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Volume of *Paulownia Shan Tong* (*Paulownia fortunei* × *Paulownia tomentosa*) plantation in Eastern Hungary: a case study

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SUMMARY

Volume tables for tree plantations are not unknown in international practice. In many places, this is due to the uniqueness of the species or variety composition of the plantations and the cultivation technology used. In most cases, this is also justified by specific soil (ecological) conditions. In Hungary, publications on Paulownia have not yet included a volume table. This is the first one we are publishing; thus, it can be considered as a gap-filler. The research was conducted in Monostorpályi, a 1.8 hectare, 8-year-old municipal plantation. 8 trees were selected randomly, and their parameters were studied.

Keywords: *Paulownia, volume table, Shan Tong, hybrid*

INTRODUCTION

Trends show that demand for industrial wood is steadily increasing. The cost of wood as a raw material is also increasing, hence the need to find and use lower cost species. The role of tree plantations, as an alternative, has become increasingly valued for commercial forest stands, but they are especially important for natural forests as a resource of required dendromass (West, 2014). In recent years, there has been increasing attention to fast growing species such as Paulownia as a solution (Dogu et al., 2017).

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Volume tables based on the single variable of diameter at breast height (dbh) may be created from existing multiple-entry volume tables or from the scaled measure of chopped trees (Avery and Burkhart, 2015). These tables are useful for quick full inventories because trees can be tallied by dbh and species. When more areas are checked within the same project zone, the exclusion of height and structure ensures consistency of volume estimates.

Creation of volume tables based on dbh alone assumes that a conclusive height-diameter correlation is for the species under discussion, in other words, that trees of a given diameter class tend to be of similar height and form. Thus, all trees in each dbh class can be given the same mean volume. For coniferous or hardwood species which growing under almost uniform place and stand density conditions height-diameter or volume-diameter relationships can often be recognized. When topography and soils vary considerably, it is frequently needed to create single-entry tables for each broad site class.

The dbh based volume tables are sometimes assembled for inventories of quite small areas, but this is not a critical term; in some cases, "local" tables may be as widely relevant as "standard" volume tables. The exact number of sample measurements required depends upon characteristics of the tree species involved, variability of soil-site conditions, and the desired geographic area of application.

MATERIALS AND METHODS

Species description

The emperor tree is a member of the family *Paulowniaceae*. There are nine species in the family, the best-known being *P. albiphloea*, *P. australis*, *P. catalpifolia*, *P. elongata*, *P. fargesii*, *P. fortunei*, *P. kawakamii* and *P. tomentosa* (Zhu et al., 1986). The best known of these is *P. tomentosa*. Paulownia, especially *Paulownia tomentosa,* appeared in Europe mainly for horticultural purposes in the 1800s, because of its interesting fruit and beautiful foliage. However, only in the last few years has its potential commercial role been recognised.

The empress tree (*Paulownia tomentosa*) is an extremely fast-growing deciduous tree native to subtropical areas of China, where annual rainfall ranges from 500 to 2000 mm (Jay, 1998). A 10–12 m tall tree with a broad canopy. It can grow up to 3–4 m per year under suitable environmental conditions. It is particularly light- and heat-demanding. Its huge, heart-shaped leaves, up to 80 cm long, are hairy on the back, and its flowers have convoluted petals that form large, purple-coloured erect inflorescences. Furthermore, *Paulownia* is a C4 plant (Woods, 2008).

It has a deep root system (up to 8 m), the development of which is strongly influenced by soil structure. Due to its high nutrient assimilating capacity, *Paulownia* plantations can have a significant impact on the soil microbial community in intensive agricultural systems (Lucas-Borja et al., 2011). One of the main concerns about the tree is its high-water demand, which can have a large effect on local water resources (García-Morote et al., 2014; McKay, 2011). The results of Baier et al. (2021) recommend that Paulownia at least does not consume significantly higher quantities of water

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than other tree species that are regularly used in plantations across Central Asia and for which there is exact data on water consumption.

The species has little sensitivity to soil type; however, it is important that the soil has good permeability. Soils with extreme clay content (30% or more) should be avoided (Barton et al., 2007). It does not tolerate soils that are too acidic, and pH should be between 5 and 8 (El-Showk and El-Showk, 2003; Zhu et al., 1986). There are only few studies focus on the impacts of soil management, equally fertilization and irrigation, on biomass (above-ground dendromass), soil structure and soil microbial community in Paulownia plantations at semi-arid sites (Lucas-Borja et al., 2011; Madejón et al., 2016).

In our days, they are grown in plantations in many other sites, and they have been crossed, creating a few inter-species hybrids whose growth dynamics is even better.

Site description

The research site (47.379651°, 21.780166°) is located in Monostorpályi, Hajdú-Bihar County (*Figure 1*). The Paulownia plantation was established in 2014 on 1.8 hectares of poorly humic sandy soil with acidic chemistry. Forest-steppe climate, free-draining site (according to the Hungarian climate classification categories). The soil test results are shown in *Table 1*. The area was previously under agricultural cultivation, as evidenced by the compacted soil layer at a depth of 40–50 cm. The plantation was planted with 1580 seedlings in a 4 m × 4 m planting space.

Figure 1: **Location of the study site within the Hajdú-Bihar County in eastern Hungary**

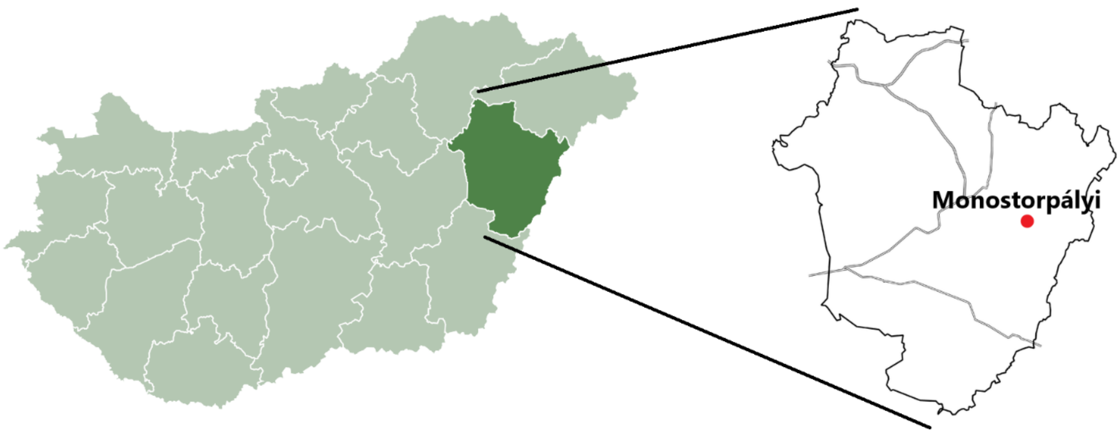

Table 1: **Results of the soil analysis**

Depth (cm)	**0–10**	**10–35**	**35–70**	**70–100**
pH value (H_2O)	4.8	5.02	5.69	5.14
pH value (KCl)	3.73	3.94	4.78	4.05
Organic carbon (humus content) (m/m) %	0.873	0.57	0.666	0.368

The assessment of volume from length and mid-diameter

This is the traditional method of assessing the volume of timber lengths, sawlogs, selected poles, billets etc.

The volume is derived from the felled tree of the length of the log or section and its mean cross-sectional area. The latter is supposed to be approximately equal to the cross-sectional area at the midpoint of the section. In practice it is the diameter at the midpoint which is measured.

The volume is derived from the following formula which is known as Huber's formula:

$$V = (\pi d_m^2/40000) \times L \qquad (1)$$

where V = volume in cubic metres
L = length in metres
d_m = mid diameter in centimetres

To subdivide the stem into sections, usually of a fixed length, for example, 1 m for trees below 12 and 2 m for those more than 12 m high. In our case, the length of the sections was 2 metres. Each of the sections is imagined as a reduced cone with the volume being obtained by multiplying the cross-sectional area at the midpoint, by the length of the section (*Figure 2*).

$$V = \pi/4 \times l \times (d_1^2+d_2^2+\ldots d_i^2) \qquad (2)$$

where d_i = diameter at the midpoint of the *i*th section
l = section length

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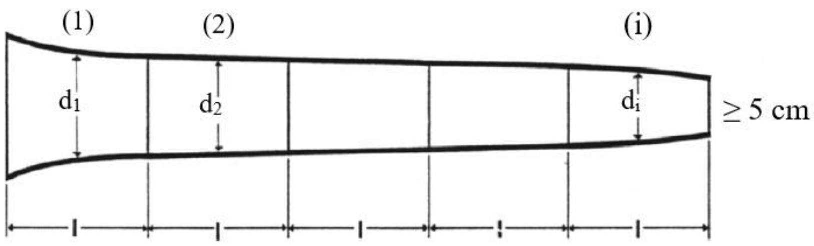
Figure 2: **Sectionize measurements on felled trees. Based on Laar and Akça (2007)**



To obtain tree volumes essential for this procedure, measurements can be obtained from felled trees on logging operations. Sample trees should be selected in an unbiased manner and enough measurements made to span the desired range of dbh classes for each species involved.

RESULTS AND DISCUSSION

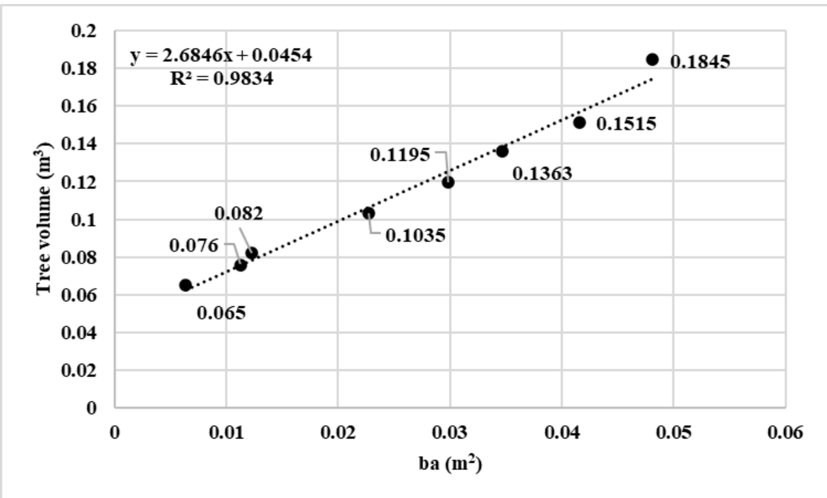
For each sample tree, measurements should be obtained of (1) dbh (in cm), (2) tree volume in m^3, and (3) total tree height (m). The last item, though not actually needed for constructing the table, serves as a useful indication of the sites or geographic areas to which the table may be applied. To illustrate the procedure of table construction, the data for Paulownia can be found in *Table 2*.

The felled-tree volumes are related to dbh through regression analysis. Tree volumes have a linear relationship with dbh but are around linearly related to ba (basal area) (*Figure 3*).

Table 2: **Paulownia data used in constructing a single-entry volume table**

dbh, cm	Volume of stemwood, m^3	Total ht., m
9.00	0.0650	11.80
12.00	0.0760	11.40
12.50	0.0820	11.60
17.00	0.1035	10.90
19.50	0.1195	10.90
21.00	0.1363	11.60
23.00	0.1515	12.00
24.75	0.1845	13.30

Figure 3: **Linear correlation of tree volume to basal area. Based on measurements of 8 felled Paulownia trees at Monostorpályi**



In general form, the volume equation relationship can be expressed as

$$V = b_0 + b_1 ba^c \quad (3)$$

where $ba = dbh^2\pi/4$.

The volume data for this example follow an approximately straight-line pattern when plotted over *ba*, indicating that *c* can be set equal to 2 and simplifying the model to

$$V = b_0 + b_1 ba^2 \quad (4)$$

Applying simple linear regression techniques to the Paulownia data results in

$$V = 2.6846ba + 0.0454 \quad (5)$$

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Table 3: **Single-entry volume table for Paulownia. Based on measurements of 10 pieces of 8-year-old felled trees**

dbh (cm)	Volume of stemwood (m^3)
6	0.0686
7	0.0687
8	0.0696
9	0.0713
10	0.0738
11	0.0771
12	0.0812
13	0.0861
14	0.0918
15	0.0983
16	0.1056
17	0.1137
18	0.1226
19	0.1323
20	0.1428
21	0.1541
22	0.1662
23	0.1791
24	0.1928
25	0.2073

Table 3, a single-entry, or local, volume table, was compiled by substituting diameter class midpoint values into the regression equation to obtain predicted average tree volumes by dbh class. Average total heights, by dbh classes, in the sample data are shown to aid users in determining whether the table is appropriate for a given inventory situation. The average total heights were determined by substituting diameter class midpoint values in a height-dbh regression fitted to the Paulownia data.

CONCLUSIONS

This method of constructing a single-entry volume table works reasonably well when felled trees of representative sizes are available for measurement. However, felled trees from harvesting operations rarely make up a typical sample of standing trees, because they may represent a different population or have distinctive characteristics that influenced their volume and, thus, caused them to be cut. When this is the case and felled trees are nonrepresentative samples, single-entry volume tables derived from such data would be biased and unreliable. As an alternative, tree volumes might be obtained from random samples of standing trees, or tables might be constructed from height-diameter relationships.

In Hungary, publications on Paulownia have not yet included a volume table. This is the first one we are publishing; thus, it can be considered as a gap-filler. The full cultivation technology for Paulownia has not yet been developed, including the economical background analysis.

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