

RESEARCH OF GROWTH DYNAMICS OF SELECTED DECIDUOUS TREES FOR THE NEEDS OF LANDSCAPE ARCHITECTURE

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Abstract

The main target of the research was to compare the growth dynamics of woody plants in relation to their age, specifically in individuals up to 10 years after planting. Five fast-growing species (*Fraxinus excelsior*, *Populus alba*, *Populus nigra*, *Ulmus laevis*, *Ulmus minor*) and four control species (*Acer campestre*, *Carpinus betulus*, *Prunus avium*, *Tilia cordata*) were selected. The model site is part of the regional biocentre in Brno. It is a warm area with an increased groundwater level. The planting took place in 2011. Evaluation was done at the turn of 2016/2017 and included measuring the following attributes: the overall height of the specimen, the annual increment of the terminal shoot and the annual increment of six lateral shoots. The highest average values were observed in *Populus nigra* which, in the context of close results of individual specimens, can be attributed the overall highest growth dynamics. The average terminal shoot increment exceeded 50 cm in all species except for *Tilia cordata*; in *Populus alba* and *Populus nigra* it exceeded 100 cm. Generally, the values of *Carpinus betulus*, *Prunus avium* and *Tilia cordata* were mutually comparable and at the same time lower than the values of woody plants labelled as fast growing. The results for *Acer campestre* were close to the category of fast-growing species.

Keywords: growth dynamics, fast-growing trees, landscape architecture

INTRODUCTION

From the landscape architecture point of view, growth dynamics is an important compositional feature. Combining woody plants with various growth dynamics enables to work with space during the development of garden and landscape design objects. The speed of growth has an impact not only on the overall functionality of the composition, but also on the properties of each specimen, its proportions, form, texture and variability during the development. Fast-growing woody plants play an irreplaceable role in landscape architecture in connection with an early development of functionality.

Research dealing with the issues of growth dynamics from the landscape architecture point of view is virtually non-existent. Fast-growing woody plants are a frequently discussed topic especially at the level of searching for renewable energy sources (Szostak *et al.*, 2013). There are numerous studies which compare biomass yield of selected species and clones under different conditions (Aravanopoulos, 2010; Benetka, Novotná and Štochlová, 2014; Štochlová *et al.*, 2019). Non-production functions of fast-growing tree plantations, such as their impact on biodiversity and landscape water regime (Havlícková and Rudisová, 2011) are also investigated.

The term fast-growing woody plant often remains to be defined at the level of a faster production of wood biomass in young plants (Szostak *et al.*, 2013). The speed of growth is usually evaluated in particular in terms of volume of wood mass annual production per area unit; in fast-growing taxa this amounts to at least 10 m³ per hectare (FAO, 1965; IUFRO, 2005; Petříková and Weger, 2015). From the landscape architecture point of view, the primary criterion for evaluating growth dynamics is mainly the size of height increment. The specific length of annual height increment for fast-growing species was defined by Weger (2011) at the value of at least 0.5 m in 1-year old plants, and at least 1 m in older plants. Kolesnikov (1974) worked with the value of more than 0.5–0.6 m for fast-growing species; he labelled plants with an annual height increment over 1 m as very fast growing.

Accessible publications on woody plants for orchard and landscape purposes do not in principle specify the values of annual increment, nor do they define based on which values the species were or were not classified as fast growing (e.g. Belke and Gaida, 1991; Hieke, 1994; Hurych, 2003; Bruns, 2013). Some publications contain only the size of adult plants (e.g. Horáček, 2007; Hieke, 2008; Málek, Horáček and Kiesenbauer, 2012). Bruns (2013) states for many species the values of annual increments in height and width, but without any connection to the age of the plant. In the 1960s, field studies in parks of the former Czechoslovakia were conducted, in which among others the values of crown height and width were ascertained in selected deciduous trees for five age categories (Kavka, 1969). However, the published data do not contain all taxa commonly used today in landscape design. Moreover, they focus only on the functional type of park greenery. More detailed data are provided by Vreštiak (1991) who examined the development of biomass in 40 most commonly used deciduous trees in selected Slovak cities in categories of 5-year intervals up to a maximum of 80 years of age (in proportion to the lifespan of the individual taxa).

From the landscape architecture point of view, the absence of information on dimensions of woody plants in connection with their age may lead to mistakes and insufficient utilization of the plant potential. Woody plants with considerable growth dynamics can be used for filling spaces, for instance in newly created elements of residential and landscape greenery. On the contrary, when using fast-growing species in places with significant space limitations, the plant may soon grow to undesirable proportions which must be corrected by pruning. It may result in worsening the esthetical and functional state of the plant and at the same time in increasing the expert and financial demands for maintenance. Systematic research of growth dynamics of woody plants might contribute to their adequate use.

MATERIALS AND METHODS

The experimental plot is part of the regional biocentre Ráječek in the municipal district Brno-Černovice. The locality is situated in the first altitudinal zone, approximately 195 m above sea level. It belongs to the T4 warm climate region (Agentura, 2012). According to the meteorological station Brno-Tuřany, which is closest to the model locality, the average air temperature in 2016 was 10.6 °C, the annual precipitation amounted to 524 mm (Český, 2019). In terms of biogeographical zoning, the area is part of the Pannonian biogeographical province. Potential vegetation consists of oak-hornbeam forest (*Primulo-veris Carpinetum*) and elm-oak forest (*Quercu-Ulmetum*) (Agentura, 2012). Geological subsoil is made of fluvial loamy sediments (Česká, 2014). There is waterlogged soil with regularly varying groundwater level on the site (ZO ČSOP, 2019).

The evaluated specimens are situated inside an area 1.25 hectare within five separate groups that are planted of assortment of five fast-growing species (*Fraxinus excelsior*, *Populus alba*, *Populus nigra*, *Ulmus laevis*, *Ulmus minor*) and four species with a standard speed of growth (*Acer campestre*, *Carpinus betulus*, *Prunus avium*, *Tilia cordata*). The furthestmost groups are planted 170 m apart. The local site conditions are entirely comparable for all groups. Each group consists of approx. 175 trees planted with the spacing of 1.5 m. The planting took place in 2011. The planting material were bare-rooted young plants, transplanted twice. The plants were watered when planted (40 l/piece) and mulched with wood chips (layer thickness 5 cm). When planting and during the follow-up care no fertilizers were applied and no pruning was conducted. In the first year, weeding and checking the mulch was done twice. The plants were watered 5 times with 40 l/piece (Kaisler, 2016).

Five specimens of each observed species were evaluated in each group, i.e. 25 specimens for each species, in total 225 pieces. Within each particular group measurements were done on developmentally medial specimens, which showed increase in all evaluated parameters and had at least seven undamaged shoots. The measuring included the following parameters: tree height, annual terminal shoot increment, annual increment of six lateral shoots. The tree height was determined as the distance from the base of the trunk to the treetop, measured by a levelling rod. Annual increments were determined as the length of the current-year shoots after the end of growth (evaluation was done after leaf fall in the time of vegetation dormancy), they were measured with a measuring tape if accessible, or using a levelling rod. All values had the accuracy of cm. Should the terminal shoot be damaged, the highest shoot was measured. If more equal shoots were identified, without one clearly dominant shoot, all of them

were measured and the value of the longest one was counted. Lateral shoots were measured using a unified scheme: two shoots nearest the terminal shoot; further the height of 1.5 m from the trunk base was marked and the four shoots upwards nearest from this border were measured. If there were not enough undamaged shoots above this border, shoots downwards were measured too. In case of several shoots growing from one place, all of them were measured and the values of the longest ones were counted. Always the living, undamaged shoots showing growth were measured.

The established data were evaluated using Microsoft Excel and Statistica. The analysis of variance ANOVA with interactions was used. For each parameter, the arithmetic mean, standard deviation, maximum and minimum values were determined for individual species.

RESULTS AND DISCUSSION

Growth dynamics of woody plants can be determined based on various parameters. From the landscape architecture point of view, the annual height increment is fundamental. The increments of terminal shoots can be seen in Tab. I. The highest average annual increment was observed in *Populus nigra* (135.4 cm), with a standard deviation of 22.96 cm. The values ranged between 100 and 189 cm. The average value exceeded 100 cm also in *Populus alba*; however, the standard deviation was 33.79 cm. There were considerable differences between the specimens. The lowest value was 48 cm, the highest 166 cm.

All control taxa (*Acer campestre*, *Carpinus betulus*, *Prunus avium*, *Tilia cordata*) achieved similar average increments of the terminal shoot (between 50 and 67 cm). A comparable value was also observed in *Ulmus laevis*, but there was a considerable standard deviation at the same time. The lowest measured value was 28 cm, the highest increment was 160 cm. The result may be a consequence of an irregular

growth of the species, where there was often not one terminal shoot but several equal shoots. Thus, the potential growth energy of the tree could be divided among several shoots, out of which none created a dominant increment.

According to Kolesnikov (1974), based on the length of increments, all taxa could be classified as fast growing (annual height increment of at least 50 cm). The smallest increment was observed in *Tilia cordata* (49.80 cm), all other species exceeded 50 cm. When interpreting the results, it is however necessary to consider the fundamental factors of the experiment, mainly the age of the plants, conditions of the site and the character of the experiment that took place at model site in non-urban area during limited period of one year. The specimens are young, well rooted. The environmental requirements of the species in the given situation correspond to the natural conditions of the site. In comparison with the long-term average of the years 1981–2010, the year 2016 with its average annual temperature and the annual precipitation amount was slightly higher than average (Český, 2019). Kolesnikov (1974) does not specify to which age of the trees his published data refer. Had the experiment been conducted in adult specimens, the increments would probably have been smaller. Similarly, smaller overall increases probably would be observed for woody plants growing in a less favourable site conditions in urban area. In case of long-term observation, there could also have been deviations between individual years. The overall increment may also be influenced by the planting spacing, which was only 1.5 m. It is possible that the trees then grow more upwards, than they would have grown, had they been planted with larger spacing.

The comparison of data in Tab. I clearly shows that similar values of annual increments of terminal shoot were measured only in *Prunus avium*. Bruns (2013) states 50 cm, the average value of measured

I: Annual shoot increments – comparison of the experiment data (2016/2017) with data published in Bruns (2013)

Species	Annual increment of terminal shoot (cm)			Annual increment of selected lateral shoots (cm)	
	Average	Stand. deviation	Bruns, 2013	Average	Stand. deviation
<i>Acer campestre</i>	65.00	28.64	40–45	47.44	7.59
<i>Carpinus betulus</i>	66.56	17.33	35	39.85	9.26
<i>Fraxinus excelsior</i>	73.40	26.65	30–45	55.36	6.00
<i>Populus alba</i>	102.84	33.79	not stated	73.22	19.86
<i>Populus nigra</i>	135.40	22.96	70	77.78	9.04
<i>Prunus avium</i>	53.56	14.02	50	39.13	9.35
<i>Tilia cordata</i>	49.80	15.43	30	36.35	9.01
<i>Ulmus laevis</i>	64.92	31.43	40–50	43.79	14.59
<i>Ulmus minor</i>	86.68	31.22	40	53.33	7.95

II: Tree height – comparison of own data (2016/2017) with the data of other authors (for the age category up to 10 years)

Species	Height (m)			
	Average	Stand. deviation	Kavka, 1995	Vreštiak, 1991
<i>Acer campestre</i>	3.27	0.5803	0.8–1.5	2.9
<i>Carpinus betulus</i>	2.59	0.2820	2–5	4.2
<i>Fraxinus excelsior</i>	2.81	0.3873	3–4	5.3
<i>Populus alba</i>	3.85	0.8061	6–8	9.4
<i>Populus nigra</i>	3.92	0.3702	3–6	5.6
<i>Prunus avium</i>	2.51	0.3142	3–4	not stated
<i>Tilia cordata</i>	2.01	0.3247	1.5–3	4.3
<i>Ulmus laevis</i>	3.40	0.5086	1.5–4	not stated
<i>Ulmus minor</i>	3.61	0.6362	2–5	not stated

specimens was 53.56 cm. All other species deviate considerably, with the measured values being always higher, e.g. in *Ulmus minor* more than twice. Bruns (2013) does not state to how old specimens the annual height increment refers. It cannot be identified whether the data come from the period of growth culmination, or whether this is for instance a long-term average. Moreover, the evaluation was conducted in tree nursery sites, whereas the measured values refer to plants on their permanent site, where the measurements were done only during one year. Hence it is necessary to understand the results as preliminary.

Apart from the terminal shoot increment, Tab. I also shows the average value of six measured lateral shoots. None of the species came close to the value of 100 cm. The highest average increment was observed again in *Populus nigra* (77.78 cm) and *Populus alba* (73.22 cm). The increments exceeding 50 cm were further identified in *Fraxinus excelsior* (55.36 cm) and *Ulmus minor* (53.33 cm). Although a certain distortion given by the selection of measured shoots according to the unified scheme can be expected, the classification of the mentioned species as woody plants with high growth dynamics was confirmed.

Average lateral shoots increments are smaller than terminal shoot increments, which corresponds to the type of branching of the evaluated species. At the same time, the standard deviations and the differences of minimum and maximum measured values for the individual species were larger in the terminal shoot than in the lateral shoots. The values of six measured lateral shoots thus contain less extreme values within the individual taxa than the terminal shoot increments.

Tab. II shows results summarizing the identified average heights of the evaluated species. The highest average height was observed in *Populus nigra* (3.92 m), whereas the standard deviation was among the smallest (0.37 m). The lowest measured figure was 3.12 m, the highest one was 4.6 m.

In *Populus alba*, the average height was similar to the previous species (3.85 m) but the standard deviation was clearly the highest (0.81 m). The smallest evaluated specimen measured 2.5 m, the highest one had 6.25 m. On the whole, the average height of fast-growing species exceeded 2.8 m. In *Carpinus betulus*, *Prunus avium* and *Tilia cordata* the height was between 2.0 m and 2.6 m. The results confirmed the assumption that fast-growing woody plants achieve larger sizes earlier than species with standard speed of growth. The exception is *Acer campestre* which with its average height of 3.27 m is comparable with fast-growing trees.

It follows from the analysis of situation that the site conditions were comparable and favourable for all observed species. At the same time these are domestic species which, in this kind of sites, should have increments even without any additional care (which is common in a number of sites in residential greenery for instance). Despite that, some specimens of *Populus alba* showed small increments, or practically stagnated in their growth. A possible cause of the unbalanced results can also be a technological error during the planting which caused a slow-down of growth. Another cause can also be a certain natural variability within the species and the propagation material.

It further follows from Tab. II that the values stated by Kavka (1995) are closest to the results of the field research. Specifically, in the species *Carpinus betulus*, *Populus nigra*, *Tilia cordata*, *Ulmus laevis* and *Ulmus minor*, the observed average height corresponds to the stated range. In *Fraxinus excelsior* and *Prunus avium*, the measured figures are lower by 0.2 and 0.5 m. The average height of *Populus alba* (3.85 m) does not come even close to the stated range of 6–8 m. However, the result does not directly indicate low growth dynamics. The lower growth of the mentioned species can also be caused by a practically absent care after planting and less mature nursery stock, whereas Kavka (1995) evaluated trees in parks, where

III: Minimum and maximum measured values of parameters for individual taxa

Species	Height (cm)		Annual increment of terminal shoot (cm)		Annual increment of selected lateral shoots (cm)	
	min	max	min	max	min	max
<i>Acer campestre</i>	240	460	23	170	36	71
<i>Carpinus betulus</i>	210	322	31	103	25	59
<i>Fraxinus excelsior</i>	243	396	18	146	42	65
<i>Populus alba</i>	250	625	48	166	29	113
<i>Populus nigra</i>	312	460	100	189	64	97
<i>Prunus avium</i>	198	332	31	93	22	60
<i>Tilia cordata</i>	162	274	25	90	26	60
<i>Ulmus laevis</i>	232	458	28	160	27	96
<i>Ulmus minor</i>	250	543	40	150	41	71

the usage of higher quality nursery stock as well as a higher level of the follow-up care can be expected. A distinctive difference in values was observed also in *Acer campestre*, whose height at the given age should not exceed 1.5 m (Kavka, 1995); the identified average value on the site, however, was more than twice as much (3.27 m), whilst the smallest evaluated specimen reached 2.4 m. Considering the comparison of similarly old specimens and despite the possible influence of climatic conditions, the result preliminarily indicates a higher growth dynamics. The hypothesis of higher growth dynamics is also supported by the comparison with Vreštiak (1991), who evaluated solitary healthy specimens in urban greenery outside extreme sites. He partly calculated the values by means of compensation polynomials. His records state the height of 2.9 m for *Acer campestre*. At the same time, for *Carpinus betulus*, *Fraxinus excelsior*, *Populus nigra*, *Populus alba* and *Tilia cordata* he states higher values; the comparison for *Prunus avium*, *Ulmus laevis* and *Ulmus minor* is

missing. Considering the character of the realised experiment which was limited to a one year period due to the realised treatment (cutting), it needs to be emphasized that the presented data comparisons are only preliminary despite the similarly old plants, and further research and verification over time are necessary.

The general overview of minimum and maximum values for the monitored parameters is stated in Tab. III. The lowest number of extreme results was identified in *Populus nigra*. By contrast, big differences in all parameters were observed in *Populus alba*. The highest evaluated tree was 2.5 times higher than the smallest specimen. The longest terminal shoot achieved approximately 3.5 times the value of the shortest one. High growth dynamics of *Acer campestre* was also confirmed. In the terminal shoot, there was a considerable difference between the smallest and highest identified figure; however, in the overall height and annual lateral shoots increment, the minimum measured values were higher than in other control plants.

CONCLUSION

It follows from the measured figures that *Populus nigra* showed the highest growth dynamics, *Tilia cordata* the lowest. On the whole, the species classified as fast growing (*Fraxinus excelsior*, *Populus alba*, *Populus nigra*, *Ulmus laevis*, *Ulmus minor*) reached higher results than trees with a standard speed of growth (*Carpinus betulus*, *Prunus avium*, *Tilia cordata*). An exception was *Acer campestre* which was with its results closer to *Fraxinus excelsior* and *Ulmus laevis*. For instance, the comparison of the average height of the slowest growing representative of fast-growing woody plants (*Fraxinus excelsior* 2.81 m) with the fastest growing species from the second category (*Prunus avium* 2.51 m) showed a difference of 30 cm in favour of the fast-growing category. The average height of *Acer campestre* amounted to 3.27 m. When comparing the maximum length of annual terminal shoot increment, the fast-growing woody plants exceeded 146 cm (*Fraxinus excelsior*), whereas in the control plants a maximum of 103 cm was reached (*Carpinus betulus*). The maximum length in *Acer campestre* was 170 cm. Despite this, only one of the used resources (Belke and Gaida, 1991) ranks this species among fast-growing woody plants.

The results of the experiment have showed higher growth dynamics in the genus *Populus* in comparison with other evaluated fast-growing species. Only in the species *Populus alba* and *Populus nigra*, the average value of the annual increment of terminal shoot exceeded 1 m.

When interpreting the results, it is necessary to consider the fact that they reflect the growth dynamics of young individuals of selected species during one year on one model locality in non-urban area with favourable site conditions. The growth characteristics of the same woody species planted in less favourable conditions and urban sites may be different. For this reason, further long-term observations on various model sites are desirable. Nevertheless, the established preliminary data are valuable for the usage of woody plants in Landscape architecture. For instance, based on the results the frequency of treatment of the trees can be appropriately modified in similar types of sites (landscape or residential), in particular specific pruning interventions, improvement cutting can be better planned, or specific changes in the spatial arrangement of vegetation elements can be implemented. After further verification and supplementation of the presented results the growing methods can be similarly modified even in less favourable growing site within the garden and landscape designs. Likewise, further time-verified results can be used for planning of complex renewal or regeneration interventions in residential and landscape greenery and for its planting.

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