

EMBEDDED WIRE IN TREE ROOTS: IMPLICATIONS FOR TREE GROWTH AND ROOT FUNCTION

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Abstract. Experiments with two-year-old seedlings of *Fraxinus pennsylvanica* and *Celtis occidentalis* and two year-old whips of *Populus angulata* x *plantierensis* were designed to study the effect of root girdling by wire. Overall growth, foliar nutrient content, xylem anatomy, root carbohydrate content, xylem water potential, and rate of transpiration were studied six months after girdling. Neither greenhouse grown seedlings nor field grown whips subjected to root girdling by wire grew less than those without girdling wire. Full girdling significantly reduced foliage dry weight in *Fraxinus* and the rate of transpiration in *Fraxinus* and *Celtis*. A gradient of water potential was observed in the xylem across the wire girdle in seedlings of these two species. The amount of carbohydrate present in root tissue and its distribution in relation to the wire was slightly influenced by girdling in all three species.

It is well documented that tree growth is linked to the performance of the root system (5, 7), and that tree longevity in urban landscapes is greatly influenced by the root zone environment (8). As a result, horticulturists and urban foresters have been paying more attention to tree roots (3, 4, 10). However, the influence of current cultural practices on tree performance is not well understood.

Wire baskets for transplanting large trees have been used extensively in the landscape industry for the past 15 to 20 years. Recently, concern has been expressed about the wire baskets, often left intact at planting, and their possible effects on tree growth and longevity (2, 6, 18). As tree roots increase in size, they come in contact with the wire which eventually becomes embedded in the root tissue. The implications of embedded wire on root function, tree growth, and tree longevity are poorly understood.

There is limited information concerning wire baskets and tree roots. Feucht (6) reported premature leaf coloration, leaf drop and tree decline at several Colorado sites caused by the girdling of roots by poultry netting left in place at planting 4 to 10 years earlier. Also, Feucht (6) suggested that root damage occurs regardless of wire grid size and that union of vascular tissue beyond the wire

did not occur because there was bark infolding and no cambial contact.

Lumis and Struger (16) published photographic evidence that root tissue formed after wire was embedded had intact periderm (bark), phloem and xylem. Further study by Lumis (15) that involved 34 individual trees of seven species planted in wire baskets up to 11 years earlier at 10 sites in Ontario, demonstrated that all species had intact root tissue without continued bark infolding, despite the embedded wire. Dye flow indicated functional phloem and xylem.

Moisture, pH and oxygen greatly affect the longevity of the wire in the soil (1, 6). Lumis (15) found at one site that galvanized baskets showed little evidence of corrosion after 11 years in the ground. At another site, wire tensile strength of both non-galvanized and galvanized baskets decreased only 3% to 5% after 4 years (15).

A major function of tree roots is transport. Carbohydrates (mostly sucrose), nitrogen containing compounds and growth regulators move in the phloem while water and nutrients move in the xylem (14). Impaired transport caused by the girdling of phloem and xylem tissue may have adverse effects on the tree, depending on the extent of the girdling (12). Reduced carbohydrate transport caused by deformities in roots results in the accumulation of sugars above the constriction, usually a stimulus for lateral root development in the region of accumulation (11).

Previous research by others indicated that severing some xylem elements had no detectable effect on the transport of water and solutes to the crown. As much as 75% of the cross-sectional area of the stem could be severed by a single cut before the rate of transpiration was affected (17). Lateral transport through the rays carries the xylem contents around the severed xylem elements to where upward movement of the solute

can continue (25).

Anatomical changes were found in the presence of naturally occurring girdling roots. Girdling caused changes in the structure of the wood, including much thinner bark, reduced xylem element conducting area and the absence of rays in the stem affected by girdling roots (13).

The purpose of this study was to determine the effect of root girdling by wire on overall growth, foliar nutrient content, root carbohydrate content, xylem water potential, xylem anatomy and rate of transpiration after six months of active growth for three species of two-year-old trees.

Materials and Methods

Two-year-old seedlings [8 mm (5/16 in) dia and 1 m (39 in) tall] of *Fraxinus pennsylvanica* (green ash) and *Celtis occidentalis* (common hackberry), as well as two-year-old whips [2 m (78 in) tall] of *Populus angulata x plantierensis* (hybrid poplar) were selected for the experiments. The *Fraxinus* and *Celtis* seedlings had a single taproot with an average diameter of 18 mm (3/4 in). The *Populus* whips had a multi-branched root system (typical of rooted cuttings) with approximately eight roots per tree. Average root diameter was 18 mm (3/4 in).

The wire used to girdle the roots was 0.7 mm green florist wire. It provided a root:wire diameter ratio similar to that found in landscape trees with wire embedded in the roots (16). The wires were placed 7.5 to 10 cm (3 to 4 in) below the root/stem collar in such a way that the root was either fully encircled by wire (full girdle treatment), (Fig. 1) or exposed to the wire on one side of the root only, the other side being protected by a rigid plastic splint (partial girdle treatment). In the case of the *Populus*, the wire girdles were applied to impose one of the following six treatments: 1/3, 2/3 or all the roots either partially or fully girdled by wire. Control trees of the three species had no wire.

The *Fraxinus* and *Celtis* were potted in 10 cm x 60 cm containers (4.7 liters) in March using a 2:1 pine bark:peat medium and grown in the greenhouse until September under ambient light. Temperatures ranged from 11° to 37°C during the six month period. The experiment was a randomized complete block design, including 25 replications with two genera and three treatments per genus. The *Populus*

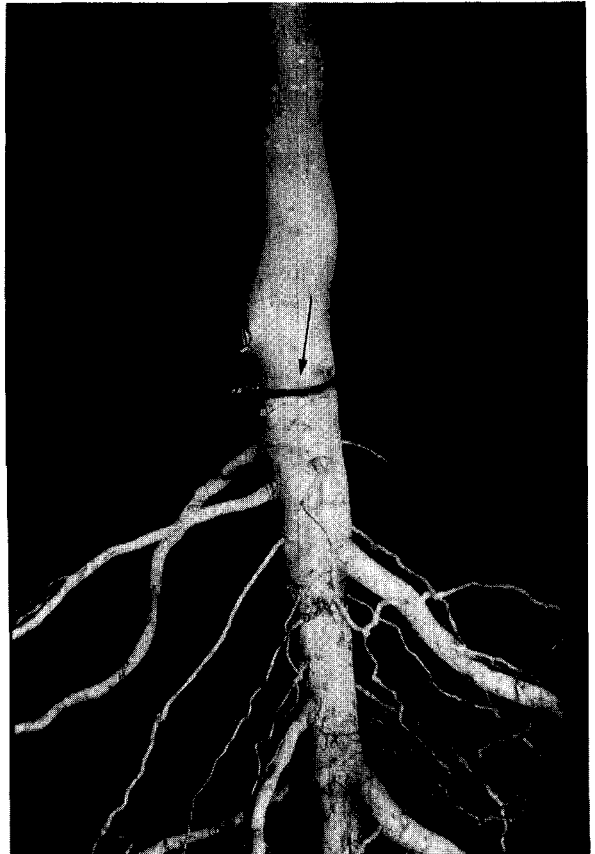


Figure 1. *Fraxinus* seedling with full wire girdle (below arrow) on the root at the beginning of the study.

whips were field planted in early May in a Fox sandy loam soil and harvested in October. The experiment was a randomized complete block design including seven treatments and 14 replications. Statistical analysis for both experiments was carried out using a general linear model procedure of the SAS system (SAS Institute Inc., 1985). Mean separation was by LS means at the 5% level of significance.

Growth parameters. Whole plant response to wire girdling of the roots was determined by the analysis of stem (including trunks), root and foliage dry weights. For *Populus*, increase in trunk caliper also was measured.

Foliar nutrient content. Fully expanded leaves were collected during early August for analysis of N, P, K, Ca and Mg. The tissue was digested in concentrated H_2SO_4 , and N and P content was determined by colorimetry. K, Ca and Mg content

was determined using atomic absorption.

Root anatomy and dye flow. The root system of *Fraxinus* and *Populus* was cut 10 cm (4 in) below the wire girdle and the excised part of the root was discarded. The cut was made under water to prevent the introduction of air embolisms into the xylem. Plants were placed upright in a 0.5% solution of acid fuchsin dye and allowed to stand overnight. A 20 cm length of root was removed and the samples were examined. Cross-sectional surface area of the root was measured 2 cm above and below the wire girdle. The diameter of 20 dyed xylem elements in each of four quadrants was measured and the number of xylem elements containing dye was counted. Comparisons of cross-sectional area of the root, xylem element diameter, and the number of functional xylem were made based on their location either above or below the wire girdle. Measurements of cross sectional area and individual xylem element diameter were made using a rear projection digitizing tablet (GTCO Corp., Columbia, MD), in conjunction with a portable computer and custom software. Root sections were then cut longitudinally and the movement of dye around the wire was examined.

Carbohydrate analysis. Root tissue glucose and starch content were measured above and below the wire girdle. Samples from the non-girdled treatment seedlings were collected in the region of the root where wire girdles would have been applied. In those roots that had been partially girdled by wire, the tissue was separated into four sub-samples: above and below the wire on both the wire side and on the splint side of the root. Starch determination was based on the acid hydrolysis of starch in ethanol-insolubles to glucose (20) and colorimetric analysis of the glucose content (18).

Xylem water potential. *In situ* measurement of xylem water potential of *Fraxinus* and *Celtis* was carried out 22 weeks after planting using temperature-corrected stem hygrometers (P.W.S. Instrument Inc., Guelph, Ont.). Readings were taken every 30 minutes for four consecutive days using a data logger (CRT Data Logger, Campbell Scientific, Logan, Utah) which was downloaded daily using a portable computer (IBM compatible).

Rate of transpiration. Plants respond to water stress by stomatal closure, therefore xylem water potential measurement alone was not considered a clear indication of impedance to xylem flow caused by wire girdling. Measurement of water loss through transpiration was carried out in conjunction with xylem water potential. The entire container and soil-root mass was wrapped in two thicknesses of plastic film to prevent loss of water from the growing container through evaporation. The seedling, in its insulated container, was weighed on an electronic balance every 30 minutes from 08:00 until 17:00 for four consecutive days. Decreasing mass was attributed to loss of water by transpiration. At the end of the experiment, the foliage was removed to measure leaf area in order to normalize transpiration measurements.

Results and Discussion

Growth parameters. There were no significant differences in overall growth (dry weight) of *Celtis* or *Fraxinus* seedlings that had been girdled by wire compared to those that had not been girdled (data not shown). It is not known whether differences would have occurred had the seedlings been grown for more than six months. The *Fraxinus* seedlings had greater radial root growth during the experiment than did *Celtis* seedlings (visual assessment) and as a result more of the girdled *Fraxinus* roots formed new tissue over the wire than did *Celtis*. Swelling above the wire was not prevalent for either species, and where swelling did occur, lateral root proliferation was evident only in *Celtis*. The lack of swelling above the wire girdle may indicate that the wire did not cause a major restriction to carbohydrate movement. Foliage dry weight of *Fraxinus* was reduced significantly on trees that had been fully girdled by wire, but stem and root dry weights were not affected (data not shown).

For *Populus*, the extent of radial root growth resulted in the partial infolding of the plastic splints in many of the roots of the partially girdled treatment plants. Because of the infolding of splints, the degree of swelling of the roots was greater than that for roots that had been fully girdled. Wire girdle treatments on the roots did not affect trunk

caliper or plant dry weight, even for trees with wire girdles placed on every root (data not shown).

Foliar nutrient content. Levels of N, P, K, Ca and Mg in leaves of *Fraxinus* and *Populus* were not significantly different among the three girdle treatments. In *Celtis*, levels of both Ca and Mg were significantly reduced in fully girdled plants. It is possible that the reduction in foliar Ca and Mg for *Celtis* occurred because of reduced flow of these xylem mobile elements through the plant as a result of root restriction. As indicated previously, radial root growth in *Celtis* was the least of the three species. The presence of a physical barrier to the movement of Ca and Mg around the wire girdle is another possibility; perhaps comparable to the restriction imposed at a graft union (23,24).

Root anatomy and dye flow. Comparisons were made of cross-sectional surface area, number of functional xylem elements, xylem diameter, total functional xylem area and percent conductive area between the root tissue above and below the girdling wire. Root anatomy did not differ significantly above

or below the wire for the three species regardless of the girdling treatment (comparison data not shown). For *Fraxinus* (Table 1), the number of functional vessels in the current season's xylem of partially girdled roots was significantly greater than in either control or fully girdled roots. The total functional xylem area (calculated from xylem vessel number and diameter) of partially girdled roots was significantly greater than that of fully girdled roots but similar to non-girdled roots. This response was the combined result of the greater number of functional xylem and the slightly smaller xylem diameter in partially girdled roots. Perhaps the response may have been due to smaller diameter xylem elements being less susceptible to stress induced cavitation (21). Cross-sectional surface area, xylem diameter and percent conductive area were not significantly different among the three girdling treatments.

For *Populus* (Table 2), the cross sectional surface area of partially girdled roots was significantly less than that of non-girdled roots. The number of functional xylem elements of both partially and fully

Table 1. Cross-sectional and conducting xylem element parameters for roots of *Fraxinus pennsylvanica* seedlings for each of the root wire girdling treatments.

Parameter	No girdle		Full girdle		Partial girdle	
Cross-sectional surface area (μm^2)	16306a ^z	$\pm 881^y$	16833a	± 881	17683a	± 1970
Number of functional vessels	671b	± 78	574b	± 78	1207a	± 175
Xylem vessel diameter (μm) ^x	0.085a	± 0.006	0.080a	± 0.005	0.072a	± 0.010
Total functional xylem area (μm^2) ^w	58ab	± 8	43b	± 8	88a	± 15
Conductive area (%) ^v	0.34a		.29a		.49a	

^z values are the mean of seven independent replications, mean separation in rows at the 5% level.

^y standard error

^x values are an average of 20 vessels in each of four quadrants.

^w number of functional xylem x xylem vessel diameter.

^vtotal functional xylem area _ cross sectional surface area x 100%.

Table 2. Cross-sectional and conducting xylem element parameters for roots of *Populus angulata* x *plantierensis* whips for each of the root wire girdling treatments.

Parameter	No girdle		Full girdle		Partial girdle	
Cross-sectional surface area (μm^2)	25556a ^z	$\pm 2152^y$	21132ab	± 2152	15322b	± 2152
Number of functional vessels	8206a	± 507	4547b	± 507	4895b	± 594
Xylem vessel diameter (μm) ^x	.293ab	± 0.045	.360a	± 0.045	.239b	± 0.045
Total functional xylem area (μm^2) ^w	2429a	± 338	1642ab	± 338	1110b	± 396
Conductive area (%) ^v	9.4a		8.8a		8.0a	

^z values are the mean of seven independent replications, mean separation in rows at the 5% level.

^y standard error

^x values are an average of 20 vessels in each of four quadrants.

^w number of functional xylem x xylem vessel diameter.

^v total functional xylem area _ cross sectional

girdled roots was significantly less than of non-girdled roots. Fewer functional xylem elements were probably the result of vessel elements adjacent to the girdling wire that were displaced from normal alignment (skewed). The displacement was greater in partially girdled roots where enclosure of the plastic splint holding the wire prevented tissue bridging and the subsequent growth of tissue containing xylem with a more normal orientation. Xylem vessel diameters were significantly smaller in partially girdled roots compared to fully girdled roots, probably due to the extent of girdling injury from the splint. The xylem vessel diameters of non-girdled and fully girdled roots were similar. Total functional xylem area of partially girdled roots was significantly less than that of non-girdled roots, but similar to fully girdled roots. Percent conductive area was not significantly different among the girdle treatments.

Visual examination of longitudinal root sections girdled by wire revealed that xylem orientation adjacent to the wire was displaced from normal alignment (skewed) in all three species. Severely skewed orientation could have resulted

in increased xylem water tension and increased xylem element vulnerability to cavitation (25). Xylem that formed further beyond the wire had a more normal orientation. In the six month studies reported here about half of the girdled roots of *Fraxinus* and *Populus* formed intact tissue (bridged) over the wire (Fig. 2). Tissue formation over the wire was infrequent in *Celtis* due to slow radial root growth. Dye movement through bridged tissue indicated it to be functional. These findings are consistent with those of Lumis (15) and Lumis and Struger (16).

Carbohydrate analysis. Root girdling had little effect on carbohydrate levels in the roots of the three species. For *Fraxinus* there were no significantly different levels of glucose above or below the wire in fully or partially girdled roots compared to non-girdled roots (Table 3). Starch content in the wood of partially girdled roots was higher above the wire on the girdled side than on the splint (non-girdled) side. Full girdling did not result in accumulation of photosynthate above the wire girdle. Thus it appears that the wire did not impede the movement of photosynthate in *Fraxinus*

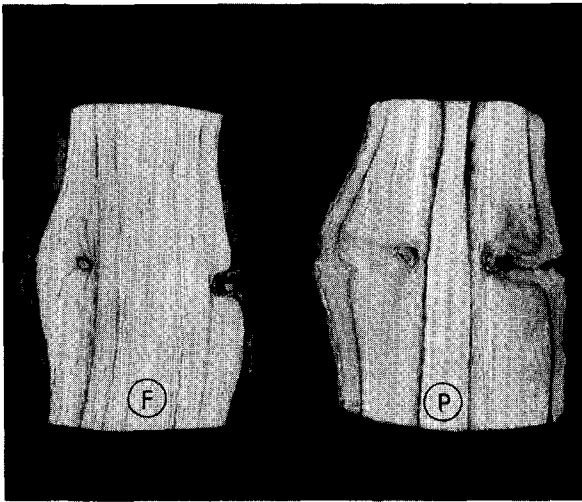


Figure 2. Longitudinal root sections of *Fraxinus* (F, left) and *Populus* (P, right), stained with acid fuchsin, showing bridging over the wire (left side of both sections) and infolding prior to bridging (right side of both sections)

roots.

For *Celtis* there were no significant differences in the amount of glucose above and below the wire in any given treatment (Table 4). The level of glucose in the wood, both above and below the wire, was significantly higher in the fully girdled roots than in non-girdled roots. Starch content in the bark above the wire was higher in fully girdled than in non-girdled roots but similar to that in partially girdled roots. In partially girdled roots there were no differences in either glucose or starch levels between the wire (girdled) and splint (non-girdled) sides of the root. Since significantly higher levels of glucose and starch were not found above or below

the wire, the girdle did not appear to act as a major constraint to photosynthate movement in *Celtis* roots.

In *Populus* roots levels of glucose were not significantly different in girdled and non-girdled roots (data not shown). Starch levels were significantly higher in the upper root portion of non-girdled roots compared to those above the wire in fully girdled roots. It would appear that the difference was due to greater translocation of photosynthate to the roots of the non-girdled trees, since the carbohydrate content of the lower root tissue was very similar for both treatments. Although differences in starch content of the root tissue were evident between the two wire girdling treatments, there was no significant difference in the carbohydrate content of the tissue above the wire compared to that below the wire. Thus it would appear that the presence of the wire did not impede photosynthate movement in the roots of *Populus*.

Xylem water potential. Psychrometric measurements made above and below the wire girdle revealed that *Celtis* and *Fraxinus* seedlings with wire girdles exhibited a larger water potential gradient across the wire than that found for non-girdled seedlings (data not shown). This indicates an impedence to normal xylem flow. The largest gradients occurred during periods of greatest transpiration demand. Xylem water potential gradients of 0.2-0.4 MPa were observed across the wire for both species. During periods when water stress decreased (at night), the xylem water potential was similar above and below the wire girdle. Xylem water potential gradients of 0.1 MPa and less were

Table 3. Carbohydrate content of root tissue (mg/g dry wt) of *Fraxinus pennsylvanica* seedlings for each root wire girdling treatment.

	NG ^z		FG		PGG		PGN	
	Above	Below	Above	Below	Above	Below	Above	Below
Glucose in bark	147a ^y	139a	155a	152a	129a	138a	127a	122a
Glucose in wood	108a	85a	131a	84a	96a	78a	80a	76a
Starch in bark	156a	175a	139a	202a	176a	160a	152a	128a
Starch in wood	141b	112b	106b	155ab	214a	125b	120b	98b

^z NG = no girdle; FG = full girdle; PGG = partial girdle, girdle side of tissue; and PGN = partial girdle, splint side of tissue.

^y Values are the mean of five independent replications, mean separation in rows at the 5% level.

Table 4. Carbohydrate content of root tissue (mg/g dry wt) of *Celtis occidentalis* seedlings for each root wire girdling treatment.

	NG ^z		FG		PGG		PGN	
	Above	Below	Above	Below	Above	Below	Above	Below
Glucose in bark	31b ^y	32ab	95a	75ab	72ab	54ab	59ab	42ab
Glucose in wood	57b	65b	125a	127a	73b	82ab	78ab	62b
Starch in bark	56b	91a	89a	83ab	62ab	94a	72ab	81ab
Starch in wood	182a	205a	156a	244a	153a	246a	176a	189a

^z NG = no girdle; FG = full girdle; PGG = partial girdle, girdle side of tissue; and PGN = partial girdle, splint side of tissue.

^y values are the mean of five independent replications, mean separation in rows at the 5% level.

observed in non-girdled roots. Seedlings that had begun to form tissue bridges over the wire had similar values to those that had not yet bridged the wires. The impedance to xylem flow probably would diminish as more xylem differentiated in the tissue formed beyond the wire.

Transpiration rate. The rate of transpirational water loss was affected by the presence of the

wire girdle (Fig. 3). *Celtis* and *Fraxinus* seedlings that had been fully girdled transpired significantly less than either non-girdled or partially girdled seedlings. The reduction in the rate of transpiration was consistent with the water potential gradient data. Assuming that transpiration and photosynthesis are linked closely (9) dry matter production (growth) could be reduced by girdling.

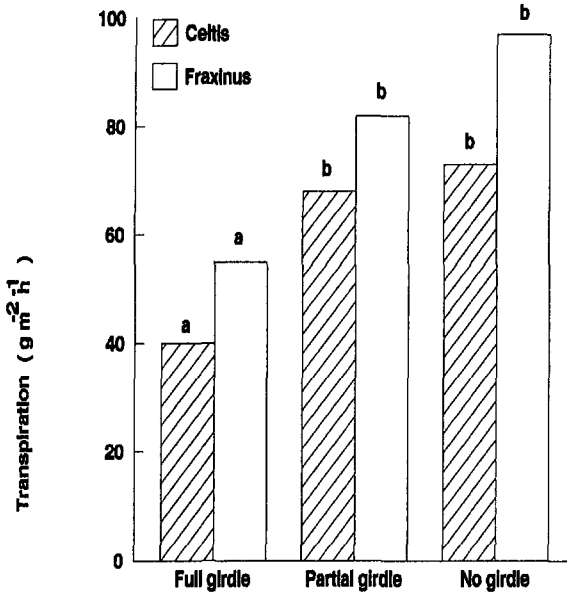


Figure 3. Quantities of water transpired by *Celtis* and *Fraxinus* seedlings for each root wire girdling treatment. Bars within a species with similar letters are not significantly different at the 5% level (LS means). Mean values were calculated from data of four consecutive days, normalized by leaf area, and from two independent replications.

Conclusion

Extrapolation of the findings of these single season experiments to the use of wire baskets in the landscape is difficult. Similar overall growth of roots, stems, leaves (except *Fraxinus*) and similar foliar nutrient levels (except Ca and Mg in *Celtis*) indicated that fully or partially girdling the single root of *Celtis* and *Fraxinus* seedlings or all the roots of *Populus* whips had no adverse effect during the first growing season.

Anatomical effects in the root caused by girdling wire were not clear-cut. Although the percent conductive area of the root was not influenced by girdling, the total functional xylem area of fully girdled *Fraxinus* roots and partially girdled *Populus* roots was somewhat reduced by girdling. Despite an increase in the number of functional xylem in partially girdled *Fraxinus* roots, water movement through the plant was not increased.

Root carbohydrate levels were similar above and below the wire girdles, indicating that girdling did not restrict the movement of photosynthate in the three species. Differences in starch levels between fully girdled and non-girdled roots were

seen in *Populus* and in the bark tissue of *Celtis*. The presence of the wire girdle resulted in accumulation of starch above the wire only in the girdled portion of partially girdled *Fraxinus* roots. With no clearly evident patterns of root carbohydrate distribution in these studies there seems to be little indication of potential long term effects of wire girdling on photosynthate movement in roots.

Full girdling reduced transpiration in *Celtis* and *Fraxinus*, both ring porous species. A reduction may not be reflected over time since tissue bridging over wire at the girdled zone could diminish an adverse effect. Also, partially girdled seedlings, which most closely simulate what occurs with wire baskets, did not transpire less water than non-girdled seedlings.

From the studies reported here we can not answer the question of whether or not wire baskets should be removed at planting. However, compared to the stresses that occur when transplanting trees from the nursery to the landscape, where as much as 98% of the root system is lost (22), the effect of roots growing over basket wires would seem to be limited.

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Résumé. Des expériences, avec des semis de deux ans de *Fraxinus pennsylvanica* et de *Celtis occidentalis* et des baliveaux de deux ans de *Populus angulata x plantierensis*, furent élaborées pour étudier l'effet du ceinturage des racines par un fil métallique. La croissance d'ensemble, le contenu nutritif foliaire, l'anatomie du xylème, le contenu racinaire en hydrates de carbone, le potentiel en eau du xylème et le taux de transpiration étaient étudiés six mois après le ceinturage. Ni les semis en croissance en serre ou les baliveaux en croissance au champ assujettis à un ceinturage racinaire par du fil métallique affichaient une croissance moindre que ceux sans fil métallique de ceinturage. Un ceinturage total réduisait significativement la masse foliaire sèche chez *Fraxinus* et *Celtis*. Un gradient de potentiel en eau était observé dans le xylème d'un côté à l'autre du fil métallique de ceinturage chez les semis des deux espèces. La quantité d'hydrates de carbone présente dans le tissu racinaire et sa distribution, en relation avec le fil métallique, étaient légèrement influencées par le ceinturage pour l'ensemble des trois espèces.