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Application of Stubble and Root Cutting in Artificial Cultivation of Non-Timber Forest Products (NTFPs): A Study Case of *Aralia elata* (Miq.) Seem

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Abstract: The increased demand for non-timber forest products (NTFPs) has led to the over-exploitation and disordered utilization of wild NTFP resources. Thus, it is important to determine how to sustainably utilize and cultivate NTFPs. Stubble and root cutting are two important methods for artificial cultivation, but little is known about their effects on the artificial cultivation of NTFP species with strong sprouting ability. *Aralia elata* is an important understory economic plant with high medicinal and edible values, and its wild resources are decreasing rapidly due to increasing demand. Therefore, *A. elata*, with its strong sprouting ability, was taken as an example to explore the effects of stubble (plant size × stubble height) and root cutting (root-cutting distance × root-cutting ratio) on its growth and sprouting ability for three years. The results showed that both stubble and root-cutting treatments could effectively facilitate the root sprouting ability of *A. elata*. The short stubble height treatment (6–15 cm) was the optimum stubble method for large *A. elata* (the mean height and basal diameter of plants were 256.65 cm and 4 cm, respectively). For small *A. elata* (plant basal diameter ranged from 1.5 cm to 3.4 cm), the optimal root-cutting method was 100% root-cutting ratio at a root-cutting distance of 0.25 m. However, the effects of stubble and root cutting on the growth and sprouting ability of *A. elata* were time-dependent, and repetitive treatment might be applied at an interval of two years to maintain its continuous growth and sprouting.

Keywords: non-timber forest products; wild vegetables; sustainable management; artificial cultivation; sprouting ability; stubble height; root-cutting distance and ratio

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1. Introduction

As the most important terrestrial ecosystem, forest ecosystems, with a large number of complex ecological processes, can continuously provide tangible or intangible benefits for human beings [1]. Serving as an integral part of the forest ecosystem/resources, non-timber forest products (NTFPs) are widely distributed in 124 countries and territories [2], and millions of households around the world rely heavily on NTFPs for material subsistence and cash income, especially in less developed countries [3–5]. Thus, NTFPs have been playing a crucial role worldwide in supporting regional economies [6–8].

The forest area of China accounts for 5.4 percent of the total forest area of the world, and about one-third of national forests are distributed in Northeast China [2,9]. Especially the East Asian temperate forest, one of the three major temperate forests in the world and the most well-preserved temperate forest, is mainly distributed in Northeast China [10]. Because the natural forests (accounting for more than 70% of total forests) in this region have been protected under the Natural Forest Protection Project of China (NFPP) since

1998, timber harvest is prohibited for natural forests. To maintain livelihoods and raise revenue, more and more local people who used to rely on timber production are turning to utilize the abundant resources of wild NTFPs. Consequently, the disordered harvesting and unreasonable utilization of NTFP resources have led to resource unsustainability. Therefore, in recent years, local people have begun experimenting with artificial cultivation of high-value NTFPs under the forests.

As an important understory economic plant with strong sprouting ability, *Aralia elata* (Miq.) Seem., is widely distributed in the forest region of Northeast China, and only a small amount spreads in Korea, Japan, Russia, etc. *A. elata* is considered as a perennial medicine–food woody plant, the tender new shoots and root bark of which have significant medical benefits such as immunity enhancement and antineoplastic [11,12]. Moreover, the tender new shoots of *A. elata* are famous for its delicious taste and rich nutrition, and are well received by the market and the public. Thus, it is one of the main NTFPs to earn foreign exchange [11,13]. The tender new shoots of wild *A. elata* are heavily harvested in spring due to their high medicinal and edible values, and the stems of *A. elata* are also harvested in large quantities to meet the demands of off-season cultivation. Consequently, the over-exploitation of wild *A. elata* has caused resource exhaustion and difficulties in its sustainable development. To sustainably utilize the *A. elata*, it is extremely urgent to conduct tending management of wild *A. elata* resources, and, in the meantime, carry out effective artificial cultivation.

Aiming to sustainably utilize *A. elata*, on the one hand, it is necessary to determine the optimum harvest methods to maximize the yield of tender new shoots during the spring harvest period while maintaining the healthy individual growth and population development [14]. On the other hand, artificial cultivation of *A. elata* is also an effective way to meet the demand for *A. elata* while conserving wild resources. The artificial cultivation of *A. elata* includes field cultivation and off-season cultivation. Field cultivation can provide both tender new shoots for sale in spring and raw materials (stems) for off-season cultivation in winter. Therefore, the key to artificial cultivation of *A. elata* in the field is to ensure the healthy growth and sustainable sprouting generation of *A. elata* and provide more stems for off-season cultivation. Our previous study has indicated that stump diameter is positively correlated with the subsequent development of stump sprouts [15]. Thus, in this study, we chose plant basal diameter growth as the variable to measure the radial growth of *A. elata* and considered that a higher plant basal diameter growth is more conducive to forming new branches and further supporting subsequent growth of *A. elata* plants. Moreover, the apical dominance of the stem inhibits its lateral bud elongation and will reduce bud yield [16]. Moreover, there are also some studies on utilizing the root sprouting ability of *A. elata* to conduct root cottage propagation [11,13]. Therefore, it is an effective way to maintain the sustainable development of *A. elata* by artificially disturbing the stem or root system of the mature plant to promote the sprout regeneration [17].

Stubble is an important technique in the cultivation and management of plants which can break the apical dominance, promote the germination of adventitious and dormant buds/new shoots on the stumps and roots, and optimize the growth [16,18,19]. Various factors can affect plant sprout regeneration [20–22], of which stump height and parent tree size have been widely studied all over the world due to their most important effects on the sprouting ability of trees [23–25]. Based on these previous studies, stubble height, as an easily controlled factor, has been used in the studies of rejuvenation of some valuable plant species [21,26,27]. However, few studies focus on the effect of plant size and the interaction between stubble height and plant size on plant rejuvenation when applying the stubble technique to artificially cultivate plants.

The non-structural carbohydrates stored in the root system can support the metabolism and growth of sprouts after disturbances [28]. Based on the importance of root sprouting ability and nutrient storage, many studies have focused on root cottage propagation around the world and have found that root-cutting diameter and location (root length) and root-cutting severity and timing are the most important impact factors [29–31]. However, there are limited studies on the application of the root-cutting technique to promote the root sprout regeneration of economic plants in situ.

Therefore, in this study, we took the artificially planted *A. elata* under the forest as an example to explore the role of stubble and root cutting in the artificial cultivation of these high-value NTFP species. Two experiments were designed to verify the effects of the stubble method (plant size × stubble height) and root-cutting method (root-cutting distance × root-cutting ratio) on the growth and sprouting ability of *A. elata*. Here, we used a flow chart to describe the structure of this study (Figure 1). The objective of this study was to determine the optimum stubble method and root-cutting method for enhancing growth and sprouting ability of *A. elata*. To achieve our objective, we need to verify the following three hypotheses: (1) the plant and new branch growth of *A. elata* will be affected by the interaction of plant size and stubble height, and the root sprout growth and sprouting ability will be affected by both the interaction of plant size and stubble height and the interaction of root-cutting distance and root-cutting ratio; (2) due to the elimination of apical dominance, the stubble treatment can effectively improve the plant and new branch growth and root sprouting ability of *A. elata*, and the short stubble height will be the optimum stubble height; and (3) the root-cutting treatment can efficiently promote the root sprouting ability and sprout growth of *A. elata*, and the larger root-cutting ratio and the smaller root-cutting distance will be more conducive to the formation of root sprouts. Through this study, we hope to provide some practical guidance for the sustainable management of cultivated *A. elata* and the protection of wild *A. elata* resources, and further contribute to provide theoretical references and technical support for domestic and foreign studies on sustainable utilization and management of NTFPs.

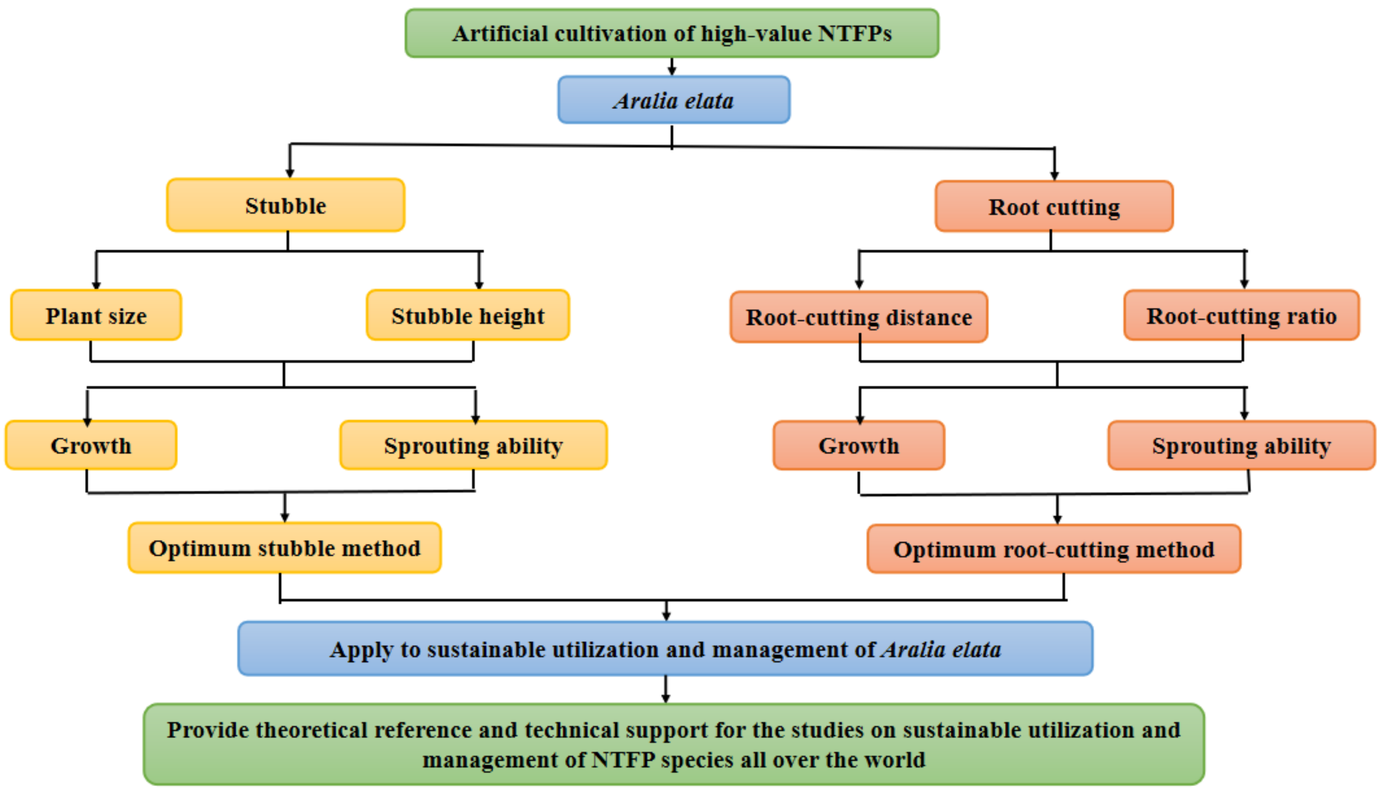

Figure 1. A flow chart to describe the paper structure.

2. Materials and Methods

2.1. Study Site

The study was conducted in Qingyuan Forest CERN, located in a mountainous region in Liaoning Province, Northeast China (41°51′ N, 124°54′ E) (Figure 2). The elevation varies between 500 and 1100 m above sea level. The climate is a continental monsoon type with a wind spring, a warm and humid summer, and a dry and cold winter. The mean annual air temperature is 4.7 °C [9,32]. The monthly mean of daily maximum and minimum temperatures during this experiment (2017–2020) are shown in Table 1. The annual precipitation ranges from 700 to 850 mm, of which 80% falls in summer (during June to August). The growing season lasts from early April to late October [9,32]. The study area is covered with a typical temperate secondary forest ecosystem (i.e., mosaic plantation/natural secondary forest landscapes) [33]. The soil is a typical brown forest soil, and consists of 25.6% sand, 51.2% silt and 23.2% clay [34]. The contents of organic matter, total nitrogen, total phosphorus and total potassium in the forest surface soil (0–10 cm) of the study area are 94.59 g·kg^{-1}, 5.09 g·kg^{-1}, 0.94 g·kg^{-1}, and 16.61 g·kg^{-1}, respectively.

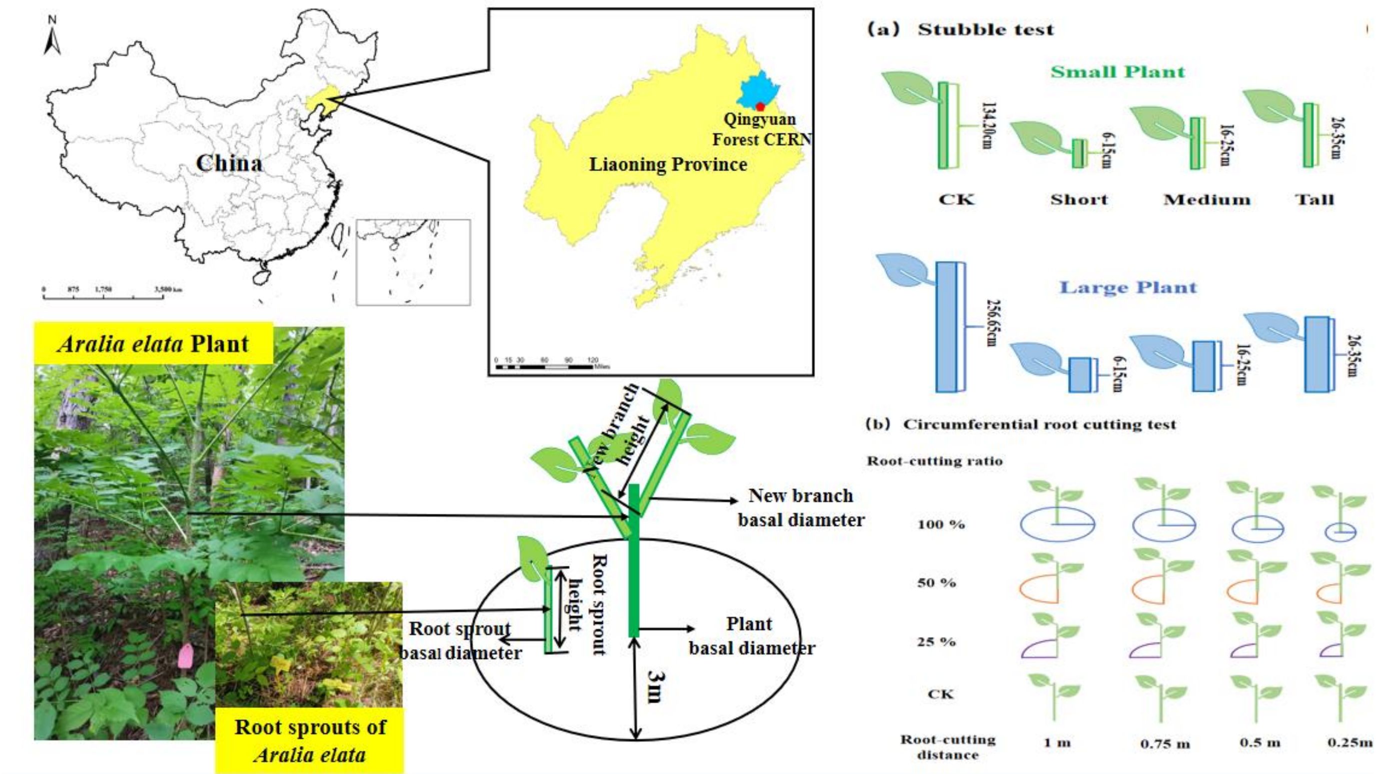

Figure 2. The location of study site and the description of experimental design. (**a**) The design of stubble test; (**b**) The design of circumferential root cutting test.

Table 1. Monthly mean of daily maximum (T_{max}) and minimum temperatures (T_{min}) during the experiment (2017–2020).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul	Aug.	Sep.	Oct.	Nov.	Dec.
T_{max} (°C)	−5.5	−3.0	5.6	14.0	20.8	24.1	27.8	25.4	20.6	13.7	3.7	−5.3
T_{min} (°C)	−19.7	−17.2	−7.1	−0.6	6.6	11.4	16.9	16.4	8.8	−0.2	−9.0	−17.9

Our experiments were carried out in a 49-year-old larch (*Larix gmelinii*) plantation stand with *A. elata* planted understory. The slope of the stand was 10~25°. The stand density of larch was 250 individuals ha^{-1} with a canopy density of 50%, which is appropriate for the growth of *A. elata* [35]. The mean height and DBH (the diameter at breast height) of the larch stand were 22.4 m and 35 cm, respectively. As an early attempt to artificially cultivate NTFPs after the implementation of NFPP, *A. elata* plants were planted in 2003 with a planting density of 6000 individuals·ha^{-1}. However, due the lack of systematic and reasonable management measures, natural and artificial disturbances caused the death or damage of many *A. elata* plants, which, in turn, led to the sprouting of new plants or stems from the residuals. Therefore, most of the *A. elata* plants were the rejuvenating plants with one or more stems. To ensure the consistency of background, only single-stem plants were selected in our experiment. The mean height and basal diameter of *A. elata* plants in the plot were 126.5 cm and 1.70 cm, respectively. Only the harvest of tender new shoots was conducted for *A. elata* plants during each harvest period (from mid-April to mid-May).

2.2. Stubble Test

The stubble test was conducted from 2017 to 2020 to determine the optimum stubble method for *A. elata*. The experimental design is shown in Figure 2. We randomly set up a 50 m × 50 m quadrat in the experimental larch plantation stand. In the quadrat, we selected healthy and single-stemmed *A. elata* plants and divided them into two groups according to plant sizes, i.e., large plant (the mean height and basal diameter of plants were 256.65 cm and 4 cm, respectively) and small plant (the mean height and basal diameter were 134.20 cm and 2 cm, respectively). In November 2017 (the dormant period of *A. elata*), we carried out the stubble treatment of the experimental *A. elata* plants. The *A. elata* plants of each plant size group were divided into four stubble treatment groups, according to the stubble height aboveground: short treatment (6–15 cm), medium treatment (16–25 cm), tall treatment (26–35 cm), and no treatment (CK). There were five replicates for each stubble height treatment. We used manual stubble method and ensured that the incision was smooth. After stubble treatment, all the tops were removed from the site. A total of 40 *A. elata* plants with a complete randomized design were used in this stubble test. These plants were labeled and used for the following growth and sprouting ability measurements.

In November 2017 and November 2018, the plant basal diameters of all labeled *A. elata* with four stubble treatments were measured at 5 cm above the surface and in the same direction. Then, the plant basal diameter growth was calculated as the plant basal diameter measured in November 2018 minus the plant basal diameter measured in November 2017. At the end of the growing season in 2018, the number of new branches of each plant with stubble treatment was recorded. Then, we measured the distance from the base of each new branch to its apex as the new branch height. The corresponding new branch basal diameter was measured at 1 cm from the base of branch, and the basal diameters of all new branches were measured in the same direction. Once there was more than one new branch generated from the plant with stubble treatment, we took the average height and basal diameter of all new branches to represent the new branch height and basal diameter of this plant.

In June and October 2018, the number of root sprouts within a radius of three meters was investigated twice using each experimental *A. elata* plant as the center, and then the total number of root sprouts was counted. After three growing seasons (in November 2020), the number of root sprouts of each experimental *A. elata* plant was investigated again, and the root sprout height and basal diameter were measured. Replicates for each stubble treatment were not equal in November 2020 due to the natural death of the experimental *A. elata* plants (especially all plants of no treatment (CK) were missing).

2.3. Circumferential Root Cutting Test

The circumferential root cutting test was conducted from 2017 to 2020 to determine the optimum root-cutting method for *A. elata*. The experimental design was shown in Figure 2. We randomly set up a 100 m × 100 m quadrat in the experimental larch plantation stand. In the quadrat, we selected the healthy and single-stemmed *A. elata* plants, and divided them into two groups, i.e., small size (plant basal diameter ranging from 1.5 cm to 3.4 cm) and large size (plant basal diameter ranging from 3.5 cm to 6.1 cm). In October 2017 (at the end of growing season), for each experimental *A. elata* plant, we took the stem as the center and the root-cutting distance as the radius to cut the roots with a sharp blade in the form of a circumference with a depth of 15 cm and set the root-cutting ratio for the entire circumference to 100%. We also set the other two root-cutting ratios: 25% root-cutting ratio (cutting the roots in the form of 25% circumference) and 50% root-cutting ratio (cutting the roots in the form of 50% circumference). We designed four root-cutting distance treatments (0.25 m, 0.5 m, 0.75 m and 1 m) and a control treatment (no treatment, CK). Each treatment had five replicates, and a total of 130 *A. elata* plants with a complete randomized design were used in this circumferential root cutting test. These plants were labeled and used for the following root sprouting ability measurement.

We recorded the number of root sprouts within a radius of three meters using the experimental *A. elata* plant as the center at the beginning of each month from June to October in 2018, and then the total number of root sprouts per experimental *A. elata* plant throughout this growing season was counted. After three growing seasons (in November 2020), the number of root sprouts of each experimental *A. elata* plant was investigated again, and the root sprout height and basal diameter were measured. The number of replicates for each treatment in November 2020 was different due to those missing as a result of natural death, and, in particular, all plants of no treatment (CK) were missing.

2.4. Data Analysis

A two-way analysis of variance (two-way ANOVA) with LSD's post hoc test was used to test the effects of plant size, stubble height and their interactions on the number, height and basal diameter of new branches, the number of root sprouts, and the plant basal diameter growth of *A. elata* in 2018, and the number, height and basal diameter of root sprouts of *A. elata* in 2020. Moreover, the two-way ANOVA with LSD's post hoc test was also used to examine the effects of root-cutting distance, root-cutting ratio and their interactions on the number of root sprouts in 2018 and 2020, and the height and basal diameter of root sprouts in 2020. All of the statistical tests were performed using SPSS 20.0, and the significance was examined at the level $p < 0.05$. For each variable in the same treatment, the average values (±S.E.) for each plant size were presented in the figures.

3. Results

3.1. Stubble Test

There was no significant interaction between plant size and stubble height on the plant growth and root sprouting ability of *A. elata* ($p > 0.05$). The number of new branches was significantly affected only by plant size ($p = 0.026$) (Table 2), and the number of new branches of the large plant was significantly higher than that of the small plant (Figure 3a). The stubble height only significantly affected the new branch basal diameter (BBD) ($p = 0.002$) (Table 2). The BBD showed a significant decrease with an increase in stubble height, and the BBDs of medium and tall stubble height were significantly lower than that of no stubble treatment ($p < 0.05$) (Figure 3e). Both plant size and stubble height showed no significant effect on the new branch height ($p > 0.05$) (Table 2). The plant basal diameter growth (PDG) and the number of root sprouts in 2018 (NRS) were significantly affected by both plant size and stubble height ($p < 0.05$) (Table 2). The PDG of large plant was significantly higher than that of small plant ($p < 0.05$), and showed a significant decrease with the increase in stubble height ($p < 0.05$) (Figure 3g,i). The NRS of the large plant was significantly higher than that of the small plant ($p < 0.05$), and the NRSs under all three stubble treatments were significantly higher than that under no treatment ($p < 0.05$) (Figure 3h,j). The plant size, stubble height and their interactions had no significant influence on the number of root sprouts, root sprout height and basal diameter in 2020 ($p > 0.05$) (Table 2). The number of root sprouts with no-stubbled treatment was close to 0 in 2018, and no living *A. elata* plant under no treatment was investigated in 2020.

Table 2. Two-way ANOVA test for the effects of plant size (PS) and stubble height (SH) on plant growth (NB, BBD, BH and PDG) and root sprouting ability (NRS, RSH and RSD) of *Aralia elata*. Significant effects ($p < 0.05$) are bolded. NB: number of new branches; BBD: new branch basal diameter; BH: new branch height; PDG: plant basal diameter growth; NRS: number of root sprouts in 2018; NRS_{2020}: number of root sprouts in 2020; RSH_{2020}: root sprout height in 2020; RSD_{2020}: root sprout basal diameter in 2020.

Variables	Effects	*df*	*F*	*p*	Variables	Effects	*df*	*F*	*p*
NB	PS	1	5.497	**0.026**	NRS	PS	1	11.831	**0.002**
	SH	3	1.487	0.238		SH	3	3.719	**0.021**
	PS × SH	3	0.053	0.984		PS×SH	3	0.661	0.582
BBD	PS	1	2.282	0.142	NRS_{2020}	PS	1	0.134	0.719
	SH	3	6.507	**0.002**		SH	2	0.634	0.543
	PS × SH	3	0.053	0.984		PS×SH	2	0.185	0.833
BH	PS	1	2.838	0.104	RSD_{2020}	PS	1	1.548	0.253
	SH	3	1.431	0.256		SH	2	0.299	0.751
	PS × SH	3	0.302	0.824		PS×SH	2	0.187	0.833
PDG	PS	1	4.438	**0.043**	RSH_{2020}	PS	1	0.887	0.378
	SH	3	11.663	**0.000**		SH	2	1.028	0.406
	PS × SH	3	1.759	0.175		PS×SH	2	1.460	0.295

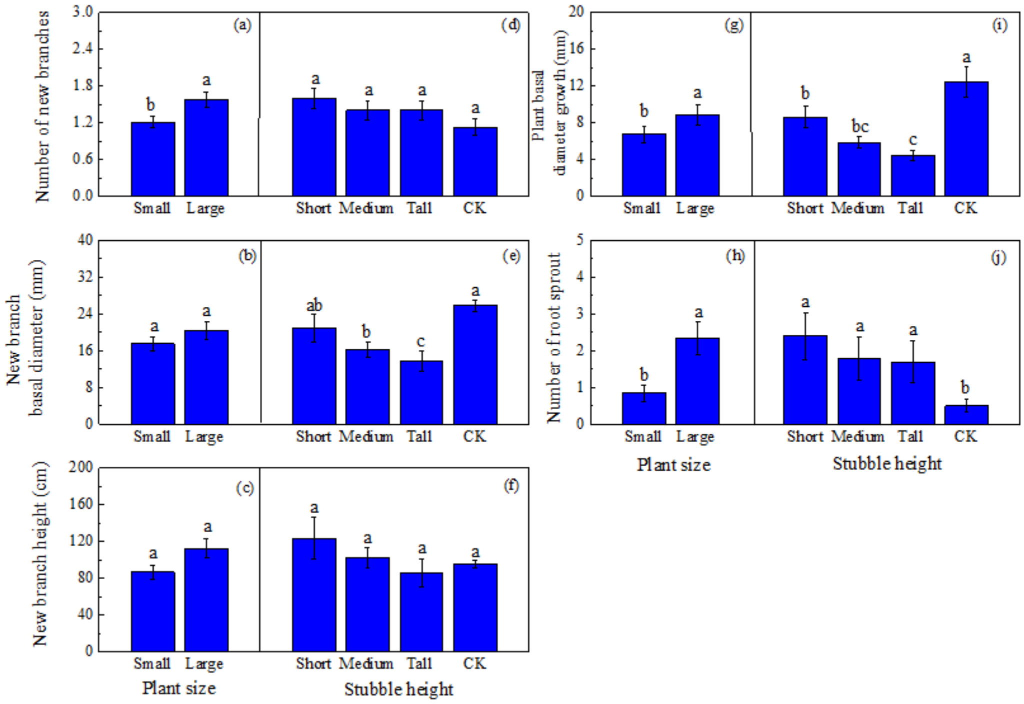

Figure 3. The plant growth and root sprouting ability of *Aralia elata* under two plant sizes (**a**–**c**,**g**,**h**) or four stubble height levels (**d**–**f**,**i**,**j**). The data are presented as the mean ± S.E. Different lowercases indicate significant differences ($p < 0.05$) between two plant sizes or among four stubble height levels.

3.2. Circumferential Root Cutting Test

No root sprout of both two plant sizes was found under the no root-cutting treatment. There was no significant effect of root-cutting distance, root-cutting ratio and their interaction on the number of root sprouts of both two plant sizes, and the root sprout height and basal diameter of large plants in 2020 ($p > 0.05$) (Table 3). The root-cutting distance and root-cutting ratio significantly affected the number of root sprouts of the small plant and the large plant in 2018, respectively ($p < 0.05$) (Table 3). The number of root sprouts of the small plant at 0.25 m (10.3 ± 2.04) was significantly higher than those at 0.5 m (2.4 ± 0.67) and 1 m

(2.8 ± 0.69) in 2018 (p = 0.001), and the number of root sprouts of the large plant with 100% root-cutting ratio (18.5 ± 3.6) was significantly higher than those with 25% (6.8 ± 1.33) and 50% (5.4 ± 1.08) root-cutting ratios in 2018 ($p < 0.001$) (Figure 4a,b). There was a significant interaction effect of root-cutting distance and root-cutting ratio on the root sprout height and basal diameter of the small plants in 2020 ($p < 0.05$) (Table 3). For the small plant in 2020, the root sprout height and basal diameter at 0.25 m with 100% root-cutting ratio was significantly higher than those with 25% and 50% root-cutting ratios ($p < 0.05$) (Figure 4c,d).

Table 3. Two-way ANOVA test for the effects of root-cutting distance (RCD) and root-cutting ratio (RCR) on root sprouting ability of *Aralia elata*. Significant effects ($p < 0.05$) are bolded. NRS: number of root sprouts in 2018; NRS_{2020}, RSH_{2020} and RSD_{2020}: number, height and basal diameter of root sprout in 2020, respectively.

Variables	Effects	*df*	Small Plant		Large Plant	
			F	*p*	*F*	*p*
NRS	RCD	3	6.227	**0.001**	2.321	0.087
	RCR	2	0.247	0.782	9.543	**<0.001**
	RCD × RCR	6	1.091	0.381	1.156	0.345
NRS_{2020}	RCD	3	0.983	0.415	0.239	0.869
	RCR	2	0.825	0.448	0.664	0.521
	RCD × RCR	6	0.280	0.942	0.296	0.935
RSH_{2020}	RCD	3	0.266	0.849	2.092	0.127
	RCR	2	0.263	0.771	1.384	0.269
	RCD × RCR	6	6.842	**<0.001**	0.779	0.594
RSD_{2020}	RCD	3	1.197	0.336	1.236	0.317
	RCR	2	0.349	0.710	0.124	0.884
	RCD × RCR	6	6.151	**0.001**	0.590	0.735

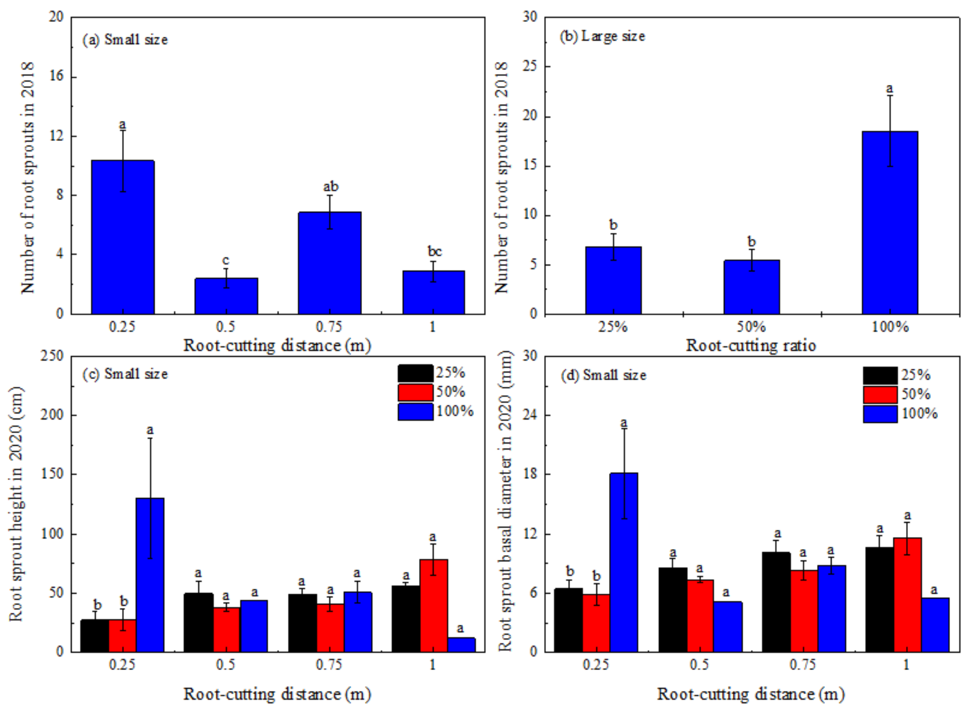

Figure 4. The root sprouting ability of *Aralia elata* in different root-cutting treatments. The data are presented as the mean ± S.E. Different lowercases indicate significant differences ($p < 0.05$) among four root-cutting distances (**a**) or three root-cutting ratios (**b–d**).

4. Discussion

4.1. Effects of Plant Size and Stubble Height on the Plant Growth and Root Sprouting Ability

Stubble is an effective technical measurement and widely applied in plant cultivation [36–38]. The main functions of stubble are to break the apical dominance of plants with sprout ability, promote the formation of new branches and root sprouts from adventitious and dormant buds/new shoots on the residual parts and root system, and increase the number of new branches and root sprouts due to more nutrients being allocated to the growth of branches and root sprouts [27,39]. Our results showed that there was no significant interaction between plant size and stubble height on the growth of the plants, new branches and root sprouts, and the number of new branches and root sprouts. These findings were inconsistent with the hypothesis (1) that the growth and sprouting ability of *A. elata* will be affected by the interaction of plant size and stubble height. In the following, we discuss the effects of plant size and stubble height on the growth and sprouting ability of *A. elata*, respectively.

Many previous studies have indicated that plant sprout regeneration is closely related to plant size (e.g., diameter at breast height and stump diameter, etc.) [20,21,23]. One year after stubble treatment (in 2018) in our study, the number of new branches and root sprouts of large plants were significantly higher than those of the small plants, and the plant growth (plant basal diameter growth) also showed the same trend. On the one hand, our results were partly consistent with previous studies that the sprouting ability of some tree species increased with the increase in stump size (e.g., stump diameter) [24], and the larger plants showed better sprouting ability. On the other hand, the growth of large plant basal diameter also showed better performance, which was conducive to the subsequent development of the plant [15]. Therefore, when using the stubble method to promote the growth and sprouting ability of *A. elata*, large plants should be preferred for stubble treatment.

Stubble height (i.e., stump height), an important factor which is easily controlled by humans in stubble treatment, has been widely used in recent years to affect plant growth and sprouting ability in forest management and artificial cultivation [23,40,41]. In our study, the stubble height had a significant effect on the basal diameter of new branches and the growth of plant basal diameter. These results revealed that the stubble height mainly affected the horizontal growth of new branches and the plant itself. Compared with non-stubbled *A. elata* plants, the number of root sprouts of stubbled plants was significantly higher. This finding supported that the stubble treatment could facilitate the regeneration of root sprouts of *A. elata*. Furthermore, previous researchers have found that the optimum stubble height on the growth and regeneration of trees or shrubs varies greatly among different species [26,27,39]. Our results indicated that the plant growth and sprouting ability of *A. elata* also varied among different stubble heights. The new branch basal diameter and plant basal diameter growth significantly decreased with increasing stubble height, and the short stubble height treatment was most beneficial to the plant and new branch growth of *A. elata*.

The stubble technique has been applied to rejuvenation of the senescent plants [42]. Based on our findings above, when using the stubble technique to rejuvenate *A. elata*, the large plant with short stubble height (6–15 cm) treatment was the optimum stubble method. This result was consistent with the hypothesis (2). In addition, we reviewed the root sprout regeneration of stubbled *A. elata* plants after three growing seasons (in November 2020) and found that there was no significant difference in the number and growth of root sprouts of *A. elata* between the two plant sizes and among three stubble height treatments. This result was partly consistent with our previous findings on root sprout regeneration in 2018 and indicated that the effect of stubble height and plant size on root sprouting ability is limited after three years of stubble treatment. Therefore, when applying stubble technology to the sustainable management of *A. elata*, more attention should be paid to the interval of stubble treatment to ensure its effectiveness.

4.2. Effects of Root-Cutting Treatment on the Root Sprouting Ability

The roots of plant species with sprout ability have adventitious and dormant buds/new shoots, which can be stimulated to regenerate into new sprouts by external disturbances (e.g., injuries and cutting, etc.), and this phenomenon can be applied to promote plant sprout regeneration [29,43]. Our study was also consistent with this phenomenon, i.e., the *A. elata* plants without root cutting treatment did not produce root sprout. However, only the root sprout height and basal diameter of *A. elata* in 2020 were affected by the interaction of root-cutting distance and root-cutting ratio.

In the first growing season after root-cutting treatments (i.e., in 2018), our results showed that the number of root sprouts of small *A. elata* plants reached the maximum at the root-cutting distance of 0.25 m, while the number of root sprouts of large *A. elata* plants with 100% root-cutting ratio was significantly higher than those with other root-cutting ratios. Thus, the root sprouting ability of small *A. elata* plants and large *A. elata* plants were mainly affected by the root-cutting distance and root-cutting ratio, respectively. The plant root structure is closely related to the plant size [44] Thus, in this study, the root sprouting ability of *A. elata* plants with different sizes showed different responses to root-cutting treatment. When cutting the roots of small *A. elata*, the root-cutting distance of 0.25 m could be the most conducive to the early formation of root sprouts. The root system can provide the initial carbon source for sprouts and play an important role in carbon balance and the allocation of sprouts [45]. Therefore, previous studies on sprout regeneration after disturbance indicated that the non-structural carbohydrates (NSCs) stored in root system can support the metabolism and growth of new sprouts to rapidly occupy the ecological niche [35], until the photosynthetic products can meet the carbon requirement of the sprouts.

In this study, we found that, after three growing seasons (in November 2020), the root sprout height and basal diameter of small *A. elata* reached the maximum at the root-cutting distance of 0.25 m with 100% root-cutting ratio. On the one hand, this may be because the roots which are closer to the plant stem with a larger diameter and dense distribution can provide sufficient carbon storage to support the growth of root sprouts before their photosynthates can meet the carbon requirement. On the other hand, previous studies have indicated that the degree of root disturbance and root-cutting diameter and location have a significant influence on the root sprouting ability of plants, but the effects vary between species [29,43]. Our results concerning the best growth of small *A. elata* may also relate to the residual root segment after cutting in the soil. As the root-cutting location was near the stem, the size of the residual root segment (i.e., length and diameter) in the soil was larger. The nutrients stored in the residual root segment were more abundant to support the early growth of root sprouts. Therefore, the optimum root-cutting method to promote the root sprout regeneration of the small plant was a 100% root-cutting ratio at a root-cutting distance of 0.25 m.

Compared with the small *A. elata* plants, the effect of root-cutting treatment on the root sprouting ability of large *A. elata* plants was weakened. For large *A. elata* plants, our results only showed the significant effect of root-cutting ratio on the number of root sprouts in the first growing season after root-cutting treatment, and the 100% root-cutting ratio was beneficial to the root sprouting ability of large *A. elata* plants. However, the effect of root-cutting treatment vanished in the subsequent root sprout regeneration. Consequently, when cutting the roots of large *A. elata* plants, only the optimum root-cutting ratio (100% root-cutting ratio) should be considered. These results supported our hypothesis (3). Therefore, the root-cutting technique can also be applied to the sustainable management of *A. elata*.

5. Conclusions

All the results presented here indicate that, as two important artificial cultivation technologies, stubble and root cutting can be applied to the sustainable management of *A. elata*. Compared with no treatment, both stubble and root-cutting treatments can effectively facilitate root sprout regeneration. When we chose stubble as the management method, the large plant with short stubble height (6–15 cm) treatment was the best choice to promote the growth and sprouting ability of *A. elata* (Figure 5a). When we conducted the root-cutting treatment, 100% root-cutting ratio at the distance of 0.25 m was the best option to promote the root sprout regeneration of small *A. elata* plants. While managing the root-cutting of large *A. elata*, only the root-cutting ratio should be considered, and the 100% root-cutting ratio is optimum to promote the number of root sprouts at the early stage after root-cutting treatment (Figure 5b). These results indicate that after 3 years of stubble and root-cutting treatment, the effects of stubble treatment on the growth and sprouting ability of *A. elata* vanished, while the effects of root-cutting treatment on the root sprouting ability of large *A. elata* plants also vanished. Therefore, to maintain the promoting effects of stubble and root-cutting on the growth and sprouting ability of *A. elata*, corresponding treatments should be performed on the target *A. elata* plant at an interval of two years. The findings of this study can be applied to the development of management rules for both wild and artificially cultivated *A. elata* plants to improve the growth and sprouting ability of *A. elata*. Appropriate regulations for the management of *A. elata* could help to increase the yield of NTFPs (e.g., stems, shoots, etc.) and further increase local population revenues. Moreover, the findings of this study can also provide a theoretical reference and technical support for studies on sustainable utilization and management of NTFP species all over the world.

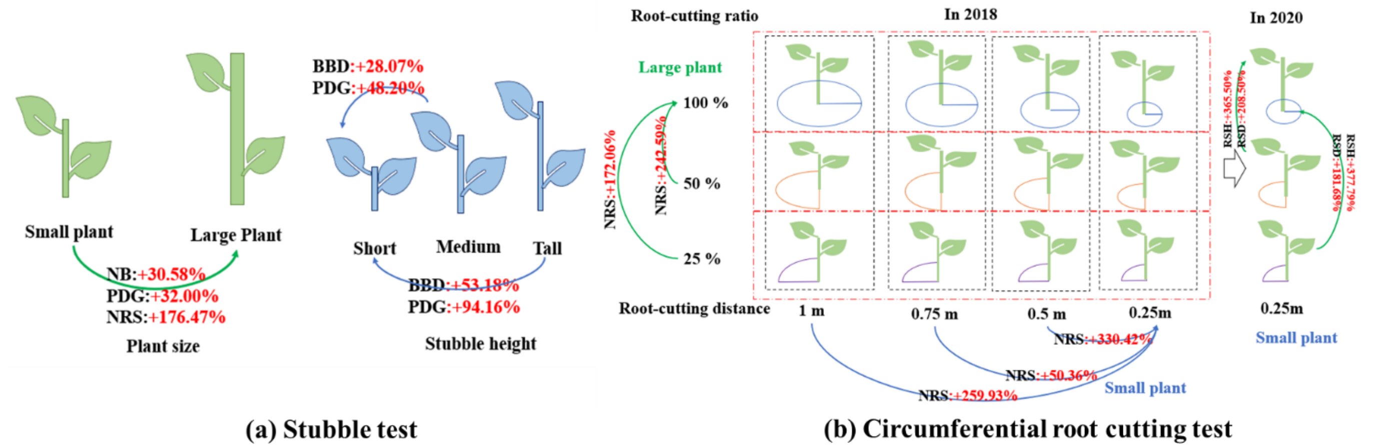

Figure 5. Conceptional diagram of the effects of stubble test (**a**) and root cutting test (**b**) on plant growth and sprouting ability. For each experimental treatment, the arrow direction represents the optimal treatment level among all treatment levels. NB: number of new branches; BBD: new branch basal diameter; PDG: plant basal diameter growth; NRS: number of root sprouts in 2018; RSH: root sprout height in 2020; RSD: root sprout basal diameter in 2020.

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References

1. Moradi, S.; Limaei, S.M.; Lohmander, P.; Khanmohammadi, M. Quantitative and financial evaluation of non-timber forest products (case study: Zemkan basin forests, West of Iran). *J. For. Res.* **2017**, *28*, 371–379. [CrossRef]
2. FAO. *Global Forest Resources Assessment 2020: Main Report*; FAO: Rome, Italy, 2020. [CrossRef]
3. Taghouti, I.; Ouertani, E.; Guesmi, B. The Contribution of Non-Wood Forest Products to Rural Livelihoods in Tunisia: The Case of *Aleppo pine*. *Forests* **2021**, *12*, 1793. [CrossRef]
4. Abtew, A.A.; Pretzsch, J.; Secco, L.; Mohamod, T.E. Contribution of small-scale gum and resin commercialization to local livelihood and rural economic development in the drylands of Eastern Africa. *Forests* **2014**, *5*, 952–977. [CrossRef]
5. Aye, W.N.; Wen, Y.; Marin, K.; Thapa, S.; Tun, A.W. Contribution of mangrove forest to the livelihood of local communities in Ayeyarwaddy region, Myanmar. *Forests* **2019**, *10*, 414. [CrossRef]
6. Feurer, M.; Gritten, D.; Than, M.M. Community forestry for livelihoods: Benefiting from Myanmar's mangroves. *Forests* **2018**, *9*, 150. [CrossRef]
7. Weiss, G.; Emery, M.R.; Corradini, G.; Živojinović, I. New values of non-wood forest products. *Forests* **2020**, *11*, 165. [CrossRef]
8. Soe, K.T.; Youn, Y.-C. Livelihood dependency on non-timber forest products: Implications for REDD+. *Forests* **2019**, *10*, 427. [CrossRef]
9. Yan, Q.L.; Gang, Q.; Zhu, J.J. Size-dependent patterns of seed rain in gaps in temperate secondary forests, northeast China. *Forests* **2019**, *10*, 123. [CrossRef]
10. Wang, C. Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. *For. Ecol. Manag.* **2006**, *222*, 9–16. [CrossRef]
11. Liang, S.N. Study on Cultivation Techniques of *Aralia elata* (Miq.) Seem. Master's Thesis, Shangdong Agricultural University, Tai'an, China, 2014.
12. Hou, H.H. Study on Extraction of Polysaccharide and Determination of Composition on Monosaccharide from the Root Skin of *Aralia chinensis* L. Master's Thesis, Northwest Normal University, Lanzhou, China, 2015.
13. Zhao, W.B. Effects of Cultivation Measures on Root Cuttage Propagation and Overwintering Ability of *Aralia elata* (Miq.) Seem. Master's Thesis, Northeast Agricultural University, Harbin, China, 2021.
14. Zhang, T.; Yu, L.Z.; Man, Y.; Yan, Q.L. Effects of harvest intensity on the marketable organ yield, growth and reproduction of non-timber forest products (NTFPs): Implication for conservation and sustainable utilization of NTFPs. *For. Ecosyst.* **2021**, *8*, 56. [CrossRef]
15. Zhang, T.; Yan, Q.L.; Wang, G.G.; Zhu, J.J. The effects of stump size and within-gap position on sprout non-structural carbohydrates concentrations and regeneration in forest gaps vary among species with different shade tolerances. *Ecol. Process.* **2021**, *10*, 25. [CrossRef]
16. Shao, Q.F. Effects of Pruning and Exogenous Substances on Dwarfing and Growth of Lateral Branch of *Aralia elata* (Miq.) Seem. Master's Thesis, Northeast Agricultural University, Harbin, China, 2020.
17. Vesk, P.A.; Westoby, M. Sprouting ability across diverse disturbances and vegetation types worldwide. *J. Ecol.* **2004**, *92*, 310–320. [CrossRef]
18. Bond, W.J.; Midgley, J.J. Ecology of sprouting in woody plants: The persistence niche. *Trends Ecol. Evol.* **2001**, *16*, 45–51. [CrossRef]
19. Mwavu, E.N.; Witkowski, E.T.F. Sprouting of woody species following cutting and tree-fall in a lowland semi-deciduous tropical rainforest, North-Western Uganda. *For. Ecol. Manag.* **2008**, *255*, 982–992. [CrossRef]
20. Keyser, T.L.; Loftis, D.L. Stump sprouting of 19 upland hardwood species 1 year following initiation of a shelterwood with reserves silvicultural system in the southern Appalachian Mountains, USA. *New For.* **2015**, *46*, 449–464. [CrossRef]
21. Knapp, B.O.; Olson, M.G.; Dey, D.C. Early stump sprout development after two levels of harvest in a midwestern bottomland hardwood forest. *For. Sci.* **2017**, *63*, 377–387. [CrossRef]
22. Spinelli, R.; Pari, L.; Aminti, G.; Magagnotti1, N.; Giovannelli1, A. Mortality, re-sprouting vigor and physiology of coppice stumps after mechanized cutting. *Ann. For. Sci.* **2017**, *74*, 5. [CrossRef]
23. Handavu, F.; Syampungani, S.; Chisanga, E. The influence of stump diameter and height on coppicing ability of selected key Miombo woodland tree species of Zambia: A guide for harvesting for charcoal production. *J. Ecol. Nat. Environ.* **2011**, *3*, 461–468. [CrossRef]
24. Matula, R.; Svátek, M.; Kůrová, J.; Úradníček, L.; Kadavý, J.; Kneifl, M. The sprouting ability of the main tree species in Central European coppices: Implications for coppice restoration. *Eur. J. For. Res.* **2012**, *131*, 1501–1511. [CrossRef]
25. Xue, Y.Q.; Zhang, W.H.; Zhou, J.Y.; Ma, C.; Ma, L.W. Effects of stump diameter, stump height, and cutting season on *Quercus variabilis* stump sprouting. *Scand. J. For. Res.* **2013**, *28*, 223–231. [CrossRef]
26. Hou, X.F.; An, Y.P.; Ciren, D.J.; Li, Y.X. Effect of different stubble height on growth of *Populus alba*. *J. Plateau Agric.* **2020**, *4*, 157–161, (In Chinese with English Abstract)
27. Geng, B.; Zhao, D.X.; Dong, Y.R.; Guo, H.E.; Wang, X.Y.; Sun, J.S.; Gao, J.B.; Wang, Z.H. Effects of different stubble heights on seedling growth of hybrid mulberry. *Shandong Agric. Sci.* **2020**, *52*, 128–130, (In Chinese with English Abstract)
28. Shibata, R.; Kurokawa, H.; Shibata, M.; Tanaka, H.; Iida, S.; Masaki, T.; Nakashizuka, T. Relationships between resprouting ability, species traits and resource allocation patterns in woody species in a temperate forest. *Funct. Ecol.* **2016**, *30*, 1205–1215. [CrossRef]
29. Stenvall, N.; Haapala, T.; Pulkkinen, P. The role of a root cutting's diameter and location on the regeneration ability of hybrid aspen. *For. Ecol. Manag.* **2006**, *237*, 150–155. [CrossRef]

30. Kouakou, K.L.; Dao, J.P.; Kouassi, K.I.; Beugré, M.M.; Koné, M.; Baudoin, J.P.; Zoro Bi, I.A. Propagation of *Garcinia kola* (Heckel) by stem and root cuttings. *Silva Fenn.* **2016**, *50*, 1588. [CrossRef]
31. Mohd Idris, N.I.; Cameron, R.W.F. Cut-off in their prime? Response of two landscape shrubs to different levels of root pruning, during active and quiescent growth phases. *J. Hortic. Sci. Biotechnol.* **2020**, *95*, 734–745. [CrossRef]
32. Lu, D.L.; Zhang, G.Q.; Zhu, J.J.; Wang, G.G.; Zhu, C.Y.; Yan, Q.L.; Zhang, J.X. Early natural regeneration patterns of woody species within gaps in a temperate secondary forest. *Eur. J. For. Res.* **2019**, *138*, 991–1003. [CrossRef]
33. Lu, D.L.; Wang, G.G.; Yu, L.Z.; Zhang, T.; Zhu, J.J. Seedling survival within forest gaps: The effects of gap size, within-gap position and forest type on species of contrasting shade-tolerance in Northeast China. *Forestry* **2018**, *91*, 470–479. [CrossRef]
34. Yang, K.; Shi, W.; Zhu, J.J. The impact of secondary forests conversion into larch plantations on soil chemical and microbiological properties. *Plant Soil* **2013**, *368*, 535–546. [CrossRef]
35. Zhang, B.T.; Liu, J.Q.; Wei, Y.Z. Survey on main wild vegetables in headstream regions of Hunhe River. *J. Liaoning For. Sci. Tech.* **2010**, *1*, 31–33. (In Chinese)
36. Cutforth, H.W.; Angadi, S.V.; McConkey, B.G. Stubble management and microclimate, yield and water use efficiency of canola grown in the semiarid Canadian prairie. *Can. J. Plant Sci.* **2006**, *86*, 99–107. [CrossRef]
37. Vacchiano, G.; Meloni, F.; Ferrarato, M.; Freppaz, M.; Chiaretta, G.; Motta, R.; Lonati, M. Frequent coppicing deteriorates the conservation status of black alder forests in the Po plain (northern Italy). *For. Ecol. Manag.* **2016**, *382*, 31–38. [CrossRef]
38. Hamilton, S.A.; Kallenbach, R.L.; Bishop-Hurley, G.J.; Roberts, C.A. Stubble height management changes the productivity of perennial ryegrass and tall fescue pasture. *Agron. J.* **2013**, *105*, 557. [CrossRef]
39. Zhang, Z.N.; Li, F.; Guo, G.Y.; Chen, W.H.; Liu, C.H.; Gao, H.Y. Response of sprouting ability of *Hippophae rhamnoides* ssp. *sinensis to stubble height*. *J. Southwest For. Univ.* **2020**, *40*, 34–39. (In Chinese with English Abstract)
40. Clary, W.P.; Leininger, W.C. Stubble height as a tool for management of riparian areas. *J. Range Manag.* **2020**, *53*, 562–573. [CrossRef]
41. Wang, X.; Li, H.Y.; Wu, Z.B.; Wang, W.S.; Meng, H. Effects of different stumping methods on growth of degenerated *Nitraria tangutorum*. *Prot. For. Sci. Technol.* **2020**, *5*, 18–20. (In Chinese with English Abstract)
42. Wang, Z. Effects of Different Stubble Height on Growth and Physiological Biochemical Characteristics of *Tetraena mongolica* Maxim. Master's Thesis, Chinese Academy of Forestry, Beijing, China, 2013.
43. Guo, L.J.; Shao, X.H.; Xue, P.P.; Tian, Y.Q.; Xiao, Z.P.; Wu, Y.P. Root sprouting ability and growth dynamics of the rootsuckers of *Emmenopterys henryi*, a rare and endangered plant endemic to China. *For. Ecol. Manag.* **2017**, *389*, 35–45. [CrossRef]
44. Sun, P.; Li, J.H.; Liu, H.X.; Wu, J.; Liu, C.; Xu, C.Y. Relationship between root structure and health level of *Cotius Coggygria* trees. *J. Northwest For. Univ.* **2016**, *31*, 20–27. (In Chinese with English Abstract)
45. Xie, H.T.; Yu, M.K.; Cheng, X.Y. Leaf non-structural carbohydrate allocation and C:N:P stoichiometry in response to light acclimation in seedlings of two subtropical shade-tolerant tree species. *Plant Physiol. Biochem.* **2018**, *124*, 146–154. [CrossRef]