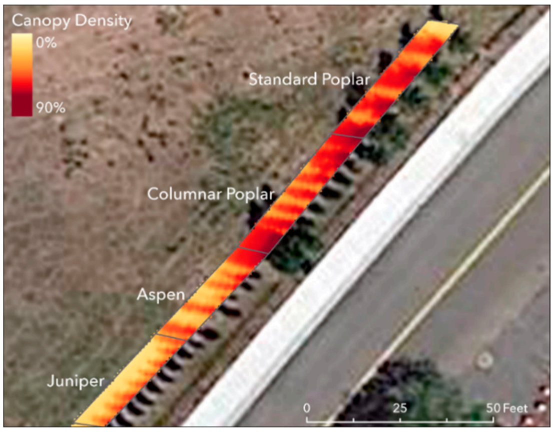

Figure 3. Density in the bottom 3 m of the canopy as measured by light interception. Spatial variability in light interception is shown superimposed on a satellite image (Google Earth) of part of the study area. The satellite image was not taken at the same day or time as the light interception measurements.

3.5. Insect and Disease Issues

Although insect and disease observation was not a main focus of this research, observation of the occurrence of pest damage should be mentioned as it contributes to mortality. The most pronounced insect damage was on standard poplar and hackberry. Standard poplar is known for being prone to insect damage. Extensive borer damage was noted on the trunks in the spring of 2019, however, the borer was not identified. In spring of 2019, the Poplar Petiole Aphid (*Pemphigus* spp.) was observed in all standard poplar in the study. This insect forms a gall on the leaf petiole where insects can be hatched and reared. Damage from the insect did not appear to affect the health of the trees. Hackberry trees in the study showed damage from the Hackberry Gall Psyllid (*Pachypsylla celtidismamma*). This insect is quite small and resembles a miniature cicada. Developing nymphs feed on Hackberry leaves, causing distinct galls to form. High levels of infestation can cause early leaf drop.

Iron chlorosis is a common problem for many trees and shrubs in the Intermountain West due to the high pH and clay content of the soils. Iron chlorosis was noted in a few hackberry trees, but the condition was not apparent across all the trees of that species. It should be noted that hackberry is typically well adapted to the harsh soil and climate conditions of the Intermountain West. The noted iron chlorosis was likely due to poor health of individual trees, as it was not consistent across all the hackberry trees. Iron chlorosis was not apparent in any of the other species.

3.6. Purchase Cost

Tree purchase cost is a factor that limits tree selection for windbreaks, but is perhaps a less limiting factor for the residential interface situation than for large scale agronomic crops. Trees that are highly cultivated with high propagation costs may be prohibitively expensive. Current pricing was obtained through local nurseries in the Intermountain West and internet nursery sources to compare cost among trees grown in a standard 18.9 L container, commonly referred to as a #5 container. Trees in smaller pot sizes, such as 3.8 (#1) or 7.6 L (#2), would be more cost-effective for planting a windbreak, however, limited availability in smaller size classes made price comparisons difficult. Trees with the lowest pricing per tree included standard poplar ($28) and columnar poplar ($35; Table 2). When price was compared per linear meter, standard poplar was the least expensive ($9/m), followed by columnar poplar ($22/m). Hackberry was the most expensive ($85/m; Table 2). Trees purchased in bulk from local nurseries or online sources may receive a discount and tree prices may decrease with higher numbers of trees purchased, or with custom orders of smaller-sized trees. Values are given to compare relative cost only.

4. Discussion

Windbreaks have historically been used to protect soil and sensitive crops in windy areas, and may also be useful at the agricultural–residential interface to reduce noise, minimize dust and chemical drift, and improve privacy for both the grower and neighbor. With increasing residential development adjacent to agricultural lands, it is becoming more critical that regionally adapted species be found with appropriate characteristics. Our objectives were to screen species for regional adaptation as windbreaks in the rural–urban interface. These characteristics would include: survival under low-input conditions, rapid establishment, appropriate canopy size and density, low establishment and maintenance costs, and adaptability to regional climate and soil conditions. Drought tolerance, water use efficiency, and alkaline soil tolerance are important adaptation characteristics specific to America's Intermountain West. The specific paper focus is on initial survival and establishment characteristics.

Canopy density and porosity are important measures of windbreak efficiency, and effective density can be difficult to determine. Canopy density is the ratio of the solid portion of the windbreak to the total area [18], whereas porosity is the inverse and represents the portion of the canopy that is open [18]. Previously, it has been suggested that an effective windbreak would typically have an average porosity of 35%–40% [6]. Hagen and Skidmore used an equation to calculate barrier drag to find the most effective porosity of a slat-fence windbreak [6]. Unlike a slat fence, plants lack uniformity, as the size, shape, and arrangement of leaves and branches will vary.

The previous literature on windbreak effectiveness used optical density to evaluate canopy properties [19]. However, optical approaches are difficult to use in orchard settings where identifying porous portions of a planar canopy is confounded by background foliage in neighboring rows or plantings. Here, we used a novel approach of ceptometry to estimate canopy density. Ceptomety measures the properties of the canopy shadow, and is typically used to estimate leaf area index and overall light capture by the crop [15] (Figure 3). By using ceptometry at the appropriate sun angle, canopy density can be determined without the challenge of optically separating the windbreak canopy from background foliage. One of the long-term objectives of this project is to evaluate the efficacy of windbreaks for the capture of spray drift. The relationship between spray drift capture and either optical or ceptometry density measures is not well defined. However, we have made some preliminary comparisons between ceptometry measures of canopy density and spray drift capture in a planar orchard system [17]. As these windbreaks mature, we plan to directly measure spray drift capture.

Fast-growing trees and those that have regenerative properties are often selected as they provide the most cost-effective means of rapidly establishing a windbreak. However, fast-growing trees can also become too large and may produce brittle wood, both of which would contribute to higher long-term maintenance costs. In this study, the two poplar selections had the fastest growth rates and good survival and were the lowest cost trees. However, these species have shown some wind damage and are approaching a height where shading of adjacent crops will need to be considered, and therefore may soon become more expensive to maintain.

Juniper, aspen, and hackberry showed intermediate growth rates, reaching 3 m height within the first five seasons. To date, these have shown little or no wind damage, but initial plant costs are higher. Further, the selected initial planting density was inadequate, and so the overall space fill and canopy porosity were lower. These trees are more difficult to propagate than poplar and therefore would represent higher per-plant costs, which would be exacerbated by the need for higher pant density. Whether or not these higher initial costs would be offset by lower long-term maintenance costs will need to be determined through long-term observations. The benefits of evergreen vs. deciduous windbreaks would need to be considered for the intended crops, with deciduous windbreaks allowing for better cold air drainage during spring frost events, but the evergreen species potentially providing a much more dense windbreak. Although the slow growth rate of columnar oak was expected, the repeated deer injury, winter dieback, and high initial cost also contribute to this species being unsuitable as a windbreak in the region. Cypress and hornbeam both proved to be insufficiently cold-hardy.

Considering all factors, none of the species selected for this trial were particularly suitable at the plant spacing used here, as they have yet to provide a full windbreak. Of the species selected for the trial, the standard and columnar poplar were the most effective species for rapid windbreaks establishment, but those with more moderate growth rates may be more cost-effective due to lower long-term maintenance costs. We plan to continue to observe the growth, survival and maintenance costs of these plots, and also measure dust and spray drift capture as the windbreaks mature. The results will provide urban farmers with ideas and guidelines for establishing effective buffers between their farms and residential neighbors.

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