Felling maturity criteria of beech stands in Slovakia

Rudolf PETRÁŠ[1], Julian MECKO[2], Aleš KADUNC[3]

Abstract

In this paper, we focus on the felling maturity of beech stands in Slovakia. From an economic point of view, felling maturity of stands depends on volume production, assortment composition at different stand ages, and costs of forest labour. The culmination of net value production serves as a prevailing criterion of felling maturity. Our analyses showed a modest decrease in felling costs after the stand age of 40 years. The mean value increment of beech stands was yield class dependent. The ages of stands when total mean increments culminated were, in comparison with volume production, older on average by 15 years for gross yield and by 28 years for net yield. The latter culminated between 105 and 150 years.

Key words: felling maturity, volume production, value production, yield class, beech stand, Slovakia

Kriteriji sečne zrelosti bukovih sestojev na Slovaškem

Izvleček

Prispevek obravnava sečno zrelost bukovih sestojev na Slovaškem. Z ekonomskega zornega kota je sečna zrelost odvisna od volumenske produkcije, sortimentne strukture pri različnih starostih sestoja in stroškov gozdnega dela. Kulminacija neto vrednostne produkcije je prevladujoči kriterij pri določitvi sečne zrelosti bukovih sestojev. Analize kažejo, da stroški pridobivanja lesa po starosti sestoja okoli 40 let pričnejo umirjeno padati. Povprečni vrednostni prirastek bukovih sestojev je odvisen od bonitetnega razreda. Bruto vrednostni prirastek kulminira v povprečju 15 let kasneje kot volumenski prirastek, neto vrednostni prirastek pa v povprečju 28 let kasneje. Slednji kulminira pri starosti med 105 in 150 leti.

Ključne besede: *sečna zrelost, volumenska produkcija, vrednostna produkcija, bonitetni razred, bukov sestoj, Slovaška*

1 Introduction
1 Uvod

One of the most exacting and important tasks of forestry is to determine the felling maturity of stands. Felling maturity of forest stands is usually determined by the state when the stands reach the required economic objective. The long-term production process in forests determines maximal mean annual timber production as a main economic criterion for the determination of felling maturity. According to forestry terminology, it is a state when total mean (volume) increment of the stand culminates (ASSMANN 1961). This increment determines first of all the amount of timber being produced from the establishment of the stand. In the event that a financial yield is the required economic objective – as it is in managed forests – the structure of produced assortments of raw wood and their relation to prices are very important as well. This aspect is important for tree species capable of producing high quality wood, such as European beech (*Fagus sylvatica* L.). Beech is characterized not only by its relatively quick height and diameter growth, but also by the fact that the stems are capable of quickly removing their branches (WIEDEMANN 1951). The proportion of such stems increases with increasing age and increasing yield classes of stands. A higher proportion of high quality stems may also be obtained by intensive tending of beech stands. A particular risk is high susceptibility of beech stems to mechanical damage and subsequent spread of decay and red heartwood (PETRÁŠ 1996a, 1996b). Although the total mean increment is a decisive criterion for the determination of felling maturity, its form of expression is also important. It can be expressed in volume units, but from an economic

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viewpoint it is more significant to express its values in monetary units. To derive felling maturity of stands, it is important to know the whole-life production of stands. Should models with full stocking be used for estimation of felling maturity, models of whole-life development of stocking must also be added to the models. It is generally known that stocking of a stand drops with higher age.

The aim of this work was to evaluate possibilities and criteria for determination of felling maturity of beech stands using the models of volume and value production of beech stands. In this paper, the impact of non-timber forest values or effects is not analysed due to the insufficient knowledge regarding economic characteristics of those forest values or effects.

2 Material and methods
2 Materiali in metode

2.1 Models of volume and quality production
2.1 Modeli volumenske in kakovostne produkcije

For volume production we used the Czechoslovak yield tables constructed by HALAJ *et al*. (1987), which illustrate, by means of continuous mathematical functions, a whole-life development of mean and hectare parameters in dependence on age *t* and yield class *q* (yield class refers to site index, defined as average height of 10% thickest beech trees at the age of 100 years, yield classes increases for 2 m; e.g. yield class 30 is equal to SI_{100} = 30 m) of the stand. For beech, 892 plots were measured between 1965 and 1980. They were models of mean diameter *d* and growing stock *V* for the main stand (the part of the stand that remains after the thinning) and secondary crop (the part of the stand harvested at the thinning), as well as of total production *TP* according to the relation:

$$d, V, TP = f(t, q) \qquad (1)$$

Quality production was expressed by means of the models of assortment yield tables by PETRÁŠ *et al*. (1996) that present the structure of basic assortments *AS* in dependence on the age *t* and yield class *q* of the stands according to the relation:

$$AS\ (\%,\ m^3\ ) = f(t, q) \qquad (2)$$

Assortment yield tables were constructed by adding together models of yield tables according to the relation (1), stand assortment tables according to the relation (3), models of quality and damage to stands. Altogether, 4,203 stems of beech were analysed for assortment yield tables.

Models of stand assortment tables (PETRÁŠ 1992) present the structure of assortments *AS%* in dependence on mean diameter of the stand *d*, quality *qua* and damage *dam* of stems in the stand according to the relation:

$$AS\% = f(d, qua, dam) \qquad (3)$$

Models of the stand quality (HALAJ *et al*. 1990) express empirical dependence of external quality of stems *qua* given by degrees *A, B,* and *C* in dependence on the yield class *q* of the stand according to the relation:

$$qua\ (\%\ A,\ B,\ C\ ) = f(q) \qquad (4)$$

Models of damage to stems (HALAJ *et al*. 1990) express empirical dependence of the proportion of mechanically damaged stems *dam* on the age of the stand *t*:

$$dam\ (\%\ ) = f(t) \qquad (5)$$

2.2 Models of value production
2.2 Modeli vrednostne produkcije

Models of value production were used in the form of value yield tables that give gross or net yield *VAL* of stands in monetary units in dependence on their age *t* and yield class *q*:

$$Val\ (\text{€}) = f(t, q) \qquad (6)$$

Gross yield was derived as a product of the amount of produced assortments according to the relation (2) and their unit prices given in Table 1. These were average prices in Slovakia in 2006 and are arranged according to quality and diameter classes of logs.

Assortment diameter classes 1-6+ are defined pursuant to their mean diameter without the bark. The highest quality classes *I* and *II* are intended mainly for the production of furniture and industrial veneer, whereas in class *II* the requirements on the quality of wood are slightly lower than for the class *I*. Class *I* requires a minimal log diameter of 30 cm and class *II* requires 20 cm. Quality classes *IIIA* and *IIIB* represent high and lower quality saw logs with a minimal diameter of 16 cm. Pulpwood assortment of class *V* is intended mainly for the pulp industry and class *VI* is fuel wood.

Net yield was obtained from gross yield from which costs of timber felling were deducted. They are production costs of whole logging operations, i.e. timber felling, its skidding, handling and transport as well as other logging

Table 1: Average prices (€m⁻³) according to quality classes and diameter classes

Preglednica 1: Povprečne cene (€m⁻³) po kakovostnih in debelinskih razredih

Quality class / Kakovostni razred	Diameter class /Debelinski razred					
	1 (10-19 cm)	2 (20-29 cm)	3 (30-39 cm)	4 (40-49 cm)	5 (50-59 cm)	6+ (60+ cm)
I			185.22	221.74	255.56	274.88
II		113.32	140.41	155.02	163.28	174.93
IIIA	44.68	49.49	67.55	71.70	74.49	76.08
IIIB	43.12	46.41	53.48	56.40	58.45	60.18
V	38.04					
VI	29.14					

costs. These production costs consist of direct costs, which are mainly labour and material costs for whole logging operations, and indirect costs related to logging organization and securing. A basis for labour costs are work standards of 1992 that set standardized time consumption in standard hours (SHm⁻³) for the production of 1 m³ of raw wood in a concrete logging operation (PETRÁŠOVA *et al.* 2001). In timber felling, time consumption is a function of site index and average volume of exploited trees, while in skidding, handling and transportation of wood time consumption depends solely on average volume of stems or their logs. All other data necessary for the calculation of logging costs were obtained from records of Slovak national state forest enterprises for the year 2006. In the costs calculation, an average skidding distance of 750 m is taken, while for timber transport a distance of 27 km is considered. Based on these data, the coefficient of calculation of direct costs to total (production) costs was also derived.

Precommercial silvicultural costs were not considered, because they do not affect the shape of the value growth curve and because the analysed mature stands were not tended according to contemporary standards.

The model of stocking development was derived from the data in the database of beech stands of Slovakia for the years 2002 and 2008 in dependence on the age of the stand. It is considered a model of actual stocking. On that basis, the total volume and value productions and their increments according to the relation (1) and (6) were calculated.

2.3 Full or actual stocking?

2.3 Polna ali dejanska zarast?

Models of yield tables express production of the stands being tended with full stocking 1.0. This is theoretical stocking determined for the growth regions, which is hardly reached in real stands. It gives the relative rate of full covering of production area by growing trees and it is lower than natural stocking. For real stands, lower

stocking is characteristic, which usually drops with higher age. This may be represented by actual stocking of stands in a larger area, which become steady as a result of stand management over a longer period. The development of actual stocking was derived from the data in the database of beech stands in the category of managed forests. The database is updated every year during forest inventory in Slovakia (GREEN REPORT 2009). In Fig. 1 it is obvious that approximately to the age of 80 years the stocking of stands has been decreasing smoothly in the interval of 0.92-0.77 values (actual stocking is not dependent on site productivity). It will grow slightly to the age 120 years, but will then drop to the value of 0.73. Whole-life development of stocking st was smoothed in dependence on the age of stand t by the exponential function:

$$st = p_1 + p_2 \cdot \exp(p_3 \cdot t) \qquad (7)$$

Parameters p_1-p_3 have the following values: p_1 = 0.7562560209, p_2 = 0.2656294817, p_3 = -0.025834819. Coefficient of determination is R^2 = 0.853.

Total production was calculated as the product of total production of fully stocked stands according to the relation (1) and actual stocking according to the relation (7).

3 Results

3 Rezultati

3.1 Volume production

3.1 Volumenska produkcija

According to Figure 2, we can state that the values of total mean annual increments (TAI) change smoothly with age, yield class and stocking of stands. Fully stocked
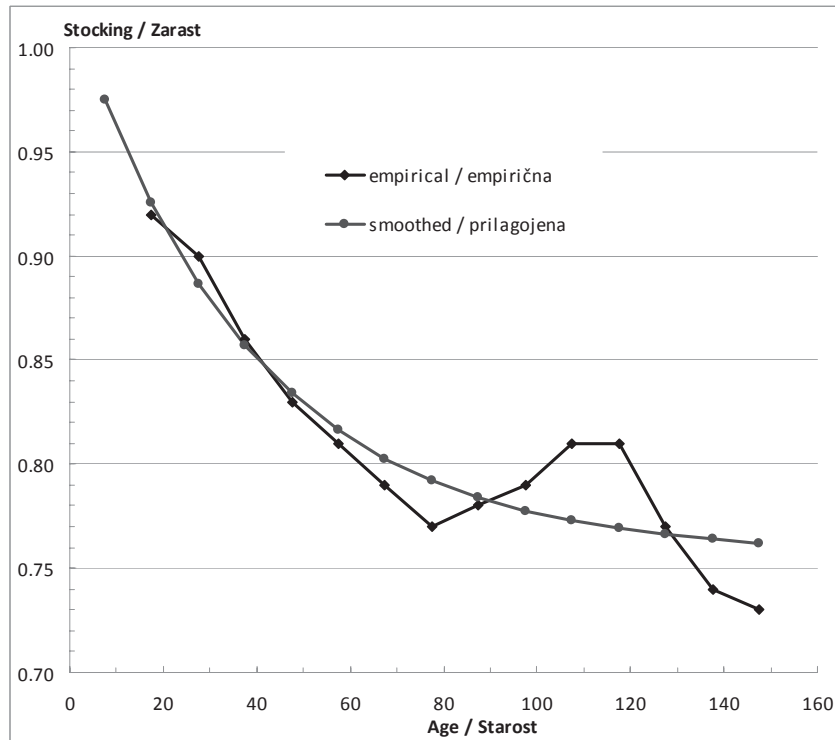
Figure 1: Development of the actual stocking of beech stands
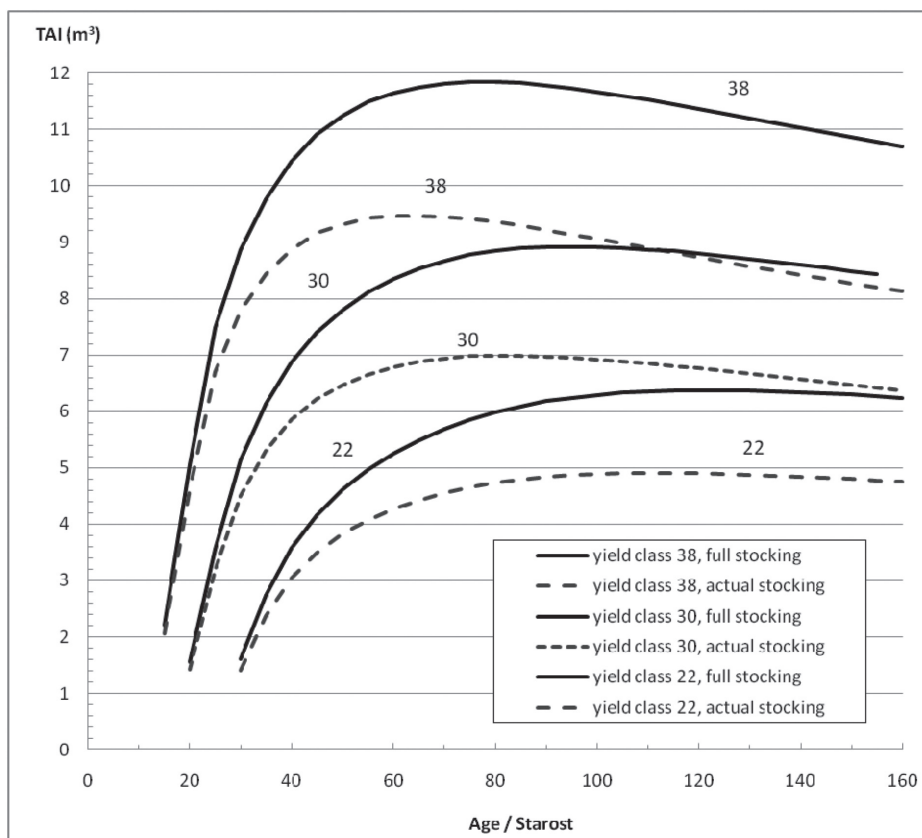*Slika 1: Razvoj dejanske zarasti v bukovih sestojih*

Figure 2: Total mean annual increment (TAI) of beech stands of yield class 22, 30 and 38 with full and actual stocking
Slika 2: Povprečni starostni volumenski prirastek (TAI) bukovih sestojev bonitetnih razredov 22, 30 in 38 pri polni in dejanski zarasti

stands of yield classes 22-38 reach, at the time of culmination, the values 6.4-11.8 m³ and the stands with actual stocking 4.8-9.5 m³. Also the ages change smoothly when increments culminate. In fully stocked stands of yield classes 22-38, it is at the age between 123-77 years and in the stands of actual stocking at the age 110-63 years. This means that in the stands with actual stocking mean increments culminate about 13-14 years earlier.

3.2 Value production
3.2 Vrednostna produkcija

For value production, gross and net yield were derived according to the relation (6). Figure 3 illustrates their development for yield class 30. For the other yield classes, value production, i.e. gross and net yields and their total mean increments, was calculated as well, but is not shown herewith due to the limited space. Curves for gross yield have a shape of a typical growth curve with an interval of slower and stronger growth and an inflexion point between them. Curves of the costs of felling have the opposite development. At lower age they are growing markedly and they are higher than gross yield. At middle and higher ages, they have a moderate linear trend. Net yield is the difference between gross yield and the costs of felling. As such, it has negative values to about the age of 50 years. At higher age, the shape of the curves is already typical of growth functions.

To determine the age of optimal felling maturity, it is important to know the mean annual production of stands and especially the age, when mean production culminates. Looking at Figure 4, we can state that in the stands with yield class 30 with full and actual stocking mean gross yield culminates at the ages of 112 and 107 years with respective values 550 and 430 €ha⁻¹year⁻¹. Mean net yield culminates at the age of 123 years equally for fully stocked stands as well as for the stands with actual stocking and with the values 282 and 207 €.ha⁻¹year⁻¹. Mean annual costs of felling are an auxiliary indicator of net yield of stands, and they have economic importance. With higher age of the stands they decrease slightly and at an age more than 100 years they are approximately at the level of net yield. For practical needs, the average costs per 1 m³ of felled timber are more convincing. In the interval 20-160 years, they drop from the value 57 €m⁻³ to about 29 €m⁻³.
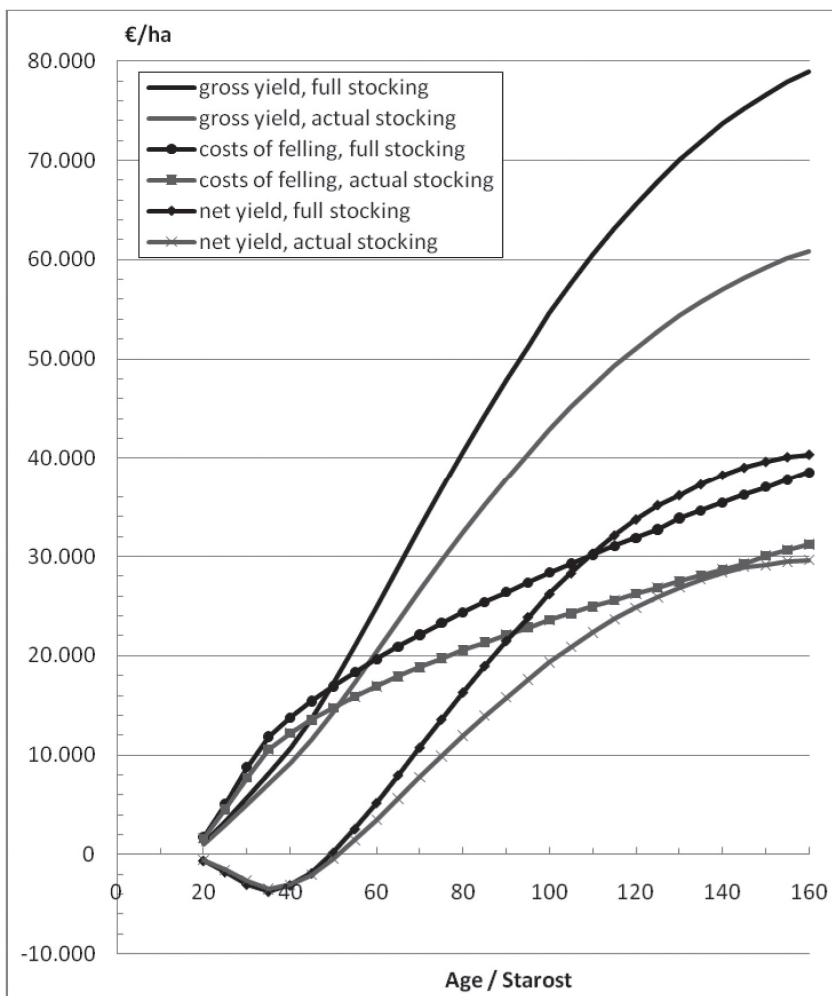
Figure 3: Development of gross and net yield as well as costs of felling in € ha⁻¹ of beech stand for yield class 30 with full and actual stocking

Slika 3: Razvoj bruto in neto vrednostne produkcije kot tudi stroškov pridobivanja lesa v bukovih sestojih bonitetnega razreda 30 pri polni in dejanski zarasti
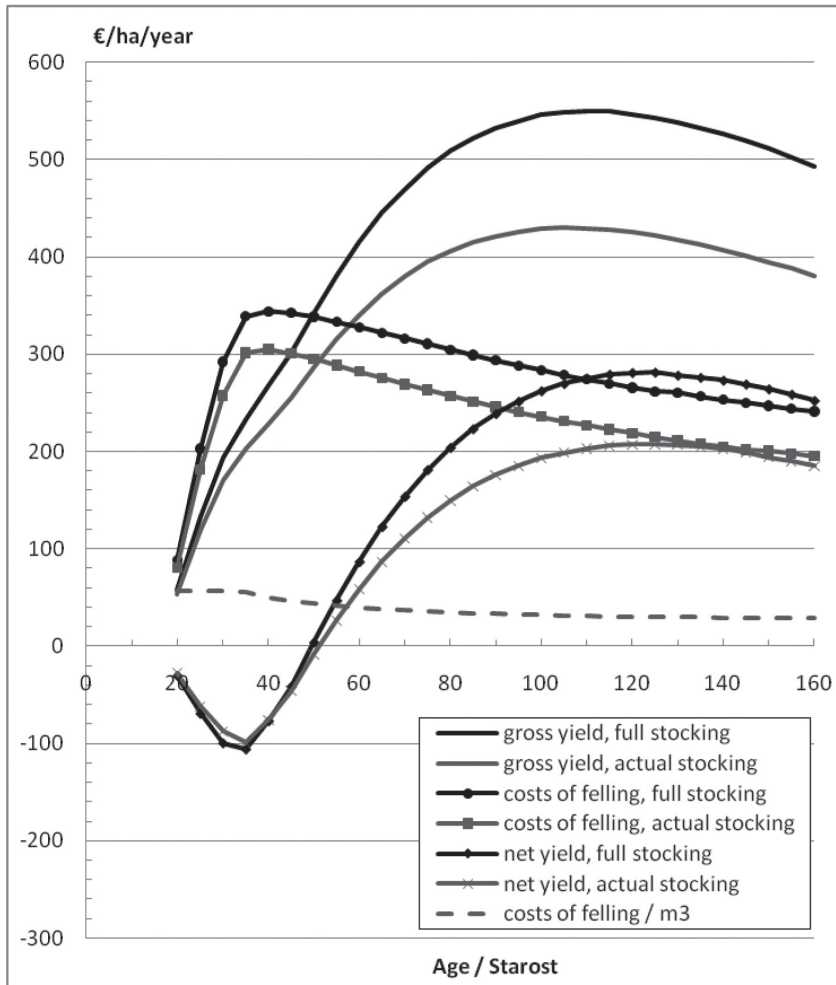
Figure 4: Total mean increments of gross and net yield and costs of felling (in € ha^{-1}year^{-1}) of beech stand with yield class 30 and full stocking and actual stocking

Slika 4: Bruto in neto povprečni vrednostni prirastek ter stroški pridobivanja lesa (v € ha^{-1}year^{-1}) v bukovem sestoju bonitetnega razreda 30 pri polni in dejanski zarasti

3.3 Culmination of total mean increment with regard to yield class

3.3 Kulminacija povprečnega starostnega prirastka sestoja glede na bonitetni razred

Figure 5 illustrates ages when these increments culminate and the ages of volume production culmination, as well. A known regularity was confirmed that increments of stands with higher yield class culminate at lower age and that this age of culmination drops in dependence on the yield class of stands nearly linearly. The lowest ages of culmination are related to volume production. For the stands with full stocking and yield classes 22-38, the age reaches 123-77 years. In the same stands but according to gross yield the age is 132-94 years, and according to net yield as much as 150-105 years. This means that the ages of stands when total mean increments culminate are, in comparison with volume production, older on average by 15 years for gross yield and even by 28 years for net yield. This trend may be explained by the change in value

proportions in the production process of beech stands. For gross yield it is mainly higher production of more valuable assortments at middle and higher ages. For net yield it is also whole-life trend of cost reductions in felling per 1 m^3 of felled timber. This trend shows that it is more effective to fell down older stands with higher diameters.

The effect of stocking on felling maturity is very significant as well. Lower stocking causes felling maturity to shift to a lower age, mainly in volume production. Stands with actual stocking have lower felling maturity by about 13-14 years than fully stocked stands. For gross yield, this difference is reduced to approximately only 5 years, and is practically identical for net yield the age of felling maturity of the stand with full and actual stocking.
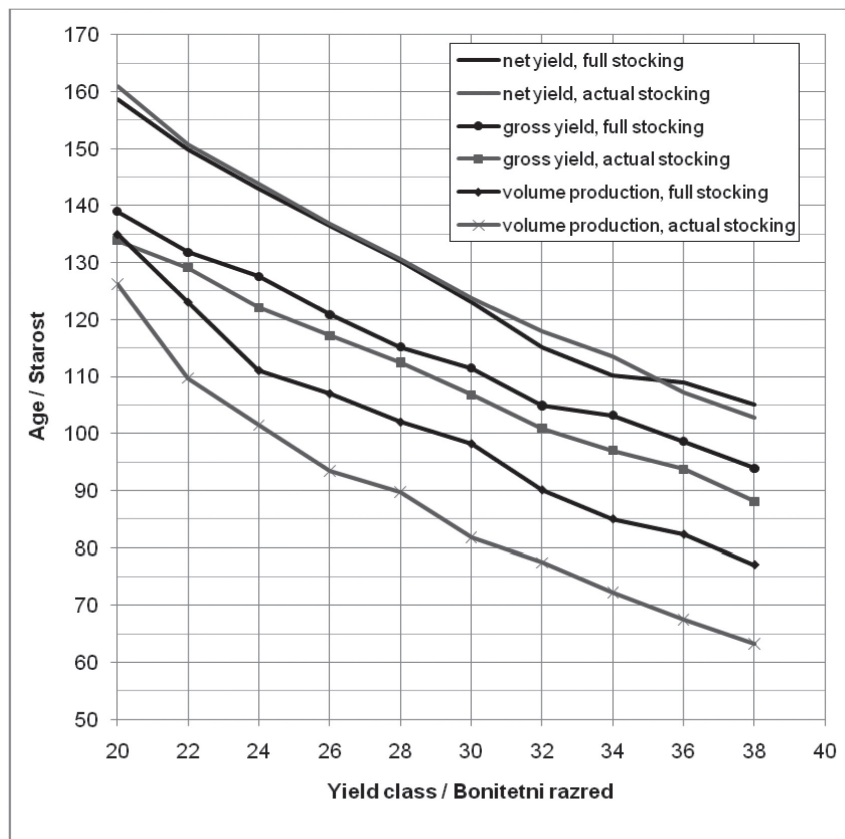
Figure 5: Ages of culmination of total mean increments from volume production, gross and net yield in dependence on yield class of stand with full and actual stocking

Slika 5: Starosti v času kulminacije povprečnega prirastka glede na volumensko in bruto oziroma neto vrednostno produkcijo v odvisnosti od bonitetnega razreda pri polni in dejanski zarasti

4 Discussion

4 Razprava

After the analysis, the question arises about the criteria for the determination of felling maturity of beech stands. Criterion of maximal mean annual volume production evaluated only the amount of produced wood regardless of wood quality and price. Therefore, we can consider this criterion an extensive one. The effect of lower stocking on felling maturity is highest in this case. Maximal mean annual production in gross financial yield concentrates not only the amount but also the quality and utility value of produced timber. Higher quality timber with large diameter is more valuable and has higher price. Higher ages of felling maturity appear here due to the fact that higher quality wood is being formed mainly in the middle and higher age classes. Higher quality production has its own limit with beech. It is red heartwood that at the age of about over 120 years decreases markedly the quality of wood inside stems. In addition to the wood quality, the prices of particular assortments are very significant as well.

With regard to timber prices, the change of ratios and not the change of their absolute values exerts influence on the felling maturity. Maximal mean annual net yield (forest rent) is very often used as the main economic criterion. It integrates utility value of wood as well as the value of human work including material costs of whole felling. Natural wood production on particular forest sites may be considered a long-term constant parameter. But costs of timber felling cause some uncertainty here as they may change more markedly, such as prices on timber during the long production period of forest stands.

Other often used criteria of felling maturity considering only timber value of forests are maximal land expectation value (financial maturity) and maximal share of target assortment (technical maturity)(e. g. ENDRES 1923, KOTAR 2005). The former is used more often in forests owned by larger landowners or companies, and the latter in forests owned by farmers. Both criteria usually lead to shorter production periods or rotations (e. g. LEUSCHNER 1984).

This paper examined only timber values of the beech stands, although we are aware of the important influences

of other non-timber forest values for the society and ecosystems. Due to the insufficient knowledge concerning these values, we limited our analysis only to timber value of beech stands. Mainly, non-timber values lengthen production periods or felling maturities, but not always (e.g. MARSHALL *et al.* 2000, KADUNC 2008). Taking non-timber values (amenity production) into account, Hartman (1976, quot. AMACHER *et al.* 2009) proposed an application of Faustmann's model. He assumed that amenity services depend solely on stand age. As a consequence the rotation periods according to Hartman's model could be longer, shorter or the same (e. g. AMACHER *et al.* 2009). It depends on characteristics of amenity type; amenity benefits increase with age (e. g. wildlife species adapted to old forest), amenity benefits decrease (species adapted to young forest), or amenity benefits are constant.

The obtained results suggest that 105-150 years is the most appropriate interval of felling maturity of the beech stands in Slovakia. In Slovenia, KOTAR (2000) proposed for (productive) beech stands the production period of 90-110 years; for wider site range, KADUNC (2006) established an interval of 80-160 years (and more on extremely unproductive sites) as economically optimal for beech stands. For Switzerland, LEIBUNDGUT (1966) alleged that beech achieves its economic maturity between 80 and 140 years of age. In contrast, French foresters try to obtain an optimal rotation length of 150 years (BASTIEN 2000). Many German foresters advocate rotations of 150-170 years long (KRAMER 1988), with caution that timber is not importantly degraded by red heartwood. In Croatia, a 100 year rotation length for even-aged beech forests was prescribed (MEŠTROVIĆ / ČAVLOVIĆ 2003, ČAVLOVIĆ / ANIĆ 2008).

Red heartwood formation has been usually treated as a very important factor influencing felling maturity in beech stands (e. g. NECESANY 1969, KNOKE 2003). The advertising campaigns for "red beech" are trying to change this, but they are probably not very successful (KNOKE *et al.* 2006).

The differences in felling maturities (production periods, rotations) are explainable with different prices of assortments (Slovenian prices of high quality timber are lower and they are not size-dependent), with different harvesting costs and with different tending or thinning regimes. Interest rate has a very strong impact, whereby low rates usually lengthen rotations (e.g. PRICE 1989). In our analysis, interest rates were not applied due to the standpoint of Ministry of Finance of the Slovak Republic. Taking precommercial silvicultural operations into account usually shortens rotations, especially if interest rates are considered. Other factors to be discussed are the reasons of net value production decreasing. Foresters often believe that it is a consequence of red heartwood formation in beech at higher stand ages. But, it is usually the age-related decreasing volume production that contributes to the diminishing value increment more than worse assortment

structure in overmature stands. Recently, researchers established accelerated growth trends in many European forests (e.g. SPIECKER *et al.* 1996), therefore age-related volume decline in older stands is probably less obvious.

It has to be noted that the present paper refers to even-aged (pure) beech stands. In uneven-aged stands, felling maturity is based on a target diameter. But as yield tables or production models are almost impossible to construct for these stands, single-tree based growth models are proposed instead.

5 Povzetek
5 Summary

Določanje sečnih zrelosti sestojev je ena zahtevnejših nalog gozdarjev. V tem prispevku se omejujemo na sečno zrelost bukovih sestojev, ki je določena upoštevaje le lesnoproizvodno funkcijo.

Na podlagi donosnih in sortimentnih tablic, ki so jih izdelali na Slovaškem (HALAJ *et al.* 1987, PETRÁŠ *et al.* 1996), ter stroškov gozdnega dela smo izpeljali optimalne sečne zrelosti bukovih sestojev na Slovaškem. Obrestnih mer zaradi stališča resornega slovaškega ministrstva za gozdarstvo nismo upoštevali. Z ekonomskega zornega kota je sečna zrelost odvisna od volumenske produkcije, sortimentne strukture pri različnih starostih sestoja in stroškov gozdnega dela. Na Slovaškem je kulminacija neto vrednostne produkcije prevladujoči kriterij pri določitvi sečne zrelosti bukovih sestojev. Analize kažejo, da stroški pridobivanja lesa po starosti sestoja okoli 40 let pričnejo umirjeno padati. Povprečni vrednostni prirastek bukovih sestojev je odvisen od bonitetnega razreda. Bruto vrednostni prirastek kulminira v povprečju 15 let kasneje kot volumenski prirastek, neto vrednostni prirastek pa v povprečju 28 let kasneje. Slednji kulminira pri starosti med 105 in 150 leti. Rezultati so pokazali na veliko odvisnost kulminacije vrednostnega prirastka od volumenske produkcije. Slovaške sečne zrelosti so v veliki meri skladne s slovenskimi in švicarskimi, med drugim tudi zato, ker so diferencirane glede na boniteto rastišč.

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