# Parent Stand Growth Following Gap and Shelterwood Cutting in a Sessile Oak-Hornbeam Forest

Tamás TOBISCH*

Department of Ecology and Silviculture, Forest Research Institute, Sárvár, Hungary

**Abstract –** In this paper, effects of uniform shelterwood cutting (SWC) and gap cutting (GC) on total volume and value increment of the parent stand, volume increment of individual sessile oak trees, as well as, on crown expansion of sessile oak are compared for the first five years of the regeneration period of an oak-hornbeam forest. The gaps were circular and of one tree height in diameter. During SWC, there were two harvesting occasions, on each of which 30% of the standing volume was removed. Total volume increment of the remaining sessile oak trees relative to the initial standing volume of sessile oak was approximately identical between the two methods. However, individual trees grew faster if applying SWC. Volume increment of sessile oak decreased with the distance from gap centres. Crowns expanded mostly southwards and westwards both in the cases of GC and SWC. Value increment of the parent stand did not differ considerably between the two methods.

**crown expansion / gap cutting / *Quercus petraea* / shelterwood cutting / value increment / volume increment**

**Kivonat – Az anyaállomány növekedése ernyős felújítóvágás ill. lékvágás során gyertyános-kocsánytalan tölgyesben.** Jelen tanulmányban gyertyános–tölgyesben végrehajtott lékvágásnak ill. egyenletes bontáson alapuló felújítóvágásnak az anyaállomány térfogat- és értéknövedékére, a kocsánytalan tölgy faegyedek térfogatnövedékére valamint a kocsánytalan tölgyek koronáinak növekedésére gyakorolt hatását hasonlítom össze a felújítás első öt évére vonatkozólag. A lékek kör alakúak, egy fahossznyi átmérőjűek voltak. Az ernyős felújítóvágás során az anyaállományt két alkalommal bontották meg, mindkét esetben az élőfakészlet 30%-át termelték ki. A kocsánytalan tölgy összesített térfogatnövedéke a kocsánytalan tölgy kiindulási élőfakészletéhez viszonyítva közel megegyezett a két felújítási módszer esetében. Egyenletes bontásnál azonban a kocsánytalan tölgy faegyedek gyorsabban növekedtek. A léktől távolodva a kocsánytalan tölgyfák térfogatnövedéke csökkent. Mindkét technológia alkalmazásakor a koronák leginkább déli ill. nyugati irányban nyúltak meg. Az anyaállomány értéknövedékét tekintve a kétféle eljárás nem különbözött számottevően.

**ernyős felújítóvágás / értéknövedék / koronák növekedése / lékvágás / *Quercus petraea* / térfogatnövedék**

*tobisch.tamas@aesz.hu; H-9600 SÁRVÁR, Várkerület 30/A

## 1 INTRODUCTION

One main tool of close-to-nature forestry is mimicking natural processes (Somogyi 2000, Gamborg – Larsen 2003). As temperate deciduous forests often regenerate themselves by spontaneous gap formation (Runkle 1989), it seems logical that gap cutting is one of the regeneration methods of close-to-nature forestry (Schütz 2002). However, the ecological and the economical advantages of gap cutting over the traditional uniform shelterwood system are not obvious and should be demonstrated in appropriate field trials.

Whereas shelterwood cutting of pedunculate (*Quercus robur*) and sessile oak (*Q. petraea*) stands has been practiced for a long time (e.g. Szappanos 1967a, 1969a, 1969b, Kelly 2002, Harmer et al. 2005, Harmer – Morgan 2007, Tobisch 2008), very little is known in such oak stands about spontaneous gap formation or the effects of gap cutting (Lüpke 1998, Nicolini et al. 2000, Bobiec 2007, Collet et al. 2008, Diaci et al. 2008).

Canopy closure plays a key role during natural regeneration. It influences the intensity and spatial pattern of light reaching the understory and affects soil water content (Szappanos 1967a, Bréda et al. 1995, Emborg 1998, Lüpke 1998, Ostrom 2005). For sessile oak seedlings, both light and soil moisture conditions are especially important. Although sessile oak is normally regarded as a light-demanding species (Krahl-Urban 1959 cit. Lüpke, 1998), its shade tolerance increases from northwest to southeast in Europe (Krahl-Urban 1959 cit. Kelly 2002). Therefore, under the Hungarian site conditions, survival of young seedlings is often limited by soil moisture (Magyar, 1933). It is also well-known that decreasing the canopy density during shelterwood cutting promotes weed proliferation in many sites and can lead to serious problems of sessile or pedunculate oak regeneration (Humphrey – Swaine 1997, Kelly 2002, Harmer et al. 2005, Harmer – Morgan 2007).

Although the structure of the canopy greatly influences the regeneration processes, as well as, crown size correlates with volume growth of the parent stand (Drobyshev et al. 2007), growth rate of sessile oak crowns has been rarely studied (Longuetaud et al. 2008). Sessile oak is known as a species the crown plasticity of which is very low at the age of regeneration (Szappanos 1967b) but no data is widely available on crown expansion during shelterwood or gap cutting.

Volume and value increment of sessile oak trees can be considerable even during the quite short regeneration period (lasting for maximum 10-15 years on Hungarian mesic sites) of shelterwood cutting (Szappanos 1967a, Götmark 2009) By contrast, effects of gap cutting on parent stand growth are not well-known. Based on some evidence (mainly from North America), it can be assumed that trees at the edge of gaps grow faster than those inside the closed stand (Poage – Peart 1993, Pedersen – Howard 2004). However, hardly any information is available about sessile oak in this context.

In this paper, some preliminary results of a comparative study of a sessile oak-hornbeam forest are presented. The following questions are addressed based on the first five years of the regeneration period:

1. How do shelterwood and gap cutting affect the volume and value increment of the parent stand?
2. How do size and shape of sessile oak crowns change in the shelterwood stand and at the edge of gaps?

## 2 MATERIALS AND METHODS

### 2.1 Study area

The study stand (47°42'N, 18°52'E) occurs at 470 m a.s.l. on a slight south-southwest-facing slope in Visegrádi Mountains, North-Hungary (*Figure 1*). The mean annual precipitation at the nearest meteorological station (Dobogókő, 699 m a.s.l.) is 790 mm of which 239 mm falls during the main growing period (i.e. from 1 May to 31 July). The mean annual temperature is 7.1 °C. The mean temperature of the warmest month (July) is 17.5 °C while the coldest one is January with a -4.1 °C mean.

The soil of the study stand was examined at sampling plot level (Tobisch 2009). According to these investigations, the soil is mainly of a transitional type between ranker and some brown forest soil (i.e. clay migration was noticeable but to a lower extent than in the case of brown forest soils) which is loamy and developed on andesite bedrock. The rootable depth varies between 60 cm and 75 cm. However, in one of the sampling plots, pseudogleyic brown forest soil with a rootable depth of 35 cm occurs (see the description of the sampling design). Although soil properties of this plot differed from those of the others, it was not excluded from the experiment because some useful information would have been lost if omitting this plot. Furthermore, it was possible to detect possible effects of differences in site conditions since data were evaluated at plot level.

The study stand was a sessile oak-hornbeam forest with sessile and turkey oak (*Quercus cerris*) in the upper layer and hornbeam (*Carpinus betulus*), as well as, European beech (*Fagus sylvatica*) in the lower layer. The stand was 82 years old in 2002, i.e. at the beginning of the experiment. The stand of the plots is described in details in the results section. The shrub layer was patchy and consisted mainly of *Crataegus monogyna* and *Carpinus betulus*. Characteristic type indicator species of the herb layer (sensu Majer 1963) were *Carex pilosa*, *Galium odoratum*, *Melica uniflora*, *Poa nemoralis*.

### 2.2 Experimental design, and the regeneration techniques studied

The study forest subcompartment was divided into two parts along a natural border (a little stream) and an artificial one (*Figure 1*). Five more or less circular gaps of 25-30 m in diameter (i.e. approximately one tree height) were cut in one part (hereinafter abbreviated as GC stand where GC refers to 'gap cutting') during the winter of 2002-2003. Distances between margins of neighbouring gaps were at least one tree height. The other part of the study area (hereinafter abbreviated as SWC stand where SWC refers to 'shelterwood cutting') was evenly opened at the same time. Around one third of the trees (in respect of volume) of the SWC stand was removed. Here, a second cut was carried out with the same intensity as the first one during the winter of 2006-2007.

### 2.3 Sampling

Eight sampling plots of 55 m x 45 m in N-S and E-W direction, respectively, were distributed in the study area (*Figure 1*). Five of them were regenerated by gap cutting (hereinafter called GC plots), three of them were regenerated by shelterwood cutting (hereinafter called SWC plots). In the former case, gap centres were located approximately 5 m south to the plot centres. In this way stands at the north edge of the gaps in which sunlight penetrates most deeply and for the longest time (Mihók et al. 2005, Ritter et al. 2005) can be studied more thoroughly. All plots but No. 4 and 7 were fenced to study the effects of browsing on regeneration (data not published in this paper).

All trees of the parent stand of the eight plots were sampled on two occasions, after the vegetation period of 2002 and after that of 2007. In 2002, separate point maps of all trees of the sample plots were created by theodolite (Zeiss – DAHLTA 010A) and sonic distance measurer (SONIN Combo PRO). Furthermore, the longest horizontal crown radii of all trees were measured in direction of N, W, E and S. Moreover, two perpendicular diameters (dbh) of each tree were recorded. Height of one average tree of each 1 cm-wide diameter class was measured by standard hypsometer (Vertex III) in each plot to generate diameter-height curves for each species (if it was necessary due to the high number of trees).

In contrast to 2002, height of all trees was measured in 2007 since it was supposed that trees surrounding the gaps had not grown at the same speed. Furthermore, in GC plots, the crown radii of only trees directly at the edge of gaps were measured because crown expansion of trees inside the closed stands surrounding the gaps was assumed to be very low (Longuetaud et al. 2008).

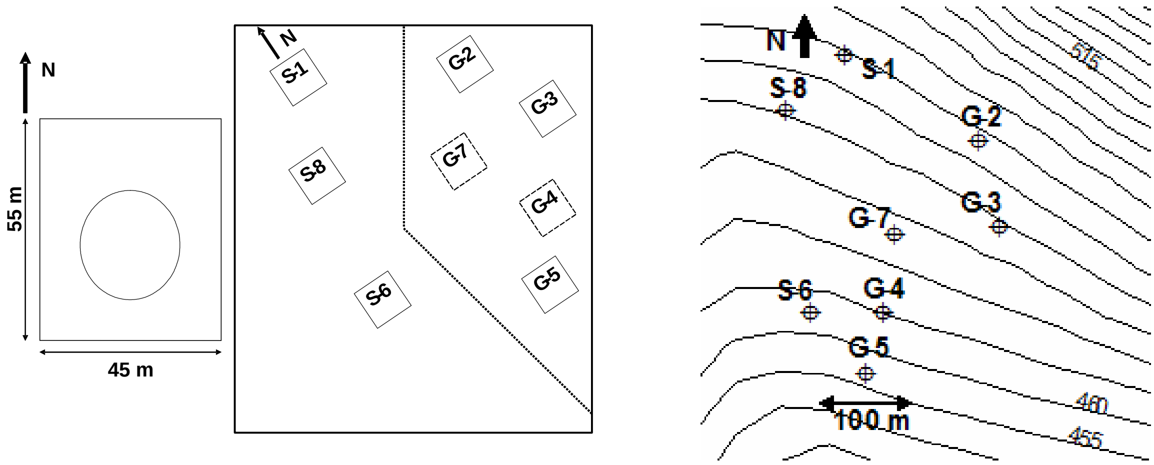


*Figure 1. Experimental design. On the right side a schematic map of the study stand is shown with the six fenced (delineated by solid lines) and the two unfenced plots (delineated by broken lines) and a plot of gap cutting can be seen. The area of the gap is indicated by a circle. On the left side the real topographical position of the plots is indicated. G – plots of gap cutting; S – plots of shelterwood cutting; dotted lines – border-lines of the two regeneration methods. The numbers refer to plot numbers. Source of the topographical map: Hungarian Institute of Geodesy, Cartography and Remote Sensing.*

Beside the two sampling occasions of the complete parent stands (i.e. all living trees), diameters of those trees which were cut in the winter of 2006-2007 (i.e. at the second cut of shelterwood cutting) had been measured after the vegetation period of 2006. Height of these trees was calculated from the diameter-height curves.

## 2.4 Data analysis

Data of each plot (except for those on crown expansions) were analyzed separately. Thus, the applied significance tests were performed pairwisely which means that every SWC plot was compared with every GC plot. In this way, possible effects of small-scale differences in site conditions or tree stand structure between the plots on parent stand growth could be revealed.

Diameter-height curves were created from diameter and height data of 2002 by natural logarithmic regression (Veperdi 2008) for each tree species per plot. These curves were then used to estimate the height of those individuals which were not measured directly.

Total above-ground volume of each tree was calculated for 2002 and 2007 using the Hungary-specific Király volume function (Király 1978). Volume of those trees which were cut in the winter of 2006-2007 was calculated by the same method for 2006. Total increment of the remaining trees of each species was examined at plot level for the first five years of the regeneration. Total increment of the remaining trees of a given species was divided by the total initial volume of all trees of that species and multiplied by 100. Thus, total increment of the remaining trees was expressed on a percent scale relative to the initial standing volume of the given species. Furthermore, total volume of the removed trees was studied by the same method.

Increment of the remaining sessile oak trees in absolute, as well as, in relative value was analyzed also for the first five years of the regeneration (individual-level analyses). The differences occurred in these types of increment were compared by single classification ANOVA-s. However, increment distributions were both non-normal and heteroscedastic therefore the classical F test of ANOVA cannot be used. Furthermore, it has been shown recently that even the non-parametric Kruskal-Wallis test assumes the equality of variances (Fagerland – Sandvik 2009). Thus, significance of the $F$ statistic was checked by sampled randomization tests with 1000 resamplings (Sokal – Rohlf 2003, McDonald 2009). The randomization tests were performed by randomly permuting the assignment of observations to the groups (i.e. to the plots). The sizes of the groups were fixed.

Kendall's rank correlation coefficient was applied to analyze the relation between the distance from the gap centre in the four cardinal directions and the increment of sessile oak trees. If the correlation proved significant Kendall's robust line fit method was used to fit a regression line on the data.

Crown expansion of sessile oak trees was examined in two ways. On the one hand, SWC and GC plots were compared according to the expansions of crown quarters (N, E etc.). The applied method was the Kruskal-Wallis test because distributions of the expansions were non-normal but homoscedastic as indicated by Levene tests. On the other hand, trees of all plots were grouped according to the regeneration type, as well as, in the case of GC, according to the location (N, S, E, W) relative to the gaps. Thus, five groups (one group of SWC and four groups of GC) were distinguished. The expansions of crown quarters were then compared by groups using Wilcoxon's signed ranks tests. These tests were carried out as unplanned comparisons (every possible comparison was done). In this way, expansion of a crown quarter of a given tree was compared to that of the other three crown quarters of the same tree (paired comparisons, Sokal – Rohlf 2003). Due to the unplanned character of the tests, significance levels were modified according to the Bonferroni-Holm method (Sokal – Rohlf 2003). It should be noted that by the Bonferroni-Holm method, significance tests become conservative which means that the power (the probability of rejecting the null hypothesis when it is false) of the tests decrease. Thus, the null hypothesis is accepted too often. However, there were no reasons to make *a priori* decided (planned) comparisons.

Value increment of the parent stand was analyzed using the mean market values (without VAT) of the local forestry practice in 2008 (*Table 1*). Harvesting costs and selling revenues apply to net volume which was calculated as 80% of the total above-ground volume following the local forestry practice. 30% of the harvested sessile oak wood was considered as industrial wood while the remaining 70% was regarded as firewood following the local practice again. 100% of the harvested wood of other species was considered as firewood.

*Table 1. Costs and revenues by forestry operation used for economical calculations. The applied exchange rate (as of November 2008) was 1 EUR to 260 HUF.*

| Forestry operation | Costs/revenues ($EUR/m^3$) |
|---|---|
| harvesting | 11.54 |
| revenue from selling industrial timber | 84.62 |
| revenue from selling firewood | 50.00 |

Value of all living trees was calculated for the initial stage of the regeneration ($value_i$) and for the fifth year of that ($value_f$) from the revenues and costs of wood harvesting and selling (*Table 1*). Furthermore, value of the removed trees ($value_r$) was calculated by the same method. Value increment ($I_v$) of the parent stand referring to the first five years of the regeneration was then expressed as interest from the following equation:

$$I_v = \left[ \frac{(value_f + value_r) - value_i}{value_i} \right] * 100$$

Data were evaluated by the BIOMSTAT 3.3 (2002) program.

## 3 RESULTS

### 3.1 Standing volume at the initial stage and volume of the removed trees

Tree stand structure of the plots was diverse at the initial stage of the experiment (*Figure 2*). Volume of the removed sessile oak trees varied between 20% to 56% in the SWC plots whereas almost all trees of the associated species were cut from here during the first five years of the regeneration (note that some beech trees were removed only on the second harvesting occasion, thus due to their increments, volume of the removed trees was higher than 100% in plot No. 1; *Figure 3*). 20-30% of sessile oak and the same amount of turkey oak were cut in most GC plots. In plots No. 2 and 3, 40% of hornbeam while in plots No. 4 and 7 20% of that was removed.

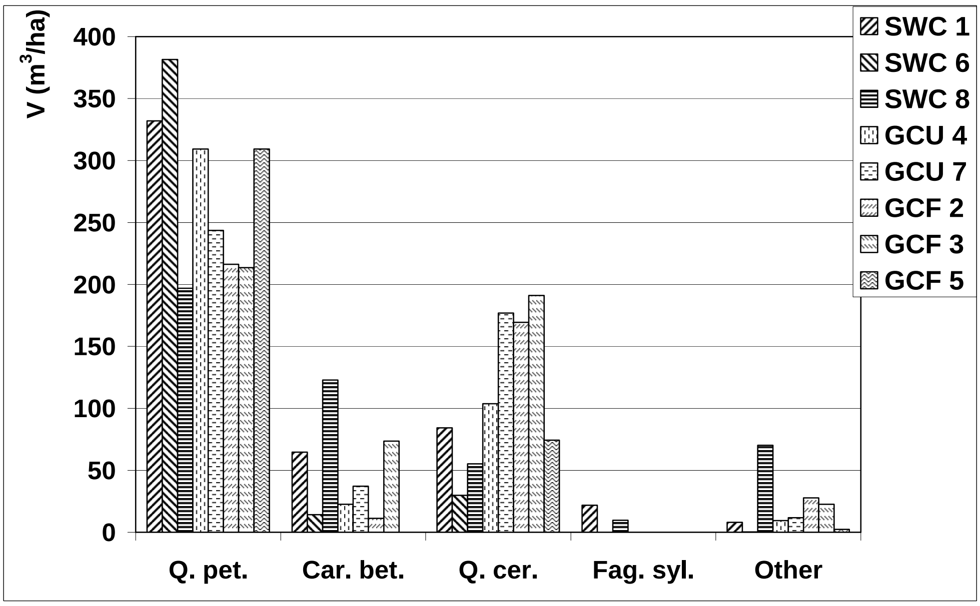


*Figure 2. Initial standing volume of tree species. The numbers refer to plot numbers. SWC – plots of shelterwood cutting; GCU – unfenced plots of gap cutting; GCF – fenced plots of gap cutting; Q. pet. – Quercus petraea; Car. bet. – Carpinus betulus; Q. cer. – Quercus cerris. Fag. syl. – Fagus sylvatica.*

### 3.2 Volume increment

Total increment of the remaining sessile oak trees relative to the initial standing volume of sessile oak was approximately identical, 7–9% in most of the plots (plot-level analyses, *Figure 4*). The only exception is plot No. 8 in which it was higher, 12%. However, considering the absolute, as well as, the relative increment values, sessile oak trees grew significantly faster ($p \leq 0.01$ and $p \leq 0.05$, respectively, in all the 15 possible cases) in SWC plots according to the pairwise randomization tests (individual-level analyses, *Figure 5*).

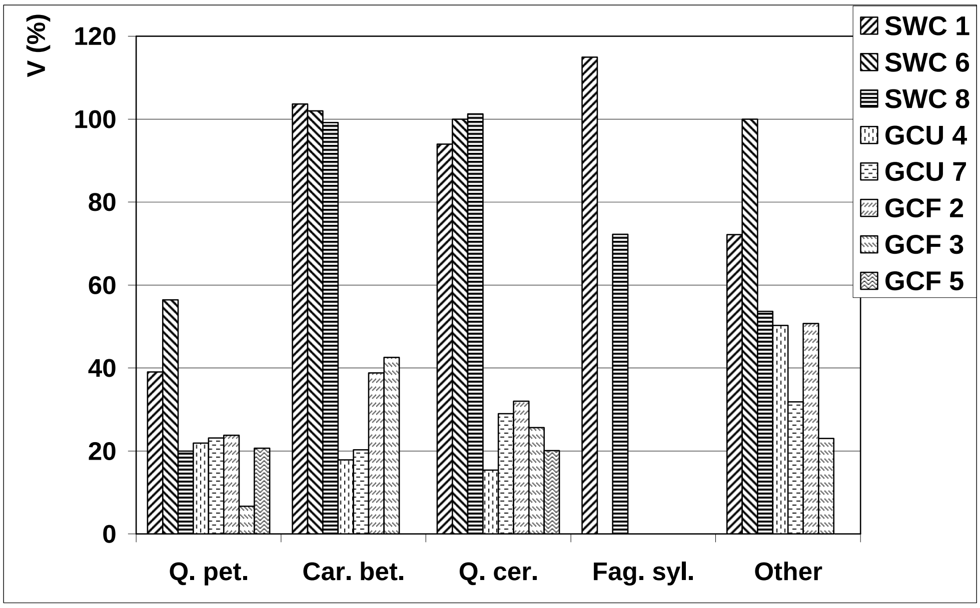


*Figure 3. Volume of the removed trees by species relative to the initial standing volume of the given species during the first five years of the regeneration. For abbreviations see Figure 2.*

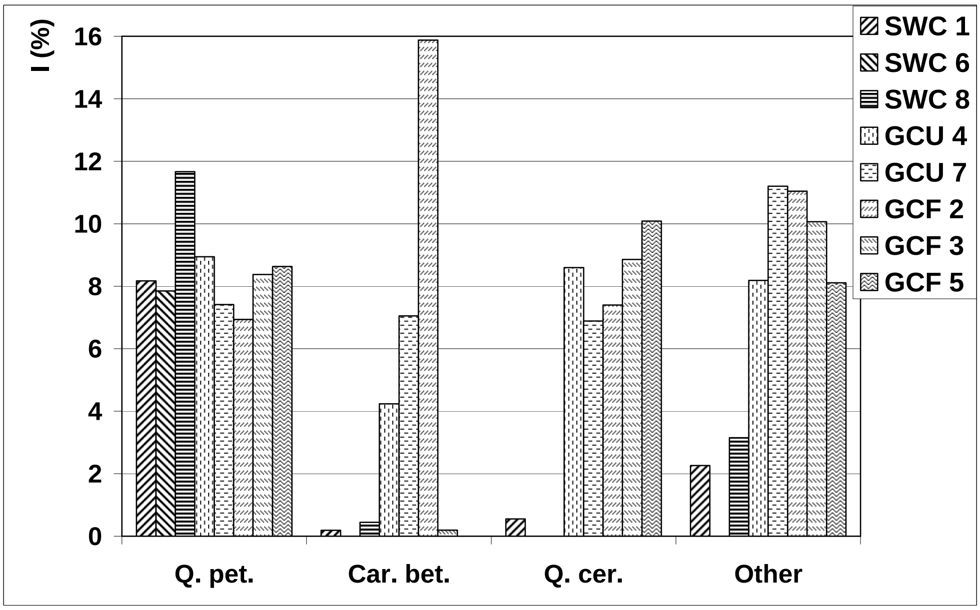


*Figure 4. Total increment of the remaining trees by species relative to the initial standing volume of the given species during the first five years of the regeneration (plot-level analyses). For abbreviations see Figure 2.*

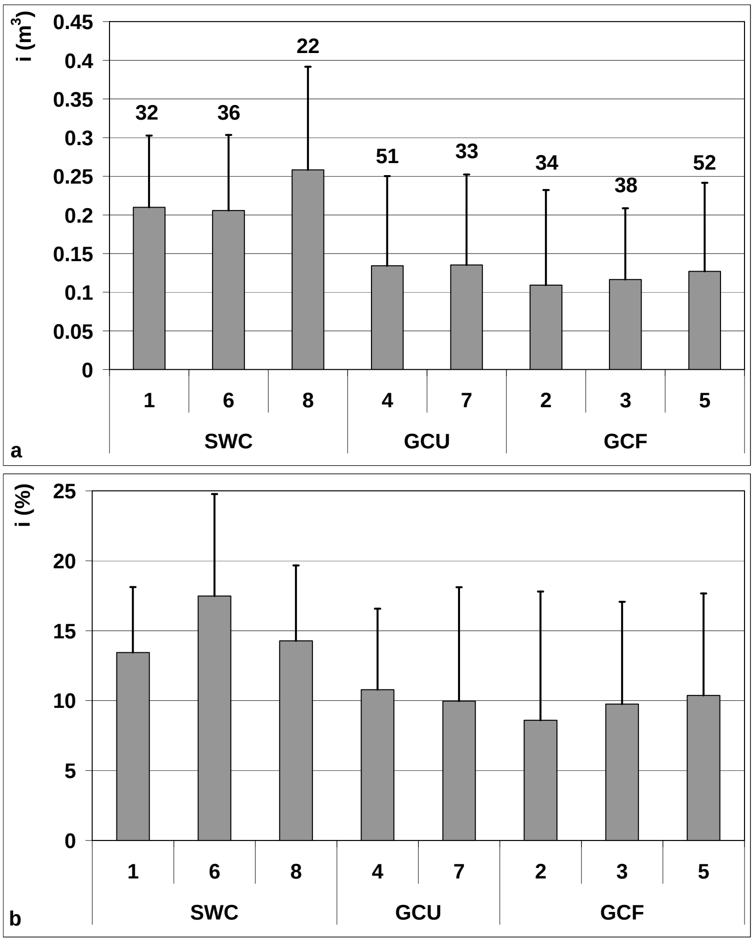


*Figure 5. Increment (i) of the remaining sessile oak tress in absolute (a) and in relative value (b) during the first five years of the regeneration (individual-level analyses). Standard deviations are indicated by whiskers above which observation numbers are shown on Figure 5a. For abbreviations see Figure 2.*

In GC plots, significant negative correlations were found between distance from gap-centre and growth of sessile oak trees mainly northwards (in three out of the five possible cases; *Table 2*). In addition, the correlation was significant eastwards (in two cases) and westwards (in one case). Increment of those trees, which were located farther away than 30–35 m from the centre of the gaps was usually lower than 0.1 $m^3$ (*Figure 6*). Increment of turkey oak was similar to (or, in plot No. 5, somewhat higher than) that of sessile oak in GC plots (*Figure 4*). Growth of hornbeam and the other associated tree species was very diverse, no regularity could be found in that issue.

*Table 2. Kendall's rank correlation coefficients (τ) between increment of sessile oak trees and distance from the gap centres in the four cardinal directions.*

| | N | | E | | S | | W | |
|---|---|---|---|---|---|---|---|---|
| | τ | n | τ | n | τ | n | τ | n |
| GCF 2 | –0.35* | 16 | – | 3 | 0.17 | 9 | –0.33 | 6 |
| GCF 3 | –0.49* | 15 | 0.02 | 11 | 0 | 4 | –0.29 | 8 |
| GCF 5 | –0.02 | 20 | –0.62* | 7 | –0.6 | 5 | –0.32* | 20 |
| GCU 4 | –0.16 | 23 | 0.07 | 10 | –0.07 | 6 | –0.06 | 12 |
| GCU 7 | –0.35* | 15 | –0.87* | 6 | 0.71 | 7 | -0.2 | 5 |

Kendall's robust lines corresponding to the significant correlations (*; p ≤ 0.05) are shown on *Figure 6*. Abbreviations are given at *Figure 2*.

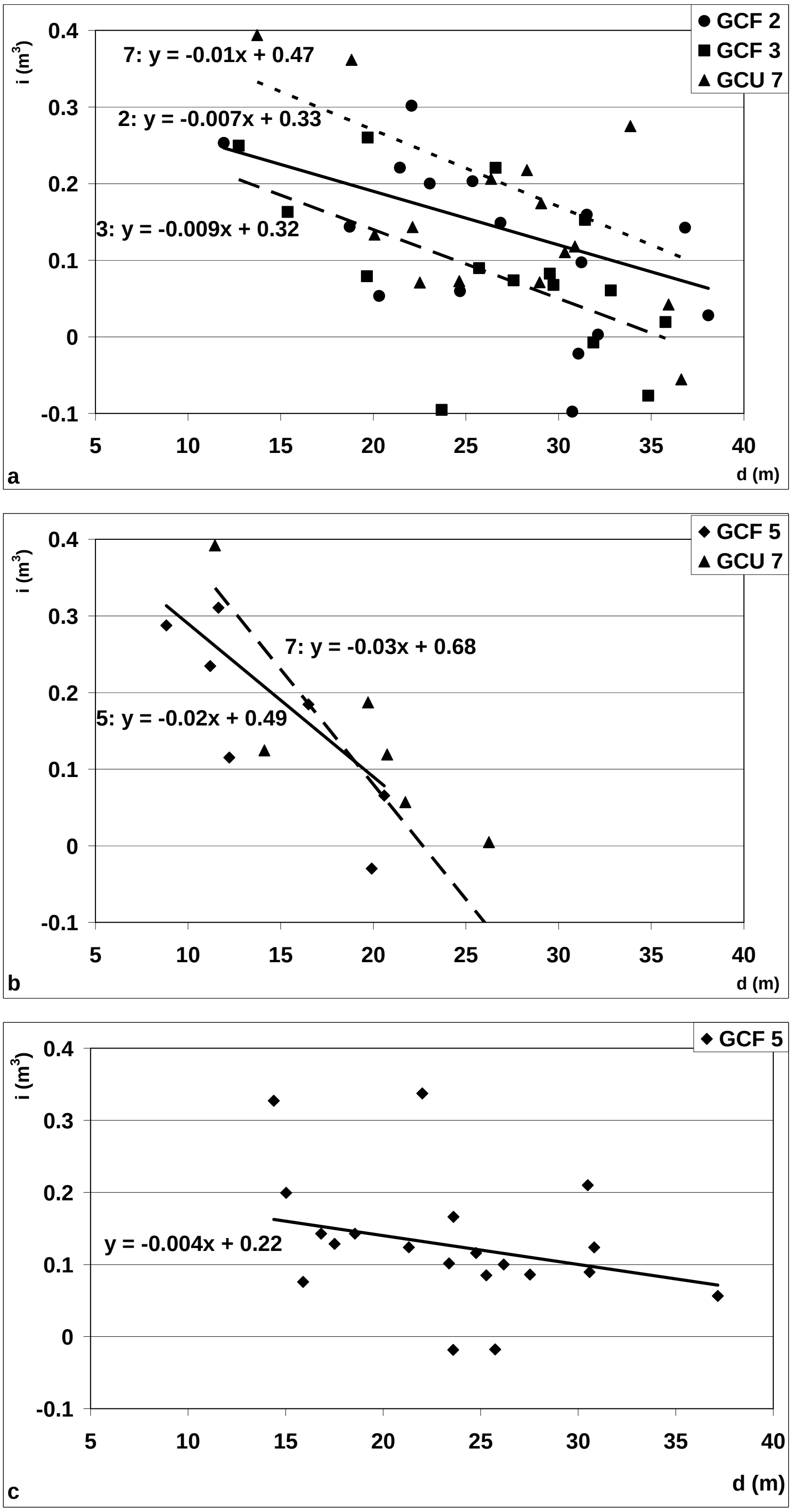


*Figure 6. Kendall's robust lines for the significantly negative correlations between distance from the gap centres (d) and increment of sessile oak trees (i) northwards (Figure 6a), eastwards (Figure 6b) and westwards (Figure 6c). The negative increment values are consequences of crown breaks or measurement errors. Equations of the robust lines are shown on the diagrams with the corresponding plot numbers. For abbreviations see Figure 2.*

### 3.3 Crown expansion of sessile oak trees

Results of the Kruskal-Wallis tests (*Table 3a*) do not prove that SWC and GC affect crown growth differently. The differences are often not significant and no clear trend can be recognized even in the significant differences.

Sessile oak crowns expanded mainly southwards and westwards in the SWC plots. The expansion was often considerable (even several meters as indicated by the standard deviations; *Table 3b*). Effects of the gaps on crown expansions are not always obvious if considering the location of the oak trees relative to the gaps (*Table 3b*). The expansion of many crowns was the highest not towards the gaps but southwards again (even by up to 5.5 m) though the differences between the expansions of crown quarters were not always significant.

*Table 3a. Crown expansions (ce) of sessile oak trees in the four cardinal directions.*

| | ce (m) | | | | n |
|---|---|---|---|---|---|
| | N | E | S | W | |
| SWC 1 | 0.0 (0.9) | 0.4 (1.0) | 2.2 (1.0) | 1.7 (0.7) | 32 |
| SWC 6 | 0.1 (0.8) | 0.7 (1.3) | 2.3 (0.8) | 1.1 (0.8) | 36 |
| SWC 8 | 0.4 (0.9) | 1.0 (0.8) | 1.8 (1.6) | 0.9 (0.6) | 23 |
| GCU 4 | 0.5 (0.9)$^{1}$ | 1.0 (0.8) | 1.9 (1.1) | 1.2 (0.9) | 16 |
| GCU 7 | 0.5 (1.0) | 1.3 (1.1)$^{1}$ | 2.2 (2.3) | –0.3 (0.9)$^{1,6,8}$ | 9 |
| GCF 2 | 0.2 (1.0) | 0.3 (0.7)$^{8}$ | 1.3 (0.9)$^{1,6,8}$ | 1.5 (0.8)$^{8}$ | 14 |
| GCF 3 | 0.4 (1.0) | 0.8 (0.9) | 1.5 (1.5)$^{6}$ | 0.3 (1.3)$^{1}$ | 10 |
| GCF 5 | 1.0 (0.5)$^{1,6,8}$ | –0.3 (1.4)$^{6,8}$ | 1.3 (1.0)$^{1,6,8}$ | 1.5 (0.6)$^{8}$ | 12 |

*Table 3b. Crown expansions (ce) of sessile oak trees at different positions relative to the gaps and in the SWC plots in the four cardinal directions.*

| Position | ce (m) | | | | n |
|---|---|---|---|---|---|
| | N | E | S | W | |
| N | 0.6 (1.0)$^{a}$ | 0.9 (1.2)$^{a}$ | 1.8 (1.3)$^{b}$ | 1.0 (1.3)$^{a,b}$ | 24 |
| E | 0.3 (0.9)$^{a}$ | 0.4 (1.3)$^{a}$ | 1.7 (1.0)$^{b}$ | 1.0 (1.0)$^{a,b}$ | 14 |
| S | 0.3 (0.6) | 0.4 (0.8) | 1.3 (1.4) | 0.8 (1.0) | 10 |
| W | 0.9 (0.9) | 0.4 (0.8) | 1.5 (1.7) | 1.1 (0.9) | 13 |
| SWC | 0.2 (0.9)$^{a}$ | 0.7 (1.1)$^{b}$ | 2.1 (1.1)$^{c}$ | 1.2 (0.8)$^{d}$ | 91 |

Standard deviations are shown in parentheses. The numbers in the upper index of cell values of *Table 3a* indicate the numbers of those SWC plots from which the given GC plot is significantly different ($p \leq 0.05$). In *Table 3b*, mean values of significantly different crown expansions are marked with different letters in the upper index (comparisons were carried out by positions). For abbreviations see *Figure 2*.

### 3.4 Value increment

There were no substantial differences in value increment of the parent stand between the plots of the two regeneration methods (*Figure 7*). Value increment of plots No. 4, 5 and 6 was slightly higher than that of the other plots.

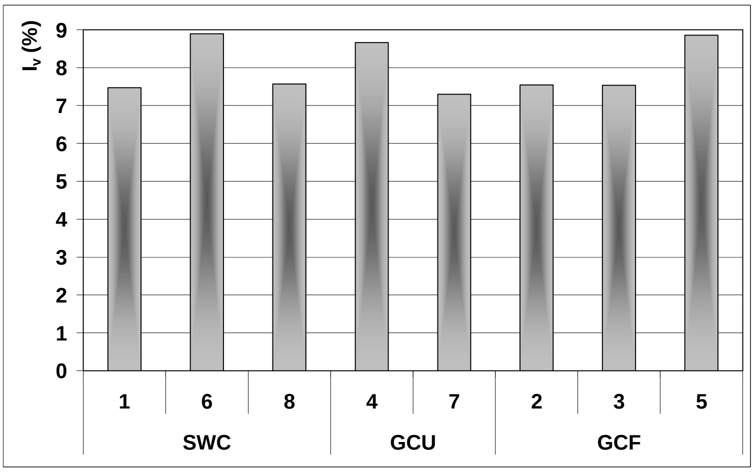


*Figure 7. Relative value increment ($I_v$) of the tree stand. For abbreviations see Figure 2.*

## 4 DISCUSSION

### 4.1 Volume increment

Although total increment of the remaining sessile oak trees relative to the initial standing volume of sessile oak was approximately identical in most plots, the same amount of increment was produced by relatively much fewer trees in two SWC plots (No. 1 and 6; *Figure 3*). Furthermore, volume of the removed sessile oak trees in plot No. 8 was similar to that in the GC plots but relative total increment of sessile oak was higher in the former (*Figure 4*). These results indicate that in the SWC plots individual trees had larger increments in absolute value than those surrounding the gaps, as it was proved by the pairwise randomization tests. The explanation of the higher plot-level increment of sessile oak in plot No. 8 compared to the other SWC plots is the fact that relatively more trees remained (volume of the removed trees was smaller) in plot No. 8 than in the other SWC plots.

The higher absolute increment of sessile oak following SWC could be explained by two distinct reasons. On the one hand, it would be possible that trees grew really relatively faster due to the reduced competition occurred in the tree stand. On the other hand, it could also be assumed that the differences between SWC and GC plots are only results of artificial selection of the larger trees in the former case. That is, all trees were removed from gap areas and all of them remained in the stand nearby the gaps irrespectively of their size when applying GC, whereas with SWC, trees were selected according to their attributes, including size as well. Therefore, even if the larger trees of the evenly opened plots had grown relatively similarly to trees surrounding the gaps, their increments would have been larger in absolute value. However, the results of pairwise tests on relative increment values disprove this assumption. Moreover, it can be stated that differences in soil properties did not influence the character of differences in effects of the regeneration methods. That is, the contrasts between SWC and GC plots were of the same nature independently from the unique site conditions of plot No. 8.

Presumably, the significant decreases of increment of sessile oak trees northwards and eastwards from the gaps are related to crown expansions (Drobyshev et al. 2007). The crown of these trees grew southwards to a significantly greater extent than eastwards and northwards. The southwards growth of crowns seems to be the most advantageous for sessile oak trees (see below).

Apart from the asymmetric expansions, differences in illumination of crowns could also influence the spatial pattern of volume increment of sessile oak trees surrounding the gaps. Crowns of trees north to the gaps were illuminated by direct sunshine for the longest time, whereas those of trees south to the gaps were shaded mostly by the closed stand nearby (see Mihók et al. 2005 and Ritter et al 2005). That can be the reason for the phenomenon that the most frequent direction in which increment of sessile oak trees significantly decreased was north, whereas the opposite was true for south. Consequently, the results indicate that growth of the assimilating surface of sessile oak can mostly be facilitated by cutting elliptical gaps with the long axis oriented E-W (on south-facing slopes). However, increase of the assimilating surface is obviously not the primary goal of regeneration. Several other factors must be taken into consideration (e.g. seedling mortality, seedling growth, wood quality of the parent trees etc.).

### 4.2 Crown expansion of sessile oak

Crown expansions in the SWC plots show that southwards growth of crowns was the most advantageous for sessile oak trees. Again, the results were independent from soil differences between the plots. The asymmetric crown expansion can be caused by the extra high solar energy which the south part of the crowns gained (Péczely 1998). This effect was further facilitated by the S-SW aspect of the slope on which the stand can be found since the intensity of light received by the south part of the crowns became even higher.

It is not so clear, however, why west crown parts grew significantly faster (horizontally) than east parts following SWC. One possible explanation is that the angle of incidence of west light on west crown parts is smaller (i.e. the amount of solar energy per unit surface area is higher) than that of east light on east crown parts due to the southwest aspect. Another reason can be that light of warm afternoons may be more advantageous to the photosynthesis of sessile oak than that of cooler mornings. However, this assumption is very difficult to verify since photosynthesis is influenced by many factors simultaneously (Kramer – Kozlowski 1979 cit. Collet et al. 1998).

The results show that SWC and GC do not affect crown growth differently if considering trees at the edge of gaps and if overlooking the location of those trees relative to the gaps. However, in the case of GC, crowns are expected to expand towards (over) the gaps to gain more light (Muth – Bazzaz 2002). The present study disproves this assumption.

Although expansion of crown quarters of trees west and south to the gaps was not significantly different, growth rate of these crowns was highest southwards, similarly to that of crowns of trees at the two other locations. Considering also the fact that by the Bonferroni-Holm method significance tests become rather conservative, it can be supposed that irrespectively of the position of the trees relative to the gaps, crowns grew more or less alike. Thus, effects of angle of incidence of sunlight and those of Sun moving on crown expansion of sessile oak seem to be stronger than gap effects.

Despite the stand age, sessile oak crowns were rather plastic. Therefore, the results contradict the widespread theory that, after the age of selective thinnings, crown plasticity of sessile oak decreases greatly (Szappanos 1967b).

### 4.3 Value increment

Value increment of the parent GC stand was considerably influenced by the associated tree species. Although sessile oak trees grew significantly faster and volume of the removed trees was much higher in the SWC plots, increment of the associated tree species was higher in the stands nearby the gaps. The reason for this phenomenon is not only the differences between the initial tree stand structures of the plots but mainly the fact that fewer trees of the associated species were cut from the GC plots than from the evenly opened stands (*Figure 3*). Therefore, growth of the associated tree species could balance the value increment between the two regeneration methods. The unique soil properties of plot No. 8 did not cause any differences in value increment between the SWC plots.

The reason for the phenomenon that the value increment of plots No. 4, 5 and 6 was higher than the average is the tree stand structure of these plots. That is, initial sessile oak volume in these plots was higher than the average and sessile oak was the only species in the study forest which produced industrial wood. Despite the high initial sessile oak volume of plot No. 1, the value increment of this plot was lower than that of the three other plots rich in sessile oak. The difference between plot No. 1 and the others is that individuals of the associated tree species were cut to a great extent from the former plot while in two of the latter plots (No. 5 and 6) hardly any individuals of the associated tree species could be found at the beginning of the experiment or in the third plot (No. 4) they were not removed to such a great extent. These results suggest that the initial structure of the tree layers modified slightly the value increment both in the cases of SWC and GC. However, these modification effects did not cause any substantial differences between the two regeneration methods.

### 4.4 Additional considerations

Gap cutting should also be examined in long-term because wood quality of sessile oak trees located directly at gap edges can be greatly reduced by epicormic branches since their stems are exposed to direct sunshine. This question is of high importance since these are the trees, the volume increment of which is the largest. With uniform SWC, epicormic branch development is a less serious problem because due to shading by the neighbouring trees and to the short regeneration period, it does not decrease wood quality considerably (Szappanos 1967a, Papp 1983 see also Johnson et al. 1998).

Another important issue in connection with gap cutting is the spatial distribution of gaps. The present study shows that increment of trees far away from the gaps can be much lower than that of trees at gap edges. Thus, increment at stand level strongly depends on gap distribution. The results point out that if between-gap distances are larger than one tree height (~ 30 m), volume and value increment at stand level are smaller with the applied GC than with the applied SWC until the third (final) cut of the latter one. However, regeneration period of the stand is longer in the former case, which means that trees have more time to grow. Further long-term research is needed to evaluate the effects of the gap cutting system on parent stand growth at stand level.

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