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Propagation

Root pruning of pecan rootstocks in different containers

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Abstract - Quality pecan rootstocks that ensure genetic and phytosanitary safety, besides having good vegetative development, are extremely important to implant a successful orchard. Rootstocks with vigorous radicular systems affect plant growth. This study aimed at evaluating rootstock growth as the result of root pruning and the use of different containers to grow pecan rootstocks in an organic system. The experiment was conducted with "Barton" rootstocks in the experimental area at the Embrapa Clima Temperado in Pelotas, RS, Brazil, in 2018, 2019 and 2020. Rootstocks were evaluated in plastic bags and tubes and in the soil, associated with root pruning. Evaluation 280 and 480 days after transplant comprised the following: height of the aerial part, length of primary and secondary radicular systems, stem diameter, leaf area, dry mass of the aerial part, dry mass of the radicular system, dry mass of secondary roots and the Dickson Quality Index. The use of plastic bags to produce pecan rootstocks was found to coil roots at the bottom of the container. Neither containers nor root pruning affected stem diameter, an important parameter to carry out grafting. Pecan rootstocks with a non-pruned radicular system grown in plastic bags developed large main root and aerial part. Pruning of pecan radicular systems in containers and in the soil leads to increase in the number of main roots but decreases root length.

Index Terms: *Carya illinoinensis,* rootstock production, radicular system.

Poda de raízes de porta-enxertos de nogueira-pecã em diferentes recipientes

Resumo - A qualidade do porta-enxerto de nogueira-pecã com segurança genética, fitossanitária e com bom desenvolvimento vegetativo é de suma importância para o sucesso na formação do pomar. O porta-enxerto com vigoroso sistema radicular influencia no crescimento da muda. O objetivo deste trabalho foi avaliar o crescimento do porta-enxerto em função da poda de raiz e de diferentes recipientes para a produção de muda de nogueira-pecã em sistema orgânico. O experimento foi conduzido com o porta-enxerto da cultivar Barton, na área experimental da Embrapa Clima Temperado, Estação Experimental Cascata, nos anos de 2018, 2019 e 2020. Os porta-enxertos foram avaliadas em sacos plásticos, tubetes e diretamente no solo, associado ao manejo da poda de raiz. Avaliaram-se, após 280 e 480 dias do transplante: altura da parte área, comprimento do sistema radicular primário e secundário, diâmetro de caule, área foliar e massa seca da parte aérea e do sistema radicular, e secundárias, e o Índice de qualidade de mudas de Dickson. Verificou-se que o uso do saco plástico para a produção de porta-enxertos de nogueira-pecã enovela as raízes no final do recipiente. Os recipientes e a poda de raiz não afetam o diâmetro do caule, característica importante para a execução da enxertia. Os porta-enxertos de nogueira-pecã com sistema radicular não podado e cultivado em saco plástico desenvolvem maior raiz principal e parte aérea. A poda do sistema radicular da nogueira-pecã, em recipientes e no solo, promove o aumento do número de raízes principais, mas diminui o comprimento das raízes das mudas.

Termos para indexação: *Carya illinoinensis*, produção de porta-enxertos, sistema radicular.

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Introduction

Commercial pecan orchards in Brazil comprise trees propagated by grafting whose crown cultivars were grafted on rootstocks propagated by seeds (FRONZA et al., 2018). Rootstocks are grafted and directly formed either in the soil (bare roots) or in recipients (potted roots) (POLETTO et al., 2015; BILHARVA et al., 2018). Pecan growth is affected by edaphoclimatic conditions and genetic characteristics, which are determined by both rootstocks and crown cultivars (CAO et al., 2019). Therefore, rootstock formation is a crucial step in quality rootstock production. Well-developed rootstocks depend on vigorous radicular systems which are associated with management conditions applied to plants and interfere with rootstock vigor (OLIVEIRA et al., 2020). Poor development and/or death of pecan rootstocks in the field may be directly related to bad formation of secondary roots (ZHANG et al., 2015).

In the process of rootstock production, certain problems may interfere with quality, such as root entanglement and successive cuts in roots while they are transplanted (seedbed-nursery-orchard). They may affect the dominance of taproots which may be replaced with fasciculate radicular systems that tend to concentrate on superficial horizons, a fact that contributes to make orchards vulnerable to environmental adversities (MENEZES et al., 2020).

In the developmental process of rootstocks with potted roots, the choice of containers must be based on size, longevity, handling, storage, transportation and market availability of rootstocks (CRUZ et al., 2016; PINHO et al., 2018). Besides, rootstock survival in the field must be considered, precocity must be promoted and production costs must be reduced. Some plastic packaging does not enable adequate radicular development and may lead to root entanglement at the bottom (VARGAS et al., 2011), a fact that may retard rootstock development. To avoid these deadlocks, alternative plastic tubes may be used because their internal grooves guide the thickest roots to the bottom of containers, as observed in the cases of several fruit trees.

Other techniques, such as root pruning, may be associated with the use of plastic tubes to grow rootstocks. According to Vargas et al. (2011), rootstock transplant, mainly when it is associated with root pruning, may change the pattern of rootstock growth. Radicular pruning may be considered an effective operation to reach adequate balance between vegetative and radicular growth (CARRA et al., 2017). Root pruning is not an advisable practice in some cases of fruit trees, such as jaboticaba, cherry of the Rio Grande and uvaia ones, since it interferes negatively with their survival and development in the field (HOSSEL et al., 2014). However, it is a promising practice in pecan farming since the radicular system of pecan trees is characterized as a pivot – composed of a dominant main root and lateral ones (GRAUKE, et al., 2016) –, pruning the main root may favor development of secondary roots (ZHANG et al, 2015), which are responsible for water and nutrient uptake.

Organic pecan production is a sustainable system and has become a market opportunity because nut differentiation and valuation make production attractive, even though its management is limited in terms of cultivars and control of diseases and pests (WELLS, et al., 2018; BOCK et al., 2019). In Brazil, studies have been carried out to improve cultivars that adapt to the system and have satisfactory production indexes (BRILHARVA et al., 2018). Barton is the main cultivar grown in Brazilian orchards since it adapts to the climate, tolerates scabs (*Venturia effusa*) and propagates easily (FRONZA et al., 2018).

Therefore, not only strategies for decreasing time needed to produce quality rootstocks have been developed but also the possibility of reducing production costs of pecan rootstocks grown in organic systems has been investigated. Thus, this study aimed at evaluating vegetative and radicular growth of rootstocks as the result of root pruning and use of different containers to produce pecan rootstocks.

Material and methods

The experiment was carried out in the experimental area at the Embrapa Clima Temperado in Pelotas, RS, Brazil (31°37’09”S, 52°31’33”W and altitude of 70 m), in 2018, 2019 and 2020. In the Köppen classification, the climate in the region is ‘Cfa’ – humid subtropical, i. e., it is humid temperate with hot summers (ALVARES et al., 2013).

In May 2018, seeds from the cultivar Barton were scarified by an angle grinder, stratified in wet sand boxes and taken to a cold chamber at 3ºC for 95 days. In mid-August, after they broke dormancy, seeds were placed on sand beds in a greenhouse so that they could germinate. On October 15th, 2018, fifty-three days after sowing, rootstocks were subject to the process of root pruning and then transplanted to containers and to the field to carry out the experiment.

The experiment was carried out in two conditions, using root pruning with containers using the substrate (simulating the production of containers rootstock) and another with pruning roots transplanted directly into the soil (simulating the production of bare-root rootstock).

The experiment had a completely randomized design in a 2x2 factorial scheme (two types of pruning and two containers) with 50 replicates. Twenty-five plants developed in the field were also individually evaluated and subject to treatments with and without pruning. The pruning factor consisted of rootstocks subject to root pruning and others that were not subject to any pruning. Root pruning, which was carried out by pruning shears, left 5 cm in length. Regarding containers, plastic tubes (15.0 x 15.0 x 35.0 cm) and plastic bags (49.0 x 10.0 cm) were used. They were filled with the Ecocitrus® commercial substrate and evaluated in 2019 and 2020. Rootstocks that grew in the field were evaluated in 2020. Plants were grown in a greenhouse with no environmental control at mean temperatures that ranged from 9.9°C (minimum) to 25.4ºC (maximum). Throughout the experiment, rootstocks were manually irrigated, depending on crop needs determined by the field capacity, i. e., once a week in cold and humid periods and daily in hot periods. Plants were neither subject to any phytosanitary treatment nor fertilization applied to soil and leaves.

To evaluate growth, 25 rootstocks per treatment were evaluated in July 2019 (280 days after transplant, before leaf drop) and 25 rootstocks were evaluated in February 2020 (480 days after transplant, when plants reached minimum grafting point). In the second period, it was also used for evaluating plants in the field, i. e., plants were 480 days old when they were evaluated, right after the transplant to the orchard soil. In the field, plants were neither subject to any phytosanitary treatment nor fertilization applied to soil and leaves. They were not irrigated, either. The orchard soil had been corrected and fertilized. Its chemical analyses (0–20 cm soil depth) showed the following characteristics: 5.5 pH (H2O), 2.5 mg.dm^3, 0.1 cmolc dm^{-3} aluminum, 4.1 cmolc dm^{-3} calcium, 1.3 cmolc dm^{-3} magnesium, 2.2 mg dm^{-3} phosphorus, 82 mg dm^{-3} potassium, 4.3 mg dm^{-3} iron, 1.1 mg dm^{-3} copper, 22.8 mg dm^{-3} manganese and 4.1 mg dm-^{3} zinc. The soil was moderately deep with medium texture in A horizon and clayish in B horizon, classified into Red Yellow Argisol (SANTOS et al., 2006).

The following variables were analyzed in plants throughout both years: height of the aerial part and length of primary and secondary radicular systems were measured by a metal tape measure (cm); stem diameter was measured by a digital pachymeter (mm) three centimeters above the substrate; leaf area was read by a LI-COR® - LI-300C area meter (cm2); and dry mass of the aerial part (stem, twigs and leaves) and of the radicular system (primary and secondary roots) was determined by a Bioscale electronic scale. Material (stem and leaves) (g) was dried in a forced air circulation oven at 65o C, up to constant weight.

Taking into consideration indicators of dry mass of the aerial part and roots, besides total dry mass, height and base diameter, rootstock quality was evaluated by the Dickson Quality Index (DQI), proposed by Dickson et al. (1960). DQI = TDM/(H/BD) + (DMAP/DMR), where TDM is total dry mass (g); H is plant height (cm); BD is base diameter (mm); DMAP is dry matter of the aerial part (g); and DMR is dry matter of roots (g). Resulting data were subject to the Analysis of Variance and means were compared by the Tukey's Test at 5% probability by the SISVAR statistical program version 5.6 (FERREIRA, 2014).

Results and Discussion

Two hundred eighty days after transplant, the number of roots was larger in rootstocks that were subject to root pruning in the transplant phase, mainly in the ones that were transplanted to plastic tubes (Table 1). No difference in number of roots was found between non-pruned rootstocks grown in plastic bags and plastic tubes. The radicular system is an important parameter to produce rootstocks since plants that have a large number and long roots exhibit good water and nutrient absorption which may improve rootstock development and survival in the field (SOUZA et al., 2018). Root pruning enables rootstocks to increase emission of new roots in every pruned extremity, thus, contact with the soil increases and favors water and nutrient absorption (FREITAS et al., 2009). One of the main functions of roots is nutrient absorption, but if elements have low mobility in the soil, such as phosphorus – needed for early rootstock growth in the field –, root pruning may favor their absorption along with other nutrients. Thus, root pruning was found to be an interesting practice in the search for increase in the radicular system.

Table 1. Main root number, secondary root length, plant height, leaf area and dry mass of the aerial part in pecan rootstocks grown in different containers and root management processes 280 days after transplant.

	Plastic bags	**Plastic tubes**
	Main root number	
With pruning	1.40aB	2.04aA
Without pruning	1.00bA	1.00bA
	Secondary root length (cm)	
With pruning	34.00aA	24.81bB
Without pruning	28.92bA	31.34aA
	Plant height (cm)	
With pruning	21.07aA	20.02bA
Without pruning	21.55aB	25.10aA
	Leaf area (cm²)	
With pruning	276.92bA	242.08aA
Without pruning	559.92aA	249.80aB
	Dry mass of the aerial (g)	
With pruning	4.66bA	4.74aA
Without pruning	8.36aA	4.86aB

Means followed by a certain small letter in a column and a capital one on a row do not differ by the Tukey's test at 5% significance.

Variation in length of secondary roots resulted from pruning and containers (Table 1). However, when roots are not pruned, growth of secondary roots is significantly similar, regardless of containers. Pruned rootstocks exhibited longer secondary roots in plastic bags by comparison with the ones in plastic tubes while non-pruned rootstocks had better performance in plastic tubes. Plants in plastic tubes with a non-pruned radicular system may have reached their bases faster, thus, growth of the main root may have stopped and growth of secondary roots may have been stimulated. In citrus, for instance, when the main pivot root reaches the basis of the plastic tube, there is swelling in the apical region and root ramification, followed by subdivision of the radicular system, the so-called morphological anomalies, caused by root guidance to the basis of the tube, where roots end up being exposed to growth restrictions imposed by its walls (BALDASSARI et al., 2003; TEIXEIRA et al., 2009). Such phenomenon may be seen if pecan rootstocks are kept longer in their plastic tubes than the period proposed by the experiment.

Pruned rootstocks grown in plastic bags increased their number of roots and length of secondary ones (Table 1). However, roots of rootstocks grown in plastic bags exhibited entanglement 280 and 480 days after transplant while plastic tubes enable growth interruption due to their base narrowness. Equidistant grooves in plastic tubes aim at guiding roots to the bottom of containers and at avoiding deformation in the radicular system, such as entanglement and bending of the taproot (ALVES et al., 2020). Entangled roots must be pruned again when they are planted to avoid damage to rootstock growth. Root entanglement is not desirable because it causes stress to rootstocks (PINHO et al., 2018). According to Vargas et al. (2011), root entanglement resulting from rootstock production in plastic bags is harmful to rootstock development after planting since it retards both root fixation in the soil and early growth.

Rootstocks were higher on rootstocks that were not pruned when they were transplanted. Significance was only found in plastic bags 280 days after transplant (Table 1). This result may be related to the fact that when rootstocks are pruned, plants use energy resources to emit new roots. The use of plastic bags led to rootstocks with a large leaf area and dry mass of the aerial part when root pruning was not carried out (Table 1). In plastic tubes, these variables did not exhibit any significant difference, regardless of pruning (Table 1).

Main root length and dry mass of roots were not affected by root pruning when rootstocks were transplanted. Neither variable nor stem diameter exhibited any significance related to containers (Table 2). However, main root length and dry mass of roots were significantly higher 280 days after transplant when rootstocks grew in plastic bags (Table 2). Increase in main root growth may be related to the capacity and length of the container since a plastic bag is 50 cm high and a plastic tube is 35 cm high, thus, influencing root mass. The largest containers usually lead to better development of variables that refer to the aerial part (height, stem diameter and dry mass of the aerial part) and production of total dry mass (FERREIRA et al., 2017).

Table 2. Stem diameter, main root length and dry mass of roots in pecan rootstocks grown in different containers and root management processes 280 days after transplant.

Pruning	Stem diameter(mm)	Main root length (cm)	Dry mass of roots (g)
With pruning	4.99^{ns}	44.36^{ns}	17.14^{ns}
Without pruning	5.14	44.36	19.48
$F_{pruning}$	0.3542	0.9665	0.2205
Containers			
Plastic bags	5.06^{ns}	51.82a	20.10 a
Plastic tubes	5.08	37.00b	16.32 b
$F_{containers}$	0.9143	0.0001	0.0484
$F_{pruning\ x\ containers}$	0.6724 ^{ns}	0.9665 ^{ns}	0.2183 ^{ns}

Means followed by different letters in a column differ by the Tukey's Test at 5% error probability.

Concerning rootstocks subject to containers and pruning, the ones whose radicular system was not pruned and were placed in plastic bags exhibited the longest main roots and the highest dry mass of roots (Table 3). Pecan trees are classified into phreatophytes since, in their native habitat; they develop roots that search for the water table (SPARKS, 2005). Their radicular systems consist mainly of a main root with more fragile lateral roots in the early developmental phases (ZHANG et al., 2015). As a result, root pruning may be a technique that helps lateral roots to develop at early rootstock development.

Table 3. Means of the Dickson Quality Index (DQI) in pecan rootstocks grown in different containers and root management processes 280 and 480 days after transplant.

	DQI	
Pruning	280 days after transplant	480 days after transplant
With pruning	4.92^{ns}	8.86^{ns}
Without pruning	5.51	9.32
$F_{pruning}$	0.6720	0.6930
Containers		
Plastic bags	5.48^{ns}	11.26a
Plastic tubes	4.95	6.92b
$F_{containers}$	0.2126	0.0001
$F_{pruning\ x\ containers}$	0.3540	0.4450

Means followed by different letters in a column differ by the Tukey's Test at 5% error probability.

Regardless of radicular system management, rootstocks grown in plastic bags exhibited high radicular development. These results also reflected on increase in leaf area and dry mass of the aerial part (Table 3). It may also be the effect of the fact that rootstocks in plastic tubes stop their root growth at the bottom of containers. However, non-pruned rootstocks in plastic bags enable taproots to develop and increase volumes of root mass and aerial parts (leaf area and mass of aerial part).

Pecan rootstocks are not affected by root pruning when they are placed in plastic tubes (Table 3) since they also exhibit radicular and vegetative development in terms of main root length, dry mass of roots, dry mass of aerial part and leaf area. It suggests that rootstocks developed in these containers exhibit high balance between their radicular systems and aerial parts. In the case of forest species, the use of plastic tubes outperforms the use of plastic bags not only because the former are easier to operate and require less workforce but also because rootstock transportation costs to the field are lower (LISBOA et al., 2014).

Stem diameter is an important indicator to determine pecan grafting point. However, this study shows that types of containers and/or root pruning do not affect stem diameters of pecan rootstocks (Tables 2 and 4). Regarding the DQI, there were no interactions among factors under study (Table 3). The factor pruning did not influence the significant increase in the index in evaluations that were carried out 280 and 480 days after transplant. However, when the factor container was evaluated separately, results showed that rootstocks grown in plastic bags had high DQIs 480 days after transplant.

Root pruning of pecan rootstocks influenced their height. When rootstocks were not subject to root pruning, they were higher than the pruned ones (Table 4). Four hundred and eighty days after transplant, root pruning led to a large number of roots, but plant height was not altered (Table 4).

Table 4. Main root length, dry mass of roots, leaf area and dry mass of the aerial part in pecan rootstocks grown in different containers and root management processes 480 days after transplant.

	Plastic bags	**Plastic tubes**
	Main root length(cm)	
With pruning	54.64bA	37.00aB
Without pruning	64.98aA	37.00aB
	Dry mass of roots(g)	
With pruning	33.38bA	25.38AA
Without pruning	46.99aA	21.86aB
	Leaf area (cm²)	
With pruning	744.44bA	523.36aB
Without pruning	1060.04aA	372.16aB
	Dry mass of the aerial (g)	
With pruning	11.26bA	10.27aA
Without pruning	15.61aA	9.69aB

Means followed by different letters in a column differ by the Tukey's Test at 5% error probability.

Concerning the effect of root pruning on rootstocks that were transplanted directly to the soil, their height, stem diameter and leaf area had no relation with pruning (Table 5). However, pruning was found to be responsible for increasing the number of roots significantly, while it showed negative significance of the main root, dry mass of the aerial part, dry mass of roots and the DQI.

Table 5. Plant height, stem diameter, secondary root length and number of roots in pecan rootstocks grown in plastic bags and tubes 480 days after transplant.

Pruning	Plant height (cm)	Stem diameter(mm)	Secondary root length (cm)	Number of roots
With pruning	27.95b	6.54^{ns}	33.51^{ns}	1.76a
Without pruning	33.19a	6.69	36.00	1.10b
$F_{pruning}$	0.0042	0.4869	0.4199	0.0001
Containers				
Plastic bags	30.60^{ns}	6.78^{ns}	33.55^{ns}	1.40^{ns}
Plastic tubes	30.54	6.46	36.00	1.46
$F_{containers}$	0.9670	0.1447	0.5004	0.5883
$F_{pruning\ x\ containers}$	0.2369^{ns}	0.7248^{ns}	0.7349^{ns}	0.8562^{ns}

Means followed by different letters in a column differ by the Tukey's Test at 5% error probability.

In the field experiment, when pecan rootstocks are subject to root pruning, they exhibit low development of the main root and low dry mass of roots by comparison with non-pruned ones, a fact that reflects on low dry mass of aerial parts of plants (Table 6). ZHANG et al. (2015) reported that, when pecan rootstocks are pruned, they develop a compact and fibrous radicular system. This effect, which was found in pruned rootstocks, with a little main root and more secondary roots, may be lessened by the fact that the finest roots are responsible for water and nutrient absorption and may influence plant height positively in the future. Secondary roots are responsible for most water and nutrient absorption, thus, production of rootstocks with fewer secondary roots may lead to a low survival rate of plants after cultivation. Therefore, root pruning is advantageous to quality rootstock production. Since the choice of containers is an important factor to produce quality rootstocks, further studies of large packaging should be carried out to produce pecan rootstocks.

Table 6. Plant height, stem diameter, leaf area, main root length, number of roots, dry mass of the aerial part and of roots and the Dickson Quality Index (DQI) in pecan trees grown in the soil 480 days after transplant.

Pruning	Plant height (cm)	Stem diameter(mm)	Leaf area(cm²)	Main root length(cm)
With pruning	27.95^{ns}	3.33^{ns}	951.75^{ns}	69.90b
Without pruning	25.18	3.51	1183.6	113.92a
$F_{pruning}$	0.4529	0.6575	0.1870	0.0001
Pruning	Number of roots	Dry mass of the aerial part	Dry mass of roots (g)	DQI
With pruning	1.65a	13.46b	47.13b	7.10b
Without pruning	1.00b	51.55a	75.76a	15.08a
$F_{pruning}$	0.0463	0.0168	0.0374	0.0001

Means followed by different letters in a column differ by the Tukey's Test at 5% error probability.

Even though further studies are needed to know the relation between pruning of the radicular system and its survival and performance throughout time, the analysis of total data showed that there is a trend to make beneficial effects on rootstock development occur with pruning of the radicular system, mainly favoring growth of secondary roots, a fact that may lead quality plants. According to Sparks (2005), root development on the soil surface ensures nutrient absorption from the richest layer of the soil and, when the inferior profile of the soil is saturated, it promotes aeration and absorption of water and nutrients by roots. Quedraogo et al. (2018) reported that survival and the resilience of rootstock to transplant stress depends on their ability to produce a root system rapidly that is capable of invading the new. According to these authors**, s**hoot growth was slowed during the first year for trees with taproot pruned and potting medium removed, but there was no significant effect over the entire 4-year period. Results show the trees were largely resilient to their transplanting method.

Conclusion

Neither containers nor root pruning affects stem diameters.

Pecan rootstocks with non-pruned radicular systems grown in plastic bags develop large main roots and aerial parts.

Pruning of pecan radicular systems of rootstocks grown in containers and in the soil leads to a high number of secondary roots but decreases the sizes of the main ones.

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