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Structural Pruning in Callery Pear Does Not Change Apparent Branch Union Strength in Seventh Year Static Load Field Testing

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Abstract. Callery pear (*Pyrus calleryana*) is a tree notorious for poor branch union and breakage during storms. Structural pruning is a pruning technique that can be practiced on young trees to strengthen tree branch attachment. Callery pear (*Pyrus calleryana* 'Redspire') was structurally pruned and allowed to grow for 7 years and compared to an unpruned control. A breaking device was used to determine branch strength by providing a static load to simulate a snow or ice load. Branches from pruned and unpruned trees were pulled to failure to observe any difference from pruning. Regardless of the structural pruning treatment, trees that were unpruned were larger in diameter at breast height (DBH) and width at the end of the test. No differences were found in testing branch union strength for either pruned or unpruned trees, suggesting that more time is needed to determine the long-term benefits of structural pruning. Branch tissue moisture content was greater than trunk tissue both in immediate post-harvest testing and in samples over time. Also, branch moisture content observations suggested the time available for field testing branch union strength could be as much as 5 to 9 days after harvest.

Keywords. Branch Union; Callery Pear; Structural Pruning.

INTRODUCTION

Pyrus calleryana Decne. 'Bradford' ('Bradford' Callery pear) is a shade tree that has a showy early spring display of white flowers and is tolerant of many urban environmental conditions (Gilman et al. 2018). However, Callery pear has vertical limbs, embedded bark, and long branches which lack taper, making the tree susceptible to damage during inclement weather (Gilman et al. 2018). Strong wind, snow, or ice can cause a 'Bradford' pear tree to break apart. This generally occurs 15 to 20 years after planting (Culley and Hardiman 2007). This damage generally disfigures the tree, which causes the tree to lose its full, original shape.

In addition to 'Bradford' pear, several cultivars of Callery pear have been developed with improved branching structure (Dirr 1998). For example, *Pyrus calleryana* Decne. 'Redspire' has been rated as resistant to breakage (Gilman and Watson 1994). However, Kuser et al. (2001) reported that 2 of 7 'Redspire' Callery pear trees planted over 20 years showed breakage of stems at V-shaped branch unions. As with 'Bradford' pear, this characteristic can cause 'Redspire' pear to split apart during wind events. To avoid this condition, it is recommended that 'Redspire' pear receive pruning to develop strong structure (Gilman and Watson 1994).

Codominant branches are forked branches nearly the same size in diameter arising from a common junction and lacking a normal branch union (ISA International Dictionary 2019). Codominant branches are weaker than lateral branches in branch union strength (MacDaniels 1923, 1932; Miller 1959; Gilman 2003; Smiley 2003). However, Slater and Ennos (2015) found a range in the strength of bark-included bifurcations in young hazel trees associated with the level of occlusion of bark into the bifurcation. Bifurcation is natural division of a branch or stem into 2 or more stems or parts (ISA International Dictionary 2019).

Several investigators have suggested that branch attachment angle is an indicator of branch attachment strength. However, research has shown that this is not the case (MacDaniels 1932; Miller 1959; Lilly and Sydnor 1995; Gilman 2003; Dahle et al. 2006; Kane et al. 2008). The best predictor of branch attachment strength is aspect ratio (Gilman 2003; Kane 2007; Kane et al. 2008). Aspect ratio is defined as the size of a branch or stem relative to its parent, measured just beyond the union (American National Standards Institute 2017). Strong branch attachment occurs when the diameter of the tree trunk or parent branch is larger than the diameter of the smaller branch (Farrell 2003; Gilman 2003; Harris et al. 2004). More specifically, the branches should be less than 2/3 the size of the trunk from which the branch union arises (Farrell 2003). However, trees with included bark are weaker in branch union strength (Smiley 2003). Included bark is bark that becomes embedded in a union between branch and trunk or between codominant stems that causes weak union strength (ISA International Dictionary 2019).

The material properties of wood are known to have an inverse relationship with moisture content (MC). Wood below fiber saturation point (MC < 30% to 35%) is stiffer and stronger than green wood (MC > 35%)(Cousins 1976, 1978; Cannell and Morgan 1987; Kane 2007; Kane and Clouston 2008; Kane 2014; Dahle et al. 2017b), and when MC is above 50%, material properties tend to remain constant (Lavers 1983; Kretschmann 2010; Spatz and Pfisterer 2013). Researchers have utilized static load trials on intact branch unions in the field to understand failure behavior (MacDaniels 1932; Miller 1959; Lilly and Sydnor 1995; Gilman 2003; Dahle et al. 2006), and some have employed static load tests in a laboratory setting after removing the branch unions from the tree (Kane et al. 2008; Eckenrode 2017). If MC were to change greatly or drop below 50%, the results of testing in the laboratory may be different than in situ. Eckenrode (2017) reported that MC was greater than 50% when testing within 2 days, and Kane et al. (2008) reported that MC stayed above fiber saturation when testing within 45 days. While some of these studies utilized protective measures to slow moisture loss, it remains unclear how long a sample will remain at field MC levels.

Structural pruning is the elimination of branches and stems to influence the orientation, spacing, growth rate, strength of attachment, and ultimate size of branches and stems. Likewise, structural pruning is performed on small- to medium-sized trees to create a lasting trunk and branch arrangement (Gilman and Lilly 2008).

The objective of this research was to determine if there is an effect from structural pruning of young 'Redspire' pear trees on branch union strength during early crown development. In addition, 'Respire' pear was monitored for growth during the test period to record impacts on tree dimension over time. Lastly, the interval between tree harvest and breakage testing strength was noted by testing moisture levels. This was performed to determine if wood moisture content influenced the branch strength and if there was a critical timing element in the harvest time moisture response which would limit study results and interpretation.

MATERIALS AND METHODS

To increase the chances of subjecting trees to storm events, 'Redspire' Callery pear trees were planted in three locations in Ohio (USA) in the spring of 2011. The first location was at The Davey Nursery at 5509 Congress Road, Wooster, Ohio. This area was designated as the northern Ohio planting site. The soil was a fine-loamy, mixed, active, mesic Aquic Fragiudalfs (Canfield sandy loam). The second location, or the central Ohio location, was at Columbus State Community College, Delaware Campus, at 5100 Cornerstone Drive, Delaware, Ohio. The soil was a combination of a fine, illitic, mesic Aeric Epiaqualf (Blount silt loam) and a fine, illitic, mesic Aquic Hapludalf (Glynwood silt loam). The third site was in southern Ohio at the Spring Grove Cemetery and Arboretum, 4521 Spring Grove Avenue, Cincinnati, Ohio. The soil was a fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs (Cincinnati silt loam).

A total of 45 branched trees 1.8 m (6 ft) tall were planted in the spring of 2011 at each location. Trees were planted in an orchard grid on a 4.6-m (15-ft) spacing.

The planting areas were mowed monthly, fertilized once every 2 years, and mulched once every 3 years. The trees were fertilized with 30-10-7 slow-release fertilizer (Davey Arbor Green Pro[R], The Davey Tree Expert Company, Kent, OH, USA). The fertilizer was mixed with water and applied below ground under hydraulic pressure 0.10 m to 0.30 m (4 in to 12 in) deep. Injections were made at 0.91-m (3-ft) intervals underneath the tree canopy using the standard liquid injection technique for trees. This delivered 2.0 kg (4.5 lb) of nitrogen per 92.9 m^2 (1,000 ft^2) each time the trees were fertilized. The trees were mulched with hardwood bark to a depth of 5.0 cm (2 in) in a circular ring 0.91 m (3 ft) out from the trunk. The trees received only natural rainfall during the test.

One-half of the trees received structural pruning while the other half were not structurally pruned. The structural pruning treatment included (1) removal of broken, dead, and dying branches; (2) establishment of a dominant leader (subordinate upright branches were removed as needed to reduce codominance); (3) removal of branches such that the branches that remained were spaced vertically 7.5 cm to 15 cm (3 in to 6 in) apart in a spiral pattern vertically on the trunk; (4) removal of clusters of branches emanating from the trunk; and (5) removal of lower branches on the trunk to a distance of 1.4 m (4.5 ft) above the soil surface. The pruning treatment occurred in years 2 to 4 following planting. The pruning practices implemented generally conform with industry standards (American National Standards Institute 2017; Lilly et al. 2019).

Throughout the testing period from 2012 to 2018 (7 years), trees were measured for their diameter at breast height (DBH) at 1.37 m (4.5 ft) above ground. Measurements of tree height and width were taken with a 7.62-m (25-ft) Leveling Telescoping Rod (CST/Berger, Mount Prospect, IL, USA). Tree dimensions and their change from initial size to year 7 were compared between sites and treatments using a General Linear Model with Tukey pairwise comparison at a 95% confidence interval to account for the unequal population sizes wrought by losses over time and site plantation differences.

During the 7-year growing period, fire blight disease (*Erwinia amylovora*) was the only pest observed infecting the plants. The infection only occurred in a few plants to a limited extent. Observations on the ‘Redspire’ cultivar indicate a range of susceptibility, from resistant (SelecTree 2020), to light to moderate susceptibility (Gilman and Watson 1994), to quite susceptible to fire blight (Dirr 1998).

During the 7 years of planting, none of the tree branches were broken naturally by high winds or ice storms. This required the breaking of stems using artificial means.

Twenty-two random trees, one-half structurally pruned and one-half not structurally pruned, were cut down from the northern Ohio site and transported to The Davey Tree Research Farm on 2 August 2019. Limb breakage tests were conducted during one week at the 2019 Tree Biomechanics Week at The Davey Tree Research Farm located at 6220 State Route 303, Ravenna, Ohio.

Each tree was sectioned to isolate trunk sections extending 0.30 m (1 ft) above and 0.30 m (1 ft) below a targeted branch union. The branch axis was retained. One branch was chosen in the lower canopy (LC) to capture the first or second lateral branch from the ground at 1.5 m (5 ft). The second branch chosen was higher in the canopy (HC), 0.4 m to 1.4 m (1.5 ft to 4.5 ft) above the lower tested branch union section.

To determine moisture content at the time of load testing, wood samples (whole disk from a 2.5-cm to 10.2-cm [1-in to 4-in] section) were taken on the trunk above and below the branch connection and a branch sample beyond the branch collar zone. Dry weight was determined by oven drying wood cross-sectional samples at 101 °C (214 °F) until constant mass was obtained. Moisture content data was calculated by sample (wet mass − dry mass)/dry mass.

A data set was developed on live trees at the same northern planting site for comparison. Tree samples were coded for the time between cutting the tree and the time of load testing. Lower branches were tested as a group before upper branches in the first data set. The result was a temporal series of:

- Lower branches tested 5 to 7 days post-harvest
- Upper branches tested 7 to 9 days post-harvest
- Second field set tested as live (pre-harvest)

Moisture data was broken into one-way ANOVA with Tukey separation on whole-sample average moisture as a temporal series of unequal sizes, and in a one-way ANOVA with equal sample sizes to compare sample position (trunk below, trunk above, and branch). Finally, a pairing process was attempted to match post-harvest and pre-harvest testing pairs based on trunk-branch aspect ratio, angle of departure, and branch diameter.

A freestanding metal device (Figure 1) was used for the branch breaking test (Goodfellow et al. 2013). A 2.5-cm to 7.6-cm (1-ft to 3-ft) long trunk with a branch attached was strapped vertically to the metal frame. The branch to be broken was connected to a 2,000-lb (907-kg) capacity Optima Scale Tension/Compression Crane Scale with digital weight indicator (Model #OP-926-2K, #OP 019A, Northern Tool & Equipment, Burnsville, MN, USA). The scale was then attached to a cable through a redirect pulley to a winch. The winch was a battery powered 5,000-lb (2,267-kg) capacity ATV/UTV electric winch (Badland Winches, Camarillo, CA, USA). The winch was used to pull in (wind up) the tension on the wire cable, directing the force to break the limb.

To determine the force required to break a branch, multiple measurements of tree sections were made. The measurements included the diameter of the trunk below and above the branch that was to be broken and the diameter of the top and bottom of the branch. Angles of the trunk, branch, and rope used to pull the branches were also measured. The angle of the branch and angle of the pulley rope were used to calculate the final angle (180° − [branch angle + pulley angle]).

During the breaking test, the Tension/Compression Crane Scale was attached, which gave a reading of the amount of force in pounds it took to break the branch. The load at auditory popping (noise at breaking) was then converted to the overall applied load from pounds to newtons (1 lb = 4.448 N).

Axial and bending load were calculated (Figure 2). For axial force (P_x), P_x was divided by the branch cross-sectional area, or πr^2. For bending load (P_y), P_y was multiplied by failure moment (L) and then multiplied by the center point (Y). This product was divided by the moment of inertia ($0.25 \times \pi \times r^4$) in the pear branches. Axial force and bending load were then added together to find the force/resistance.

Comparisons of pruning treatment and canopy location for the mechanical breakage data using the northern site trees was analyzed with a one-way ANOVA using a Student-Newman-Keuls stepwise procedure of pairwise comparisons. A regression plot

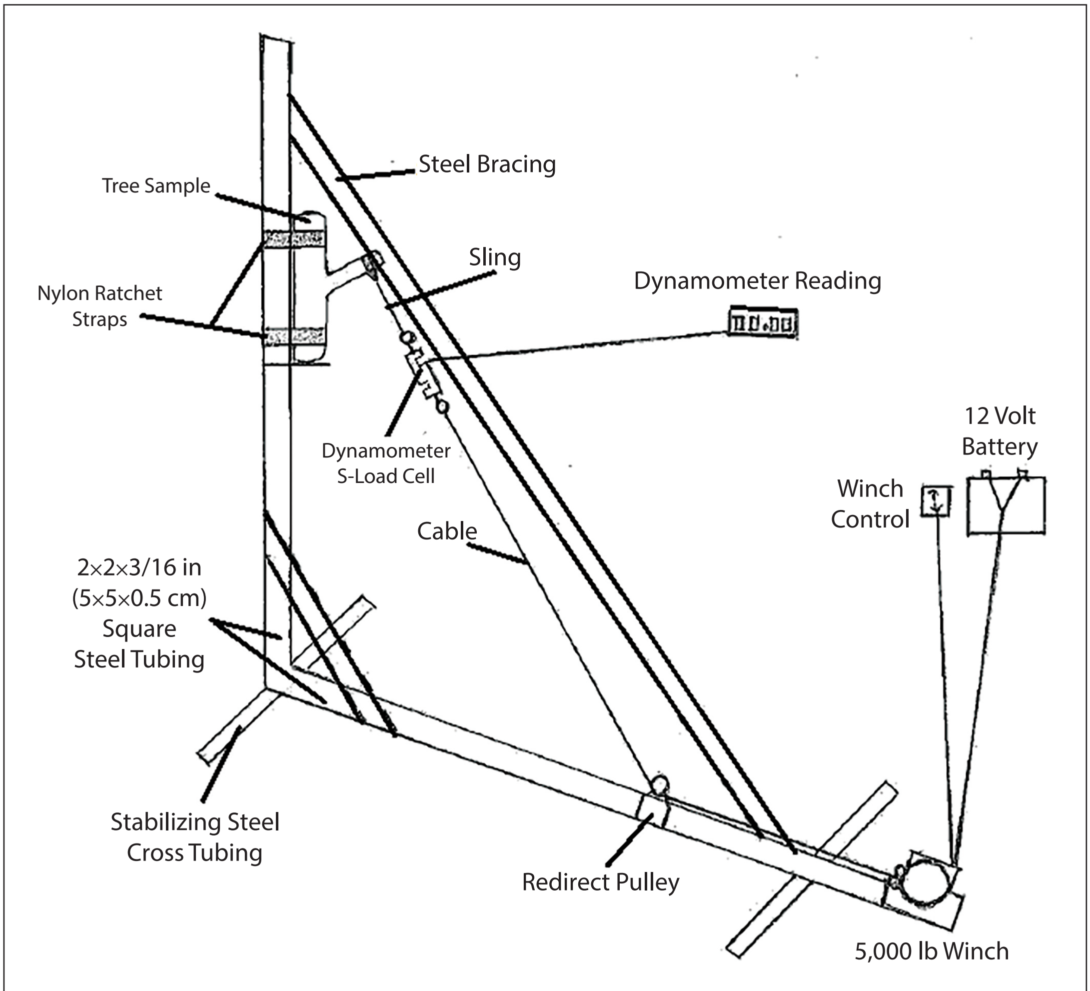

Figure 1. Freestanding metal device used for breaking branches.

$$Stress = \frac{-P_x}{\pi r^2} + \frac{P_y(L)Y}{\frac{1}{4}\pi r^4}$$

Figure 2. Equation for calculating stress on the lower side of the branch.

was developed to compare branch to trunk diameter aspect ratio and breaking load.

Statistical analysis was performed in Minitab-19 (State College, PA, USA), excepting the load analysis and moisture content ANOVA which was analyzed using ARM statistical software (Gyrling Systems, Atlanta, GA, USA).

RESULTS AND DISCUSSION

Growth measurements showing the effects of pruning treatment and geographic site (planting site) are given in Table 1. The trees were planted in 2011, and one-half of the trees were structurally pruned each year in 2012 to 2014 prior to data collection. Considering the treatment effect, the trees were initially the same size in DBH and height, but unpruned trees were larger in canopy width. At the end of the test in 2018, unpruned trees were slightly larger in DBH and width. Translated into a total percent growth after the seventh year, unpruned trees were greater in DBH and width, but not height. This reflected a higher growth percentage in line with their common starting size and larger ending size. This effect agrees with the principle that unpruned or lightly pruned trees have more growth (Harris et al. 2004) and that removing branches from a tree slows growth (Gilman 1997).

Considering the geographic sites, the northern trees were slightly larger in DBH and width in 2012 and remained larger for DBH or obtained a larger height at the end of the test in 2018. There was a geographic effect evident from the outset of the study, with the southern site having smaller trees that grew more as a percentage in DBH throughout the study period. While not a specific aspect of this study, the authors note that the northern site had a history of soil cultivation which might have improved root colonization and thus growth, and the southern site did receive a higher degree of natural precipitation (Current Results 2021). In the aggregate, the mathematical differences between were rather small with respect to 7 seasons of response, but they did demonstrate the lack of an effect from pruning on height and minor impacts in trunk and canopy width.

Breakage strength calculations were not significantly different when compared by canopy position or by pruning treatment (Table 2). The relatively young age of the trees and the short growth response interval may account for this observation, but it is a useful observation when considering immediate consequences of pruning if the purpose is one of safety and tree architectural training. Lack of breakage by natural means was also found during a 12-year study of Callery pear as street trees (Gerhold 2007). Possibly, if structural treatments were continued for a longer period, the impact of treatments on branch strength would become evident.

Table 1. Callery pear growth measurements by pruning treatment and geographic site (planting site).

	N	DBH (cm)			Height (cm)			Width (cm)		
		2012	2018	Growth %	2012	2018	Growth %	2012	2018	Growth %
Treatment effect										
Pruned	45	2.0a*	11.2b	464b	280.4a	676a	141a	92.1b	334b	276a
Unpruned	49	2.0a	11.7a	488a	281.9a	678a	142a	102.3a	368a	280a
Geographic effect										
North	45	2.3a	12.2a	432b	283.3a	689a	139a	117.4a	374a	224b
Central	31	2.0b	11.5b	483b	281.5a	674b	143a	95.9b	355ab	284a
South	18	1.8c	10.7b	512a	278.7a	674b	144a	78.50c	322b	326a

*Letters within groups represent means separation by Tukey Pairwise Comparisons at 95% confidence interval.

Table 2. Callery pear branch union failure stress for the lower and upper canopy (Newtons or N).

Canopy position			
Lower canopy		Upper canopy	
Pruned	Unpruned	Pruned	Unpruned
4005.4a	3872.9a	3679.3a	2917.1a

Means followed by same letter do not significantly differ ($P = 0.05$, Student-Newman-Keuls).

Table 3. Moisture content of wood in relationship to the number of days after harvesting. Letters denote significant difference ($P < 0.0001$).

Days since harvest	Moisture content	*N*
0	0.644a	36
5-7	0.546b	60
7-9	0.546b	60

Perhaps more interestingly, there was no apparent or significant relationship between the aspect ratio and apparent breakage strength. Regression model: breakage stress = 25.0 + 14.3 × aspect ratio $r^2 = 0.014$ (data not shown).

The mean gravimetric moisture content (sum of below, above, and branch samples/3) on the temporal splitting of samples was not found to differ between the samples tested after 5 to 7 days (MC = 0.546, n = 60) or 7 to 9 days (MC = 0.546, n = 60), but these groups were found to be lower than the samples broken pre-harvest (MC = 0.644, n = 36)(Table 3).

The material properties of wood are constant when moisture content is above 50% (Lavers 1983; Kretschmann 2010; Spatz and Pfisterer 2013; Dahle et al. 2017a). While this moisture content dropped 5 to 9 days after harvest, the moisture content was still above 50%, and thus it appears that researchers may not need to worry about moisture loss over a limited time when conducting static loading trials. In many ways, this would be entirely consistent with our lack of observed difference in the breakage data regarding the temporal series in time from harvest whether blocked by group or within order of testing as a more continuous variable. Setting of paired data pre-harvest vs. post-harvest found no influence on the relationship between breakage stress and aspect ratio, branch angle of departure, or raw branch size.

We observed that branch samples were higher in moisture as compared to trunk samples in 43 of 52 cases, and equal in moisture as compared to trunk samples in 5 cases. This would suggest that there is both an importance in sampling protocol when measuring moisture in such studies, and potential opportunity for field studies regarding moisture, sampling, and engineering testing while on the ground.

CONCLUSION

No differences were found in branch strength for either pruned trees or unpruned trees. Likewise, no difference was found in branch strength regardless of the position of the branch union in the canopy. This suggests that arborists working in relatively young trees like 'Redspire' Callery pear should not expect immediate benefit from structural pruning in the early stages of a tree's life. Trees broken on the day of harvest, as well as 5 to 9 days post-harvest, were both found to have an acceptable moisture content of 50% or more. This implies that researchers experimenting with trees in the field may have time post-harvest (in our case at least 9 days post-harvest) before a change in wood moisture is a concern in some static load testing based on drying alone.

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Résumé. Le poirier (*Pyrus calleryana*) est un arbre connu pour ses fourches de mauvaise qualité et leurs bris fréquents lors des tempêtes. L'élagage structural est une technique d'élagage pouvant être pratiquée sur de jeunes arbres afin de renforcer l'attachement des branches au tronc. Le poirier Redspire (*Pyrus calleryana* 'Redspire') a été élagué structurellement et laissé croître pendant 7 ans puis a été comparé à un arbre témoin non élagué. Un dispositif de rupture a été utilisé pour déterminer la résistance des branches en générant une charge statique simulant une charge de neige ou de glace. Les branches provenant d'arbres élagués et non élagués ont été tirées jusqu'au bris sans qu'aucune différence n'ait été observée par rapport à l'élagage. Indépendamment de l'élagage structurel pratiqué, les arbres non élagués avaient un diamètre à hauteur de poitrine (DHP) plus important et étaient plus larges à la fin de l'étude. Aucune différence n'a été constatée lors des tests de traction des fourches de branches, que les arbres aient été taillés ou non, ce qui suggère qu'il faut davantage de temps pour déterminer les avantages de pratiquer l'élagage structurel à long terme. La teneur en humidité des tissus des branches était supérieure à celle des tissus du tronc, tant dans les tests effectués immédiatement après la récolte que pour les échantillons prélevés au fil du temps. De plus, les observations de la teneur en humidité des branches ont suggéré que le temps disponible pour les tests de traction des branches pourrait être de 5 à 9 jours après la récolte.

Zusammenfassung. Die Callery-Birne (*Pyrus calleryana*) ist ein Baum, der dafür berüchtigt ist, dass die Äste bei Stürmen schlecht zusammenhalten und brechen. Struktureller Schnitt ist eine Schnitttechnik, die bei jungen Bäumen angewandt werden kann, um die Zweigverbindung zu stärken. Die Callery-Birne (*Pyrus calleryana* 'Redspire') wurde strukturell beschnitten und 7 Jahre lang wachsen gelassen und mit einer unbeschnittenen Kontrolle verglichen. Zur Bestimmung der Aststärke wurde eine Brechvorrichtung verwendet, die eine statische Last bereitstellt, um eine Schnee- oder Eislast zu simulieren. Zweige von beschnittenen und unbeschnittenen Bäume wurden bis zum Bruch gezogen, um einen Unterschied durch das Beschneiden zu beobachten. Unabhängig von der strukturellen Schnittbehandlung waren die Bäume, die nicht beschnitten wurden, am Ende des Tests größer im Durchmesser auf Brusthöhe (DBH) und in der Breite. Es wurden keine Unterschiede bei der Prüfung der Astverbindungsstärke zwischen beschnittenen und unbeschnittenen Bäumen festgestellt, was darauf hindeutet, dass mehr Zeit benötigt wird, um die langfristigen Vorteile des Strukturschnitts zu bestimmen. Der Feuchtigkeitsgehalt des Astgewebes war sowohl bei den Tests unmittelbar nach der Ernte als auch bei den Proben im Laufe der Zeit höher als der des Stammes. Die Beobachtungen des Feuchtigkeitsgehalts der Äste deuten auch darauf hin, dass die Prüfung der Stärke der Astverbindungen im Feld erst 5 bis 9 Tage nach der Ernte erfolgen kann.

Resumen. La pera (*Pyrus calleryana*) es un árbol importante para valorar para la mala unión de ramas y la rotura durante las tormentas. La poda estructural es una técnica de poda que se puede practicar en árboles jóvenes para fortalecer la unión de las ramas de los árboles. La pera (*Pyrus calleryana* 'Redspire') fue estructuralmente podada y se le permitió crecer durante 7 años en comparación con un control no manipulado. Se utilizó un dispositivo de rotura para determinar la resistencia de la rama proporcionando una carga estática para simular una carga de nieve o hielo. Las ramas podadas y no podadas fueron esforzadas sin observar diferencia de la poda. Independientemente del tratamiento de poda estructural, los árboles que no se podaron tenían un diámetro mayor a la altura del pecho (DBH) al final de la prueba. No se encontraron diferencias en la prueba de la resistencia de la unión de ramas para árboles podados o no podados, lo que sugiere que se necesita más tiempo para determinar los beneficios a largo plazo de la poda estructural. El contenido de humedad del tejido de las ramas fue mayor que el tejido del tronco tanto en las pruebas inmediatas posteriores a la cosecha como en las muestras a lo largo del tiempo. Además, las observaciones de contenido de humedad de las ramas sugirieron que el tiempo disponible para la prueba de campo de la fuerza de la unión de la rama podría ser de hasta 5 a 9 días después de la cosecha.

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