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Impact of Different Pruning Practices on Height Growth of Paulownia Clon in Vitro 112®

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Abstract: We focused on the ability of one-year-old and two-year-old plants of Paulownia Clon in vitro 112® to sprout and grow branches, and on their pruning for their best possible growth on a plantation in Střelice u Brna. Furthermore, we carried out pruning on selected parts that comprised: spring pruning; reduction in the angle between the stem axis and one new growing sprout; and year-long pruning. The sprouting capacity of Paulownia was high—up to 56% (one-year-old plants) and 50% (two-year-old plants). Branches grew on 34% of all one-year-old plants and on 57% of all two-year-old plants. The best possible spring pruning method seems to be the keeping of one stem sprout or one stump sprout for one-year-old plants and one stem sprout for two-year-old plants. The newly growing stem sprout should be formed by bandaging it to the stem, and, as a result of this, the angle between the stem and the sprout can be reduced to 20° in contrast to 50° when the sprout is not bandaged. Our results suggest that it is best to take off the lower $^1/_3$ of the branches and leaves, which leads to faster height growth of the plant.

Keywords: spring pruning; year-long pruning; branching; angle diversion of sprout

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1. Introduction

Paulownia spp. Siebold & Zucc. is a fast-growing deciduous tree; it can grow up to a height of 12 to 30 m [1] and can reach a stem diameter of around 1 m at breast height [2]. The area of origin of *Paulownia* spp. is China [3], Laos and Vietnam [4]. It was first used as a decorative tree in other areas such as Japan and the Korean peninsula [2]. Today, it grows on all continents, except for Antarctica. The first time that *Paulownia tomentosa* was planted in the region of today's Czech Republic (CR) was in 1844 [2].

New types of hybrids were made from original Paulownias, especially to increase timber production. This hybrid clone cultivation widened the ecological valence and spread its growth beyond its original habitat. These new types of hybrids were planted in the CR in the past ca. 10 years [5]. Paulownia Clon in vitro 112® has high resistance to extremely low temperatures down to −25 °C [6] and shows high adaptability to local climatic conditions [7]; therefore, it seems to be the best choice for the CR. Additionally, Paulownia Clon in vitro 112® grows faster compared to other Paulownia hybrids, and its volume is around 0.3 m^3 after three years from planting [6]. Its wood is easy to work (with) and therefore suitable for carving [8], and it can be used to produce wood fiber products or for cellulose and biofuel production [9], for building construction [10] and in the energy and sawmill industries [11].

Based on information from Zhao-Hua et al. [12], it forms thick branches already on two-year-old plants after the first winter period. Furthermore, it has a tendency to form many widely spread branches, if grown in an open space [6]. Trees of Paulownia are always planted in open spacing in plantations (for example, according to UCLM [13], 5 × 5 m for sawmill logs or 3.3 × 1 m for biomass). Another factor influencing the growth habit is damage to the buds (i.e., the apical bud, similar to the second to fourth pairs of axillary buds) caused by frost, which is typical for Paulownia [12]. The frost can be early, late [14] or hard frost [15]. All these types of frost can cause damage, which leads to hormonal imbalance, thanks to which the surviving lateral buds accelerate their growth, and the sprouts originating from them take over the function of the dead apical sprout [12,16]. As a rule, only one of the newly formed lateral sprouts is significantly dominant and assumes the function of a terminal sprout, and the other sprouts turn into branches. However, in the event of unclear dominance, multiple terminal sprouts occur [17]. Moreover, Paulownia is a plant with a very strong sprouting ability [12] to create root, stem [18] and stump sprouts [6]. With only a few exceptions, the root and stem sprouts appear on the trees every year, and frost damage to the trees in their first years after planting stimulates the formation of both types of sprouts. Due to a combination of these factors, the stem can become crooked, and we could say that it manifests bushy (broom-like) growth, which was described by Narovcová et al. [17].

This is why pruning is applied to attain an upright stem without sprouts and branches in the lower part of the tree [19,20]. There can be two different types of pruning. The first type is applied for the formation of the tree habit in the way that undesirable newly created sprouts are removed (i.e., "spring pruning"). These sprouts come in three types: root sprouts, which grow from adventitious buds on the roots [21]; stump sprouts, which grow in multiple places around the edge of stump sprouts [22]; and stem sprouts, which grow from adventitious buds on the stem [23]. When all the sprouts are left to grow, a tree with multiple stems growing from the roots, stem or stump is formed, and such a tree grows more slowly and creates dense bushy growth. The occurrence of multiple stems can be successfully reduced via spring pruning [24], and the newly formed tree consists of one strong terminal sprout [25]. The second type is the elimination of the leaves and branches at the start of or during the vegetation period (i.e., "year-long pruning"). Open-space-planted Paulownia, such as *Eucalyptus nitens* (H.Deane & Maiden) Maiden, generates and retains large branches and, due to this, does not produce sawlog, veneer-quality timber [26] or knot-free timber known as clearwood [27]. Year-long pruning is carried out for the purpose of increasing wood quality [26,27] and, also, accelerating the height increment [28]. However, severe year-long pruning can reduce height growth and have a negative impact on the quality of the wood [29,30].

The reason why we researched the ability of young Paulownia trees to generate sprouts and branches and compared the effects of spring and year-long pruning was to grow trees with upright stems and crowns set high, which is lucrative, especially for plantation growing.

We investigated the following:

- Whether one-year-old and two-year-old plants produce branches and root, stem and stump shoots, and, if yes, how many.
- Whether bandaging of the stem sprout to the stem influences the straightness of the stem while pruning—we tried to reduce the angle between the axis of the original stem and that of the new sprout.
- Whether it is possible to achieve a greater height growth of the tree in the event that a different type of sprout (stem, stump, root) is supported after apical bud frost injury (i.e., spring pruning).
- Whether the plant grows faster with year-long pruning (i.e., the removal of different volumes of branches and leaves).

2. Materials and Methods

The research plot was situated on a private, fenced, agricultural area in Střelice u Brna (49°15′460.56″ N; 16°47′179.14″ E) with an altitude of around 300 a.s.l. and a slope from 0 to 10°. The soil is Cambisol with a loam soil texture; it contains about 1.6% organic matter, has a pH/KCl of around 6.3 and pH_{H_2O} of about 7.1 and goes down to a depth of 110 cm. In 2018, the average yearly air temperature was 8.3 °C, the minimum yearly air temperature was −10.2 °C and the annual rainfall was 448 mm [31]. The plantation was established with ramets of Paulownia Clon in vitro 112®, which were bought from the company Oxytree Solution s.r.o., which is registered in the CR [32].

Paulownia Clon in vitro 112® is a hybrid that originated as a natural cross between *Paulownia elongata* S.Y.Hu and *P. fortunei* (Seem.) Hemsl., and the newly created plants, which had the required properties, were reproduced using the in vitro method in order for their cultivated properties to be maintained [33]. This hybrid was created in the laboratory of the company IN VITRO S.L. (Sant Feliu de Llobregat, Spain), and the World Intellectual Property Organization has given it the trademark application number of 1,181,727, expiration date 25 September 2023 [34]. The adaptability of this hybrid to various soils and climates was tested by the University of Castilla-La Mancha [35].

A total of 686 in vitro container-grown ramets (height: 20 ± 2 cm; root neck thickness: 5 ± 1 mm; mean ± SD) were planted in 2016 and 737 in 2017, with a spacing of 4 × 4 m. After the planting of the ramets, we referred to them as plants. Each plant was assigned a unique code according to the row and its position in each for improved identification during the measurements.

We performed three experiments in the plantation to better document the natural development of one- and two-year-old trees without any silvicultural treatments and the influence of pruning on the heights of the plants.

Gardening shears were used for cutting off the above-ground part of the plant. Spring pruning and year-long pruning were carried out with the use of a sharp knife (or pruning shears), in accordance with Arborist Standards [36]. Cut wounds were not treated and were left to heal naturally. The height of the plant and the length of the sprout were measured with a folding rule, and the angles between the rest of the stem and the sprouts were measured using a protractor.

2.1. Spring Pruning

The height was measured on all plants in February 2018. Those that were chosen in each of the two years (i.e., 125 one-year-old plants and 125 two-year-old plants) were all within a specified range of heights and thicknesses, close to the average (Table 1). The ground around each of these plants was marked with a color spray so that the plant was easy to find for each successive measurement.

Before the start of the vegetation period (the 70th day of the year (DOY)), we performed spring pruning in five variants on the plants with frost-damaged stems planted in 2016 and in five variants on the plants planted in 2017, where each variant was conducted on 25 plants:

- Stump pruning, where the plant was cut on the 70th DOY (leaving a maximum 5 cm stump) and, on the 100th DOY, the thickest stump sprout was left, and all the other sprouts were removed (Figure 1).
- Root pruning, where the plant was cut on the 70th DOY (leaving a maximum 5 cm stump) and, on the 100th DOY, the thickest root sprout was left, and all the other sprouts were removed (Figure 1).
- Stem pruning, where, on the 100th DOY, the thickest stem sprout was left, and the rest of the plant (approximately 10 cm above that sprout) was removed, together with all the other sprouts. Stem pruning was carried out in two different ways:
    - Stem pruning without bandaging, where the sprout that was saved was not bandaged to the remaining part of the stem (Figure 1).
    - Stem pruning with bandaging, where the sprout that was saved was bandaged to the remaining part of the stem to ensure straight growth (Figure 1).
- Reference plant, where the plant with sprouts was left to grow naturally (Figure 1).

Table 1. Average values of the heights of the trees and the thicknesses of the stems measured 10 cm above the ground for experimental trees, and the statistical significance of the differences in these parameters between the variants.

Experiment	Variant	Average Height (±SD) [cm]	SS	Average Thickness (±SD) [mm]	SS
		Plants planted in 2016			
Spring pruning	Stump	72.5 (±24.9)	Ns	17.6 (±5.6)	ns
	Root	72.6 (±28.2)	Ns	17.4 (±6.1)	ns
	Stem with bandaging	75.2 (±19.1)	Ns	16.8 (±5.4)	ns
	Stem without bandaging	74.6 (±18.6)	Ns	17.9 (±4.8)	ns
	Reference plant	76.0 (±17.9)	Ns	16.0 (±4.2)	ns
Year-long pruning	Pruning $^{1}/_{3}$	77.5 (±22.7)	Ns	18.9 (±5.0)	ns
	Pruning 2/3	74.9 (±20.3)	Ns	17.1 (±5.1)	ns
	Regular pruning	73.4 (±19.7)	Ns	15.9 (±5.2)	ns
	Reference plant	72.8 (±21.2)	Ns	17.8 (±4.5)	ns
		Plants planted in 2017			
Spring pruning	Stump	61.6 (±14.4)	Ns	12.2 (±4.6)	ns
	Root	62.3 (±18.4)	Ns	12.4 (±6.3)	ns
	Stem with bandaging	64.6 (±15.7)	Ns	11.3 (±4.2)	ns
	Stem without bandaging	63.6 (±16.6)	Ns	12.4 (±4.1)	ns
	Reference plant	62.1 (±15.1)	Ns	12.3 (±4.9)	ns
Year-long pruning	Pruning $^{1}/_{3}$	62.4 (±13.6)	Ns	12.4 (±4.1)	ns
	Pruning 2/3	64.1 (±11.5)	Ns	13.4 (±4.7)	ns
	Regular pruning	62.3 (±12.8)	ns	13.1 (±4.5)	ns
	Reference plant	62.1 (±14.3)	ns	12.9 (±4.5)	ns

SD—standard deviation; SS—statistical significance; ns—no statistical significance (p = 0.95).

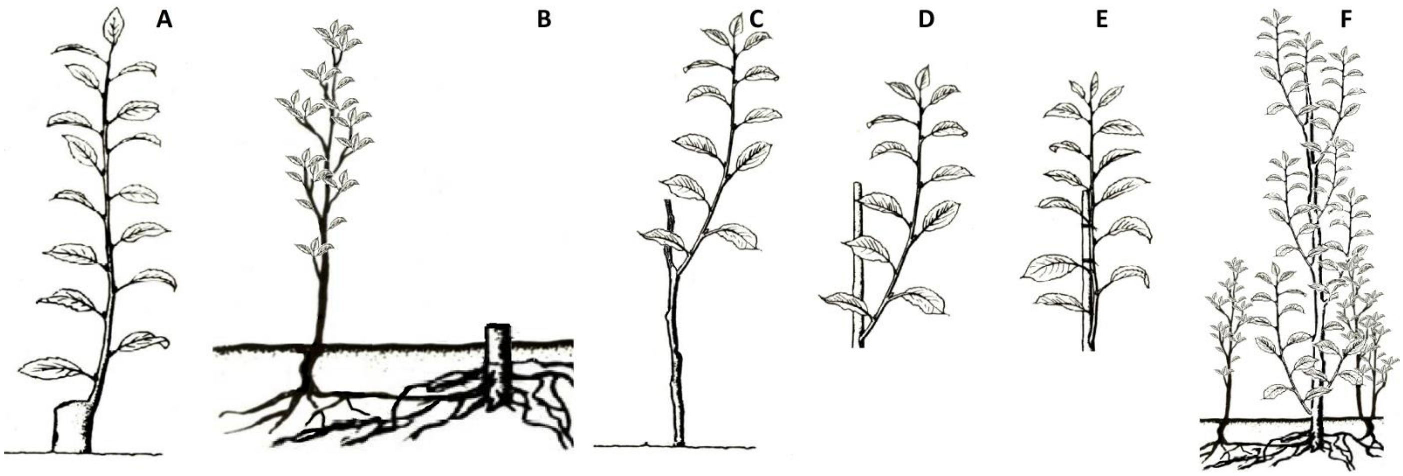

Figure 1. Line drawings of the variants of spring pruning (**A**—stump pruning; **B**—root pruning; **C**—stem pruning; **D**—stem pruning without bandaging; **E**—stem pruning with bandaging; **F**—reference plant).

The height of the entire plant and the length of the sprout that was left to grow were measured on the 100th DOY. The angle diversion between the rest of the stem (i.e., the stem axis) and the axis of the sprout that was left to grow was also measured—the smaller the angle between the stem axis and the sprout axis, the smaller the sprout diversion from the rest of the stem. The stem sprout (in this variant) was bandaged to the rest of the stem with a jute cord, and a paper bag was inserted between the sprout and the jute cord to protect the sprout. The height of the plant was measured repeatedly at about one-month intervals during the entire vegetation period. The sprout bandage was removed for the time of the measurement, the diversion angle of both stem variants was measured (with and without bandaging) and the sprout was re-bandaged after measurement. The last measurement of the height of the plant was carried out on the 301st DOY, the bandage was permanently removed and the angle between the rest of the stem and the sprout that was left to grow was also measured.

We used the length of the new sprouts for a better comparison of the spring pruning results, instead of the total height of each plant. We deducted the height of the stump and/or stem from the growth from the previous year (or two years) from the total plant height.

2.2. Year-Long Pruning

The height was measured on all plants in February 2018. Those that were chosen in each of the two years (i.e., 100 one-year-old plants and 100 two-year-old plants) were all within a specified range of heights and thicknesses, close to the average (Table 1). The ground around each of these plants was marked with a color spray so that the plant was easy to find for each successive measurement.

Year-long pruning proceeded on the 70th DOY: the above-ground part of the chosen plant was removed (leaving stumps with heights not exceeding five centimeters). After 30 days from the date of removal, the strongest stump sprout was left, and all other new stump sprouts or new root sprouts were removed. Year-long pruning was carried out in four variants on the plants planted in 2016 and on the same number of those planted in 2017 (Table 1). Each variant was conducted on 25 plants. These variants were as follows:

- Pruning $^{1}/_{3}$, where the lowest $^{1}/_{3}$ of the leaves and branches was removed from the plant on the 151st DOY.
- Pruning 2/3 , where the lowest 2/3 of the leaves and branches were removed from the plant on the 151st DOY.
- Regular pruning, where the lowest leaves were removed from the plant (on the 151st DOY), so only the last four rows of the leaves growing opposite each other remained, and each began regular removal of leaves approximately 14 days from this date.
- Reference plant, where the plant with sprouts was left to grow naturally.

The height of the entire plant (including the stump) and the length of the new growing sprout were measured on the 100th DOY. At approximately one-month intervals from this date, the heights of all of the plants were measured. On the 151st DOY, the first removal of leaves and branches was carried out on the plants with the pruning $^{1}/_{3}$, pruning 2/3 and regular pruning variants. When measuring the heights of the plants, in the cases where there were more than the last four rows of pairs of leaves growing opposite each other, the bottom rows of leaves were removed using the regular pruning variant. The measurements were carried out until the 301st DOY, when the last measurement of the plant height was conducted on the plants with year-long pruning.

For a better comparison of the results of the year-long pruning, we used the length of the new sprouts instead of the total height of each plant, so we deducted the height of the stump from the total plant height.

2.3. Sprouting Capacity and Branching

The plantation owner removed the above-ground parts of all one-year-old and two-year-old trees (which were not used for spring and year-long pruning) on the 70th DOY. The thickest stump sprout was left, and all other sprouts were removed on the 100th DOY. From this date, the owner did not perform any silvicultural treatment, and the plants were left to grow naturally. We recorded the numbers of newly emerged stem, stump and root sprouts and branches (i.e., “sprouting capacity and branching”) on 270 of the plants planted in 2016 and on 423 of those planted in 2017 (i.e., on a total of 693 plants). The stump sprouts, stem sprouts, root sprouts and branches on each of the plants were counted on the 301st DOY. Consequently, the plants were sorted into groups based on the numbers of root, stem and stump sprouts, and also on the numbers of branches that were found on each plant (0—no sprout/branch; 1—one sprout/branch; n—n sprouts/branches). Sprouting capacity and branching were investigated, also according to the age of the plant, because those planted in 2016 were two years old at the time, and those planted in 2017 were one year old.

Statistical data were evaluated in TIBCO Statistica™, with a reliability interval of 95%. The Shapiro–Wilk test was employed to find out the data dispersion normality and homogeneity. Analysis of variance (ANOVA) was used to evaluate the suitability of the annual and biennial plants selected for spring pruning and year-long pruning. The nature of the results of the experiment did not make it possible for parametric testing to be applied for the evaluation of the differences; therefore, the Kruskal–Wallis non-parametric test was employed next, after which the Dunn test was applied to identify differences among the main effects and interactions.

3. Results

3.1. Spring Pruning

On the 186th DOY, stump sprouts (56 ± 6 cm; average length ± SD) and stem sprouts (with bandaging 50 ± 2 cm; without bandaging 49 ± 4 cm) grew best on the one-year-old plants (Figure 2). These differences between the first group (of stem sprouts with/without bandaging and the stump sprouts) and the second group (of root sprouts and the reference plants) on the one-year-old plants grew with each new measurement during the season. During the last measurement (the 301st DOY), the average length of the stem sprouts without bandaging was 119 ± 7 cm, that of the stem sprouts with bandaging was 115 ± 6 cm and that of the stump sprouts was 114 ± 8 cm. These lengths were statistically different from those of the root sprouts and reference plants. Percentage differences among the individual variants are presented in Table 2.

Table 2. Percentage differences and statistically significant values among the spring pruning variants of one- and two-year-old plants. The percentages indicate how much shorter the sprout named in the row is, compared to that named in the column, e.g., the reference plant was 46% shorter than the stem sprout with the bandaging.

One-year-old plants				
DOY	Variant	Stem sprout with bandaging	Stem sprout without bandaging	Stump sprout
186th	Reference plant	46% (p = 0.0001)	44% (p = 0.0018)	52% (p = 0.0001)
	Root sprout	30% (p = 0.0062)	28% (p = 0.0058)	38% (p = 0.0086)
301st	Reference plant	46% (p = 0.0001)	48% (p = 0.0001)	45% (p = 0.0001)
	Root sprout	49% (p = 0.0009)	51% (p = 0.0001)	48% (p = 0.0001)

Two-year-old plants					
DOY	Variant	Stem sprout with bandaging	Stump sprout	Stem sprout without bandaging	Root sprout
186th	Stem sprout without bandaging	24% (p = 0.0058)			
	Stump sprout	22% (p = 0.0068)			
	Root sprout	42% (p = 0.0032)	26% (p = 0.0075)	24% (p = 0.0089)	
	Reference plant	61% (p = 0.0004)	50% (p = 0.0032)	48% (p = 0.0002)	32% (p = 0.0045)
301st	Stem sprout without bandaging	14% (p = 0.0174)			
	Root sprout	19% (p = 0.0168)			
	Stump sprout	18% (p = 0.0423)			
	Reference plant	54% (p = 0.0021)	44% (p = 0.0023)	46% (p = 0.0025)	43% (p = 0.003)

DOY—day of year.

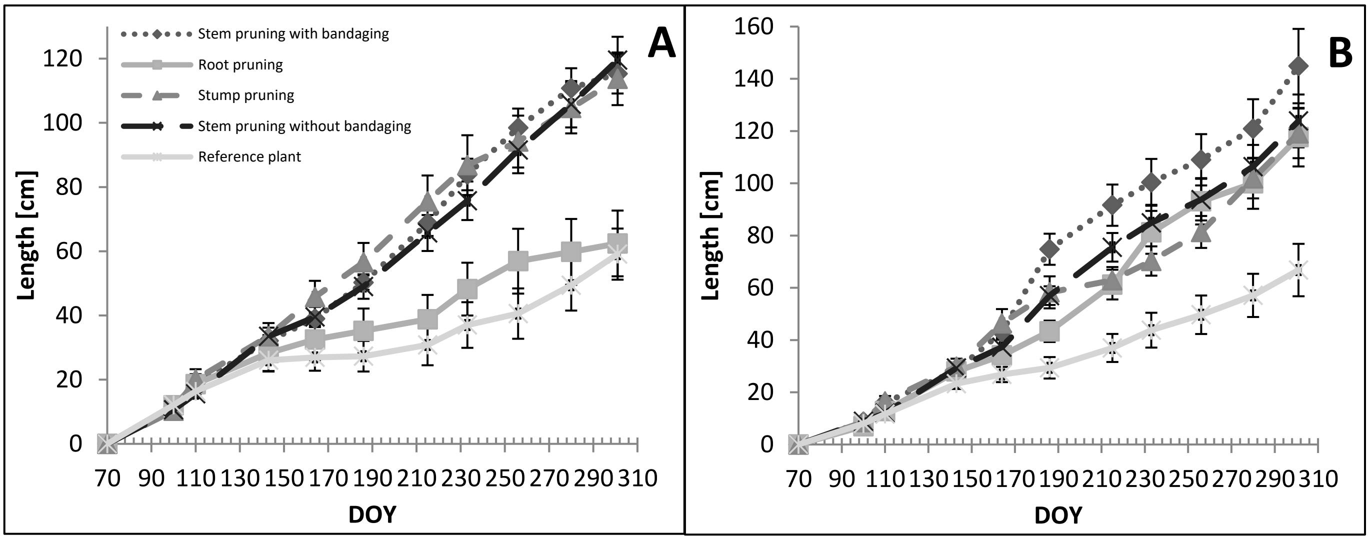

Figure 2. Average sprout length. **A**—one-year-old plants; **B**—two-year-old plants. Whiskers denote SD.

On the 186th DOY, we divided the two-year-old-plant results into four groups, based on statistical significance (Figure 2). The best growth was found on the stem sprouts with bandaging (75 ± 6 cm). The stump sprouts and the stem sprouts without bandaging made up the second group of the longest sprouts. The root sprouts made up the third group, and the reference plants created the last group. The order of the groups changed during the measurement period. On the 301st DOY, it was possible to divide the average sprout lengths into three groups, based on their statistical differences. The longest sprouts were stem sprouts with bandaging (145 ± 14 cm), and they made up the first group. The stump sprouts and the stem sprouts without bandaging created the second group. The reference plants made up the last group. Percentage differences among variants are presented in Table 2.

We conducted an experiment on the stem sprouts to change the angle diversion from the straight-stem axis (Figure 3). The closer the top of the sprout to the stem axis, the straighter the alternative apical sprout. On the 100th DOY, the angle diversion was similar: one-year-old plants with bandaging 59 ± 5°, without bandaging 61 ± 4°; two-year-old plants with bandaging 58 ± 4°, without bandaging 59 ± 4°.

The difference in the angle diversion on the one-year-old plants became visible on the 143rd DOY. The stem sprout with bandaging had an average angle of 47 ± 4°, which was about 16% smaller than that of the stem sprout without bandaging (p = 0.0047). On the 301st DOY, the average angle of the stem sprout with bandaging was 21 ± 4°, and it was about 51% smaller than the other (p = 0.0003).

The measured results on the two-year-old plants were similar to those on the one-year-old plants. The difference in the angle diversion became visible from the 143rd DOY. The stem sprout with bandaging had an angle of 49 ± 4°, and it was about 16% smaller than the average angle on the stem sprout without bandaging (p = 0.0326). On the 301st DOY, the difference between both variants was 37% (p = 0.0031), and the sprout which was straighter was the one with bandaging (29 ± 5°).

In addition, we compared what influence the age of the plant had on the angle diversion. At the start of the measurement, there were no statistical differences in the angles between the ages of the plants or the variants of bandaging. On the 301st DOY, the difference in angle diversion of the sprout without bandaging was 13% (p = 0.0498), where the average angle of the one-year-old plants was smaller than that of the two-year-old plants. Additionally, the average angle diversion of the sprout with bandaging was different. On the 301st DOY, the difference in the angle between the one-year-old and two-year-old plants was 29% (p = 0.0254), where the average angle of the one-year-old plants was smaller (21 ± 4°) than that of the two-year-old plants.

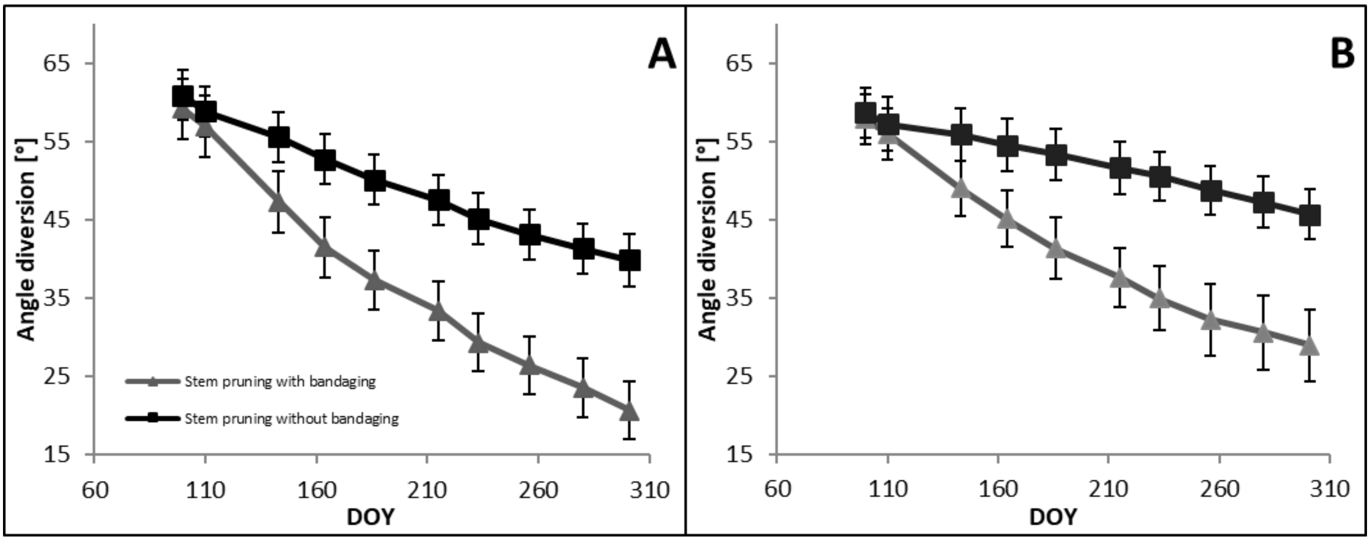

Figure 3. Average angle diversion between substitute stem sprout and stem axis. **A**—one-year-old plants; **B**—two-year-old plants. Whiskers denote SD.

3.2. Year-Long Pruning

The start of growth was the same for all variants of the one-year-old plants (Figure 4). We found three statistical groups on the 186th DOY. The plants with the pruning 1/3 variant (84 ± 6 cm) had the longest average sprout. The plants with the pruning 2/3 variant and the reference plants had the second longest sprout and created the second statistical group. The plants with regular pruning made up the third statistical group. The statistical groups were the same on the 301st DOY as on the 186th DOY. The plants with the pruning 1/3 variant (157 ± 7 cm) had the longest average sprout, and those with the pruning 2/3 variant and the reference plants had the second longest. The plants with regular pruning made up the third statistical group.

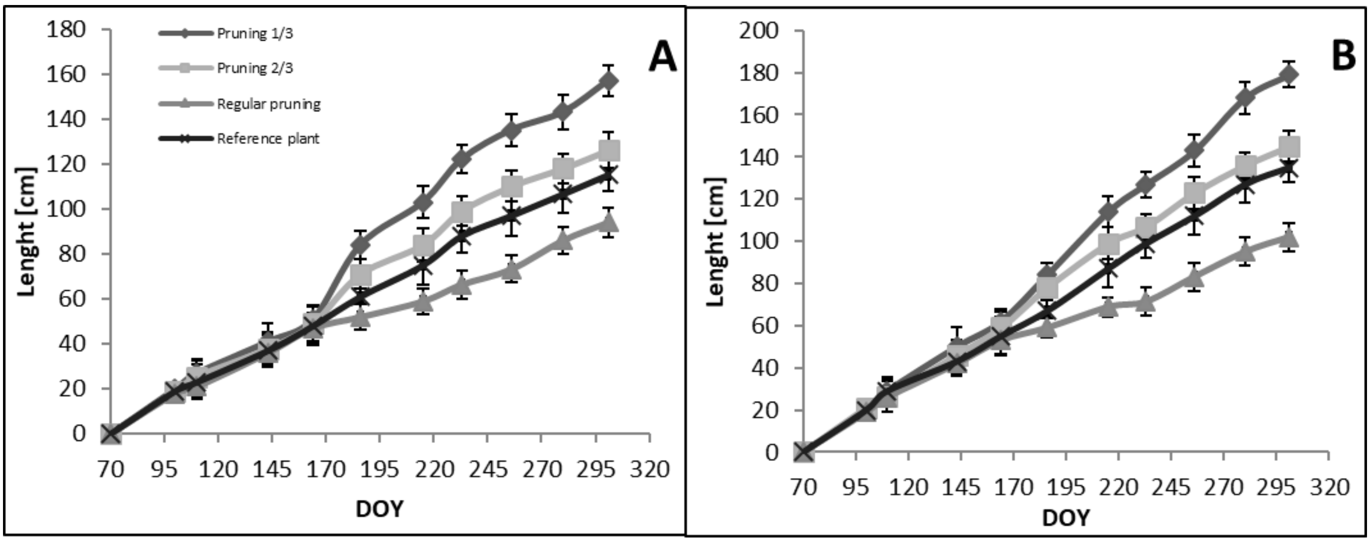

Figure 4. Average length of sprouts supplying stems during the vegetation period according to the variant of year-long pruning (1/3 pruning, 2/3 pruning, regular pruning and reference plants). **A**—one-year-old plants; **B**—two-year-old plants. Whiskers denote SD.

The start of growth was the same for all variants of the two-year-old plants (Figure 4). The first measurement that revealed visible differences was carried out on the 186th DOY and showed statistically significant differences among the variants. The plants with the pruning $^{1}/_{3}$ variant (84 ± 6 cm) and those with the pruning $^{2}/_{3}$ variant (78 ± 6 cm) created the first statistically homogenous group, and the plants with regular pruning and the reference plants created the second statistically homogenous group. The last measurement (on the 301st DOY) showed that the plants with the pruning $^{1}/_{3}$ variant (179 ± 6 cm) had the longest average length. The plants with the pruning $^{2}/_{3}$ variant and the reference plants made up the second statistical group. The plants with regular pruning created the third statistical group. Percentage differences among the variants are presented in Table 3.

Table 3. Percentage differences and statistically significant values among the year-long pruning variants of one- and two-year-old plants. The percentages indicate how much shorter the sprout named in the row is, compared to that named in the column, e.g., the sprout with $^{2}/_{3}$ pruning was 15% shorter than that with $^{1}/_{3}$ pruning.

		One-year-old plants		
Day of year	Variant	$^{1}/_{3}$ pruning	$^{2}/_{3}$ pruning	Reference plant
186th	$^{2}/_{3}$ pruning	15% (p = 0.0365)		
	Reference plant	27% (p = 0.0097)		
	Regular pruning	38% (p = 0.0071)	27% (p = 0.0104)	14% (p = 0.0345)
301st	$^{2}/_{3}$ pruning	20% (p = 0.0145)		
	Reference plant	27% (p = 0.0066)		
	Regular pruning	40% (p = 0.0024)	25% (p = 0.0128)	18% (p = 0.0172)
		Two-year-old plants		
DOY	Variant	$^{1}/_{3}$ pruning	$^{2}/_{3}$ pruning	Reference plant
186th	Reference plant	30% (p = 0.0249)	24% (p = 0.0217)	
	Regular pruning	20% (p = 0.0347)	14% (p = 0.0422)	
301st	$^{2}/_{3}$ pruning	23% (p = 0.0004)		
	Reference plant	25% (p = 0.0002)		
	Regular pruning	43% (p = 0.0001)	30% (p = 0.0001)	24% (p = 0.0003)

3.3. Sprouting Capacity and Branching

We can conclude that Paulownia has a high sprouting capacity (Table 4). The total sprouting capacity of the one-year-old plants was 80.6%, where the most frequent number of sprouts per plant was three (on 16.7% of the plants) and the maximum number of sprouts per plant was nine (on 1.2% of the plants), regardless of their origin. Depending on the origin of the sprout, the one-year-old plants had the lowest sprouting capacity from the stump (48%) and the highest sprouting capacity from the roots (56%). The most frequent number of root, stem and stump sprouts per plant was one (on 11.4%, 13.5% and 15.2% of the plants, respectively). The maximum number of sprouts per plant was seven (root sprouts on 6.1% of the plants; stem sprouts on 5.9% of the plants) and six (stump sprouts on 3.9% of the plants).

The total sprouting capacity of the two-year-old plants was 69.8%, where the most frequent number of sprouts per plant was three (on 16.1% of the plants) and the maximum number of sprouts per plant was eight (on 0.9% of the plants), regardless of their origin. Depending on the origin of the sprout, the two-year-old plants had the lowest sprouting capacity from the stump (34%) and the highest sprouting capacity from the roots (50%). The most frequent number of root, stem and stump sprouts per plant was one (on 10.1%, 12.5% and 14.7% of the plants, respectively). The maximum number of sprouts per plant was seven root sprouts (on 1.0% of the plants), six stem sprouts (on 5.1% of the plants) and five stump sprouts (on 2.5% of the plants).

Branches grew on 34% of all one-year-old plants. The most frequent was the occurrence of one pair of mutually opposite branches (on 12% of all plants), and the maximum number of mutually opposite branches was five (on 0.2% of all plants). Branches grew on 57% of all two-year-old plants. The most frequent was the occurrence of one pair of mutually opposite branches (on 23% of all plants), and the maximum number of mutually opposite branches was five (on 0.1% of all plants).

Table 4. Percentage shares of the numbers of each type of sprout (root, stem and stump) and of branches per plant of the plants planted in 2017 and 2016—one year and two years after planting.

	Number of Sprouts/Branches (Groups)										
	0	1	2	3	4	5	6	7	8	9	Sum
One-year-old plants (planted in 2017)											
All sprouts	19.4	6.2	9.4	16.7	12.2	10.4	10.4	8.4	5.7	1.2	100.0
Root sprout	44.4	11.4	8.9	8.4	7.5	6.5	6.8	6.1	0.0	0.0	100.0
Stem sprout	49.2	13.5	8.4	6.1	6.0	5.5	5.4	5.9	0.0	0.0	100.0
Stump sprout	52.1	15.2	9.5	7.5	6.0	5.8	3.9	0.0	0.0	0.0	100.0
Branches	66.5	11.9	10.9	7.1	3.4	0.2	0.0	0.0	0.0	0.0	100.0
Two-year-old plants (planted in 2016)											
All sprouts	30.2	8.4	9.6	15.1	12.0	9.9	8.7	5.2	0.9	0.0	100.0
Root sprout	50.0	10.9	9.4	9.1	8.1	6.2	5.3	1.0	0.0	0.0	100.0
Stem sprout	59.6	12.5	6.5	5.5	5.4	5.4	5.1	0.0	0.0	0.0	100.0
Stump sprout	65.9	14.7	7.6	5.2	4.1	2.5	0.0	0.0	0.0	0.0	100.0
Branches	43.4	23.0	18.2	11.2	4.1	0.1	0.0	0.0	0.0	0.0	100.0

4. Discussion

The presented results can be marked as unique and applicable to the growing of Paulownias—especially in areas where Paulownia Clon in vitro 112® does not reach the common annual growth, as it does in its homeland or in areas with optimal soil and climatic conditions.

Paulownia has a strong sprouting capacity [6,12,18]. Sprouts can grow from the roots [12,18], the stem [18] and/or the stump [6,12]. Our results confirm the frequent occurrence of sprouts, even in the climatic and common soil conditions of the CR. Paulownia has sprouts of all three of the above-mentioned types. At least one type of sprout grew on almost every second plant, be it a one-year-old or a two-year-old plant. Unfortunately, the above-mentioned authors do not state if some type of sprout appears more often than others. The results indicate that the most common are root sprouts, and, on the other hand, the least common seem to be stump sprouts.

Our results show that Paulownia in the CR grows branches in one third of all one-year-old plants. In most cases, on plants which had branches, there was only one row of branches growing opposite each other. There were very few plants that had as many as five rows of branches growing opposite each other. There were branches growing on more than half of the two-year-old plants. The number of branches was from one to five rows of branches growing opposite each other on the plants which had branches. Our results confirm the high branchiness described above. The results of measurements conducted on the one-year-old plants, in contrast to those conducted on the two-year-old plants, were not confirmed by the study of [12], who described that thick branches do not appear until the second year after planting. We assume that, in our plantation, as well as in other open spacing plantations (where the recommended spacing is, for example, 3.3 × 1 m or 2 × 1.5 m [6], 3 × 2 m or 5 × 5 m for timber [13] or 550 pcs/ha [37]), such a low density of trees can lead to a very low set crown and a larger number of branches at a young age.

In view of the fact that Paulownia has the ability to create root, stem and stump sprouts, and that the climate in the CR is the cause of apical sprout frost damage, we have come up with an experiment that would show the growth curve based on the selected type of apical sprout. This method is named spring pruning [19], where undesirable sprouts are removed. Spring pruning was carried out at the beginning of the vegetation period, and several different types of sprouts were left to grow. The best growing proved to be stem sprouts and stump sprouts on one-year-old plants and stem sprouts on two-year-old plants. It is assumed that the reason for the best stem sprout growth is hormonal imbalance caused by death of the apical sprout [17]. This imbalance could be the reason for the situation where the buds that were closest to the apical bud were supported by chemical processes, so they could replace the apical sprout as soon as possible, to keep the plant growing. Even Zhao-Hua et al. [12] found that the first buds under the apical bud took over its function once the terminal bud was damaged by frost. There is no mention of the length and increment of a stem sprout originating from an axial bud in the available literature. On the other hand, these authors described the length and increment of a stump sprout. The reason why they mention this, in general, is that the above-ground part of the plant is cut after the first year [6,12,13]. This is carried out to support the root system or to support the growth of the sprouts after the tree has been felled upon reaching the desired dimensions [12], which can be performed in three to five cycles [36–38]. Icka et al. [6] indicated that we can expect a four-meter stump sprout of Paulownia Clon in vitro 112®, even in the first year after planting. Zhao-Hua et al. [12] (without specifying the species) stated that an average stump sprout grows to a length of five to six meters, but individually, they can also grow to a length of up to ten meters. The average length of the sprouts on our plantation was 50–160 cm, which was much less than that described by the authors above. It is the different climatic and pedological conditions that could be responsible for this (when we compare them with those in the homeland of Paulownia). Above all, this can be caused by different temperature and rain progress according to what Icka et al. [6] or Zhao-Hua et al. [12] describe.

The experiment with the bandaging of the stem sprout to the stem was conducted together with the spring pruning. So-called bayonet growth will follow when the closest live bud takes over the apical sprout function on the stem that was damaged by frost [39]. Diversion can (sporadically) reach up to 80° from the stem axis (according to our measurements), but the average diversion reaches about 45° on one-year-old plants and 50° on two-year-old plants at the end of the vegetation period. On the other hand, when the sprout was bandaged to the rest of the stem that had been damaged by frost from the very beginning, and it was straightened up in this way, it showed an angle of diversion of about 10° on the one-year-old plants and about 30° on the two-year-old plants. This technique (i.e., process) helped the stems to be more upright.

Year-long pruning was another experiment designed to affect the height growth speed and stem straightness. This approach is applied when there is a small number of plants per hectare, together with the greater branching ability of these plants [20]. As a result, the increment is lower because the plant sends the necessary nutrients into its branches and sprouts [40]. On the other hand, when too many branches and leaves are taken away, height growth slows down because the assimilation part is eliminated. The taller the plant, the more it needs twigs and branches, as those create supportive tissue for tree stability, and the leaves support the transport of water from the ground up to the leaves via a sufficient negative water potential [41–43]. The reason behind our experiment was to find the most effective year-long pruning method that would support the growth of the plant, even if we reduce the assimilation part. Our results suggest that the best approach to year-long pruning is to remove all leaves and branches in the lowest third of the stem. This variant took away the unnecessary ineffective leaves and branches because the investment of nutrition and water into these ineffective leaves and branches reduces the utilization of nutrients and water, thanks to the higher-up leaves and branches that encourage accelerated growth of the entire plant. The limited growth, as a result of the preservation of the ineffective leaves and branches, is visible on the reference plants. We can say that the number of leaves that were taken away was not reduced more than necessary. Photosynthetic production, nutrition and energy income were not as low as those in the regular pruning variant with a greatly reduced assimilation part. We were able to see it even on the $^{2}/_{3}$ pruning variant where the branches up to $^{2}/_{3}$ of the plant height above the ground were taken away.

5. Conclusions

This work was aimed at influencing the growth of Paulownia Clon in vitro 112®, which was grown in the conditions of the CR, outside of its homeland. This study can be considered unique; however, it covers only one plot in the CR, and therefore the presented results are only preliminary.

Based on the height growth measured in Spain, Albania, Hungary and Romania, it can be assumed that straight stems without so-called elbow bends can grow thanks to high one-year-old sprout growth, even when the apical bud is replaced by a lateral bud. Paulownias growing in Střelice u Brna are smaller and their average height is far below one meter. As a result of this, we can expect a decrease in the quality of the assortment because there will be no long straight stems, and the length of the potential saw log will be less than 3 m, which is the minimum length of a saw log according to the rules recommended in the CR [44].

Spring pruning seems to influence the speed of growth of the plant. The reaction to year-long pruning was not similar for the one-year-old and two-year-old plants.

In terms of the one-year-old plants:

- The plants with stem or stump pruning grew higher than those with root pruning and the reference plants.
- The reference plants became bushy and had slow growth. We do not recommend leaving the plants without pruning.
- When we used root pruning, the new plants grew slowly, and they were smaller than those with the other variants of pruning (including the reference plants) at the end of the vegetation period. We do not recommend root pruning.

In terms of the two-year-old plants:

- We found out that the best pruning (according to the growth of the plants) was stem pruning.
- Next, with an almost insignificant difference, were the plants with root pruning and stump pruning.
- It is important to carry out some pruning and not leave the plant to grow naturally. We do not recommend leaving the plants without pruning.

However, when we use stem pruning, we should use bandaging. This treatment straightens the stem and reduces the angle between the elbow bend and the rest of the stem.

Additionally, year-long pruning appears to influence the speed of growth of the plant. The reaction to year-long pruning was similar for the one-year-old and two-year-old plants.

- The best year-long pruning (according to the growth of the plants) seems to be pruning $^{1}/_{3}$.
- The reference plants became bushy and had slow growth. We do not recommend leaving the plants without pruning.
- Plants with the pruning $^{2}/_{3}$ variant had similar growth to the reference plants. We do not recommend pruning $^{2}/_{3}$.
- The plants with regular pruning were smaller, even compared to the reference plants. We definitely do not recommend using regular pruning.

Our current results indicate that, in the following years, it would be advisable to leave the stem sprout and direct its growth by bandaging the apical part to the stem that is damaged by frost. This approach would be applied until the apical bud reaches a height beyond the reach of frost (i.e., approximately 4 m). It is also advisable that the newly growing branches, together with the leaves that grow up to the height of the lowest third of the stem, be regularly removed.

These silvicultural measures support the growth of plants that grow beyond the frost layer faster, thereby reducing the extent of damage by frost and the shape unevenness (elbow bends) of the stem. This could result in an increased economic valuation of wood cultivated in a plantation.

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