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Initial Sprouting of Some Tree Species in Natural Forests Following 9–Month Cutting in Kasuya Research Forest of Kyushu University Forest, Japan

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Two deciduous species, *Castanea crenata* Sieb. & Zucc. and *Quercus serrata* Thunb., and two evergreen species, *Quercus glauca* Thunb. and *Symplocos lucida* Sieb. & Zucc., in natural forests at Kasuya Research Forest of Kyushu University Forest, Japan were selected in order to assess their regeneration ability through vegetative reproduction (coppice pathway). After 9–month cutting, results showed that the number of shoots was not different between species. The average leading shoots of *C. crenata* and *Q. serrata* were nearly twice as long as the average leading shoots of *Q. glauca* and *S. lucida*. This gives an indication of high resilience of deciduous species after cutting in comparison with that of evergreen species. The size of stump had a significant effect on the diameter and height of leading shoots rather than its effect on the number of leading shoots produced. The species sampled showed significant differences in their ability to regenerate through vegetative reproduction pathway.

INTRODUCTION

The ability of some tree species to resprout after harvest has been widely used since ancient time in agriculture and forestry (Rydberg, 2000). While most forest communities arise from seedlings, foresters routinely regenerate some tree species primarily by vegetative means (Nyland, 2002). Vegetative regeneration of tree species includes three aspects (Jeník, 1994; Rodrigues *et al.*, 2004): the capacity of aerial branch reiteration (epicormic shoots), sprouting of basal portions of trunk (coppice shoots), and sprouting from root buds (sucker shoots). Sprouting of coppice shoots plays an important role in stand restoration as a form of direct regeneration during the initial successional stages following severe disturbances. Shoots can grow quickly because of their already established and functioning root system. Therefore, sprouting is an efficient way for woody plants to recover lost biomass during disturbances (Miura and Yamamoto, 2003). Moreover, the formation of coppice shoots depends upon such other factors as species, cutting season, age, dimension of stumps and site quality (Lust and Mohammady, 1973; Johansson, 1992).

In many temperate species, sprouting capacity also differs between the growing and dormant seasons. Generally, dormant trees sprout more vigorously than those felled during periods of active growth. This may result from the greater concentrations of carbohy-

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drates in root systems during periods of dormancy. Coppice method involves clear felling, i.e. cutting all trees by blocks, strips or patches. This allocates total space to the new age class and makes maximum resources available to shoots (Nyland, 2002). Coppice crops are mostly worked in small coupes thus even small woodlands usually contain several different age classes. This provides great structural diversity because stands at different stages of development create variety of habitats which are able to support a wide range of wildlife (Evans, 1984).

In Japan, coppice silviculture has been used for a long time under the means of charcoal production and short rotation wood production. Therefore, coppice is an effective way to restore forest environment after clear cutting. To understand the restoration of trees after clear cutting through coppice pathway, one study was carried out in Kasuya Research Forest of Kyushu University Forest with two types of natural forests: mixed deciduous broad–leaved forest and mixed evergreen broad–leaved forest. The objectives of this study were to assess the ability of some species in these forests to regenerate by vegetative reproduction (coppice pathway) after clear cutting and to examine the effects of stump diameter on number of shoots and height and diameter above the base of leading shoots at the beginning period of shoot formation and growth.

MATERIALS AND METHODS

Study area

The study area is located at Kasuya Research Forest of Kyushu University Forest with latitude 33° 37' N and longitude 130° 35' E, representing two types of natural forests: mixed deciduous broad–leaved forest and mixed evergreen broad–leaved forest. According to climatic data of the Kasuya Research Forest (2004), the mean temperature ranging from April to November is 25.38 °C, of which maximum temperature is 32.9 °C in July and minimum temperature is 19.9 °C in April. This area was experienced by a typhoon occurred in September 2004 that caused some damage to shoot growth of some species in the two sample plots.

In January 2004, two permanent sample plots measuring 100 m^2 (10 × 10 m) were selected. These two plots were used as small patches (treatments for clear cutting applied) but there was no control plot to compare with and the different species composition and range of stump diameter meant it was not possible to separate the effects of the treatments from the effects of stump diameter and species. Therefore, species were used as replicates with the dependent variables of shoot number and shoot height and diameter. Plot No. 1 consisted of 4 species belonging to 2 families and plot No. 2 included 8 species belonging to 6 families. Because the number of stumps in each plot and between species was very little then only species represented by at least four or more individuals were used to analyze. Two species in plot No. 1 (*C. crenata* and *Q. serrata*) and two species in plot No. 2 (*Q. glauca* and *S. lucida*) met this criterion.

Data collection

Before clear cutting of all trees, all woody stems in these plots, including some coppices, were tagged and measured in height and diameter at breast height (D.B.H. $\geq$ 5 cm). At the beginning of February 2004, all trees were cut at standard height of 20 cm and diameter of each cut stump was measured. The age of each cut stump was determined by counting the number of rings on cut disks above 20 cm height of cut stumps. Some species had multi–stem structure so the age was estimated by counting the rings in each bole and then averaged for all. Therefore, the age of each stump was relatively determined for each stump.

Data were collected every month, starting from June 2004 to October 2004 with the main criterion was the number of coppice shoots per each stump to be counted. In October 2004, approximately 9 months after cutting, all cut stumps were finally assessed before winter season had come as deciduous species would stop growing and leaves would defoliate. For each cut stump, a maximum of 10 of the largest/leading shoots were identified, tagged and height and diameter above the base of leading shoots were measured. Un–measured shoots and the number of dead shoots were counted.

Data analysis

Statistical analyses were mainly carried out using SPSS 12.0 software package (Norušis, 2004). For the number of shoots, height and diameter above the base of leading shoots, analysis was carried out using a one–way analysis of variance (one–way ANOVA) with species as factors. Post–hoc multiple comparisons within functional groups were measured using Bonferroni test. The effects of stump diameter on the number of shoots, height and diameter of leading shoots were also examined with a regression analysis. Most studies of forest recovery by coppice sprouting use height at the time of sampling in assessing the recovery or resilience of a forest. Resilience can be defined as the rate at which an ecosystem returns to its initial condition following perturbation (McLaren and McDonald, 2003). In this study, the average height of leading shoots was used as an important indicator for assessing the resilience of each species following cutting.

RESULTS AND DISSCUSSION

Sprouting ability of coppice shoots

An average of 21 shoots per stump after 9–month cutting was recorded for all individuals in final observation (October) (Table 1). Anderson (1966) (cited from Johansson, 1992) studied the sprouting ability of a deciduous species, pubescent birches (*Betula pubescens* Ehrh), in Sweden and found that 12–22 shoots appeared per living stump 2 year after cutting, which was a very high number of shoots per stump especially some years after cutting. In our study, the average number of 21 shoots per stump was recorded showing a high number of shoots for four species. In general, the number of shoots increases during first year then tends to decrease each year because of lack of nutrient supply from root system and self–thinning process takes places. Results of the one–way ANOVA revealed that the average number of shoots found alive over 5 months was not significantly different between species ($P>0.05$, Table 1). The highest average number of shoots recorded was 27 shoots per stump for *Q. glauca* in July and this species showed having higher shoots per stump in comparison with other species. The lowest average number of shoots recorded was 12 shoots per stump for *S. lucida* in June and this species also showed having fewer shoots per stump rather than three other species. At species level, the number of shoots tended to increase every month but not signifi-

Table 1. Number of shoots alive for 4 species with >4 stems following 9-month cutting at Kasuya Research Forest of Kyushu University Forest, Japan[a]

ANOVA results	N	Number of living shoots per stump				
		June	July	August	September	October
F-value		1.698	1.588	1.425	1.299	1.451
P-value		>0.05	>0.05	>0.05	>0.05	>0.05
df		3	3	3	3	3
Species						
C. crenata[d]	4	23.75(13.06)	24.25(12.86)	24.25(12.86)	23.25(12.77)	22 (11.92)
Q. serrata[d]	8	23.13(6.01)	24 (5.89)	24.25(5.41)	23.75(5.41)	23.38(5.38)
Q. glauca[e]	7	25.29(4.44)	27.71(4.06)	26.43(4.77)	26.57(4.75)	26.86(4.63)
S. lucida[e]	11	12 (1.78)	14.09(2.28)	14.55(1.40)	14.82(1.50)	14.45(1.65)

[a] Means for each species are given for the total number of stumps sampled for each species (N) and average number of shoots sampled alive from June to October 2004 (shoots) and standard errors of mean (in brackets).

[d] Means deciduous species belonging to Fagaceae.

[e] Means evergreen species belonging to Fagaceae and Symplocaceae, respectively.

cantly different between each month. The number of shoots was not different between species. Therefore, it is difficult to use initial number of shoots as a variable to predict medium and long-term changes in the number of shoots per stump.

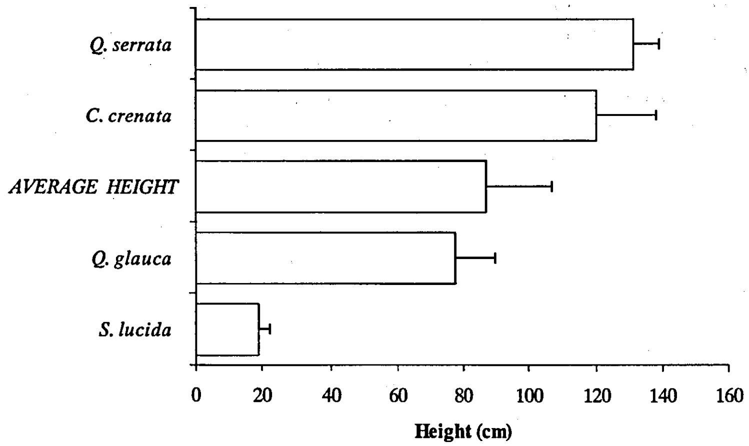
The size of coppice shoots

Only data of leading shoots were used to assess the growth of coppice shoots. The average number of the leading shoots per species was not significantly different between each species. The height and diameter above the base of the leading shoots was significantly different among the species ($P<0.05$, and $P<0.05$, respectively; Table 2, Fig 1(a)

Table 2. Age, number of leading shoots per stump, stump diameter and diameter and height of leading shoots for 4 species following 9-month cutting at Kasuya Research Forest of Kyushu University Forest, Japan[a].

ANOVA results	A	N	Stump diameter (cm)	Diameter of leading shoots (mm)	Height of leading shoots (cm)
F-value			1.926	57.896	40.380
P-value			>0.05	<0.05	<0.05
df			3	3	3
Species					
C. crenata	15	5	15.25(3.52)	9.60(1.15)	120.29(18.00)
Q. serrata	18	5	17.25(3.10)	10.82(0.47)	131.50(7.85)
Q. glauca	21	5	18.71(3.36)	5.68(0.57)	77.68(11.97)
S. lucida	17	3	10.86(1.64)	3.48(0.10)	18.73(3.50)

[a] Means for each species are given for the average age of stumps sampled for each species (A), average number of leading shoots per stump (N) and average diameter of stump, average diameter of leading shoots and average height of leading shoot with standard errors of mean (in brackets), respectively.



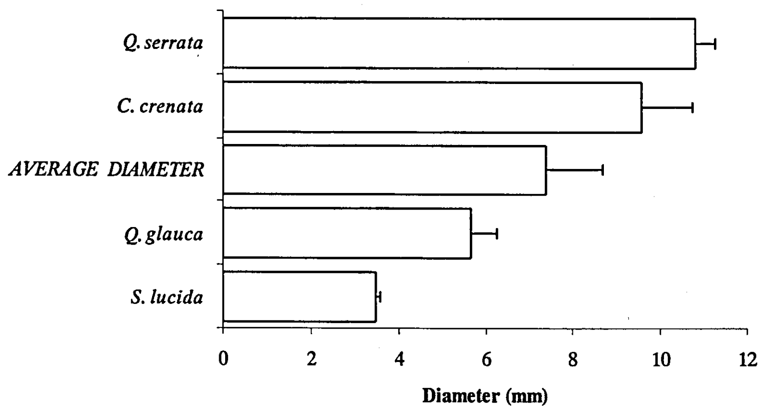


Fig. 1. For 4 species represented by >4 stumps (a) average height (cm) and (b) diameter above the base of leading shoots produced by 4 species following cutting at Kasuya Research Forest of Kyushu University Forest, Japan. For (a) and (b) species were ranked form highest to lowest (+standard errors of means (S.E.M)).

and (b)). The average height recorded of the leading shoots was 87.0 cm while the average diameter above the base recorded was 7.39 mm. The species that recorded the tallest average height of leading shoots was *Q. serrata* (131.5 cm). Also, *C. crenata* was recorded as the second tallest average height of leading shoots (120.0 cm). The species with the shortest average height was *S. lucida* (18.73 cm) which was significantly shorter than other species. For diameter, the species that recorded the largest diameter was again *Q. serrata* (10.82 mm) and this was significantly higher than the remaining evergreen species. Here again the species with the smallest average diameter was *S. lucida* (3.48 mm), which was significantly lower than that of the remaining deciduous species.

Results of post hoc multiple comparisons using Bonferroni test showed significant differences in the growth on height and diameter between deciduous species and evergreen species and, at species level, only evergreen species showed significant differences. Both *C. crenata* and *Q. serrata* represented a higher resilience rate in comparison with that of *Q. glauca* and *S. lucida*. Rydberg (2000) studied the initial growth of European aspen (*Populus tremula* L.) and birches (*B. pendula* and *B. pubescens*) in central Sweden and indicated that birch shoots were almost twice as long as European aspen shoots. Result of our study also showed the average leading shoots of *C. crenata* and *Q. serrata* were nearly twice as long as the average leading shoots of *Q. glauca* and *S. lucida*. This gives an indication of high resilience of deciduous species after cutting in comparison with that of evergreen species. However, it is unlikely that this initial high rate of resilience will be maintained over a long period of time perhaps because of limited nutrient supply of their root systems. The complexity of the resprouting process, influenced by both species characteristics and site quality (i.e. a compound of soil and climatic conditions), should be taken into account when planning management strategies to improve extensive mixed coppices (Espelta *et al.*, 2003). It was found that almost all the stump of deciduous species was decayed following 9 months and it might be suggested that it is their strategy to grow fast after cutting until all carbohydrates accumulated in the root system are used.

The relationships between stump diameter and number of shoots, height and diameter of leading shoots

In this study, the relationships between stump diameter and number of shoots, height and diameter of leading shoots were analyzed under the form of linear regression for each species rather than considering this relationship at community level because of least variation in the stump diameter. Interestingly, the relationship between stump diameter and the number of shoots produced was only found in *Q. serrata* with a fairly positive relationship ($P=0.125$; $R^2=0.346$; $y=0.9956x+6.3875$; Table 3; Fig. 2). Therefore, variation in the number of shoots in accordance with stump diameter cannot be used as an indicator of coppicing effectiveness, which is the number of coppice shoots per stump for each species. It seemed that the differences in the stump diameter did not show any effect in the number of shoots produced in each stump, except for *Q. serrata* in which the bigger the stump size, the higher the number of shoots produced.

Khan and Tripathi (1986) studied the effects of diameter and height of stumps on sprouting and survival of shoots of *Alnus nepalensis*, *Quercus dealbata*, *Q. griffithii* and *Schima khasiana* in a disturbed sub-tropical wet hill forest of Northeast India. It was found that both diameter and height of stumps had significant effects on sprouting of species studied. In *Q. dealbata*, *Q. griffithii* and *S. khasiana* maximum number of shoots was given out from the stumps of >15–30 cm diameter, whereas in *A. nepalensis* the stumps of >30–45 cm diameter showed maximum sprouting. McLaren and McDonald (2003) studied the relationship between the stem diameter and number of shoots produced of 27 species in a disturbed tropical dry limestone forest in Jamaica and found that

Table 3. Summary of regression analysis of stump diameter against the number of coppice shoots produced and the diameter and height of the leading shoots for 4 species following 9-month cutting at Kasuya Research Forest of Kyushu University Forest, Japan[a].

Species	Shoots × Stump Diameter		Diameter × Stump Diameter		Height × Stump Diameter	
	P-value	R^2	P-value	R^2	P-value	R^2
C. crenata	–	–	<0.05	0.880	<0.05	0.987
Q. serrata	0.125	0.346	<0.05	0.545	<0.05	0.894
Q. glauca	–	–	<0.05	0.726	0.200	0.303
S. lucida	–	–	–	–	0.053	0.356

[a] Only species showing a significant relationship are shown

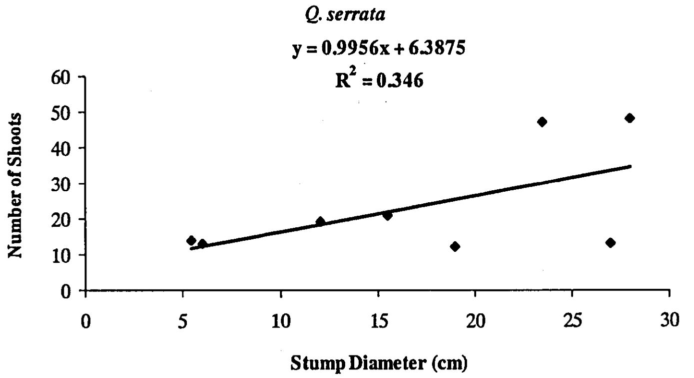


Fig. 2. Regression analysis of stump diameter (cm) on the number of shoots produced by *Q. serrata*, showing a significant relationship following 9-month cutting at Kasuya Research Forest of Kyushu University Forest, Japan.

only 7 species showed a significant relationship and concluded that this was due to the variation in stem size between species. In summary, the number of shoots produced depends not only on the diameter and height of stump but also on physiology of species and in relationship with the environment. In our study, the height of stumps was not used because each stump was cut with standard height of 20 cm.

For relationships between stump diameter and diameter of leading shoots, only three species showed a significant positive relationship ($P<0.05$; Table 3; Fig. 3). Two species, *C. crenata* and *Q. glauca* ($P<0.05$; $R^2=0.880$; $y=0.3008x+5.0602$ and $P<0.05$; $R^2=0.726$; $y=0.1464x+2.9657$, respectively), showed a very strong relationship and a moderately strong relationship, respectively with increasing stump size. *Q. serrata* showed a fair relationship (R2=0.545; $y=0.1111x+8.925$) while S. lucida did not show any relationship.

For relationships between stump diameter and height of leading shoots, all species showed a positive relationship with different significant levels ($P<0.05$; Table 3; Fig. 4).

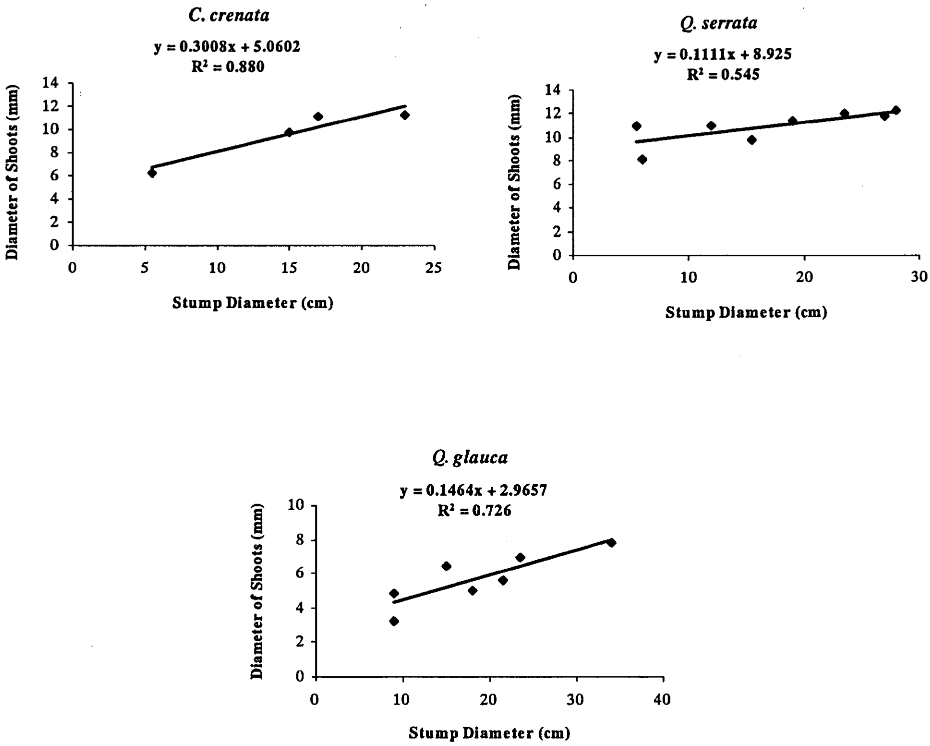


Fig. 3. Regression analysis of stump diameter (cm) on the diameter of leading shoots (mm) produced by 3 species showing a significant relationship following 9-month cutting at Kasuya Research Forest of Kyushu University Forest, Japan.

Two deciduous species, *C. crenata* and *Q. serrata* ($P<0.05$; $R^2=0.987$; $y=4.9169x+45.924$ and $P<0.05$; $R^2=0.894$; $y=2.3744x+90.992$, respectively), showed a very strong relationship with increasing stump diameter. On the contrary, *Q. glauca* and *S. lucida* ($P=0.200$; $R^2=0.303$; $y=2.0034x+40.478$ and $P=0.053$; $R^2=0.356$; $y=1.2598x+5.1616$, respectively) showed a fair relationship with stump size.

Results on relationships between stump diameter and size of leading shoots were considered to be more important than those on relationship between stump diameter and number of shoots produced. It is clear that at the beginning of development stage of coppice shoots, the size of stump had a significant effect on the height of leading shoots rather than its effect on the number of leading shoots produced and diameter of leading shoots. The bigger the stump size, the higher the leading shoots was found in two deciduous species. The species sampled showed significant differences in their ability to regenerate through vegetative reproduction pathway. The rapid initial growth is considered one of the most important features of sprouting species after disturbance (Midglei, 1996; Kruger *et al.*, 1997; Espelta *et al.*, 1999) (cited from Gracia and Retana, 2004). Of the

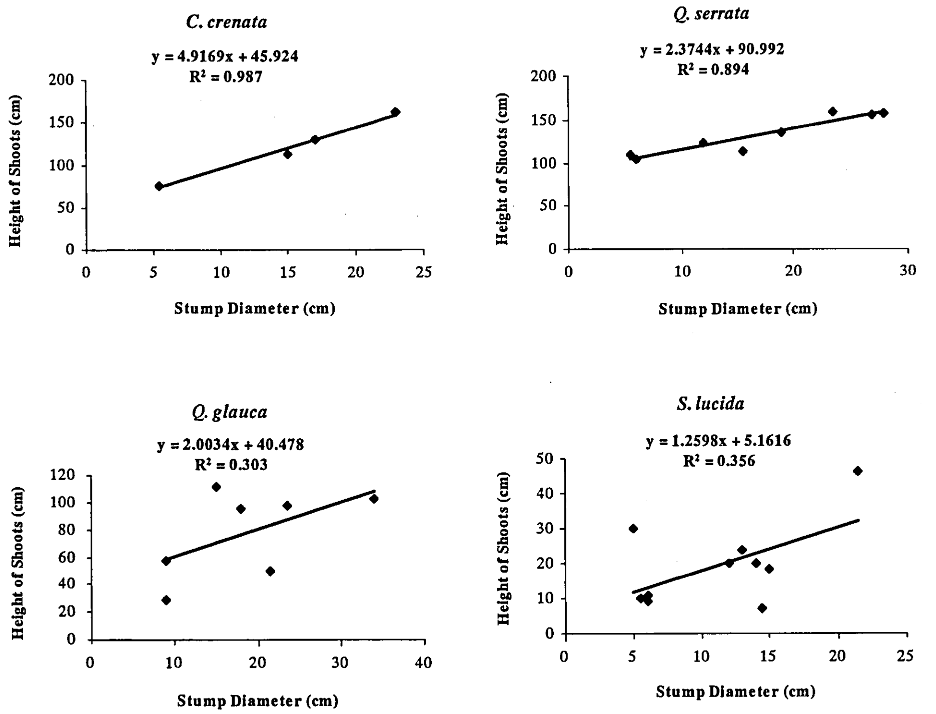


Fig. 4. Regression analysis of stump diameter (cm) on the height of leading shoots (cm) produced by 4 species showing a significant relationship following 9–month cutting at Kasuya Research Forest of Kyushu University Forest, Japan.

four species analyzed two deciduous species, *C. crenata* and *Q. serrata*, showed greater resilience ability in terms of height growth for coppice sprouting in comparison with that of two evergreen species, *Q, glauca* and *S. lucida* at least in the first growing stage.

Conclusions

The sprouting ability of two deciduous species and two evergreen species was assessed based on their resilience to recover after clear cutting. There was a high resilience ability recorded for two deciduous species to recover in comparison with that of two evergreen species. Moreover, the significant relationship could be found between stump diameter and diameter and height of leading shoots. Further medium– and long–term studies are needed to understand about factors affecting the number and growth of coppice shoots in relation with their environment (site quality) and felling season.

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