Importance of logging technologies for economic effectiveness of tending Norway spruce stands

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ABSTRACT: This article examines the impact of modern harvesting and hauling technologies on the economic effectiveness of tending Norway spruce stands. The analysis of more than 70 tending treatments showed how fundamental the choice of technology is with respect to the impact of tending treatments. The introduction of harvesters and forwarders, compared with traditional technologies, conclusively demonstrated a higher gross profit per unit area ($CZK\cdot ha^{-1}$) as well as per unit volume of harvested timber ($CZK\cdot m^{-3}$). In addition, the paper demonstrated economic effectiveness even in the first thinning operations in relatively young stands (30 years old).

Keywords: economic effectiveness; harvesting technologies; spruce stands; stand tending

The tending of forest stands is an important silvicultural measure that can be used to affect the development of forest stands in terms of both the productive and non-productive functions of forests. In Central Europe, the policies of spruce forest tending were formulated soon after the introduction of rational management (Hartig 1814; Cotta 1835; Bohdanecký 1917). Since the very beginning of the systematic tending of forest stands the fundamental question has been whether these silvicultural measures could be used to increase the volume of wood production of the stands (Vyskot 1962; Assmann 1968; Kramer 1988; Schmidt-Vogt 1986; Chroust 1997; Pretzsch 2005).

Purposeful tending measures can also be used to influence the tree species composition of the stand, its quality, and some constituents of the stand environment that are important in terms of ecological, environmental and even aesthetic functions (Chroust 1997). One of the basic tasks of spruce stand tending is their stabilization and increased resistance to harmful abiotic agents (Slodičák 1983, 1987; Slodičák, Novák 2006). The high percentage of spruce in the form of unmixed monocultural stands in the Czech Republic at various sites makes the differentiation of tending an indispensable part of tending programs (Pařez, Chroust 1988; Slodičák, Novák 2007). In spite of this, the optimization of the tending of forest stands remains relevant, in terms of its silvicultural effectiveness, particularly due to long-term research activities, as well as the constantly changing growth conditions.

So far, the research has somewhat neglected the economic effectiveness, or on the contrary, the cost of the stand tending. In the past, although in completely different economic conditions, this issue was methodically dealt with by Pařez (1956), and recently particularly by Pulkrab (2006), Pulkrab et al. (2010). At the same time, the importance of the efficiency of management has increasingly been emphasized. We witness an increasing pressure on making changes in the structure of forests, on the methods and intensity of their utilization, and on the increased application of the natural character of forest stands. The search for the environmental and economic optimum in forest stand management is one of the policies of the National Forestry Program for the period until 2013, approved by the Czech Government in its Decision No. 1221 of October 1, 2008, which requires “the elaboration of an analysis of the economic effectiveness of various models of management in different natural conditions, and the reflection of the

Supported by Ministry of Agriculture of the Czech Republic, Projects No. QI102A085, and No. QI92A197.

conclusions thereof in the current legislation and the governmental subsidization policy".

This issue has also been highlighted by a considerable change in technologies used in tending treatments (Malík, Dvořák 2007) with a substantial impact on the yield of intermediate harvests in recent years. For the reasons specified above, this paper tries to evaluate the economic effectiveness of tending treatments in spruce stands for different harvesting technologies.

MATERIAL AND METHODS

As input data required for determining the economic effectiveness of spruce stand tending, we used data published in the monograph of Slodičák and Novák (2007). Their paper analysed and evaluated the long-term efforts of spruce tending introduced as early as in the 1950s. For economic analyses, the paper used the basic data published for the specific years from 12 experimental areas, which referred to the number of trees (N – trees·ha^{-1}), basal area (G – m^2·ha^{-1}), mid diameter over bark (d o.b. – cm), and mid height (h – m) of stands before thinning, as well as thinned trees and stands after thinning. Obviously, the input data included absolute and relative data on intermediate harvests performed each year (T – trees·ha^{-1}, m^2·ha^{-1}). These parameters were used to calculate log volume, volume of harvested timber over bark or under bark (V o.b. – m^3 and V u.b. – m^3), and total volume stock of the stand over bark and under bark (V_{total} o.b. – m^3 and V_{total} u.b.– m^3).

In order to perform the exact calculation of tree volume, volume equations derived from the paper by Korsuň (1961), Petráš and Pajtík (1991) were used. The equations were as follows:

To calculate the volume of large timber (with a minimum top diameter of 7 cm) of spruce over bark (V l.t.o.b – m^3):

$$V\text{ l.t.o.b.} = [(0.00004013841 \times d(d+1)^{1.821816} \times h^{1.132062}) - (0.00928540767 \times (d+1)^{-1.02037409} \times h^{0.896100664})]$$

To calculate the volume of large timber (with a minimum top diameter of 7 cm) of spruce under bark (V l.t.u.b – m^3):

$$V\text{ l.t.u.b.} = [(0.000031989 \times (d+1)^{1.8465} \times h^{1.1474}) - (0.00829054252 \times (d+1)^{-1.02037409} \times h^{0.896100664})]$$

where:

d – mean diameter over bark (cm),

h – mean tree height (m).

The above calculations were used to calculate the log volume of each tending measure, which was subsequently used to calculate the total volume of the stand. To show the harvest volume in each tending measure, the log volume was multiplied by the number of trees removed during the harvest. Consequently, the result showed the harvest volume and the total volume of the stand (i.e. the sum of the harvest volume and the main stand volume). For each experimental area, initial standing volume, harvest volume at each tending treatment and final standing volume are shown.

For each tending treatment (harvest), assortment was performed according to the assortment growth tables (Petráš et al. 1996) based on harvest volume (m^3·ha^{-1} u.b.), average log volume and average diameter d (cm u.b.). As such tables show assortments for stem diameters over bark, diameters over bark had to be recalculated to diameters under bark. The actual conversion used the reduction coefficient of 0.9598 for spruce (Šmelko 2000).

Thus, the proportion of quality classes of assortments (%, m^3) was determined for each tending treatment. The proportions of quality classes of assortments were then multiplied by the selling price according to the available data of the Czech Statistical Office (ČSÚ 2008). The result of the calculation provided the potential yields of each tending treatment in Czech crowns.

In this way, the data from 12 sites were acquired for economic evaluations of 73 tending treatments.

To determine the costs of logging technologies, the current costs typical of contract prices (services) in Central Bohemia for three options (technologies) were used:

– harvester technology (HT);
– traditional method using draught horse with maximum 0.29 (CMlv) log volume;
– traditional method without draught horse (CM).

Therefore the calculation of costs was based on the options indicated above.

Harvesters – The contract price was determined according to the average log volume arising from the average skidding distance of 300 m and the delivery of timber to the roadside landing (RL), i.e. harvesting using HT, including manipulation into specified assortments and forwarding using the forwarder (F).

Traditional Method with Draught Horse – The contract price was determined according to the average log volume arising from the average skidding distance of 300 m and delivery of timber to the roadside landing RL, i.e. harvesting by one-man chainsaw (OCS), manipulation at RL using OCS, forwarding using S-HR horse, HR-RL GWT.

Traditional Method without Draught Horse – The contract price was determined according to the average log volume arising from the average skidding distance of 300 m and delivery of timber to the roadside landing (RL), i.e. harvesting using a hand-operated chainsaw (OCS), manipulation at RL using OCS, P-RL GWT.

To assess the economic effectiveness of tending treatments, the calculation of gross profit (GP) in Czech crowns (CZK) was used, with an absolute formulation per tending treatment per hectare of stand area (CZK·ha^{-1}), as well as per unit volume of harvested timber (m^3) in a single tending treatment:

$$GP = P - TC$$

where:
P – profit
TC – total cost

This was performed for each of the three technologies used:
- Calculation of gross profit in CZK for harvester technology;
- Calculation of gross profit in CZK for the traditional method of draught horse at log volume up to 0.29 only; and
- Calculation of gross profit in CZK for the traditional method without draught horse.

The calculation above applies to economically stable units with regular repetition of tending treatments, making the consideration of the time factor (Pulkrab et al. 2008) unnecessary. The statistical comparison of the economic effectiveness of the technologies used was performed by the analysis of variance, and S-PLUS software was used.

RESULTS

In total, parameters of the economic effectiveness of 73 tending treatments were calculated. The results show a noticeable differentiation in the resulting values varying between –538 CZK·ha^{-1} and 112,233 CZK·ha^{-1} per tending treatment. Table 1 shows a summary of the average economic effectiveness of tending treatments in ten-year intervals of stand age. The table also clearly shows that, apart from the technologies used, the key parameters that determine the effectiveness of tending treatments included age of the stand, volume of the harvesting operation and the average log volume of harvested trees.

With regard to the selected logging technology, the total working costs (costs of logging of 1 m^3 wood volume) were the primary parameter that fundamentally influenced the economic effectiveness of tending. The per unit production costs are definitely the lowest in the harvester technology (Table 2). This difference was greater in a lower log volume of the stand (up to 0.29), where the difference from the traditional method was the most distinct (350 CZK·m^{-3}). The comparison of harvester technology and traditional method without draught horse showed a difference of 250 CZK·m^{-3}. In log volumes over 0.29, the differences in unit production costs between individual technologies were less distinct, varying between 130 CZK·m^{-3} and 150 CZK·m^{-3} (see Table 2). These unit costs were substantially reflected in the amount of gross profit of the tending treatments. The tending treatment performed by harvester technology was always accompanied by the highest profit, with the differences from the other technologies being statistically relevant (0.05 significance level).

The significance of unit costs is also shown in the amount of gross profit recalculated to the unit volume of harvested timber, which, in 73 evaluated tending treatments, varied between –30 CZK·m^{-3} and 1,130 CZK·m^{-3}. A comparison of the economic effectiveness of the assessed harvesting technologies in relation to stand age (Fig. 1) was also interesting. The result shows that the application of traditional method

Table 1. Economic effectiveness (CZK·ha^{-1}) of tending treatments by harvesting technology and depending on stand age

Stand age intervals (years)	Average volume of tending treatment (m^3·ha^{-1} u.b.)	Average log volume (m^3)	Average dbh	Gross profit from tending treatment (CZK·ha^{-1})		
				traditional method by draft horse	harvester technology	traditional method without draft horse
30–40	12.86	0.03	8.44	59.70	4,563.28	1,346.42
40–50	30.83	0.08	12.26	4,034.95	14,825.70	7,118.02
50–60	40.85	0.16	14.59	18,035.50	29,774.61	20,957.66
60–70	42.45	0.21	15.83	18,347.99	30,455.71	21,342.94
70–80	55.00	0.38	19.80	51,764.41	58,915.29	51,764.41

dbh – diameter at breast height

Table 2. Production costs on log volume by harvesting technology and labor operation in CZK·m^{-3}

Harvester			Traditional method by draft horse			Traditional method without draft horse			Remarks
< 0.29	0.30–1.00	1 >	< 0.29	0.30–1.00	1 >	< 0.29	0.30–1.00	1 >	
			400	180	140	400	180	140	OCS harvesting
			100	0	0	0	0	0	S-HR horse
			115	110	100	130	110	100	GWT HR-RL
			185	175	160	185	175	160	OCS manipulation
440	355	235							
429	340	258							
460	325	250							
428	305	268							
539	320	270							
560	236	248							harvester
	230	230							
	348	249							
	319	278							
	357								
476	313.5	254	800	465	400	715	465	400	arithmetical mean
450	340	250	800	470	400	700	470	400	suggested mean

OCS – one-man chainsaw, S-HR – from stump to hauling road, GWT HR-RL – general-purpose wheeled tractor from hauling road to roadside landing

in stands of the age between 20 and 30 years brought about the worst economic results. The average economic loss in this period amounted to 6.79 CZK·m^{-3}. The subsequent age brackets provided economic profit, while the application of harvester technology brought about the best results. However, the difference between the technologies being used decreases with the increasing age of the stand.

There are two ways in which the average log volume or changes thereof are reflected in the calculation of the economic effectiveness of tending treatments. A positive correlation can be inferred between an increase in the average log volume and the selling price of harvested wood mass, which is primarily related to its assortment. On the contrary, a negative correlation exists between an increase in the average log volume and a decrease of unit costs of harvesting as well as skidding.

The resulting dependence between the average log volume of stand and economic effectiveness of tending is very tight (determination coefficient between 0.96 and 0.97) and applies to all the technologies evaluated (Figs. 2–4).

A comparison of balanced values between the technologies used shows a decrease in the differences in the attained gross profit per tending treatment with an increase in the average log volume of harvested trees, similarly like with the stand age.

The volume of harvested timber is a very important parameter affecting the economic effectiveness of tending. It is closely related to the stand age and to the applied silvicultural procedure. For all the technologies, the analyses performed have confirmed a tight positive correlation (determination coefficient between 0.65 and 0.83) between the harvested volume and the economic effectiveness of tending, expressed

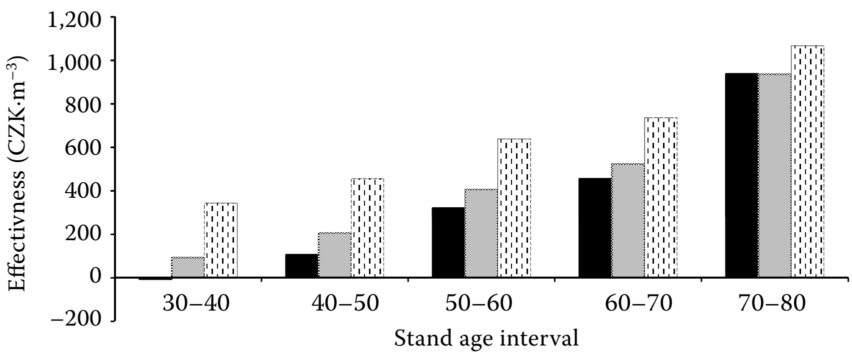

Fig. 1. Economic effectiveness of tending treatments (CZK·m^{-3}) by harvesting technology and depending on stand age

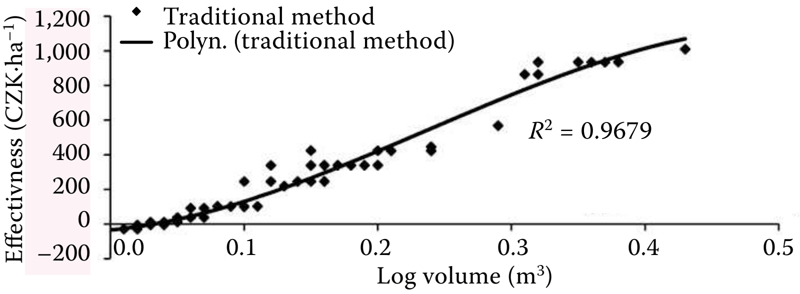

Fig. 2. Correlation between average log volume of stand and economic effectiveness of tending treatment (CZK·ha^{-1}) – traditional method by draft horse

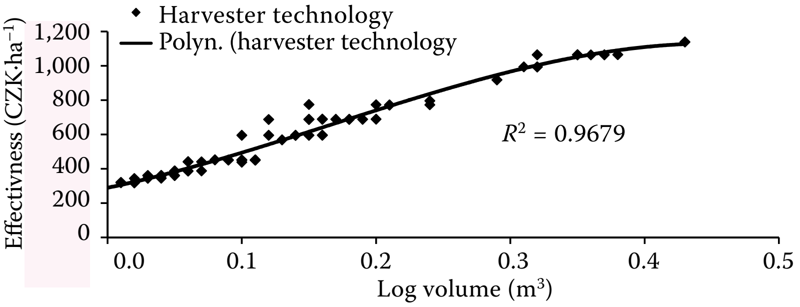

Fig. 3. Correlation between average log volume of stand and economic effectiveness of tending treatment (CZK·ha^{-1}) – harvesters

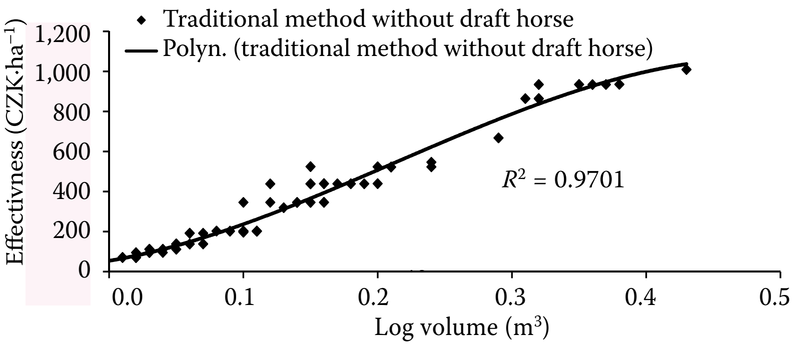

Fig. 4. Correlation between average log volume of stand and economic effectiveness of tending treatment (CZK·ha^{-1}) – traditional method without draft horse

by gross profit from a single tending treatment from the area of one hectare (Figs. 5–7). However, the search for a relationship between the volume of the harvesting (tending) operation and gross profit per m^3 shows that this correlation is still positive, but the relationship is less conclusive (determination coefficient of 0.29).

DISCUSION

Tending treatments have a significant impact on further growth and development of forest stands, affecting their production, their diameter and height structure, and their stability. Generally, the tending of forest stands is triggered by the economic requirements for maximizing and securing the volume and value of production (Poleno et al. 2009). The economic effectiveness of tending is based on an increased volume or value of production of the main stand, and therefore the tending of stands is often seen, in economic terms, as an investment. The possibility of increasing the volume of production of forest stands through tending has been discussed for a long time, and was virtually the first fundamental goal of tending (Wallentin 2007). However, today researchers see this contribution either as relatively minor (Pretzsch 2005) or even entirely insignificant (Schmidt-Vogt 1986; Kramer 1988; Chroust 1997). Even so, the resulting changes in the stand structure brought about by tending have an indisputable impact on the production value of the stands. While accepting insignificant positive changes in the production volume of the main stand, the value of production and economic effectiveness of each tending treatment are essential for the general economic profitability of stand tending. Its fundamental requirement is the existence of a market with thinner timber (Wallentin 2007). However, such a market is subjected to changes over time caused by fluctuations of price as well as demand. The performed analyses, which confirmed the considerable economic effectiveness of tending treatments, were based on the assumption that such a market exists, and enables the sale of the entire wood mass harvested by thinning. However, while largely holding true at present (2010), this assumption need not always be fulfilled. In ad-

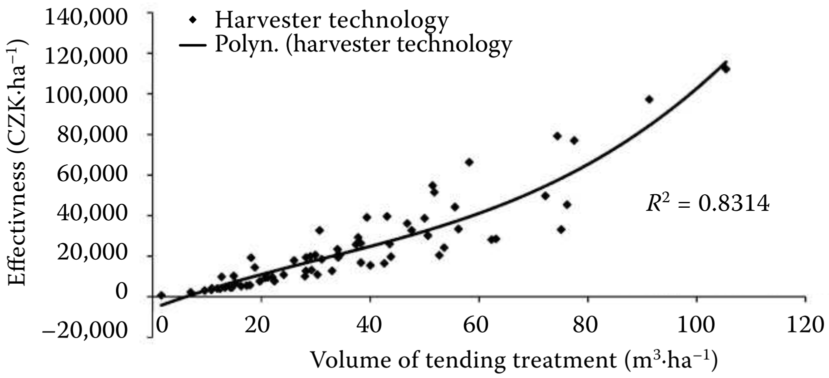

Fig. 5. Dependence of economic effectiveness of tending (CZK·ha^{-1}) on volume of timber harvested in one tending treatment – harvesters

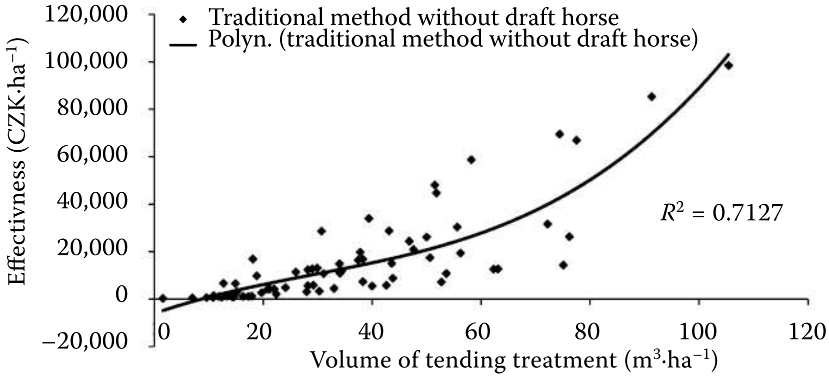

Fig. 6. Dependence of economic effectiveness of tending (CZK·ha^{-1}) on volume of timber harvested in one tending treatment – traditional method without draft horse

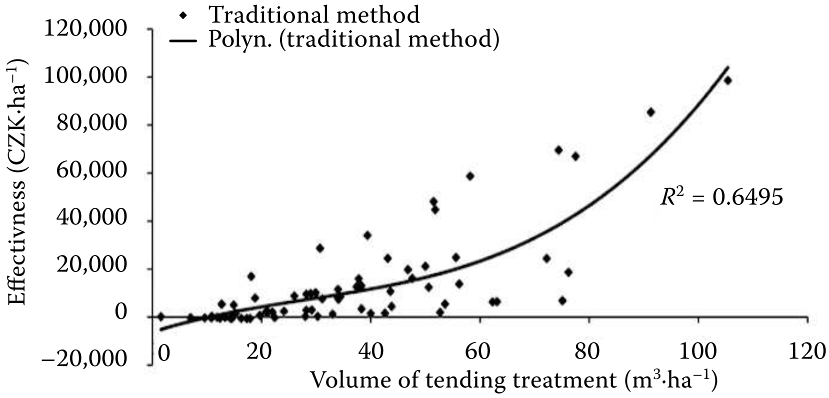

Fig. 7. Dependence of economic effectiveness of tending (CZK·ha^{-1}) on volume of timber harvested in one tending treatment – traditional method by draft horse

dition, economic calculations have unambiguously proved that the main factor that has had a fundamental impact on the economic effectiveness of forest stands is the introduction of harvester technologies. Their undisputed superiority over the "traditional" technologies is caused by significantly lower production costs based on their much higher productivity. While this development is quite new in the Czech Republic, Scandinavia saw such economic results as early as 20 years ago (Wallentin 2007).

Even so, the "traditional" technologies have yielded a positive gross profit in each analysed case, except for some tending treatments of young stands from 30 to 40 years of age using a combination of horse and tractor skidding. The economic effectiveness of tending treatments was positively affected by the increase of the stand age and the related higher log volume of harvested trees. The total volume of wood harvested in a single treatment was also an important factor. Still, it can be observed that, under the conditions considered in this model calculation, the tending treatments in spruce stands are already profitable from 30 years of age. Generally, this finding corresponds to the results of economic analyses from Germany (Möhring, Rüping 2008).

CONCLUSION

The paper provides a model evaluation of the economic effectiveness of tending treatments in spruce stands. This effectiveness is determined by the amount of gross profit from individual tending harvests, both per square and volume unit. The results of the performed economic calculations have confirmed how fundamentally important the used harvesting technologies are for the economic profitability of spruce stand tending. The greatest positive impact of harvester technologies was seen in young stands that yielded over double the gross profit from "traditional" harvesting and hauling technologies. The economic profitability of tending treatments, even in relatively young stands, compels us to change the rooted schemes of thinking that see such treatments as imperative in terms of silviculture, but unprofitable in terms of economy.

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Received for publication October 11, 2010
Accepted after corrections March 1, 2011

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