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Influence of Regeneration Method on the Yield and Stem Quality of Black Locust (*Robinia pseudoacacia* L.) Stands: a Case Study

Károly RÉDEI[a*] – Imre CSIHA[a] – Zsolt KESERŰ[a] – János GÁL[b]

[a] Hungarian Forest Research Institute, Sárvár, Hungary
[b] Institute of Forest Resource Management and Rural Development, University of West Hungary, Sopron, Hungary

Abstract – Black locust (*Robinia pseudoacacia* L.) is one of the most important forest tree species in Hungary, covering approximately 23% of the forested land and providing 25% of the annual timber output of the country. One third of these black locust stands are high forests (planted with seedlings) and the remainder coppices. According to the forestry regulations black locust stands can be regenerated both by root suckers and with seedlings in Hungary. This study investigates the influence of different regeneration methods on wood production, stem quality and health. Properly managed regeneration from root suckers produced a higher yield than regeneration from seedlings at a harvest age of 35–37 years. The results show that regeneration of black locust stands from root suckers can be recommended on good and medium quality sites without a decrease in yield or stem quality.

***Robinia pseudoacacia* L. / regeneration methods / yield / health condition**

Kivonat – Különböző felújítási módok hatása akácosok hozamára: esettanulmány. Az akác (*Robinia pseudoacacia* L.) az egyik legfontosabb állományalkotó fafaj Magyarországon, az erdőterület mintegy 23%-át borítja és az ország éves faanyag-termelésének 25%-át adja. Ezen akácállományok egyharmada szálerdő (mageredetű), a maradék pedig sarj eredetű. Magyarországon a szakmai előírások értelmében az akácosok magról és gyökérsarjról újíthatók fel. A dolgozat különböző felújítási módoknak a fatermésre, a törzsminőségre, illetve a fák egészségi állapotára gyakorolt hatását vizsgálja. A számított adatok szerint a gyökérsarjról történő szakszerű és gondos felújítás a 35–37 éves véghasználati korban magasabb hozamot eredményezett, mint a magról történő felújítás. A vizsgálati eredmények alapján az akácosok gyökérsarjról történő felújítása elsősorban a jó és közepes termőhelyeken ajánlott a fatermés csökkenése nélkül.

Fehér akác / felújítási módok / fatermés / egészségi állapot

1 INTRODUTION

Robinia pseudoacacia was the first forest tree species brought from North America to Europe (to France) sometime after 1601. Its rapid spread all over the world may be attributed to its adaptability to a wide range of conditions, favorable breeding properties, frequent and abundant seed production, excellent coppicing, fast growth and high yield (Keresztesi 1988).

[*]Corresponding author: redei.karoly@t-online.hu, H-9600 SÁRVÁR, Várkerület 30/A.

Black locust was introduced in Hungary between 1710 and 1720. The first large black locust stands were established at the beginning of the 19th century on the Great Hungarian Plain stabilizing the wind-blown sandy soil. In Hungary black locust occupied 37.000 ha in 1885, 109.000 ha in 1911, 186.000 ha in 1938 and 420.000 ha in 2010. At present, it is the most widely planted tree species in Hungary, covering 23% of the country's total forest area. One-third of these stands are high forests and two-thirds are of coppice. In the 1960s, Hungary had more black locust forests than all the rest of Europe.

The average per hectare volume in all black locust forests is 125 m^3/ha, with an average volume of 190 m^3/ha at harvest at an average harvest age of 31. Black locust forests in Hungary have been established on a range of sites; however only sites with adequate moisture supply and well aerated and loose structured soil, rich in nutrients and humus can produce good quality timber. On medium and poor sites, black locust produces fuel wood, fodder, poles and mine props as well as honey while protecting the soil and the environment (Boring et al. 1984, Keresztesi 1988, Bongarten et al. 1992, Rédei 1996).

Black locust produces abundant seed crops of long-lived viable seeds which however need treatment before they can germinate. At the same time, roots produce vigorous suckers.

The most important black locust growing regions in Hungary are in the south and southwest Transdanubia (hill-ridges of Vas-Zala county, hill-ridges Somogy county), the plain between the Danube and Tisza rivers (Central Hungary) and north-east Hungary (Nyírség region) (*Figure 1*).

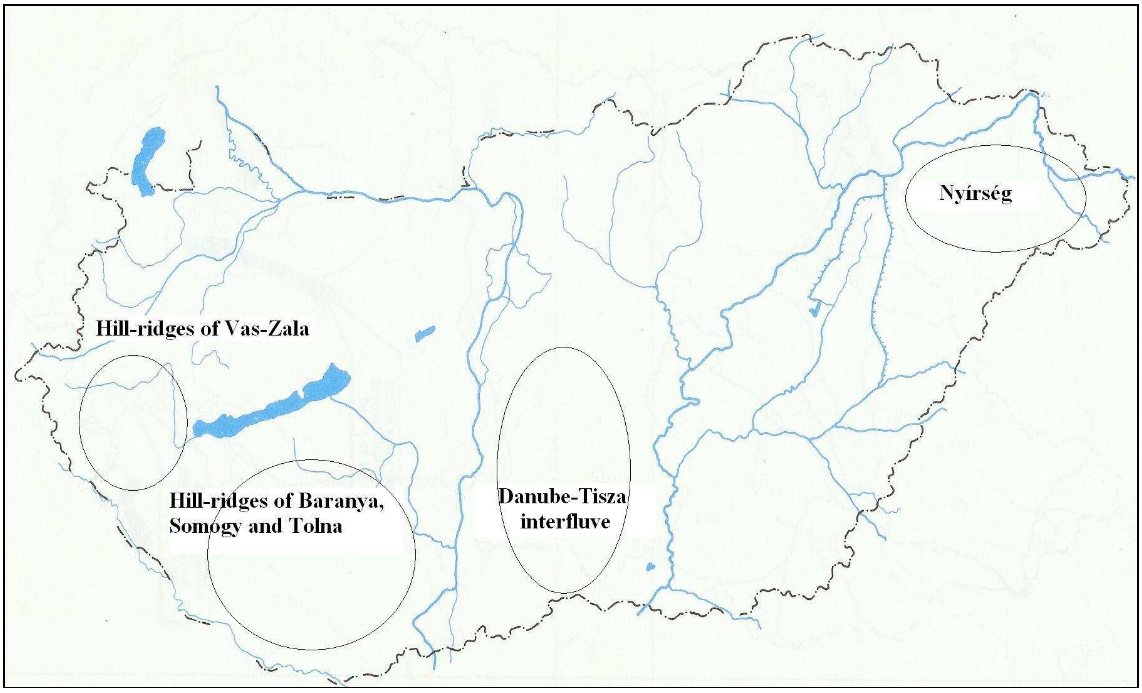

Figure 1. The main growing regions of black locust (Robinia pseudoacacia L.*) stands in Hungary*

In the future there are two regions in the world where black locust is likely to be grown in larger areas: the Mediterranean countries in Europe and China and Korea in Asia.

1.1 Stand establishment, tending and yield

Black locust requires well-drained soils with adequate moisture where the associated nitrogen-fixing *Rhizobium* bacteria are able to thrive. That is why soil preparation (total or partial) to improve aeration and the water regime of the soil and tilling between rows may become necessary. It can grow on a wide range of soil types, except on very dry or very heavy soils. The aeration and water regime of the subsoil have a major influence on growth. In general, it prefers loose, structured soils, especially silty and sandy loams. Growth is very slow where the subsoil is compact and waterlogged, especially if the root zone is less than 35 cm; excessively dry sites are also very unfavorable (Eigel et al. 1980, Keresztesi 1988).

The most popular planting spacing for black locust in Hungary is 2.4 m by 0.7 to 1.0 m, requiring at least 4000 seedlings/ha. Black locust stands are often regenerated by coppice (from root suckers). In young stands of coppice origin, a cleaning operation should be done to adjust spacing when the stands are 3–6 years old and should reduce the stock below 5000 stems/ha.

Black locust is a fast-growing tree, and is able to quickly close canopy openings created by tending operations up to the age of 10–15 years; such closure is much slower in later years. Height growth peaks within the first five years, and diameter growth peaks in the first decade. The maximum current annual increment is near age 20; while mean annual increment culminates between age 35–37 years (based on the yield table Rédei – Gál 1985).

A growing space index is used to determine tending and thinning intensity. This index expresses the mean distance between trees (assuming triangular pattern) as a percentage of mean height after tending and thinning. The mean value of this index should be 23–24% for black locust stands. Crop trees should be pruned, so after selective thinning, stems must be free of branches up to a height of 4–6 m.

The objective of tending is to produce a high proportion of good quality saw-logs from stands on good sites; some saw-logs and a high proportion of poles and props from stands on medium quality sites and poles, props and other small-dimension industrial wood from the rest of the stands (Rédei 1992).

2 STUDY OBJECTIVE

Several experimental plots were established in Hungary in order to investigate the influence of different regeneration methods on wood production and quality in black locust stands (Keresztesi 1965, 1987, Rédei 1997). The purpose was to find the best regeneration method for these stands. Unfortunately most of the plots were established without replication; yet they still provide us with valuable and long term information about the growth and yield of black locust under different regeneration circumstances.

3 MATERIAL AND METHODS

3.1 The study area

In the area between the Danube and Tisza rivers (see *Figure 1*), three experimental plots were established in the spring of 1968, each 0.24 hectare. According to the Hungarian site classification, the main ecological characteristics of the study area are as follows:

- forest steppe climate zone (humidity is less than 50% in July at 2 pm, annual precipitation is less than 550 mm);
- hydrology: water loosing site (with lack of groundwater influence);
- genetic soil type: sand with humus content.

The latitude and longitude coordinates of the experimental site are *N 47.11, E 19.30.*

3.2 Treatments

Three different regeneration methods were used after harvest with stump extraction (Keresztesi 1987):

- Treatment I: Regeneration from suckers developed from thick roots (root diameter between 3 and 6 cm);
- Treatment II: Regeneration from suckers developed from thin roots (root diameter between 1 and 3 cm) with removal of thick roots;
- Treatment III: Regeneration with seedlings planted into deep-ploughed soil.

Harvest and tending operations have been done in accordance with intensive silviculture prescriptions of the time. Two cleanings were done at age of 5 and 10, a selective thinning at age of 15 and a late thinning at age 20. The trees on the plots were harvested at age of 34 and regenerated with the three different methods described above.

The yield class of the stand is II on a relative scale of I to VI, where I is the best (Rédei – Gál 1985).

3.3 Calculation of the stand parameters

DBH and height were measured for each tree on each plot at the age of 6, 17, 24, 29 and 34; then stem number, basal area, stand volume per hectare and average tree volume were calculated. Tree volume was calculated using the volume function based on the volume table for black locust (Sopp 1974):

$$V=\frac{d^2 \cdot h^{po+1}}{(h-1{,}3)^{po} \cdot 10^8} \cdot \left(p_1 \cdot d \cdot h + p_2 \cdot d + p_3 \cdot h + p_4\right) \qquad (1)$$

where d is d.b.h.(cm),
h is tree height (m),
$p_o = 4$
$p_l = -0.6326$
$p_2 = 20.23$
$p_3 = 0.00$
$p_4 = 3034$

3.4 Tree/stem quality classification

Four stem quality classes (depending on utilization) were identified in this study:

Class 1: Trees providing high quality industrial wood: straight, cylindrical, healthy stems, reaching to the top of the crown. Crooks are tolerated in one dimension only, not more than twice the stem diameter. The lower two-thirds of the tree must be suitable for saw logs and free of live branches.

Class 2: Trees providing lower quality industrial wood: the stem is straight, forks are tolerated, but only if they are in the uppermost third of the tree. Crooks are tolerated in one dimension only, not more than four times the stem diameter.

Class 3: Trees suitable for short logs of poor quality: the stem is crooked and leaning. Crooks may reach six times the stem diameter in one dimension and minor crookedness in a second dimension is tolerated. Only short logs of poor quality and firewood can be produced from these trees.

Class 4: Trees suitable for firewood only: very crooked in more than one dimension, low branching, forked trees with stem defects, broken crown or stem rot.

For the investigation of butt rot caused by the fungus (*Fomes fraxineus* COOKE), 30 sample trees were selected in each plot. Rot on cut surface and upwards in the trunk was measured by cutting the stem along the vertical axis.

The stand value index showing the stem quality of the stands (SVI) was determined base on the following formula:

$$\text{SVI} = \frac{x_1 n_1 + x_2 n_2 + x_3 n_3 + x_4 n_4}{n_1 + n_2 + n_3 + n_4} \quad (2)$$

where $x_1, x_2, x_3, x_4 =$ tree quality classes,

$n_1, n_2, n_3, n_4 =$ tree numbers belonging to the single tree quality classes

4 RESULTS

Table 1 shows a considerable difference in initial stocking after regenerations. The best stocking was from regeneration from large roots. The lowest density was in treatment II, i.e. regeneration from fine roots. This difference also shows up in per hectare volume at harvest. There is virtually no difference in average heights and diameters between treatments I and II, i.e. regeneration from suckers, and this also applies to mean tree volumes. The lowest values for these parameters are in treatment III, i.e. regeneration with seedlings. There is no difference in terms of stand value index, meaning that the method of regeneration does not have any effect on the quality of the trees. In all treatments a tendency toward increasing SVI indices with age.

Table 1. Stand structure and quality parameters of the experimental plots

Age	Stem number per ha	Mean height	Mean DBH	Basal area	Volume	Mean tree volume	Stand-value index (SVI)
Y ear		m	cm	m^2/ha	m^3/ha	dm^3	
Treatment I Regeneration from suckers developed from thick roots							
6	5060	6.2	4.2	7.1	35.2	7.0	–
17	1283	16.8	13.7	19.0	165.8	129.2	1.7
24	607	21.6	19.0	17.2	182.6	300.8	1.8
29	601	23.1	21.5	21.8	248.5	413.5	1.9
34	601	24.2	23.2	23.6	297.1	494.3	1.9
Treatment II Regeneration from suckers developed from thin roots							
6	3872	6.6	4.9	7.2	37.2	9.6	-
17	896	17.4	15.4	16.7	153.3	171.1	1.6
24	395	22.6	19.8	12.1	135.7	343.5	1.7
29	395	23.3	22.4	15.6	178.0	450.6	1.8
34	395	23.9	23.8	15.7	200.0	506.3	1.8
Treatment III Regeneration with seedlings							
6	4004	6.2	4.2	5.5	27.6	6.9	–
17	1225	16.5	13.7	18.0	155.6	127.0	1.7
24	607	21.6	18.6	16.6	177.0	291.6	1.7
29	596	22.4	20.9	20.5	228.0	382.5	1.8
34	596	22.8	21.5	22.9	258.9	434.4	1.8

Figure 2 shows similar tendencies of height growth curves of seed and coppice origin. At the age of harvest, the mean height of the stand regenerated from suckers (treatment I and II) developed from thick roots is just as large as that of the stand regenerated from suckers developed from thin roots. The height growth of the stand regenerated with seedlings (treatment III) is somewhat lower than that of the stand regenerated from suckers.

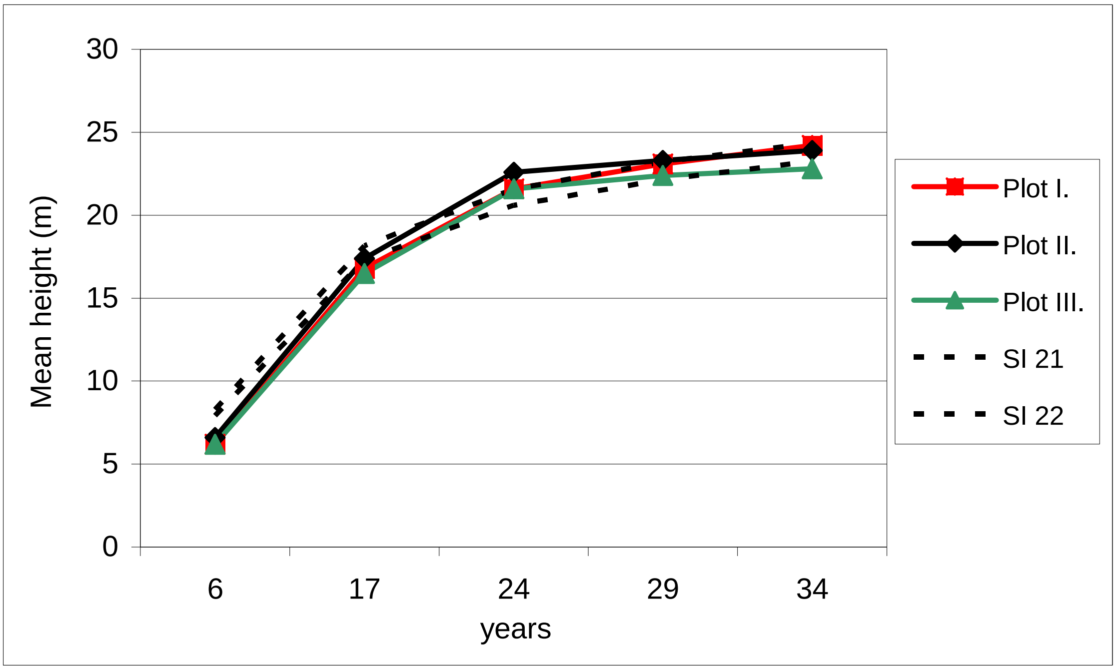

Figure 2. Mean height values of stands along with site index curves (Plot I: regenerated from thick roots, Plot II regenerated from thin roots, Plot III: regenerated with seedlings, SI 21 and 22 are site index curves)

To investigate possible differences in curve shapes and asymptotic values of height growth a growth function, the modified Chapman–Richards function was fitted to the height over age data. The function has the following form:

$$h = p_1(1 - e^{p_2 t})^{p_3} \quad (3)$$

where h is the height
t is the age
p_1, p_2 and p_3 are the parameters

Parameter p_1 is the asymptotic (maximum) value of the height growth; parameters p_2 and p_3 are responsible for the shape of the curve.

Table 2. Parameter estimates for the height growth curves of the three different plots using the modified Chapman–Richards function

	Plot I	Plot II	Plot III
p_1	27.10	25.89	24.83
p_2	–0.07968	–0.09681	–0.09624
p_3	1.5384	1.6927	1.7136

Parameter estimates in *Table 2* show that the height growth of plots II and III are similar in shape (nearly identical p_2 and p_3 parameters) at a slightly different asymptotic level, and the curve of plot I is different both in terms of asymptotic value and curve shape.

Figure 2 also compares experimental plot height growth with site index curves (Rédei – Gál 1985) for site indices 21 and 22 (height at the age 25; dotted black lines in the graph). The growth pattern is very similar, so these long term observations also support the patterns of the site index curves.

Figure 3 indicates that in spite of a difference in number of stems per ha between the plots regenerated from suckers sprouted from thick and thin roots there is no considerable difference in DBH of their crops. The DBH values of crops regenerated with seedlings are somewhat lower than that of crops regenerated from suckers but the deviation is negligible from a practical point of view.

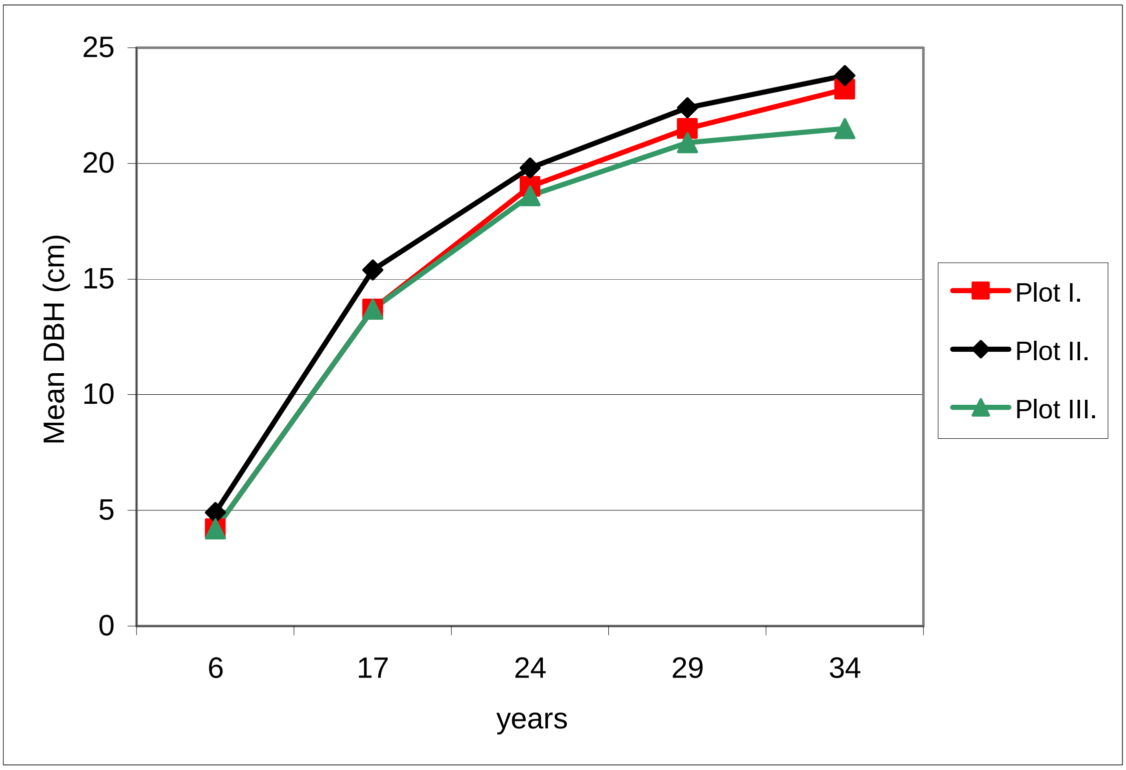

Figure 3. DBH values of the stands
(Plot I: regenerated from thick roots, Plot II regenerated from thin roots,
Plot III: regenerated with seedlings)

The parameters of the Chapman–Richards function were also estimated for the DBH over age data. The parameters are in *Table 3*.

Table 3. Parameter estimates for the DBH growth curves of the three different plots using the modified Chapman–Richards function

	Plot I	Plot II	Plot III
p_1	29.75	28.28	25.21
p_2	–0.05827	–0.06772	–0.07659
p_3	1.6260	1.5995	1.8320

According to these data, stands raised from suckers produced higher average tree volumes in both cases than stands of seed origin.

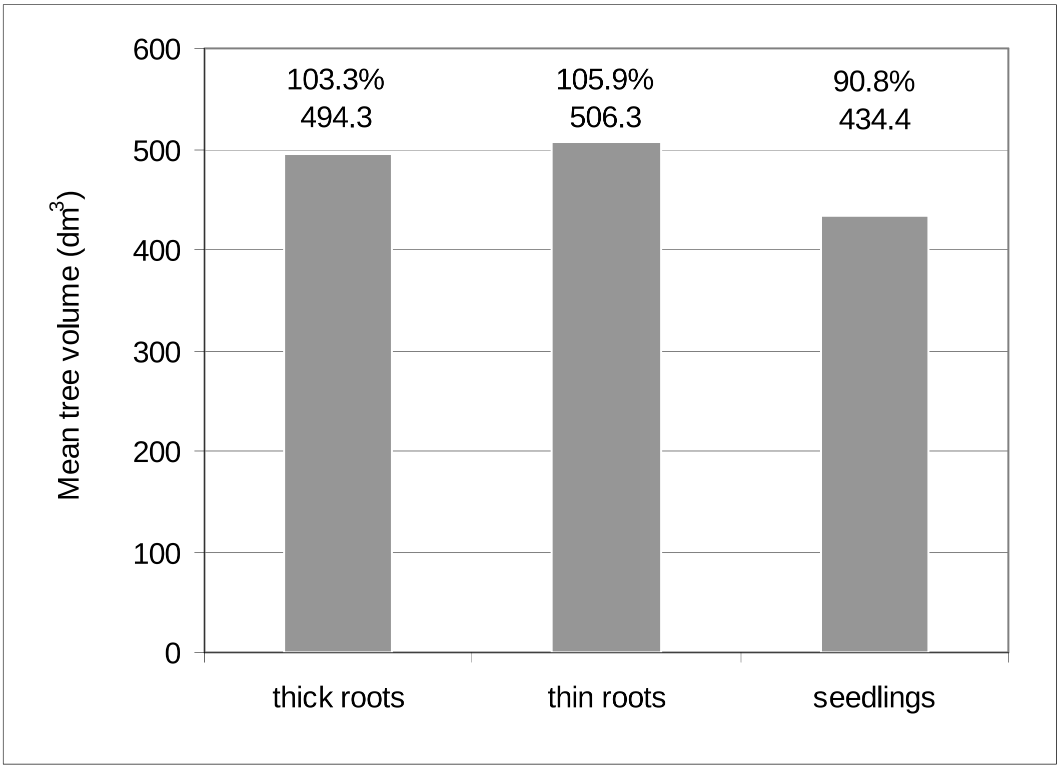

Figure 4. Mean tree volume of the crops at age of 34 years in the treatments

Investigations of stem quality of these experimental stands at harvest age 34 showed a stand value index 1.9 in treatment I (thick roots) and 1.8 in treatment II (thin roots) and III (seedlings). This suggests that differences in regeneration methods do not result in meaningful differences in the stand value index.

After harvesting, the degree of butt rot caused by *Fomes fraxineus* COOKE was investigated on 30 trees in each plot by determining the surface area of rot per cross section along the stem. 72% of the sample trees had rot extending up to 50 cm from the butt and 29% had rot between 50 and 100 cm up the stem. No trees had rot above 1 meter height. Overall 46% of the trees had butt rot on plot I, 43% on plot II, and 40% on plot III. This data would suggest that but rot is only slightly influenced by the regeneration method.

5 CONCLUSIONS

The results indicate that there is only a slight difference in stem quality and health status of stands regenerated by different methods. The differences that arose from treatments were mainly related to different initial stand densities.

Mean tree volumes of stands established by various coppicing methods and by planting have shown only minor differences at harvest. The stand of seed origin did not produce better stem quality than stands of coppice origin. The coppice stands did not produce less valuable assortments than stands of seed origin, therefore coppicing remains to be a viable management option under similar site conditions.

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