Establishing windbreaks: how rapidly do the smaller tree transplants reach the height of the larger ones?

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ABSTRACT: The aim of this study is to identify a period of time over which smaller, less costly tree transplants can reach the height of larger tree transplants and thus offset their performance. The following Central European native tree species were used: *Quercus robur* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Acer campestre* L., *Acer pseudoplatanus* L., *Tilia cordata* Mill. and *Prunus avium* L. In the period after planting, the best growth was observed for small tree transplants. These transplants reached the height of the medium-sized tree transplants for all species except *C. betulus*. However, the large transplants of *A. campestre*, *F. excelsior* and *P. avium* were still significantly taller than the medium-sized transplants ten years after planting. In contrast, slow growth was observed for the large tree transplants of *C. betulus* and *Q. robur*. During the monitoring period, the height of the medium-sized transplants of *C. betulus* even exceeded the height of the large transplants of this species. These differences suggest that the differences in the establishment rates of individual species are reflected in the growth rates of their plantations during longer periods after planting.

Keywords: landscape rehabilitation; arable soil; native woody plants; seedling size; growth rate

The favourable effects of shelterbelts in intensively farmed landscapes are well known (e.g. Kujawa, Kujawa 2008; Mize et al. 2008). For this reason, shelterbelts are used throughout the world (Cleugh et al. 2002; Peri, Bloomberg 2002; Brandle et al. 2004; Campi et al. 2009).

To strengthen the environmental balance of the landscape and to facilitate nature conservation, it is recommended that native woody species be used for planting (Webb, Erskine 2003). Several studies support the use of data on potential natural vegetation for landscape rehabilitation purposes (Miyawaki, Golley 1993; Rodwell, Patterson 1994; Farris et al. 2010; Jelínek, Úradníček 2010).

Sun and Dickinson (1997) investigated the early growth of native woody species after the planting of windbreaks on farmland in Australia. Dostálek et al. (2007) described the effects of various methods used to establish plantings. Relatively tall tree seedlings are often used to accelerate the establishment of a taller windbreak without using fast-growing woody plants. This approach is frequently discussed because of the associated high financial costs and the unsatisfactory growth of tree transplants (Watson 2005). The establishment of different-sized tree transplants in windbreaks on arable soil was evaluated by Puértolas et al. (2003) and Dostálek et al. (2009).

Previous discussions have addressed not only the economic benefits of windbreaks for agricultural production and the environment (e.g. Kulshreshtha, Kort 2009; Tyndall, Grala 2009) but also the costs of establishment (Mir, Khan 2008).

Because the price of different-sized tree transplants can differ significantly, it is important to

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learn to what extent smaller, less costly tree transplants can replace the larger transplants. This study seeks to identify a period of time over which smaller tree transplants can reach the height of the larger transplants and thus offset their performance.

MATERIAL AND METHODS

The experimental plantings investigated in this study were situated in a fertile, intensively farmed landscape at the village of Klapý, near the town of Libochovice (Czech Republic; latitude 50°25'50''N, longitude 14°0'20''E). The experimental plots were established in the alluvium of Rosovka Stream.

The area has been farmed since prehistoric times. It is located on a moderately undulating plateau at 200 to 260 m a.s.l. The site's soil conditions are characterized by mostly heavy and very heavy Chernozem soils, termed Verti-haplic or Calcaro-haplic Chernozems (CH) in the WRB: IUSS/FAO/ISRIC classification. The hydraulic conductivity of these soils is very limited, and the depressions in the substrate can collect and hold rainwater on the surface for only a few days. The skeleton is almost absent in these soils, and the wet soils are extremely sticky (for details see Dostálek et al. 2009).

The mean annual air temperature of the area is 8.5°C, and the mean annual precipitation reaches 474 mm. According to the Map of Potential Natural Vegetation, alluvial forests formerly extended through the alluvia of minor watercourses in the study area (*Alnenion glutinoso-incanae* Oberdorfer 1953). However, because of the drainage systems built in the area's alluvial sites, these habitats have shifted to more xerophilous communities. Apart from the alluvial sites, the potential natural vegetation on most of the area would consist of sub-xerophilous oak forests (*Quercion petraeae* Zólyomi et Jakucs ex Jakucs 1960). The present uses of the landscape involve many challenges (e.g. wind erosion, disturbance of the water regime, and significantly reduced biodiversity).

The experimental plantings formed part of a new windbreak established in 2001. The total area of our experimental plots was 4,680 m^2. In all, 672 trees were planted. Native woody species suitable for the existing habitats were used for planting. The species composition was selected in view of the changed conditions resulting from the drainage of the alluvial habitat. The following trees were used: English oak (*Quercus robur* L.), European hornbeam (*Carpinus betulus* L.), European ash (*Fraxinus excelsior* L.), field maple (*Acer campestre* L.), Norway maple (*Acer pseudoplatanus* L.), small-leaved linden (*Tilia cordata* Mill.), and wild cherry (*Prunus avium* L.). For planting, the following three transplant sizes were used: (a) small: 1.0–1.5 m tall seedlings; (b) medium-sized: 2.0 to 2.5 m tall seedlings; and (c) large: tall trees with a trunk circumference of 0.1–0.12 m and 2.5–4.0 m tall, depending on the tree species.

Transplants from all size categories were bare-rooted except for those of *Quercus robur* and *Carpinus betulus,* the roots of which were in soil. The planting trials were established on arable land. The plots were prepared for planting using mechanical methods, such as ploughing and slashing. Because the transplants were sufficiently large, no protection against weeds was applied after planting.

The experiment was conducted in a 550-m long and 7.8-m wide part of the windbreak. Transplants from all size categories were planted in 50-m segments, each in four randomly located replications. In each replication, 168 transplants (e.g. 24 transplants of each tree species) of a randomly established mixture of the tree species used were manually planted in three rows at regular distances. In all, 96 transplants were planted for each tree species of each size category.

The development of the tree plantings was evaluated by measuring transplant height. The initial transplant size was measured in September–October 2001, and the height was measured annually from 2002 to 2011, always during September and October. Only the living parts of the transplants were measured; dry tree tops were not included in the transplant height measurements.

The data were rank transformed and then analysed by two-way hierarchical analysis of variance (ANOVA) and Tukey's test. STATISTICA 9.0 (StatSoft Inc., Tulsa, USA) was used for the calculations. The effects of different transplant sizes for each species were compared using one-way hierarchical ANOVA and Tukey's test at the P = 0.05 significance level.

RESULTS AND DISCUSSION

Fig. 1 shows the growth of the plantations of all three types of tree transplants of the monitored species over a ten-year period. A general evaluation of the different-sized species groups was conducted. Beginning in the ninth year after planting, the total height of the small tree transplants and the medium-sized tree transplants did not differ

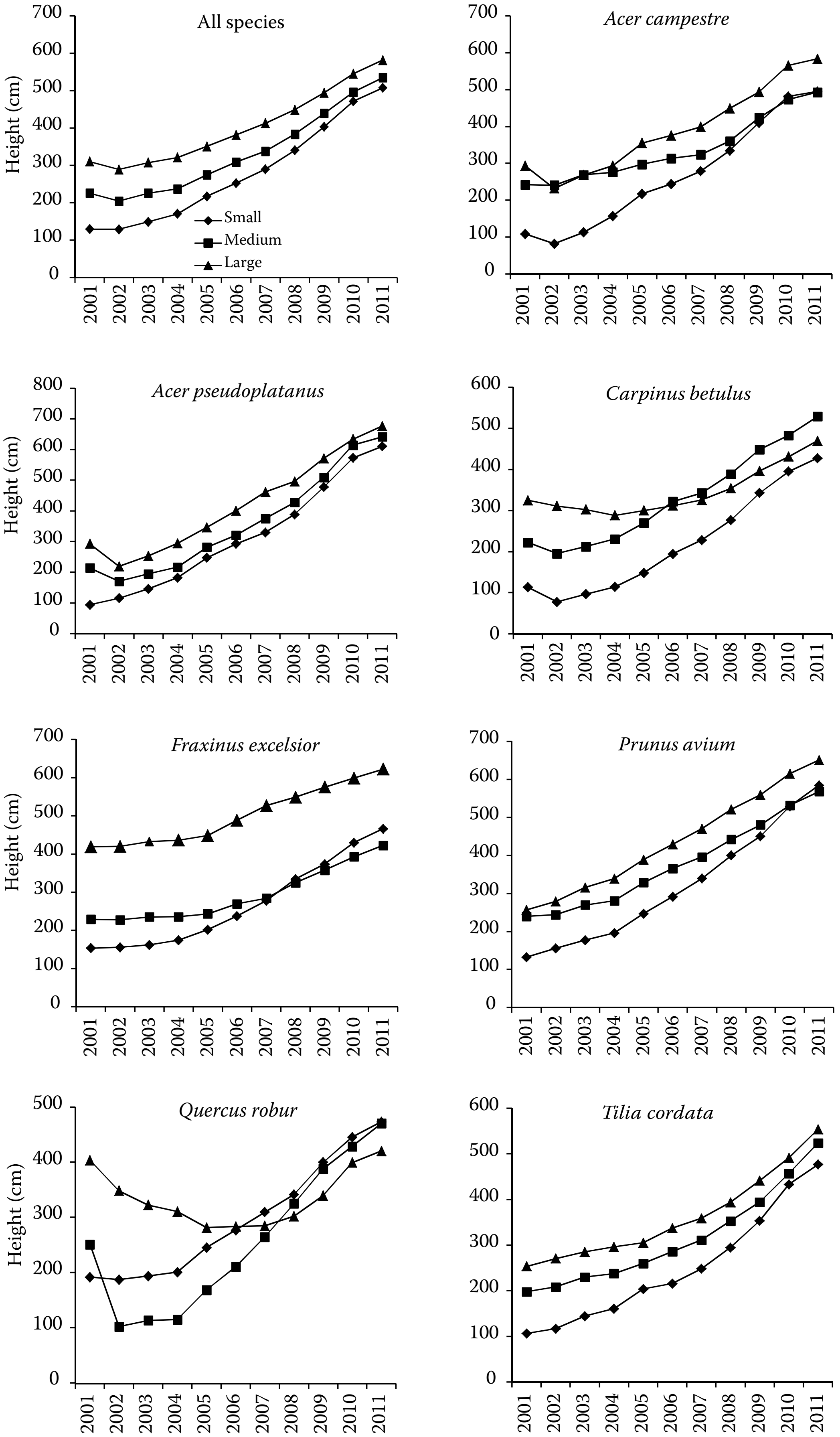

Fig. 1. Annual changes in the height of plantings as a function of the transplant size

Table 1. Two-way ANOVA with nested factor (plot) was performed separately for each year

Year	*F*-value			Tree transplant size		
	tree transplant size A 2 d.f.	tree species B 6 d.f.	plot C (A × B) 75 d.f.	small	medium	large
2001	1670.0	38.1	3.4	129[c]	226[b]	310[a]
2002	135.0	12.2	4.5	124[c]	205[b]	289[a]
2003	126.2	11.6	3.6	149[c]	226[b]	308[a]
2004	119.6	13.7	3.6	171[c]	237[b]	321[a]
2005	109.0	19.0	3.6	217[c]	275[b]	351[a]
2006	79.5	16.4	3.0	253[c]	309[b]	382[a]
2007	67.9	21.2	2.7	290[c]	338[b]	413[a]
2008	45.3	23.4	2.7	341[c]	384[b]	449[a]
2009	23.8	24.2	3.0	404[c]	439[b]	494[a]
2010	14.4	30.4	2.7	472[b]	496[b]	545[a]
2011	13.2	26.7	2.6	508[b]	535[b]	581[a]

F-values – significant at $P = 0.05$; d.f. – degrees of freedom, the same letter – not significantly different

significantly according to this evaluation (Table 1). Although the height of small tree transplants generally shows a relatively rapid increase (Wilson 2005, Dostálek et al. 2009), they did not reach the height of the large tree transplants after ten years.

It is also obvious from the results of monitoring that the individual transplanted species increased their height differently. The small tree transplants of *Fraxinus excelsior* reached the height of the medium-sized transplants of these species in the fifth year after planting, whereas the small transplants of *Acer campestre* and *Prunus avium* reached the height of the medium-sized transplants of their species only in the seventh year after planting. The large tree transplants of these three species, however, were significantly taller in the tenth year after planting. In *Acer pseudoplatanus*, the difference between the height of the small tree transplants and that of the medium-sized transplants was not statistically significant in or after the third year after planting, and the medium-sized tree transplants reached the height of the large transplants in the ninth year after planting.

In *Tilia cordata*, no significant statistical differences were found between the plants from the small tree transplants and the medium-sized transplants and between the medium-sized tree transplants and the large transplants after nine years.

The responses of the species *Carpinus betulus* and *Quercus robur* were somewhat different from the responses of the species previously discussed. From the fourth to the seventh year after planting, the medium-sized tree transplants and the large transplants of *Carpinus betulus* did not show any significant difference in height. In the following period, however, the medium-sized tree transplants became significantly taller than the large ones. Over the entire period of monitoring, the small tree transplants were significantly shorter than the medium-sized transplants.

A significant decrease in the height of the medium-sized tree transplants of *Quercus robur* was observed in the first year after planting as a result of the marked drying of the tops of the trees. From the first to the fourth year after planting, the height of the medium-sized transplants of this species was even significantly lower than the height of the small tree transplants.

Over the first four years after planting, the height of the large tree transplants of this species continued to decrease as a result of the gradual drying of the growing tops of the trees, due most likely to post-replanting stress. Beginning in the fifth year after planting, the height of the large tree transplants of this species did not differ from the height of the small and medium-sized tree transplants. The results for *Carpinus betulus* and *Quercus robur* are consistent with previous data showing that taller tree transplants are poorer at overcoming post-transplanting stress than shorter transplants (Landerdale et al. 1995; Gilman et al. 1998; Struve et al. 2000; Watson 2005).

In general, the small tree transplants of all species except *Carpinus betulus* showed the best growth during the ten-year period after planting and reached the height of the medium-sized tree transplants. Ten years after planting, however, the taller tree transplants of *Acer campestre, Fraxinus excelsior* and *Prunus avium* were significantly taller than the medium-sized transplants of the same species. In contrast, the large tree transplants of

Table 2. Proportions of prices in different transplant sizes of the individual analysed woody species (in %), the price of the most expensive large transplants was considered as 100% for comparison

Plant name	Transplant size		
	small	medium	large
Acer campestre	18	68	
Acer pseudoplatanus	18	68	
Carpinus betulus	8	77	
Fraxinus excelsior	4	69	100
Prunus avium	33	67	
Quercus robur	6	77	
Tilia cordata	12	67	

Carpinus betulus and *Quercus robur* developed poorly. Over the monitoring period, the height of the medium-sized transplants of *Carpinus betulus* exceeded the height of the large transplants. These differences confirm the hypothesis that the differences in the establishment rates of individual species cited by Gilman (1990) and Dostálek et al. (2007, 2009) are also evident in the growth rates of the plantations of these species over a longer period after planting.

From the data in Table 2 it is evident that the medium, less costly tree transplants were in comparison with large transplants less costly about 23–33%, depending on the tree species. In the case of small transplants it was even much more 67–96%. Nevertheless, in the ninth year after planting, the total height of the small tree transplants did not differ and they reached the height of medium transplants.

From the data in Table 2 it is evident that medium tree transplants were in comparison with large transplants less costly (by 23–33%) depending on the tree species. In the case of small transplants, it was even much more (by 67–96%). Further, in the ninth year after planting, the total height of the small tree transplants did not differ from the height of medium transplants.

Our results show that the selection of transplant size can have a significant impact on transplant development and can significantly contribute to an efficient use of financial resources.

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