JOURNAL OF FOREST SCIENCE, *57*, 2011 (12): 536–546

Gross value yield potential of coppice, high forest and model conversion of high forest to coppice on best sites

M. Kneifl[1], **J. Kadavý**[1], **R. Knott**[2]

[1]*Department of Forest Management, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic*

[2]*Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic*

ABSTRACT: Based on yield tables for oak high forest and oak coppice (both first site class) and using assortment tables and assortment prices in the Czech Republic in 2009, a set of variants of conversion of high forest to coppice was simulated. Average annual cut and average gross value of annual cut of such conversions were compared with those of well-established (in terms of the age structure balance) variants of coppice and high forest. Under the existing ratio of assortment prices, established coppice does not reach the gross value yield of high forest. No variant of simulated conversions was more financially profitable than the initial high forest. Furthermore, we found out that a +16.8% increase of the current fuel wood price would counterbalance the mean annual increment of gross value of the best coppice and the worst oak high forest variant. On the other hand, a +164.7% fuel wood price increase would be necessary to counterbalance the mean annual increment of gross value of the worst coppice and the best high forest variants.

Keywords: conversion; coppice; high forest; oak; average annual cut; average gross value yield

Recently, an interest in a coppice silvicultural system has been renewed (Buckley 1992; Rydberg 2000; Harmer, Howe 2003; Coppini, Hermanin 2007; Machar 2009). Among the particularly stressed advantages of the so-called open forests are their higher biodiversity (Ash, Barkham 1976; Mason, MacDonald 2002; Gondard, Romane 2005; Van Calster et al. 2008; Valbuena-Carabana et al. 2008) and higher production of firewood in short rotation periods (Proe et al. 1999). The global economic crisis, constantly increasing prices of fossil energy sources, as well as the support which the EU states channel to energy production from renewable resources have significantly boosted the interest in coppices (Jansen, Kuiper 2004). A forest owner's decision to focus on firewood as the key product which will be demanded in the future must be motivated by a thorough analysis of possible risks and advantages. Firewood production does not require a long rotation period; therefore the choice will naturally be the coppice silvicultural system (Ribeiro, Betters 1995). Generally speaking, foresters tend to view the coppice and coppice-with-standards silvicultural systems negatively. Unfortunately, we cannot draw on examples of active coppice management in the Czech Republic. General recommendations for the management of coppices in all their development stages, including the rules for regeneration, stand thinning and felling are not available at the moment.

In the past, many papers about conversion from coppice to high oak forest were published (for instance Kostov 1989; Pintarić 1999; Durkaya et al. 2009). Ciancio et al. (1995) and Röhrig and Kühne (2005) discussed conversion from coppice-with-standards to high forest. Dworschak (1996), Van Calster et al. (2007) and Baeten et al. (2009) evaluated the extent of vegetation structure changes during conversion from coppice-with-standards to high forest. Conversion from coppice to selection high forest was described by Boutteaux (2007). Utinek (2004) proposed a modified method of conversion of over-matured coppices to coppice-with-standards in the municipal forest of the town of Moravský Krumlov but he did not publish any financial figures of the conversion.

In the last three decades a few papers have been published on the economic effectiveness of coppice or coppice-with-standards as compared to that of high forest (Le Goff 1984; Schütz, Rotach 1993; Suchant et al. 1995; Bally 1999). They mostly state that the financial effectiveness of coppice and coppice-with-standards is lower than that of high forest. Chronologically, the earlier papers stress the unquestionable financial superiority of high forest while the later ones admit that coppice or coppice-with-standards could yield a higher value under certain circumstances.

Unfortunately, there is no paper available in the literature that evaluated the conversion of high forest into coppice in financial terms. An initial assessment of the coppice production potential and its comparison with that of high forests may be possible if we draw on historical data and yield tables. A model example may then test the basic questions related to the conversion of high forest to coppice.

The general model of high forest to coppice conversion was already described by Cotta (1848). An attempt to convert high forest to coppice by stepwise harvest without consequent reforestation and by leaving mature high forest stands to resprout will not offer any satisfactory results. At mature age, trees are distributed sparsely. The number of resulting sprout stools would be insufficient and their vitality would probably be poor. The harvest of all stands older than the rotation of target coppice would lead to considerable misbalance in terms of age structure, harvest and yield in the following decades. Thus, the conversion must take place in two time stages. While mature stands must be harvested in the way common to a high forest management system, e.g. regenerated either artificially by planting or naturally by seeds, young stands of seed origin can be converted to coppice by clear-cutting up to a time point when the number of trees per hectare is sufficient for the consequent coppice.

This paper aims to simulate different variants of pedunculate oak (*Quercus robur* [L.]) and sessile oak (*Quercus petraea* [Matt.] Liebl.) high forest, set of conversion variants of oak high forest to oak coppice and different variants of established oak coppice growing on comparable sites and compare all variants by means of average annual cut and average annual gross value yield.

MATERIAL AND METHODS

Historical yield tables were used to provide data on the volume growth of both oak high forest and coppice. For the calculation of oak high forest growth data of the first class Schwappach's yield tables (Schwappach 1905) were used. They provide information on standing volume, thinning intensity and on the mean diameter of standing volume and thinning volume of a "normal forest". We had to extrapolate the tables to get the missing values of volume and diameter in the range of 185 to 240 years because we found the optimum rotation of some oak high forest variants beyond the age limit of Schwappach's tables.

The first site class of Korsuň's yield tables (Korsuň 1954) was used to address the oak coppice growth. These tables show standing and thinning volumes in m^3 of timber to 3 cm top diameter over bark.

In the context of coppice management it is assumed that firewood is the only assortment. High forest provides a wide choice of assortments, ranging from valuable ones to industrial round timber, pulpwood and firewood. Our theoretical grading draws on assortment tables by Čermák and Hubač (1978). The tables enable the estimation of assortments (I, II, III, small industrial wood, fuel wood and waste) according to mean stand diameter, its variation degree and percentage of damaged trees. The percentages of quality classes A – best, B – mid and C – low quality have to be assessed.

Table 1. Variants of the stem quality composition in oak high forest

Variant	Stem quality class percentage		
	A	B	C
HF I	50	45	5
HF II	40	50	10
HF III	30	55	15
HF IV	20	60	20
HF V	10	65	25

Supported by the Ministry of Agriculture of the Czech Republic (Project No. QH71161) and the Ministry of Environment of the Czech Republic (Project No. SP/2d4/59/07).

Table 2 Original and modified limits of assortment classes of tables according to Čermák and Hubač (1978)

			Mid diameter class											
			> 60	50–59	40–49	35–39	30–34	25–29	20–24	15–19	30–39	20–29	15–19	< 19	
Stem quality class	modified	A	I	I	II	II	II	III	III	FW	FW	FW	FW	FW	
		B	III	III	III	III	III	III	III	FW	FW	FW	FW	FW	
		C							FW						
	original	A	I	I	I	I	II	II	II	III	IV	IV	IV	SIW	FW
		B	III	III	III	III	III	III	III	IV	IV	IV	IV	SIW	FW
		C						IV						SIW	FW

SIW – small industrial wood, FW – fuel wood

For our calculations we chose the average diameter variation degree, zero rate of damaged trees and five variants of stem quality distribution (Table 1).

We applied the assortment tables to the volumes and diameters of Schwappach's first site class data. At the age of 125 years the mean stand diameter of Schwappach's first site class exceeds the maximum limit of Čermák and Hubač (1978) assortment tables. Therefore it was necessary to perform the extrapolation of assortment percentages to the diameter of 74 cm. The assortment classes "small industrial wood" and "fuel wood" were merged in the fuel wood category owing to current comparable prices of both categories. Because of different criteria of assortment classes I, II and III between Čermák and Hubač (1978) and Wojnar (2007) we slightly modified the diameter limits of assortments (Table 2). This modification enabled us to calculate the gross value using today's timber prices.

The gross value of timber harvest may be expressed by the price of potential assortments. Absolute values of particular assortment prices affect the gross value of timber harvest. Mutual ratios of prices of the particular assortment classes, combined with the mean annual volume increment (MAI), affect the point of felling maturity and therefore the optimal rotation. To evaluate the gross value of timber harvest we drew on average prices of oak assortments in 2009 (Anonymous 2010). Instead of prices for assortment classes IIIA to IIID according to today's recommendations (Wojnar 2007) the average price for combined class III was used to reach compatibility with the assortment tables by Čermák and Hubač (1978; Table 3).

Table 3. Average prices of timber assortments in the Czech Republic in 2009 (Anonymous 2010)

Assortment	I	II	III*	Fuel wood
Price (CZK·m^{-3})	12,951	6,163	2,286	779

*Average price of IIIA, IIIB, IIIC and IIID assortments

Optimal rotation periods (r) were evaluated for five high forest (Schwappach's first site class) and three coppice variants (Korsuň's first site class), all with the balanced age class structure. The culmination of the mean annual increment of gross value (MAI_{GV}) was used as optimization criterion:

$$MAI_{GV_n} = \frac{TGV_n}{n \times 10} \qquad (\mathrm{CZK \cdot ha^{-1} \cdot year^{-1}}) \quad (1)$$

$$TGV_n = \sum_{a=\mathrm{I}}^{FW}(SV_{na} \times APsv_{na} \times Pr_{A_a} + \sum_{i=1}^{n}(Vt_{ia} \times APvt_{ia} \times Pr_{A_a})) \qquad (\mathrm{CZK \cdot ha^{-1}}) \quad (2)$$

where:

TGV_n – total gross value of the nth age class,

n – age class,

a – assortment class (I, II, III, FW),

SV_{na} – standing volume of the nth age class and ath assortment class (m^3·ha^{-1}),

$APsv_{na}$ – percentage of standing volume in the nth age class and ath assortment class (%),

Vt_{ia} – thinning volume of the ith age class and ath assortment class (m^3·ha^{-1}),

$APvt_{ia}$ – percentage of thinning volume in the ith age class and ath assortment class (%),

Pr_{A_a} – price of the ath assortment class (CZK·m^{-3}).

We performed simulations of 15 conversions of high forest to coppice using different initial high forest stem quality compositions (I to V) and different rotations of target coppice (r_C = 10, 20 and 30). Results of the simulations were compared with five variants of high forest with different stem quality composition variants (I to V) and three variants of coppice of different rotation (r_C = 10, 20 and 30 years). In all variants the balanced age class structure was expected.

Average annual cut (AAC) and its gross value (AGV) were used as the criteria of comparison. The average annual cut is defined as follows:

$$AAC = \frac{\sum_{n=1}^{pc/10} AC_{Total_i}}{PA} \qquad (\mathrm{m^3 \cdot ha^{-1} \cdot year^{-1}}) \quad (3)$$

$$AC_{Total} = AC_{HF} + AC_{cp} + AC_{Cop} \qquad (\mathrm{m^3 \cdot year^{-1}}) \quad (4)$$

$$AC_{HF} = \frac{\sum_{n=1}^{pc/10}(A_{HF_n} \cdot V_{HF_n} \cdot HR_n) + \sum_{n=1}^{pc/10}(A_{HF_n} \cdot V_{THF_n})}{10} \qquad (\mathrm{m^3 \cdot year^{-1}}) \quad (5)$$

$$AC_{Cop} = \frac{(A_{Cop(rc/10)} \times V_{Cop(rc/10)} + \sum_{n=1}^{r_C/10}(A_{Cop_n} \times V_{TCop_n})}{10} \qquad (\mathrm{m^3 \cdot year^{-1}}) \quad (6)$$

$$AC_{cp} = \frac{A_{HF_{cp/10}} \times V_{HF_{cp/10}}}{10} \qquad (\mathrm{m^3 \cdot year^{-1}}) \quad (7)$$

where:

AAC – average annual cut of the complete conversion period (m^3·ha^{-1}·year^{-1}),

AC_{Total} – total annual cut (m^3·year^{-1}),

AC_{HF} – annual cut of high forest (m^3·year^{-1}),

AC_{cp} – annual cut of high forest at an age class corresponding to the conversion point (m^3·year^{-1}),

AC_{Cop} – annual cut of coppice (m^3·year^{-1}),

PA – area of the property (ha),

pc – entire conversion period (years) ($pc = \mathrm{r}_{HF}/10 + 1$),

A_{HF_n} – area of the nth age class of high forest (ha),

V_{HF_n} – standing volume per hectare of the nth class (m^3·ha^{-1}),

HR_n – harvest rate of the nth high forest age class (%),

V_{THF_n} – volume of tending of the nth high forest age class (m^3·ha^{-1}·10 years^{-1}),

r_C – rotation period of coppice (years),

$A_{Cop(rc/10)}$ – area of the coppice age class corresponding to $r_{C,}$

$V_{Cop(rc/10)}$ – standing volume per hectare (m^3·ha^{-1}) of the coppice age class corresponding to coppice rotation,

A_{COP_n} – area of the nth coppice age class (ha),

V_{TCop_n} – volume of tending of the nth coppice age class (m^3·ha^{-1}·10 years^{-1}),

n – age class (n_1 = 1–10, n_2 = 11–20, ...),

i – decade of conversion period,

$A_{HF_{cp/10}}$ – area of the high forest age class corresponding to the conversion point (ha),

$V_{HF_{cp/10}}$ – standing volume of the high forest age class corresponding to the conversion point (m^3·ha^{-1}).

The average gross value of annual cuts is defined as follows:

$$\mathrm{AGV} = \frac{\sum_{i=1}^{pc/10} GV_{Total_i}}{PA} \qquad (\mathrm{CZK\ ha^{-1} \cdot year^{-1}}) \quad (8)$$

$$GV_{Total} = GV_{HF} + GV_{cp} + GV_{Cop} \qquad (\mathrm{CZK \cdot year^{-1}}) \quad (9)$$

$$GV_{HF} = \sum_{a=1}^{FW}(AC_{HF_a} \times APh_a \times Pr_{A_a}) \qquad (\mathrm{CZK \cdot year^{-1}}) \quad (10)$$

$$GV_{Cop} = AC_{Cop} \times Pr_{A_{FW}} \qquad (\mathrm{CZK \cdot year^{-1}}) \quad (11)$$

$$GV_{cp} = \sum_{a=\mathrm{I}}^{FW}(AC_{cp_a} \times Pr_{A_a}) \qquad (\mathrm{CZK \cdot year^{-1}}) \quad (12)$$

where:

AGV – average gross value of the complete conversion period (CZK·ha^{-1}·year^{-1}),

GV_{Total} – total gross value of annual cut (CZK·year^{-1}),

GV_{HF} – gross value of high forest annual cut (CZK·year^{-1}),

Pr_{A_a} – price of the a$^{\mathrm{th}}$ assortment class (CZK·m^{-3}),

GV_{Cop} – gross value of coppice annual cut (CZK·year^{-1}),

$Pr_{A_{FW}}$ – price of fuel wood (CZK·m^{-3}),

GV_{cp} – gross value of annual cut of the high forest age class corresponding to the conversion point (CZK·year^{-1}).

For simulation of conversions of high forest to coppice a program was written in the MS Visual Basic for Applications environment to simulate the flow of annual cut and its value during the conversion period. The program, being in the form of a built-in module, constitutes a part of the Microsoft Excel file, the particular sheets of which are used for simple visualization of the simulation and as a database of the growth (yield tables), harvesting, grading and evaluation of the timber. In the course of model felling, the program deducts the

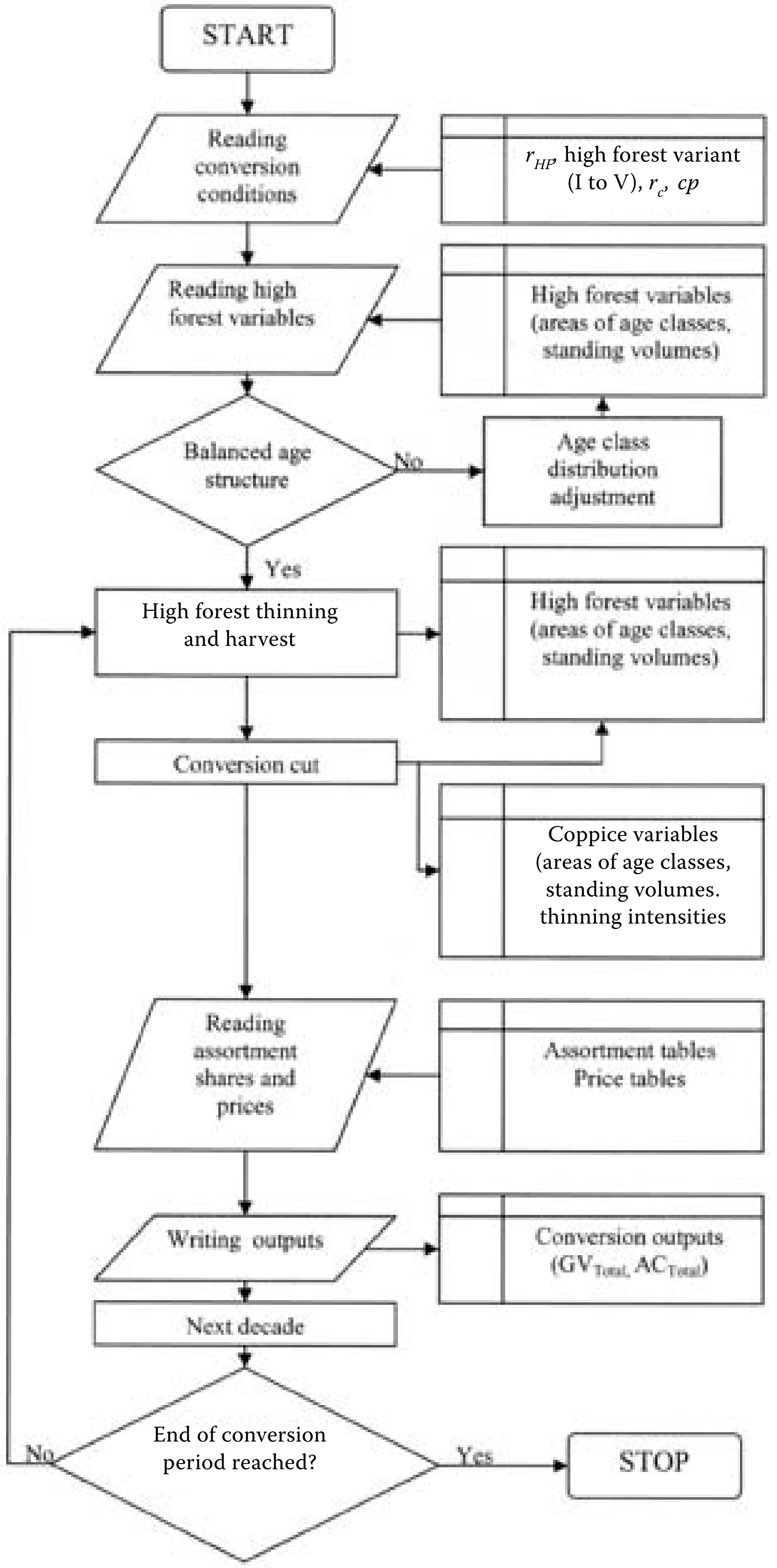

Fig. 1. Flow diagram of the conversion model

volume of thinning in corresponding age classes in 10-year intervals, as well as the volume of harvest. In all high forest and conversion harvesting ratios are applied as listed in Appendix III of Decree No. 84/1996 on forestry management planning. Harvesting ratios (*HR*) corresponding to rotation r_{HF} and 20-year regeneration period (i.e. 25% of the standing volume of age class (r_{HF}/10)–1, 67% of the standing volume of age class r_{HF}/10 and 100% standing volume of age classes over r_{HF}/10) are applied for harvest felling. In coppices and their conversions, three rotation variants are applied: r_C = 10, 20 and 30 years. The regeneration period is 10 years, which implies that the total volume of age class corresponding to r_C/10 is cut within 10 years.

The model of high forest to coppice conversion is described by a flow diagram (Fig. 1). Stands of the initial high forest property are harvested at two time points. Mature high forest stands are harvested at points of their respective rotations. Young high forest stands are harvested at the time point of conversion to coppice (*cp* = 30 years). The entire conversion period lasts for r_{HF} + 10 years.

To find out the extent of price that fuel wood would have to reach to equal the MAI_{GV} of oak high forest we developed a sub-procedure which increases the price of fuel wood in 1 CZK steps while maintaining the prices of other assortments unchanged. The procedure stops when the MAI_{GV} of coppice equals that of high forest. All combinations of three coppice variants and five high forest variants (as mentioned above) have been evaluated.

RESULTS

Optimal rotations of high forest variants

Optimal rotations for the high forest variants have been evaluated by means of MAI_{GV} culmination. For variants I, II, III, IV and V, the optimal rotations are 230, 230, 210, 180 and 170, respectively (Fig. 2). The MAI_{GV} values peak at 17,560; 15,928; 14,313; 12 758 and 11,297 CZK·ha^{-1}·year^{-1}, respectively, according to the variants.

Comparison of conversion variants

Results obtained in the course of the implemented simulations are presented in Table 4 and Fig. 3.

Variant I of high forest (*HF* I) yielded the highest *AGV*. Among the conversion variants the conversion of high forest (I) to coppice variant (*Cop* 10) yielded the highest *AGV*. The better the stem quality composition (in terms of the percentage of quality stems), the later is the optimal rotation and the higher the *AGV*. The *AGV* of the best coppice variant (*Cop* 10) reached only 58% of that of the best high forest variant (*HF* I). The best (*HF* I to *Cop* 10) and the worst (*HF* V to *Cop* 30) conversion variants yielded 94% and 62% of the initial high forest *AGV*, respectively. Among the established coppice variants the variant with rotation of 10 years (*Cop* 10) yielded the highest *AGV* value.

The *AAC* of all coppice variants and all conversion variants were higher than those of the high forest variants. After conversion, when the cop-

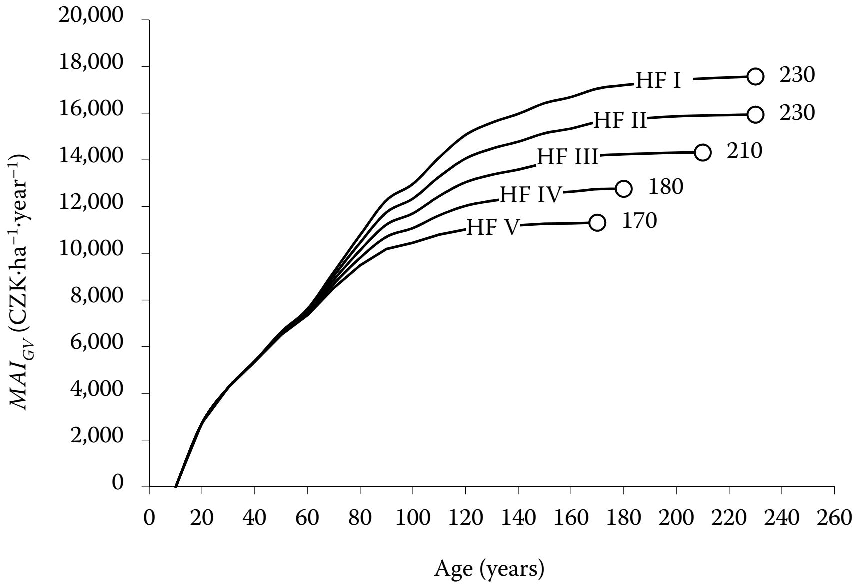

Fig. 2. Optimal rotations of high forest variants

Table 4. Comparison of high forest, conversion and Coppice variants

	Variant	Average annual cut			Average annual gross value		
		Coppice	high forest	total	Coppice	high forest	total
		($m^3·ha^{-1}·year^{-1}$)*			($CZK·ha^{-1}·year^{-1}$)		
High forest	V (r_{HF} = 170)	–	7.63	7.63	–	11,297	11,297
	IV (r_{HF} = 180)	–	7.53	7.53	–	12,758	12,758
	III (r_{HF} = 210)	–	7.22	7.22	–	14,313	14,313
	II (r_{HF} = 230)	–	7.03	7.03	–	15,928	15,928
	I (r_{HF} = 230)	–	7.03	7.03	–	17,560	17,560
Conversion	*HF* V –> *Cop* 10	6.49	4.74	11.23	5,056	7,178	12,234
	HF V –> *Cop* 20	5.69	4.74	10.43	4,430	7,178	11,608
	HF V –> *Cop* 30	4.80	4.74	9.53	3,736	7,178	10,914
	HF IV –> *Cop* 10	6.49	4.66	11.15	5,057	8,196	13,253
	HF IV –> *Cop* 20	5.70	4.66	10.36	4,443	8,196	12,640
	HF IV –> *Cop* 30	4.82	4.66	9.48	3,758	8,196	11,954
	HF III –> *Cop* 10	6.49	4.43	10.92	5,059	9,253	14,311
	HF III –> *Cop* 20	5.72	4.43	10.15	4,455	9,253	13,707
	HF III –> *Cop* 30	4.86	4.43	9.28	3,784	9,253	13,037
	HF II –> *Cop* 10	6.49	4.28	10.78	5,059	10,339	15,398
	HF II –> *Cop* 20	5.73	4.28	10.01	4,464	10,339	14,803
	HF II –> *Cop* 30	4.87	4.28	9.15	3,792	10,339	14,130
	HF I –> *Cop* 10	6.49	4.28	10.78	5,059	11,476	16,535
	HF I –> *Cop* 20	5.73	4.28	10.01	4,464	11,476	15,939
	HF I –> *Cop* 30	4.87	4.28	9.15	3,792	11,476	15,267
Coppice	r_C = 10	13.00	–	13.00	10,127	–	10,127
	r_C = 20	11.70	–	11.70	9,114	–	9,114
	r_C = 30	10.13	–	10.13	7,894	–	7,894

*Volume to 3 cm top diameter

HF – high forest, *Cop* – coppice, r_{HF} – rotation of high forest, r_C – rotation of coppice

pice has been established (the stage following concluded conversion), *AAC* would remain continually higher than that of high forest but the *AGV* would drop under the value of high forest. This could be explained by continual reduction of the standing volume of initial high forest stands older than the conversion point (*cp*) over the course of r_{HF} +10 years (e.g. 180 and 240 years in cases of HF V and HF I variants, respectively). At the end, only stands of sprout origin and of maximum age = r_C years are present. We state that upon the existing prices of wood assortments, the *AGV* of coppice on class I sites according to Korsuň (1954) is lower than *AGV* of high forest (on class I sites according to Schwappach 1905).

However, this holds true in case that the ratio of firewood price to the price of quality I assortment were the same throughout the entire conversion period, i.e. at the existing 6.02% (779 $CZK·m^{-3}$).

An increase of fuel wood prices necessary to counterbalance the MAI_{GV} of coppice and high forest

What price would firewood have to reach to equal the MAI_{GV} of converted oak coppice and that of oak high forest? If the remaining assortments remained at the same price level and if firewood prices continued to increase, pure oak coppice would reach

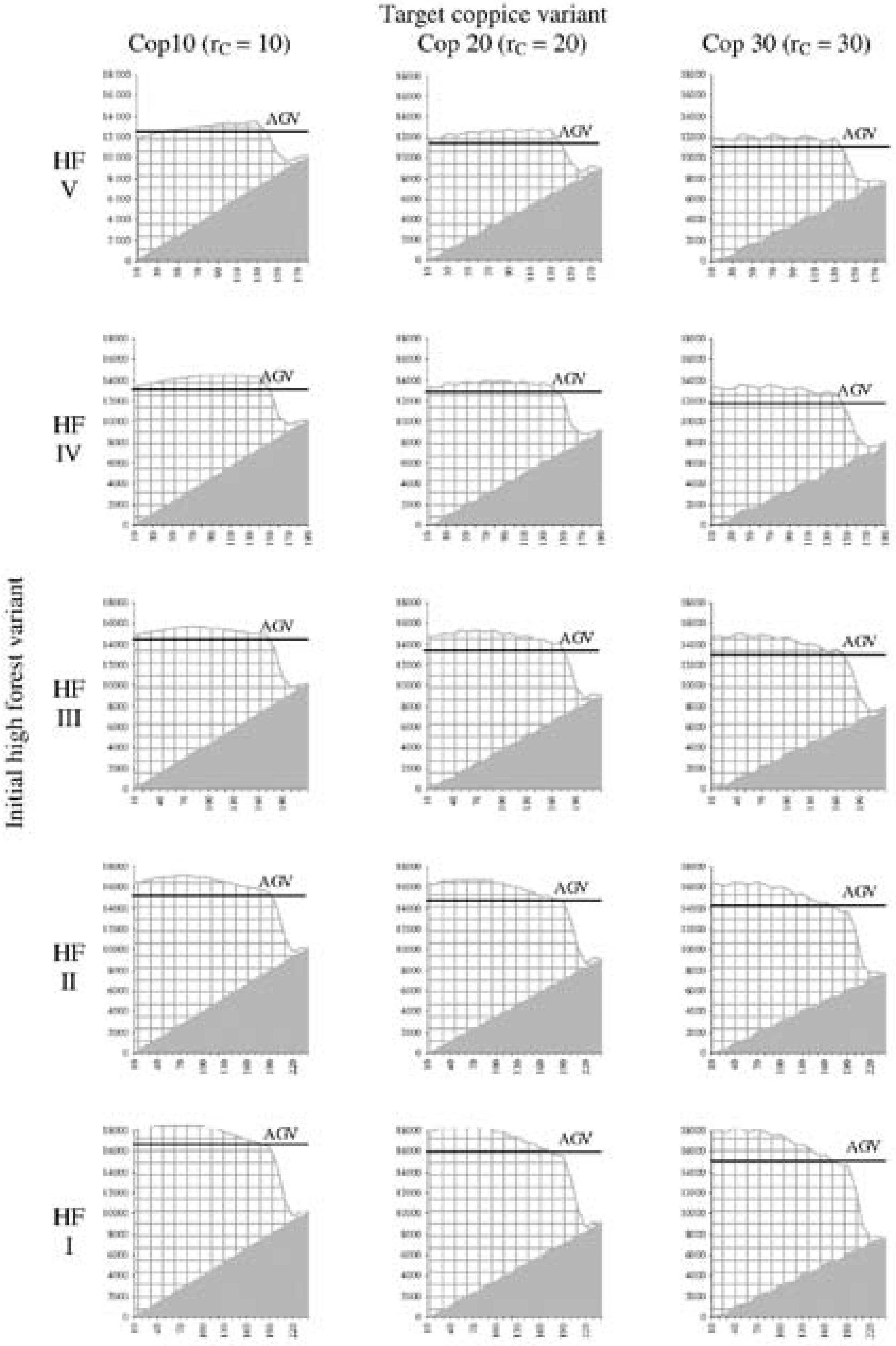

Fig. 3. Gross value of annual cut of different conversion variants

y-axis: *GV* – gross value of annual cut ($CSK·ha^{-1}·year^{-1}$), *x*-axis: years of conversion, checked area – high forest, ful gray area – coppice, *AGV* – average gross value of annual cur over the whole conversion ($CZK·ha^{-1}·year^{-1}$), HF I to HF V – variants of high forest, Cop 10 to Cop 30 – variants of coppice with rotations from 10 to 30 years

Table 5. Prices of fuel wood (CZK·m^{-3}) (and its change related to current price (%)) needed to even out the MAI_{GV} of coppice to that of high forest

	Variant	High forest I (r_{HF} = 230)	 II (r_{HF} = 230)	 III (r_{HF} = 210)	 IV (r_{HF} = 180)	 V (r_{HF} = 170)
Coppice	r_C = 10	1,497 (92.2)	1,351 (73.4)	1,206 (54.8)	1,061 (36.2)	910 (16.8)
	r_C = 20	1,710 (119.5)	1,547 (98.6)	1,388 (78.2)	1,229 (57.8)	1,060 (36.1)
	r_C = 30	2,062 (164.7)	1,847 (137.1)	1,692 (117.2)	1,513 (94.2)	1,317 (69.1)

the MAI_{GV} of pure oak high forest upon conditions shown in Table 5. The necessary change in the price of 1 m^3 fuel wood needed to counterbalance the MAI_{GV} of the best coppice (r_C = 10) and worst high forest (V) variants is +16.8% (from 779 to 910 CZK·m^{-3}). To counterbalance the MAI_{GV} of the worst coppice (r_C = 30) to that of the best high forest (variant I), +165% change (779 to 2,062 CZK·m^{-3}) of the current fuel wood price is needed.

DISCUSSION

The upward trend of fuel wood prices which has been apparent in recent years justifies efforts to reintroduce coppice forests. Historically, coppice forests covered a considerable area of the Czech Republic and provided fuel wood supply for centuries. If we rely on historically proved yield tables, which were based on extensive and at present virtually inconceivable volumes of experimental data, we can presume differences in both silvicultural systems even if in a relative degree. We preferred historical high forest yield tables (Schwappach 1905) to contemporary ones because up-to-date yield tables for coppiced oak are not available. Historical tables provide the only source of information in this respect. As to the time span of input data collection, historical tables are more closely related to Schwappach's tables for oak than the contemporary growth models.

The use of deterministic assortment tables may reduce the gross value yield variability. The representation of particular assortments of high forest is conditioned not only by the mid-diameter of the harvested stand, but also by a number of other factors ranging from the stand's gene pool and its variability, stand variability within the actual forest stand complex or its tending. That is why we compared five variants of the stem quality composition in high forest.

Costs of forest management must also be mentioned here. The paper concentrates only on the gross value yield as a potential result of virtually harvested and sold assortments, without taking into account any kind of costs. Historical records and international practice show that coppice is, in terms of costs, probably considerably cheaper than high forest. Also, by implementing a biodiversity measure into consideration, the results of the simulated conversion may be more accurate and closer to reality. Therefore, future efforts to incorporate costs and biodiversity in such calculations would be appreciated.

Each of the inputs we used may, and probably does, introduce a certain degree of uncertainty into the results. The resulting absolute values of both volume and gross value yields may differ significantly from a randomly selected real forest property. Despite all this, we believe that the mutual ratio of the resulting values in a relative expression is vital.

Our results revealed that oak high forest on best sites yielded a higher gross value than coppice. This is valid upon current timber assortment prices. Suchant et al. (1995) compared the net value of oak coppice with wild cherry standards to that of spruce high forest. They found the spruce high forest being more effective in terms of the net value yield. Nevertheless, the difference between high forest and coppice with cherry standards was not unambiguous.

Our results are consistent with those of Bally (1999), who found the financial effectiveness of coppice on best sites to be lower than that of high forest. On the other hand, she stated that the variability of coppice net financial yield was significantly lower than that of a high forest. She also found out that coppice on poor sites brought about higher net financial yield than high forest.

Durkaya et al. (2009) evaluated the conversion of oak coppice to high forest. They calculated the net present value of coppice and that of the final high forest. In all variants high forest yielded a higher net present value.

Upon our results a conclusion may be drawn that coppice is not a management option. The high prices of valuable assortments make the high forest a better choice. In our study five variants of the stem quality composition were used. In our opinion the worst high forest variant corresponds with the contemporary Czech timber market reality. Valuable assortments are rarely sold. Forest owners prefer quick sale in big supplies to prolonged search for a purchaser of high quality timber. Also, there is no valuable timber auction in the Czech Republic. Therefore, a slight change in the fuel wood price could make coppice an interesting management alternative.

CONCLUSION

We compared the gross value yield of five variants of oak high forest, three variants of oak coppice and fifteen variants of conversions of high forest to coppice (all on best site class). Historical and contemporary sources on the growth of oak in high forest and coppice forest silvicultural systems along with assortment tables and average timber prices in 2009 were used as the input data source. The following conclusions could be drawn from our results:

- out of the three coppice variants that with rotation r_C = 10 years yielded the highest *AAC* and *AGV*,
- none of the coppice variants outperformed any of the five oak high forest variants in terms of *AGV*,
- all conversion variants yielded higher *AGV* than any of the three coppice variants,
- only three conversion variants (*HF* V –> *Cop* 10, *HF* V –> *Cop* 20 and *HF* IV –> *Cop* 10) outperformed the initial oak high forest in terms of *AGV*,
- a change in fuel wood prices (while maintaining the prices of other assortments) is needed to counterbalance the MAI_{GV} of coppice and high forest. The change in the current average fuel wood price of +16.8% would counterbalance the *Cop* 10 and *HF* V variants. On the other hand, the change in the current average fuel wood price of +164.7% would counterbalance the *Cop* 30 and *HF* I variants.

References

Anonymous (2010): Average wood assortment prices. Lesnická práce, **89**: 49. (in Czech)

Ash J.E., Barkham J.P. (1976): Changes and variability in the field layer of a coppiced woodland in Norfolk, England. Journal of Ecology, **64**: 697–712.

Baeten L., Bauwens B., De Schrijver A., De Keersmaeker L., Van Calster H., Vandekerkhove K., Roelandt B., Beeckman H., Verheyen K. (2009): Herb layer changes (1954–2000) related to the conversion of coppice-with-standards forest and soil acidification. Applied Vegetation Science, **12**: 187–197.

Bally B. (1999): Energieholzproduktion in Mittel- und Niederwäldern der Schweiz. Schweizerische Zeitschrift für Forstwesen, **150**: 142–147.

Boutteaux J.J. (2007): Conversion to selection forest in the Haute-Marne: experience in the region of d'Auberive. RenDez-Vous Techniques, **18**: 45–51.

Buckley G.P. (ed.) (1992): Ecology and Management of Coppice Woodlands. New York, Chapman and Hall: 336.

Čermák V., Hubač K. (1978): Assortment Tables for Broadleaved Tree Species. Bratislava, Príroda: 203. (in Slovak)

Ciancio O., Clerici E., Iovino F., Menguzzato G. (1995): Coppice with standards, an alternative forest management system: an experimental study. Italia Forestale e Montana, **50**: 371–389.

Coppini M., Hermanin L. (2007): Restoration of selective beech coppices: A case study in the Apennines (Italy). Forest Ecology and Management, **249**: 18–27.

Cotta H. (1848): Anweisungen zum Waldbau. Dresden, **6**: 204.

Durkaya A., Durkaya B., Çetin M. (2009): Conversion possibilities of oak (*Quercus* sp. L.) coppices into high forests in Bartin, Turkey. Bartin Orman Fakültesi Dergisi, **11**: 51–59.

Dworschak U. (1996): Vegetation development in the former coppice-with-standards forests of the Lower Rhine basin. Forst und Holz, **51**: 392–395.

Gondard H., Romane F. (2005): Long-term evolution of understorey plant species composition after logging in chestnut coppice stands (Cevennes Mountains, southern France). Annals of Forest Science, **62**: 333–342.

Harmer R., Howe J. (2003): The Silviculture and Management of Coppice Woodlands. Edinburgh, Forestry Commission: 88.

Jansen P., Kuiper L. (2004): Double green energy from traditional coppice stands in the Netherlands. Biomass and Bioenergy, **26**: 401–402.

Korsuň F. (1954): The life of oak coppices in figures. Práce výzkumných ústavů ČSR, Praha: 154–169. (in Czech)

Kostov I. (1989): Conversion of *Quercus cerris/Q. petraea* and *Q. cerris/Q. frainetto* coppice stands into high forest. Gorsko Stopanstvo, **45**: 6–8.

Le Goff N. (1984): Indice de productivité des tailis sous futaie de chene dans la région centre. Annales des Sciences forestières, **41**: 1–33.

Machar I. (2009): Coppice-with-standards in floodplain forests – a new subject for nature protection. Journal of Forest Science, **55**: 306–311.

Mason C.F., MacDonald S.M. (2002): Responses of ground flora to coppice management in an English woodland – a study using permanent quadrats. Biodiversity and Conservation, ***11***: 1773–1789.

Pintarić K. (1999): Conversion of the sessil oak *Quercus petraea* Matt. (Liebl.) coppices into high forests. Radovi Šumarskog Fakulteta Univerziteta u Sarajevu, ***29***: 1–10.

Proe M., Craig J., Griffiths J., Wilson A., Reid E. (1999): Comparison of biomass production in coppice and single stem woodland management systems on an imperfectly drained gley soil in central Scotland. Biomass and Bioenergy, ***17***: 141–151.

Ribeiro C., Betters D. (1995): Single rotation vs. coppice systems for short-rotation intensive culture plantations – optimality conditions for volume production. Biomass and Bioenergy, ***8***: 395–400.

Röhrig E., Kühne C. (2005): Previous and current silvicultural management of floodplain forests of the Upper Rhine valley in special consideration of pedunculate oak. Frankfurt am Main, J. D. Sauerländer's Verlag: ***140***: 7–20.

Rydberg D. (2000): Initial sprouting, growth and mortality of European aspen and birch after selective coppicing in central Sweden. Forest Ecology and Management, ***130*** : 27–35.

Schütz J.P., Rotach P. (1993): Mittelwaldbetrieb: nostalgische Illusion oder zukunftsträchtiges Waldbaukonzept? Waldbau, ***7***: 8–12.

Schwappach A.F. (1905): Untersuchungen über die Zuwachsleistung von Eichenhochwaldbeständen in Preussen unter besonderer Berücksichtigung des Einflusses verschiedener wirtschaftlicher Behandlungsweise. Neudamm, Verlag von J. Neumann: 127.

Suchant R., Opeker K., Nain W. (1995): Der Kirschen – Mittelwald: ökonomische und ökologische Alternative für den Niederwald. Allgemeine Forst- und Jagdzeitschrift, ***167***: 139–148.

Utinek D. (2004): Conversions of coppices to a coppice-with-standards in Urban Forests of Moravský Krumlov. Journal of Forest Science, ***50***: 38–46.

Valbuena-Carabana M., Gonzales-Martinez S., Gil L. (2008): Coppice forests and genetic diversity: A case study in *Quercus pyrenaica* Willd. from Central Spain. Forest Ecology and Management, ***254***: 225–232.

Van Calster H., Baeten L., De Schrijver A., De Keersmaeker L., Rogister J., Verheyen K., Hermy M. (2007): Management driven changes (1967–2005) in soil acidity and the understory plant community following conversion of a coppice-with-standards forest. Forest Ecology and Management, ***241***: 258–271.

Van Calster H., Chevalier R., Wyngene B., Archaux F., Verheyen K., Hermy M. (2008): Long-term seed bank dynamics in a temperate forest under conversion from coppice-with-standards to high forest management. Applied Vegetation Science, ***11***: 251–260.

Wojnar T. (ed.) (2007): Recommended Rules for Grading and Sorting of Wood Assortments in the Czech Republic. Praha, Lesnická práce, ***86***: 148. (in Czech)

Received for publication March 31, 2011
Accepted after corrections October 21, 2011

Corresponding author:
Ing. Michal Kneifl, Ph.D., Mendel University in Brno, Faculty of Forestry and Wood Technology,
Department of Forest Management, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail: kneifl@mendelu.cz

JOURNAL OF FOREST SCIENCE, *57*, 2011 (12): 547–554

Drought and aluminium as stress factors in Norway spruce (*Picea abies* [L.]Karst) seedlings

K. Slugeňová[1], Ľ. Ditmarová[1], D. Kurjak[2], J. Váľka[1]

[1]*Department of Ecotoxicology, Institute of Forest Ecology, Slovak Academy of Sciences, Zvolen, Slovak Republic*

[2]*Department of Environment, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovak Republic*

ABSTRACT: Effects of drought, Al and their possible interaction on physiological characteristics were studied in four-years-old Norway spruce seedlings in a pot experiment. Drought stress was imposed by withholding irrigation. Al was applied to the soil as an $AlCl_3$ solution at a concentration of 1,500 μmol·l^{-1}. Water deficit caused a decrease in needle water potential, net photosynthetic rate (P_n) and an increase in proline accumulation. On the other hand, water potential, P_n and proline concentration in seedlings subjected to Al remained unchanged. During the experiment, no significant variation was registered in the chlorophyll *a* fluorescence parameters. Chlorophyll content was significantly reduced in the Al presence. Drought led to a lower Al accumulation in needles in comparison with well-watered seedlings. Progressive dehydration influenced the physiological state of spruce seedlings. The presence of Al in soil did not cause any negative changes in the physiological parameters under an optimal water regime. By contrast, the synergic effect of drought and Al induced the most marked changes in measured characteristics, which may indicate a possible enhanced impact of drought and Al interaction in comparison with the single effect of these stress factors.

Keywords: drought; aluminium; proline; water potential; photosynthesis; chlorophyll fluorescence

Plants growing in the natural environment are constantly subjected to various environmental stresses. Among abiotic stress factors, drought and toxic elements receive great attention. Drought is one of the most important environmental factors limiting plant growth, development and productivity (Zhang et al. 2005). Drought stress affects many metabolic and physiological processes in plants. Among others, it causes growth inhibition, reduction in photosynthesis and changes in fluorescence parameters (Zlatev, Yordanov 2004; Nayyar, Gupta 2006).

Elevated concentrations of aluminium are apparent in surface waters and in soil solutions from forest soils impacted by acid deposition (Oulehle, Hruška 2005). In spite of a sharp decrease in SO_2 and NO_x emissions, soil acidification continues to be a serious environmental and forestry related issue, and the degradation of soil-forming processes in forest soils is still in progress (Hruška et al. 2001; Pichler et al. 2006). Dissolved Al in soils, mobilized by acid deposition, is considered a threat to the forest health through hampering root growth and nutrient uptake. The presence of Al leads to decreasing concentrations of K, Ca and Mg and a decrease of the base cations to Al molar ratio in the soil solution (De Witt et al. 2010). The Ca:Al ratio in roots and soils has been used as a useful indicator of the health status in plants and a diagnostic tool for the prediction of potential stress in forest ecosystems (Konôpka, Lukáč 2010; Richter et al. 2011).

Forest environments are characterized by strongly fluctuating conditions for tree growth and development. Tree species are exposed to single and combined stresses throughout their lifetime, and

---

Supported by the Scientific Grant Agency of Ministry of Education of the Slovak Republic and Slovak Academy of Sciences – VEGA, No. 2/0006/11 and Slovak Research and Development Agency APVV, No. 0022/07.