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Beky, Albert; Somogyi, Zoltán

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UDK 630*221+653+(439) (Quercus petraea Lieb., Carpinus betulus L.)

GROWTH AND YIELD OF HORNBEAM-SESSILE OAK (*Carpinus betulus* L. - *Quercus petraea* /Matt./ Lieb.) STANDS UNDER OPTIMAL MANAGEMENT IN HUNGARY

ALBERT BÉKY[1], ZOLTÁN SOMOGYI[2, 3]

[1] Forest Research Institute, Hungary
[2] Department of Silviculture and Yield, Forest Research Institute, Hungary
[3] Contact person: Zoltán Somogyi. Mailing address: H-1277 Budapest, Pf. 17., Hungary, e-mail: som9013@helka.iif.hu

In mixed forests, a basic question is what is the optimal ratio of the species with respect to yield As a first attempt in Hungary to address this issue, a yield table for hornbeam-oak forests was developed. This indicated, at a hypothesis level, that mixed hornbeam-oak stands may have around the same yield as unmixed oak stands. In addition to publishing this new yield table, this paper directly addresses the issue of the optimal species ratio by using the data from permanent sample plots established in mixed stands of optimal structure, of too much oak and of too much hornbeam. The optimal ratio is analysed in relation to age and yield class. According to the results, it is best to mix the two species on the best sites and at middle ages; however, on poor sites and at young or old ages, pure oak stands produce the greatest yield. This paper stresses that mixing the two species, as in many other forest types, may also have many ecological and economic advantages.

Key words: sessile oak, hornbeam, mixed stands, yield optimisation, optimal stand structure.

INTRODUCTION

With the expansion of the idea of nature-oriented silviculture, the promoting of the establishment and protection of mixed structures have become key issues in forest management in many countries. In fact, mostly mixed stands would exist under natural conditions in most forests in the world. According to botanists, the number of species in many native forest types under Hungarian site conditions varies between 5-15 (Bartha and Szmorad, 1997, Bartha, 1999, ÁESZ, 1996). In natural hornbeam-sessile oak forest types, usually 8-10 mixing species occur.

In the long run, the area of mixed stands must be much larger than now. In addition to the biological role that the mixing of species can play, and the added economic value they may have, it is usually not worth fighting against naturally emerging species in natural regenerations and elsewhere, and it is also often not profitable to do so. Kerr et al. (1992) present several other benefits of mixtures.

Similar to the uneven-aged stands when compared to the even-aged ones, much less study has been done in mixed stands than in unmixed ones. A practical reason for this is that it is much more difficult to study complex structures than plantation-like, homogeneous structures. This is the case in Hungary, too, where there have only been a few studies conducted in mixed stands (Solymos and Béky, 1995, Solymos, 1998 in stands of indigenous species, and Rédei, 1984, in poplar-Black locust plantation-like stands), although some of these studies were started in the 1960s.

Mixing two or more species and controlling their ratio may be rather difficult. Controlling the species ratio, or, in general, developing an appropriate stand structure, requires the main objective of forest management to be defined. If yield is of greatest importance, the question arises whether the yield of mixed stands is more

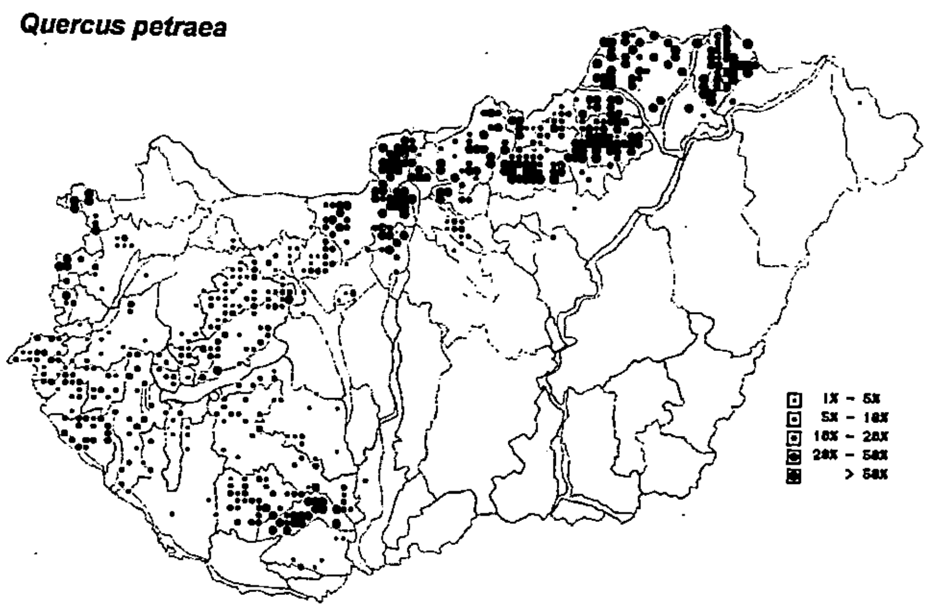

Figure 1. The distribution of sessile oak in Hungary (Bartha and Mátyás, 1995)

than that of single species in unmixed stands (the so-called "mixed species effect". Furthermore, if mixed stands seem to perform better, one may need to know what the optimal ratio of the tree species constituting the stand is. One must, of course, bear in mind that, if the amount and value of the yield is not the highest priority of forest management, the optimisation of the species ratio should not be pursued.

The above questions were studied in hornbeam-sessile oak stands in Hungary. These stands occupy large areas in the country: 7.2 % of all forests (ÁESZ, 1996). In fact, hornbeam and oak are the two main components of mixed forests under the conditions of the country. Since their requirements for site are similar, they occur in the same regions (Figure 1 and 2).

Studies on the yield of mixed stands have only been done in hornbeam-sessile oak stands in Hungary (Béky, 1978, Béky, 1986, Béky, 1987, Béky, 1989, Béky, 1997, Béky and Somogyi, 1995). These studies introduced the issues of optimal species ratio, but could not provide substantial evidence on the existence of this ratio. These studies could not even decide whether the mixture of these species could result in a higher yield than any type of unmixed stand forms. This latter issue can be reformulated this way: is it the mixed stand form or the unmixed one that can better utilise a specific site?

By using a purely theoretical approach, mixed stands may perform better. Based on the idea of an ecological niche, every species utilises a partially specific niche, and the sum of the realised niches in a mixed stand is larger than that in unmixed stands. This suggests that the yield of mixed stands is higher. On the other

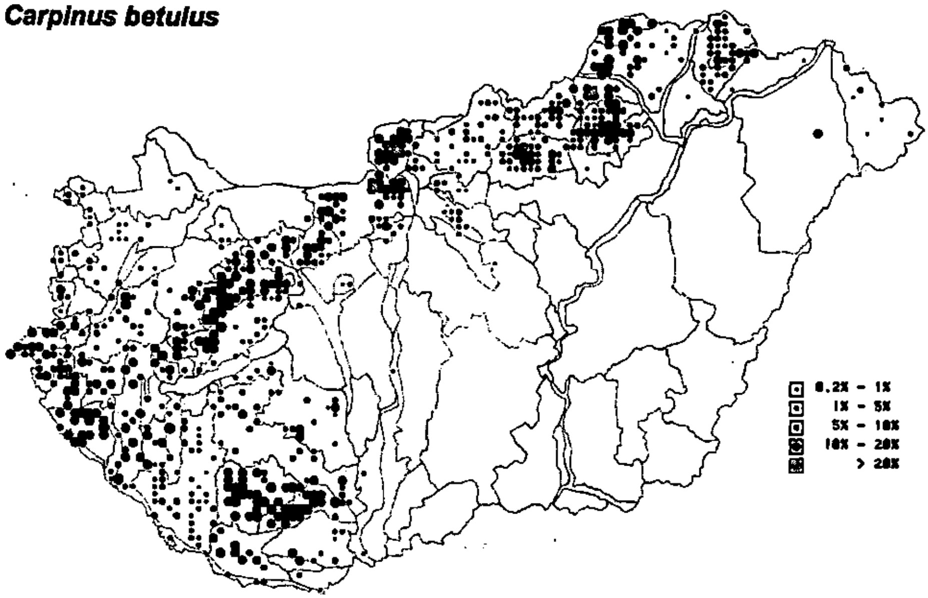

Figure 2. The distribution of hornbeam in Hungary (Bartha and Mátyás, 1995)

hand, the yield of the various species may differ a great deal on the same site, and stand structure modifies the performance of the tree individuals. Since the overall outcome of these effects cannot be theoretically deducted, field studies are required.

According to several studies in other forest types, mixed stands can often outperform unmixed ones in terms of volume. Examples include mixed Scotch pine-beech stands that, if the rotation age is 140 years, produce 20% more than the respective unmixed stands, and Scotch pine-Norway spruce stands with a 15% yield surplus if the rotation age is 120 years (Kramer, 1987). In oak-beech stands, which also occur in Hungary, this surplus accounts for 13. 21 and 27% at the ages 120, 160 and 200 years. A surplus, even if smaller, can also be attained with other mixing species of slower growth. If the mixing species is a fast growing one, such as European larch, the surplus can reach as much as 30% (Karmer, 1987). The results of many more experiences are summarised by Burkhart and Tham (1992). In most of the cases they report on, mixed stands seem to outperform pure stands.

This paper addresses the effect of mixture on the yield of sessile oak and hornbeam. As Burkhart and Tham pointed out, verification of the mixed species effect is rather difficult because it is not easy to obtain reference yields of pure stands of the species of interest, without confounding them with other factors. The results presented in this study were obtained based on data collected in permanent sample plots with a different species ratio. First, the yield table for hornbeam-sessile oak stands (the first of its kind in Hungary) is presented, which is followed by detailed analysis of the data from the parmanent plots. In this analysis, yield is also related to site and age.

MATERIALS AND METHODS

Yield tables were derived from data collected at repeated surveys of 120 permanent sample plots. To study the optimal species ratio, the data of around 100 even-aged stands were selected. All plots were established between 1968 and 1974 by Albert Beky. The size of the plots is 50x50 or 50x40 m. The stands were surveyed every 5(-7-10) consecutive years. The number of increment data per plot ranges from one to five. Data from all subsequent surveys were used, which means that correlations also include autocorrelations.

The plots were established in even-aged stands of an approximately homogenous site where three plots of different species ratios could be established. Although the yield table was made for stands of "optimal" structure, the data of stands of "oak" and "hornbeam" structure were also used. The structure was regarded "optimal" if valuable dominant oak trees that could be grown as future trees were evenly distributed, and all other places were occupied by either oak or hornbeam. The structure is an "oak" one if oak predominates and hornbeam plays an irrelevant role, and a "hornbeam" one if the ratio of oak is too low or if oak is missing in larger patches.

The plots were thinned in a way that was regarded as "optimal", i.e. approximating or maintaining the "optimal" structure. This structure can only be achieved through active silvicultural operations, since in all of the many types of mixtures, hornbeam would suppress oak until about the age of 25-30 years, but die out afterwards. Thinning out strong hornbeam individuals in young stands, as well as protecting good growing ones of good stem quality in older stands, was therefore necessary. The optimal structure can be characterised by the following (Béky, 1987):

- hornbeam is gradually suppressed by oak over time;
- the volume ratio of oak grows from 60% to 80 % over time;
- the stem number ratio of oak varies between 25-40%;
- the horizontal distribution of future oak trees approximates an even structure.

All trees in all plots were identified by specific tree numbers. In each survey, two diameters (to the nearest mm in two perpendicular directions) and total tree height (to the nearest 0.5 m) were measured for each tree. The species of trees and the age of the stands were also recorded. The main crop and thinnings were separately surveyed. Tree volume was calculated by the Király volume function (Király, 1978) which was developed by using the Sopp (1970) volume tables. From these volumes and tree numbers, stand volume, basal area, and growth could be derived for each species, after which species ratio (by number and volume) and growth could be calculated. (Other rarely occurring tree species were recorded as either oak or hornbeam. In some plots, oak disease killed some trees. The slight effects of this disease were corrected where it seemed necessary).

The yield class of mixed stands was defined by the top height of oak and age. The same height-age curves were used as those in the yield table for pure sessile oak stands (Béky, 1981). Although yield class only correlates with site in a non-linear manner, and is not a perfect measure of it, yield class was used in some analyses as a site-related independent variable. (Yield class I indicates best sites, yield class VI the poorest ones).

Age may also be used as an independent explanatory variable. Contrary to yield class, however, age is a continuous variable, which cannot be used in several analyses. Five age groups were created in these cases (Table 1).

Table 1. Five age groups that were used in some analyses

Age (year)	Age group
>30	1
40-59	2
60-79	3
80-99	4
<100	5

The functions of the yield table were developed by graphically fitting them to the data, and simple mathematical functions were then fitted to these graphic lines. The mean height of the two species were developed in the function of the top height of oak. Mean diameters were related to age and D/H values. The number of stems in the main stand was developed by the method of Reinecke (1933). Finally, volume was calculated by using form height estimated from mean height. From these data all other data in the yield table could be calculated by using standard growth and yield functions.

Data evaluation to explore the effect of mixture on yield was done by drawing graphs and by using regression analysis. Depending on the number and distribution of the data, linear, logarithmic, as well as negative exponentially-weighted fitting (NEGEXP) was used. Statistical analyses were done by the STATISTICA (StatSoft, Inc., 1998) software.

RESULTS AND DISCUSSION

YIELD OF HORNBEAM-SESSILE OAK STANDS

Yield table for hornbeam-sessile oak stands

General data

Data must be calculated for the end of 5-year intervals by functions. The main functions of the yield table are as follows (all totals are for 1 ha):

YG = yield grade; top height of sessile oak at the age of 100 years (m)

yield class	yield grade
I	32
II	29
III	26
IV	23
V	20

A = age (yr)

H_t (top height of sessile oak) =

$$= (a + b \cdot \lg(A) + c \cdot \lg(A)^2 + d \cdot \lg(A)^3 + e \cdot \lg(A)^4 + f \cdot \lg(A)^5) \cdot YG / 100$$

a = -154.958
b = 629.7612
c = -935.3223
d = 644.2674
e = -186.7059
f = 17.8086

Data for the main crop (denoted by m in the index)

H_{gm} (basal area weighted mean height, m) $= a + b \cdot H_t$

sessile oak	*hornbeam*
a = -0.25	-0.42
b = 0.98334	0.694

D_{gm} (diameter from the mean basal area, cm) $= H_{gm} \cdot (a + b \cdot A)$

sessile oak	*hornbeam*
a = 0.6425	0.545875
b = 0.011225	0.006456

G_m (basal area, m^2) $= D_{gm}{}^2 \cdot \pi / 40000 \cdot N_m$

V_m (volume, m^3) $= G_m \cdot (a + b \cdot \lg(H_{gm}) + c \cdot \lg(H_{gm})^2 + d \cdot \lg(H_{gm})^3)$

sessile oak	*hornbeam*
a = 2.2394	-8.16148
b = 16.2606	48.89907
c = -29.1697	-64.4873
d = 17.0736	30.00008

N_m (number of stems) $= 10^{a + b \cdot \lg(Dgm)}$

sessile oak	*hornbeam*
a = 4.775232	4.68307
b = -1.62601	-1.73569

Thinnings (denoted by t in the index)

$H_{gt} = a + b \cdot H_t$

sessile oak	*hornbeam*
a = -1.545	-2.79
b = 0.9665	0.79

$D_{gt} = (a + b \cdot A) \cdot H_{gt}$

sessile oak	*hornbeam*
a = 0.418857	0.472071
b = 0.011771	0.006964

$G_t = D_{gt}{}^2 \cdot \pi / 40000 \cdot N_t$

Because of the self-thinning phenomenon in young stands, the timber of which cannot be utilised, the basal area of the oak portion of the young stands must be reduced (the diameter, height and tree number are for all trees). The basal area estimated above must be divided by gdiv between the ages of 10 and 40 years, where

$gdiv = 10^{a + b \cdot A}$
$a = 0.763394$
$b = -0.01908$

$V_t = G_t \cdot (a + b \cdot \lg(H_{gt}) + c \cdot \lg(H_{gt})^2 + d \cdot \lg(H_{gt})^3)$
a, b, c, d are the same as for the main crop.

$N_t = N_{mA} - N_{m(A-5)}$.

Data for the whole stand (denoted by w in the index):

$H_w = (H_{gm} \cdot G_m + H_{gt} \cdot G_t) / (G_m + G_t)$
$D_w = (G_w / N_w \cdot 40000 / \pi)^{1/2}$
$G_w = G_m + G_t$
$V_w = V_m + V_t$
$N_w = N_m + N_t$

Growth and yield:

ΣV_t (total thinnings, m^3) = sum of all thinnings (V_t) up to A
$V_{t\%}$ (%) = $\Sigma V_t / V_y \cdot 100$
V_y (yield, m^3) = $V_m + \Sigma V_t$

MAI (mean annual increment, m^3/yr) = V_y/A.
PMAI (periodic mean annual increment, m^3/yr) = $(V_{yA} - V_{y(A-5)})/5$.

Analysis of possible yield surplus by means of yield tables

A possible yield surplus in hornbeam-sessile oak stands, relative to either pure hornbeam or pure sessile oak stands, can be studied by comparing yield levels at approximately similar site conditions. This, however, is not at all easy if only yield class can be used for site estimation. Although no correct comparison is possible between the performance of oak and hornbeam by using yield tables, it can be stated that oak generally has a substantially higher production capacity than hornbeam. Such a comparison is not possible between pure oak stands and mixed hornbeam-oak stands because the yield level of the two stand forms is too similar and yield tables cannot provide the flexibility that would be necessary to explore any surplus.

YIELD OF MIXED STANDS COMPARED TO UNMIXED ONES - AN ANALYSIS BASED ON DATA OF PERMANENT SAMPLE PLOTS

In this analysis, the data of 296 surveys were used (Table 2), of which 129, 84 and 83 were done in stands of "optimal", "oak" and "hornbeam" structures respectively.

Table 2. Frequency of surveys by age group and yield class

Yield class	age group					Total
	1	2	3	4	5	
I	9	9				18
II	2	35	29	19	9	94
III	7	24	16	21	12	80
IV	15	62	14	3		94
V	2	8				10
Total	9	85	124	54	24	296

The role of the two species in the stand is, of course, not the same. Oak is a species of continuous growth in the top storey which is usually shown by the number and the size of the tree individuals. The thinnings are usually also done in favour of oak. It is no wonder then that the relative current annual increment (CAI), calculated for each survey independently from age and site, is equal for the two species if the ratio of hornbeam is 0.6. This ratio changes over time and yield class. The ratio of hornbeam in yield class II changes from 72 to 78%, in yield class III from 68 to 72%, and in yield class IV from 75 to 70% over the 30 year period of observations. In stands of "optimal" structure, hornbeam ratios grew from 73 to 80%, in stands of "hornbeam" structure from 53 to 55%, but in stands of "oak" structure it decreased from 90 to 86%.

The yield of oak usually decreases with an increasing ratio of hornbeam (Figure 3). No species ratio can be found that could be regarded as optimal for oak with respect to yield, but, especially on better sites, the yield of oak only slightly decreases as long as the ratio of hornbeam is less than 10-15%. This decrease is more intensive at younger ages.

The issue of optimal species ratio can be studied if total CAI is graphed over species ratio (Figure 4). The surfaces show that there are only a few cases when a surplus can be achieved in hornbeam-sessile oak stands as compared to pure oak ones. It is the better sites and over 60 years of age where a surplus is obvious, but the maximal rate of this surplus is 10%. In yield class 3, the highest yield is reached in pure oak stands, and even a minimum can be found in yield class four. (In this analysis, the NEGEXP fitting was used.)

Concerning the existence of a yield optimum, there may be no single combination of the two species, not even in yield class II, where yield is at its maximum. Instead, a wide range of species ratio of approximately between 0 and 50% appears to be in this yield class at ages over 60 years where one does not have to count with yield decrease compared to pure oak stands. In yield class III, this range is only between 0 and 20%. In general, it seems important to stress that mixing species may result, at worst, in a moderate yield loss, even if one species grows relatively slowly, which may well be offset by the increase of value of the timber of the whole stand.

The reasons why there is no general yield surplus in hornbeam-sessile oak stands are severalfold. One reason is that, as was pointed out above, hornbeam in pure stands usually grows more slowly than oak. Hornbeam grows faster than oak on better sites until about the age of 30 years, after which oak outperforms hornbeam whose growth slows down substantially with age. All other species that were mentioned in the introduction keep growing fast at older ages, too. Another reason is that hornbeam is overtopped by oak in middle age, after which hornbeam does not get full sunshine, which further suppresses its growth. Because of its slower growth rate, as well as the lower value of hornbeam timber, hornbeam is also thinned out in the upper canopy layers to favour oak, which even further decreases its growth potential. In the case where beech, a fast growing species, is mixed with oak, both oak and beech are left to grow in the upper canopy layer, and the two species together can outperform pure stands.

Why is it, then, that there are cases of yield surplus in hornbeam-sessile oak stands? The explanation is, again, both biological and silvicultural. On one hand, the two species utilise partially different niches, thus making better use of the potentials of the site. On the other hand, oak individuals in mixed stands do not have to compete so much with each other, because co-dominant, intermediate and suppressed oak trees in pure oak stands are replaced by hornbeam trees in the mixed stand that partially use different resources. However, this is only true on better sites. On poorer sites, where it is the amount of available water that limits grow,

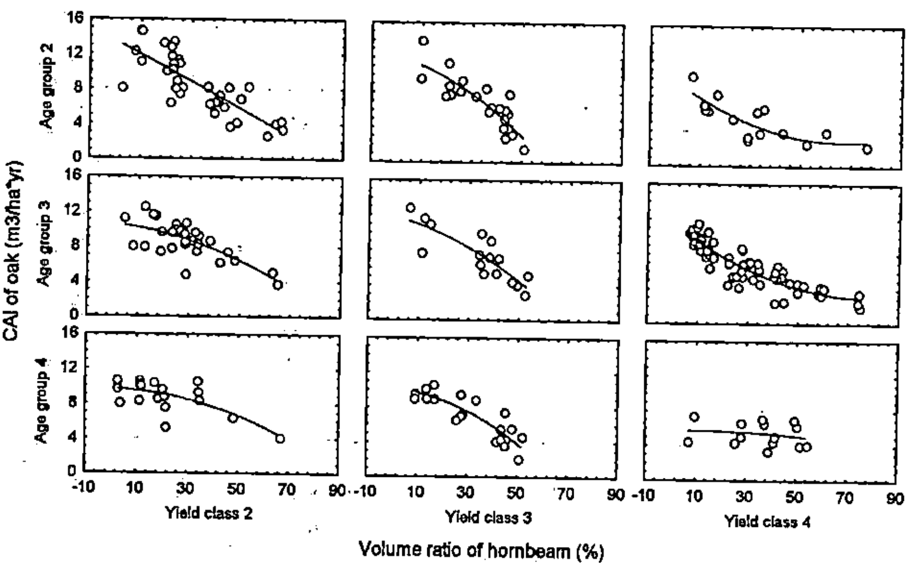

Figure 3. Current annual increment of sessile oak (CAI of oak) over volume ratio of hornbeam by yield class and age group. (The figure shows all data in those yield classes and age groups where the number of data were sufficient for a simple regression analysis)

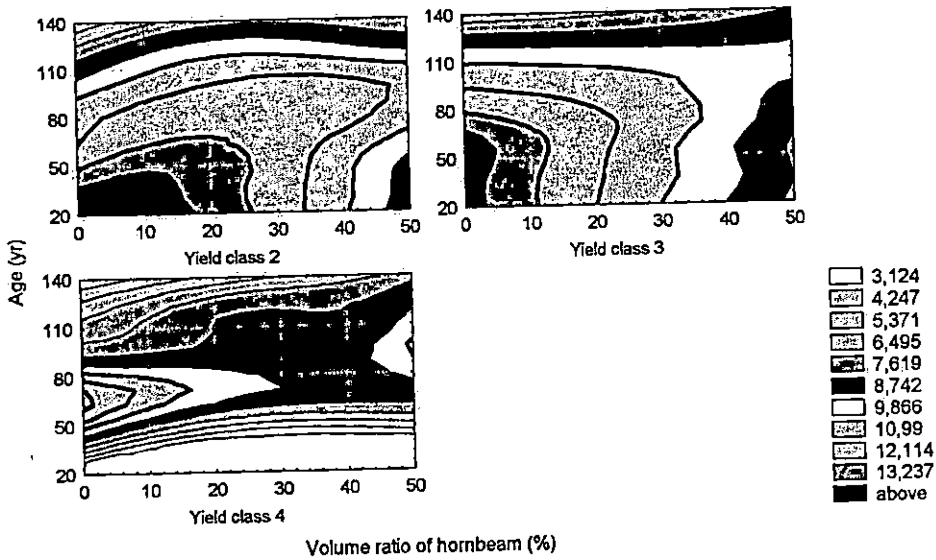

Figure 4. Total current annual increment (Total CAI) over volume ratio of hornbeam by age and in yield class II-IV. Increment categories between 9.866, 10.99, 12.114, 13.237 m3/ha and above are denoted by thick lines, whereas those below are denoted by thin lines. (This figure allows a more detailed analysis of the effect of age on the optimal species ratio, too, since here age is used as a continuous variable. Although total yield increases with age in all higher yield classes, it definitely decreases with an increasing hornbeam ratio, however small this ratio is.)

hornbeam, which less efficiently utilises water than oak, prevents oak from accessing enough water, which results in slower growth of oak, too.

It follows from the analysis above that it is worth mixing the two species, at least on better sites, purely from the point of view of yield and maximising yield. The value of mixing hornbeam with oak is, however, more than that. Oak bole of high value can better be grown if hornbeam is present than if there are only oak individuals in the stand. Therefore, a balance must be established so that hornbeam can help oaks grow timber of high quality without decreasing yield too much. It is important to stress this because, at least in some regions in Hungary, there is a tendency to suppress hornbeam too much, and thin it out well before the end of the rotation period. If high value oak timber is to be grown in subsequent rotations, hornbeam - and other mixing species - must be tended at ages when oak grows faster, and even several fast growing hornbeam individuals of good stem form must be kept in the dominant-codominant layer as long as they can compete with oak. This must be done by cutting out oak individuals of slower growth and poor stem quality (Béky, 1997).

Quite naturally, ratios of species change over time. In order to form and maintain an optimal structure, silvicultural interventions must continuously be applied. This ideal structure and its change can be well seen in Figure 5. This illustrates

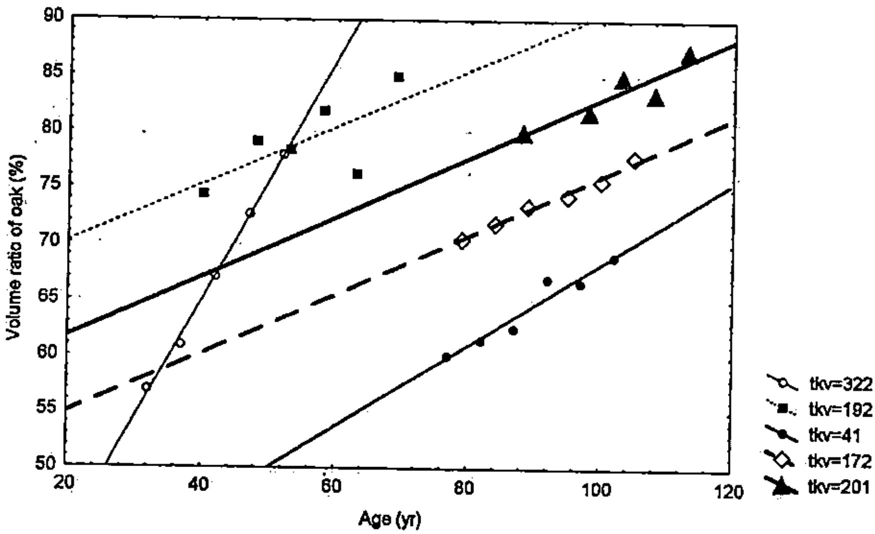

Figure 5. Ratio of oak main crop by volume over age in five hornbeam-oak stands of optimal structure. (The stands are marked by their respective registry number (tkv). Yield classes of the stands: tkv=322: III; tkv=192: I; tkv=41: IV; tkv=172: III; tkv=201: II.)

that, after having reached the optimal stand structure, the volume of oak must (and can) be increased by 7-10% in three decades. The trees in plot No. 322 were young, the yield class was III, and the volume ratio of oak was only 57% at the beginning of the surveys, therefore, heavier thinnings had to be done in favour of oak which was the reason for the more intensive increase of the oak ratio over time. On the other hand, in stands of higher oak ratio this increase is slower.

Finally, it must be emphasised that optimal stand structure, thus maximal yield production, can only be achieved if oak individuals of high growth potential can be found in a density that approximates a good even density of future trees. It is impossible to develop a good structure from a patchy stand structure. Too much hornbeam or too patchy a stand structure cannot be controlled in one rotation period.

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RAST I PRIRAST SASTOJINA GRABA I HRASTA KITNJAKA (*CARPINUS BETULUS* L. - *QUERCUS PETRAEA* /MATT./ LIEB.) U UVJETIMA OPTIMALNOGA GOSPODARENJA U MAĐARSKOJ

Temeljno pitanje u mješovitim šumama odnosi se na problem optimalnoga odnosa vrsta s obzirom na prirast. Pri prvom pokušaju da se u Mađarskoj pozabavimo ovim pitanjem napravljena je prirasno-prihodna tablica za grabove i hrastove šume. Na hipotetskoj se razini pokazalo da mješovite grabovo-hrastove sastojine daju po prilici isti prirast kao i nemješovite hrastove sastojine. Uz objavljivanje ove nove prirasno-prihodne tablice ovaj se rad izravno bavi problemom optimalnoga odnosa vrsta rabeći podatke iz trajnih eksperimentalnih ploha koje su osnovane u mješovitim sastojinama optimalne strukture s prevelikim brojem hrastova i prevelikim brojem grabova. Analiziran je optimalni odnos u pogledu dobi i boniteta. Rezultati pokazuju da je najbolje miješati te dvije vrste na najboljim staništima u srednjoj dobi; međutim, na slabim staništima i u mladoj ili staroj dobi najbolji prirast daju čiste hrastove sastojine. U ovom se radu naglašava da miješanje dviju vrsta, kao u mnogim drugim tipovima šuma, ima i mnogobrojne ekološke i gospodarske prednosti.

Ključne riječi: hrast kitnjak, mješovite sastojine, optimalizacija prirasta, optimalna struktura sastojine