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# Black walnut (*Juglans nigra* L.) standing volume in the riparian forests of the Czech Republic

Lubomír ŠÁLEK*, Daniel ZAHRADNÍK, Lubomír TIPMANN, Robert MARUŠÁK

Department of Forest Management, Faculty of Forestry and Wood Sciences, Czech University of Life Science in Prague, Prague - CZECH REPUBLIC

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**Abstract:** Black walnut (*Juglans nigra* L.) is one of the most valuable non-native tree species growing on alluvial soils in the southeastern part of the Czech Republic. However, its standing volume is currently calculated according to oak tables, although its growth and standing volume is likely different. In order to determine the observed black walnut standing volume and to express a difference between black walnut and other main tree species growing on alluvial soils, 63 temporary sample plots of pure black walnut stands were established and, for determination of tree volume, 63 sample trees with various dimensions were felled and measured in sections. Mensurational data were evaluated using a Korf growth function, which is one of best growth functions for expressing the development of standing volume. Moreover, a reciprocal Korf function was used for fitting the decline in the number of trees. For determination of standing volumes, 2 methods using Korf functions were used and their results were compared. The black walnut standing volume of 100 years is 706 $m^3$ $ha^{-1}$ if we use the fitted mean diameter and height for calculation and 724 $m^3$ $ha^{-1}$ if we use the Korf function for fitting the observed standing volumes in the sample plots. Both results are higher than the oak standing volume growing on the best site by 100 $m^3$ $ha^{-1}$ and higher than the ash standing volume by approximately 200 $m^3$ $ha^{-1}$.

**Key words:** Black walnut, Czech Republic, Korf growth function, number of trees, standing volume

## Introduction

Black walnut (*Juglans nigra* L.), originally from North America, could potentially become one of the most commonly introduced tree species in temperate forests of Europe and Asia. However, its dimensions and standing volume are calculated according to other tree species, and so a tool of growth modeling seems to be necessary for planning. One of the countries where black walnut was widely planted is the Czech Republic.

Black walnut was introduced to the forests of the Czech Republic principally for its valuable timber and better growing characteristics in comparison with other tree species, excluding poplars (*Populus* spp.) (Mráček 1925; Pokorný 1952; Hrib 2005). Due to its ecological requirements, black walnut has been planted on alluvial soils along the Morava, Svratka, and Dyje rivers in the southeastern part of the Czech Republic (Mezera 1956). Its planting is supported for quality timber, which is valuable in its native area (Illinois Agricultural Statistics Service, 1987) as well as in Europe (Schmid et al. 2006).

In the Czech Republic, the oldest stands were established in the Ždánický les (Zdanice's forest) in 1823 (Pokorný 1952). Its distribution has been gradually enlarged and, nowadays, black walnut is

* E-mail: lubomir.salek@seznam.cz

planted mainly in riparian forest in Natural Forest Area (NFA) No. 35 - Jihomoravské úvaly (South Moravian ravines). According to reports from the year 2000, the reduced area of the black walnut in NFA No. 35 is 492.8 ha, which represents 93.7% of its total reduced area in the Czech Republic (Hrib 2005). The black walnut stands in NFA No. 35 are concentrated mainly in 2 localities, close to the towns of Strážnice and Židlochovice, and the growth patterns do not differ between the 2 localities (Šálek and Hejcmanová 2011).

Although black walnut has been planted for more than 100 years and its growth habit differs from those of other riparian tree species (Pokorný 1952; Prudič 1991), its standing volume is still calculated according to domestic oaks (*Quercus robur*, *Q. petraea*, and *Q. cerris*). Determination of its standing volume is necessary for estimation of basic indicators within forest management planning such as rotation cycle, regeneration period, assortment structure, and expected production.

This study is focused on the determination of black walnut standing volume and a comparison with values of other main tree species such as ash or narrow-leaved ash (*Fraxinus excelsior* or *Fraxinus angustifolia*) and oak (*Quercus* spp.) growing in the same natural conditions. Although the previous studies dealing with the growth of black walnut in the Czech Republic claimed that there were differences between black walnut and other tree species, the data used for those studies were from forest management plans (Mráček 1925; Prudič 1991; Hrib 2005) or from one felled stand (Hrib 2003), or they used the oak tables for calculation of the standing volume (Prudič 1991; Hrib 2005). Therefore, a study calculating the black walnut standing volume from a set of sample plots seems to be necessary for comparison with the results of other studies.

## Materials and methods

### Study area

The study was conducted at 2 localities of riparian forests in South Moravia, both belonging to NFA No. 35 - Jihomoravské úvaly. The forests provide the same ecological conditions, although 2 main geological systems meet there: the Hercynian and the Carpathian (Mezera 1956). The first site, called Strážnice, is located along the Morava River between the towns of Uherské Hradiště (49°04′07.03″N, 17°27′39.07″E) and Strážnice (48°53′56.99″N, 17°18′57.62″E). The average annual precipitation was 495 mm and the mean annual temperature was 9.0 °C (UHUL 1999). The soil types are mainly Fluvisols and rarely gley soils in land depressions.

The second locality, called Židlochovice, is located along the Svratka River between the town of Židlochovice (49°02′15.39″N, 16°37′06.93″E) and the north bank of water construction system Novomlýnské nádrže (48°54′31.54″N, 16°36′24.50″E). The average annual precipitation was 585 mm and the mean annual temperature was 9.5 °C (UHUL 1999). The soil types are mainly Fluvisols and rarely gley soils in land depressions.

### Data collection

The data for both localities were obtained from sample plots in the study areas in 2008. At the Strážnice locality, 31 randomly selected circular plots of 300 m$^2$ (radius of 9.77 m) were established in pure (100%) black walnut stands, and at the Židlochovice site, 32 plots of the same area were selected using a Laser Vertex with a transponder and monopod staff. At each plot, all trees were recorded, and their diameter at breast height (DBH) (1.3 m) and height were measured using an electronic caliper (65-cm caliper, Haglof Mantax Digitech) and land laser hypsometer (Laser Vertex), respectively. A total of 573 and 670 trees were measured at Strážnice and Židlochovice, respectively.

The ages of the sampled stands were taken from forest management plans and verified by summarizing tree rings in increment cores collected using a Pressler increment borer. In randomly selected plots (30 plots of all 63 plots), the increment core was taken from a typical tree found in the plot according to mean diameter and mean height. The cores were taken at stump height and served only for verification of stand age. From data collected in sample plots, the mean DBH and mean height (MH) were calculated. The mean DBH was taken as the quadratic mean of the DBH in every plot. The MH was derived from the relationship between DBH and height, which was fitted by the logarithmic function in Eq. (1) (Šmelko 2000).

$$h = a \times \ln(d) + b \quad (1)$$

Here, a and b are parameters and d is DBH. As the measured diameters and heights within every plot are different, the parameters of the logarithmic functions also differ and, for that reason, they are not presented in the study.

For determination of the real tree volume, 63 sample trees with various dimensions were felled in both localities and measured by sections. The following measurements were taken: the DBH on standing trees, the heights and diameters of stumps, and the diameters of stem sections and branches sections after felling. The first 4 lengths of each stem section were 0.5 m long and the remaining sections were 2 m long. Finally, the residual stem length was measured. For calculating the stem volume, only merchantable timber was taken into consideration (7 cm at small end). For each section, Smalian's formula was used to calculate the volume and the results were summed.

Branches with a diameter on the stem of wider than 7 cm (merchantable timber) were also measured. The section lengths were 0.2 m, 0.3 m, 0.5 m, and then 1 m to the first diameter whose width was less than 7 cm. The length of the last branch and stem section with merchantable timber (7 cm at small end) was calculated and converted to merchantable timber volume by using Smalian's formula for each section and summing. The volume was calculated with bark because the measured stem and branches as well as the volume tables of other tree species are all over-bark. The calculated tree volumes (merchantable timber from a stem and branches) were used for calculating form heights when the volume of an individual sample tree was divided by its basal area.

As there were no differences between black walnut growth in the Strážnice and Židlochovice localities (Šálek and Hejcmanová 2011), the data were analyzed together.

**Data analyses**

One of the growth functions that can be used for standing volume calculation and for production modeling is the Korf growth function (Šmelko 2000) expressed in Eq. (2).

$$y(t) = A \times \exp((k/1\text{-}n) \times t^{1-n}) \quad (2)$$

Here, A, k, and n are parameters and t is time (Korf 1939). The Korf growth equation is suitable not only for formulation of the development of tree height (h) dependent on DBH (Zhang 1997; Liao et al. 2003), but also for curve fitting of standing volume dependence over time (Kouba and Zahradník 2005) and for the reduction of tree stem density over time (Chroust 2001). In his original work, Korf (1939) stated that the growth function was elaborated for data extrapolation to higher stand ages and for the mathematical expression of the growth function for growth tables. Zeide (1993) claimed that the Korf equation was substantially more accurate than other growth equations, such as Chapman-Richards, Weibull, Gompertz, and logistic. For those reasons, the Korf growth function was used to calculate black walnut standing volume in this analysis.

To calculate the standing volume, 2 methods were used. The first one, named Korf1, used fitted mean diameter, mean height, form height, and fitted number of trees. Form heights were derived from the fitted relationship between height and form height based on data from the sample trees. Multiplication of basal area derived from fitted diameter, form height, and number of trees then gave the values of standing volume for individual ages.

The second method, named Korf2, directly took into account the real standing volumes on sample plots by summarizing the individual tree volumes that were calculated according to their basal areas and form heights (basal areas and form heights were derived from measured diameters and heights). The volume was then recomputed per hectare and fitted according to the Korf growth function. The results of both methods should be the same or very similar because one growth function is used for fitting within both methods.

For all calculations and figure creation, Microsoft Excel and DataFit were used.

## Results

Table 1 shows the basic descriptive statistics of the measured trees in the sample plots. To determine the relationship between height and form height of black walnut, the calculated form heights of the sample trees were used as source data. The figures were fitted

Table 1. Data from the sample plots (plot characteristics and tree characteristics).

| | Number of plots | Mean | Median | Minimum | Maximum | Std. dev. | Std. error |
|---|---|---|---|---|---|---|---|
| Age | 63 | 53.2 | 59.0 | 15.0 | 109.0 | 19.7 | 2.4 |
| Mean DBH | 63 | 29.1 | 29.0 | 10.0 | 53.0 | 10.2 | 1.2 |
| Mean height | 63 | 26.3 | 27.0 | 13.0 | 36.0 | 5.2 | 0.6 |
| | Number of trees | Mean | Median | Minimum | Maximum | Std. dev. | Std. error |
| DBH | 1243 | 21.8 | 20.0 | 5.0 | 59.0 | 10.8 | 0.3 |
| Height | 1243 | 22.0 | 22.4 | 5.9 | 38.8 | 6.6 | 0.1 |

(Figure 1) using the linear regression expressed in Eq. (3).

$$y = a \times MH + b \quad (3)$$

Here, a and b are parameters and MH is mean height. The fitted line has parameters a = 0.6861 and b = –4.7424. The coefficient of determination is 0.9099.

As the Korf1 method is based on fitted diameter and height, the Korf equation was used for creation of a fitted curve of the relation between age and mean diameter on the sample plots as well as age and mean height (Figures 2 and 3). The parameters of the equation for fitted diameter, height, number of trees, and fitted real standing volume are given in Table 2.

The subsequent step is calculating the number of trees per hectare. Chroust (2001) used a reciprocal Korf growth function, expressed as N(t) = 1 / Korf growth equation, for fitting the course of tree number decline during stand development. The same formula was also used for black walnut tree number decline (Figure 4, Table 2). The curve is extrapolated to the younger age because the model should show the rapid decline in the number of trees. Therefore, the y-axis was extended to 9000 trees $ha^{-1}$.

For the Korf2 method, the Korf function was used for fitting the real standing volume in the sample plots after expansion to a per hectare basis.

The 2 methods were compared to each other (Figure 5) and the results showed that the black walnut standing volume calculations of Korf1 and Korf2 were almost the same, while the values at the reference ages (20, 40, 60, 80, and 100 years) were slightly higher with the Korf1 method. However, the values were the same at an age of 160 years (Figure 5, Table 3). Therefore, both methods can be used for production modeling, while the Korf function can be used for fitting DBH, heights, and number of trees, as well as for fitting the standing volumes in sample plots.

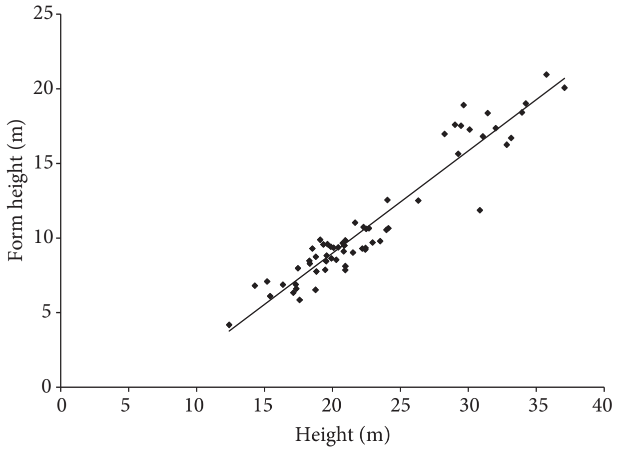


Figure 1. The relation between height and form height of the black walnut sample trees.

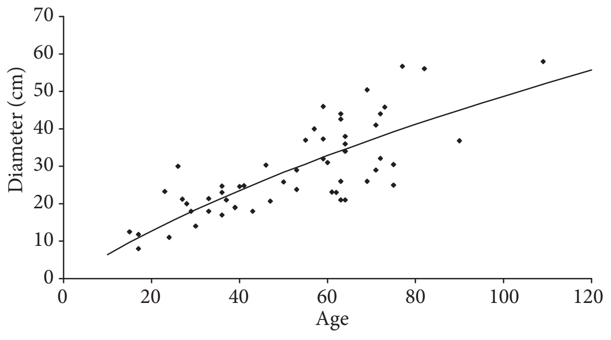


Figure 2. The relation between mean diameter and age with a Korf fitted curve.

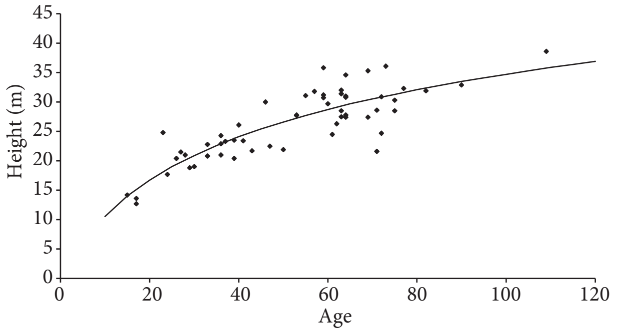


Figure 3. The relation between mean height and age with a Korf fitted curve.

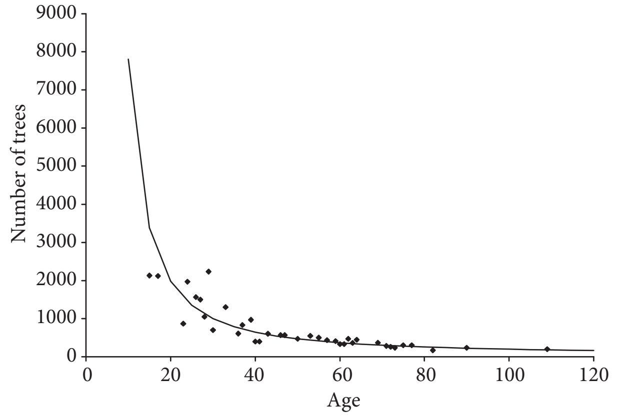


Figure 4. The number of black walnut trees per hectare with a Korf fitted curve.

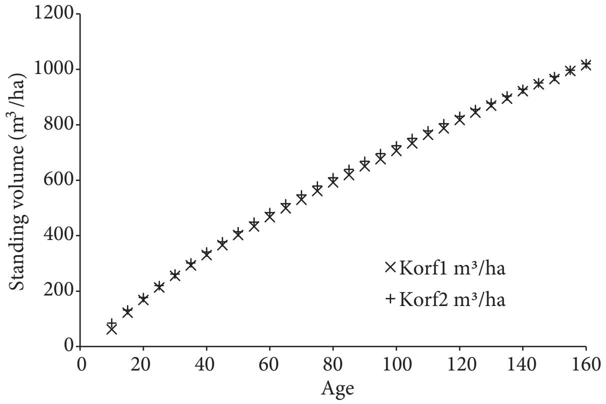


Figure 5. Comparison of 2 methods for calculating black walnut standing volume per hectare.

## Discussion

Using the Korf growth function, it was determined that the black walnut standing volume per hectare was quite different than that of other tree species growing on alluvial soils, such as pedunculate oak (*Quercus robur*) or narrow-leaved ash (*Fraxinus angustifolia*). This finding corresponds with previous studies that revealed differences in the tree growth of those 3 tree species (Pokorný 1952; Šálek and Hejcmanová 2011). Comparing the obtained results with existing works on black walnut timber production, different values were found (Table 3).

According to the measured and calculated results, black walnut production is higher than that of other main tree species growing on alluvial soils, except poplars. The difference in standing volume per hectare is approximately 100 $m^3$ when comparing black walnut with oak and more than 200 $m^3$ when comparing black walnut with ash. Differences in standing volumes shown in the works of other authors were probably caused by using different data sources. Prudič (1991) used data from forest management plans in the Strážnice area, while Hrib (2005) did not mention the source of data. However, Hrib (2003) analyzed 1 mature black walnut stand in the Židlochovice area and the standing volume per hectare in the fully stocked stand was 755 $m^3$ at 107 years, which corresponds with the standing volume calculated in this study. In addition, this figure is

Table 2. Parameters and fit statistics of the Korf equations.

| | A | k | n | Coefficient of determination | Standard error of estimate | Mean bias |
|---|---|---|---|---|---|---|
| Mean diameter for Korf1 | 9624.6079 | 1.4228 | 1.1408 | 0.5965 | 7.6384 | 0.0819 |
| Mean height for Korf1 | 91.7060 | 1.6921 | 1.3491 | 0.7198 | 3.1500 | 0.00080 |
| Number of trees for Korf1 | 0.2455 | 4.2458 | 1.2888 | 0.8428 | 0.00053 | 0.00038 |
| Observed volume for Korf2 | 59104.2807 | 1.6799 | 1.1724 | 0.5809 | 78.1278 | 0.3682 |

Table 3. Comparison of volume per hectare of black walnut and other species stands in Europe.

| **Data sources** | **20 years** $m^3$ $ha^{-1}$ | **40 years** $m^3$ $ha^{-1}$ | **60 years** $m^3$ $ha^{-1}$ | **80 years** $m^3$ $ha^{-1}$ | **100 years** $m^3$ $ha^{-1}$ |
|---|---|---|---|---|---|
| Black walnut Korf1data from the analysis | 168 | 330 | 467 | 592 | 706 |
| Black walnut Korf2 data from the analysis | 177 | 341 | 483 | 609 | 724 |
| Black walnut in riparian forest (Prudič 1991) | 48 | 195 | 407 | | |
| Black walnut (Tokár and Krekulová 2005) | | 202 (39 years) | 454 (64 years) | | |
| Black walnut MH (Hrib 2005) | 120 | 280 | 400 | 480 | 555 |
| Ash on site class +1 (Schwappach 1919 in Lesprojekt 1981) | 80 | 275 | 380 | 448 | 492 |
| Oak on site class +1 (Černý et al. 1996) | 101 | 292 | 426 | 532 | 612 |
| Oak on site class +1 (Halaj 1987) | 110 | 330 | 452 | 540 | 612 |

significantly different from the figure given in the forest management plan, which showed a standing volume of only 574 $m^3$ at 107 years (Hrib et al. 2003).

Other authors analyzing black walnut growth (Nicolescu 1998; Ares and Brauer 2004; Pedlar et al. 2007) only introduced mean heights and a site index for evaluating growth. Ferell and Lundgren (1976) derived parameters for a function describing the volume of black walnut trees reported by Kellogg (1940, in Ferell and Lundgren (1976)), but the volume was from only one tree.

Evaluation of data from several sample plots and the use of the Korf growth function for simulation of the standing volume development showed a significant difference between the observed black walnut standing volume and the used oak yield tables. Both methods for calculating black walnut standing volume can be used, and the Korf growth function can be used as a base for the creation of black walnut yield tables. The local yield tables better show the real production than tables for large areas, which could not cover all stand structures. In addition, the decline in the number of trees fitted by the reciprocal Korf function could be helpful for foresters' decisions about the amount of tree reduction during clearing and thinning. Finally, higher black walnut production than oak production could help convince foresters and landowners to plant black walnut as an alternative to other trees species growing within the same natural conditions.

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