PRODUCTIVITY AND QUALITY OF HYBRID ASPEN AT THE AGE OF 18 YEARS

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Abstract
Fast-growing hybrid aspen clones are recommended for establishment of plantation on abandoned agriculture land in Northern Europe. In this study we assessed the productivity, quality and assortment structure of hybrid aspen clones at final felling. Data were collected during the hybrid aspen clonal experiment conducted in the central part of Latvia. Large variation in the productivity level between different clones was affected by growth and survival. From the compared 5 most and least productive clones, based on the yield m^3 ha^{-1}, the faster growing clones have about 17% better survival rate at age 10. Also, the mean annual increment (MAI) differed notably and significantly ($p<0.05$, $\alpha = 0.05$) between hybrid aspen clones at the age of 18 years ranging from 7 to 34 m^3 ha^{-1} $year^{-1}$. Theoretical assortment structure of hybrid aspen at the age of 18 years was the following: 43 ± 4.86% of small dimension saw logs (SDS logs), 21 ± 4.86% high quality saw logs (HQS logs), 18 ± 4.33% pulpwood, 4 ± 0.77% firewood and 13 ± 0.08% of logging residues (tops). The outcome of HQS logs on average is more than 30% from the 5 best clones and further increase can be predicted with age. Stem volume ($H^2 = 0.32$), height ($H^2 = 0.47$) and quality parameters (stem straightness - $H^2 = 0.73$, branch angle - $H^2 = 0.60$) had a high heritability and large differences between clones, indicating notable possibilities to improve the productivity of plantations via selection of the best-growing genetic material.
Key words: survival, thinning, heritability, *Populus tremula* × *P. tremuloides.*

Introduction

Broadleaved tree species (*Populus, Salix*) and their hybrids are most often used for establishment of short-rotation plantation on abandoned agricultural lands in the Baltic and Nordic countries (Zeps *et al*., 2008; Tullus *et al*., 2012). One common choice is crossing between European aspen *(Populus tremula* L.*)* and American aspen *(Populus tremoloides* Michx.), in the literature referred to as "hybrid aspen". Due to the heterosis effect, the potential productivity of hybrid aspen exceeds that of any of the parent species (Smilga, 1968; Liesebach *et al*., 1999) as well as other short-rotation tree species (Jansons, 2013, 2014a). Productivity can further be boosted by fertilization, creating both short-term (Van den Driessche, Rude & Martens, 2003) and long-term – up to 15 years (Jansons *et al*., 2016) – effect on the increment of trees. The recommended length of rotation period for hybrid aspen in Finland and Sweden is between 20 and 30 years. Production goal of the first rotation – saw logs and pulpwood; the target yield – 300-400 m^3 ha^{-1} (Hynynen, Ahtikoski, & Eskelinen, 2004; Rytter & Stener, 2005, Tullus *et al*., 2012). The second rotation originates from root suckers (Smilga, 1968; Liesebach *et al*., 1999) and, due to low (no) costs of early management and relative high density, its production goal can also be biomass for energy: using 10-year rotation as much as 9 tons of dry matter per year can be produced (Rytter, 2006). The demand for energy wood is increasing in recent years primarily due to different support mechanisms intended to reduce the use of fossil fuels and reach the European Union's CO_2 emission reduction targets (COP21). Combined heat and power plants are built in municipalities, ensuring the demand for woody biomass 7.5 mill m^3 loose already in 2011 and steady increase of it since then due to opening of larger plants in the cities like Jelgava and Ventspils (Būmanis *et al*., 2014). Also, a number of pellet factories have been built during recent years, increasing the demand for firewood and creating a potential market also for biomass from short-rotation plantations (Būmanis *et al*., 2014).

Tree breeding as a financially viable activity is practised in a number of countries in the Baltic Sea region, including Latvia (Gailis & Jansons, 2010; Jansons, Gailis, & Donis, 2011; Jansons *et al*., 2015a) and it has showed a notable effect on the growth traits (Jansons, 2005; Jansons *et al*., 2006). Continuous selection of clones capable to produce the highest increment in particular climatic conditions (Jansons *et al*., 2014b; Šēnhofa *et al*., 2016) as well as to reduce damages (Zeps *et al*., 2016) is feasible for hybrid aspen. Since profitability of hybrid aspen plantation at the first rotation to a large extent depends on the proportion of high-quality saw logs, also traits affecting natural pruning and stem straightness need to be included in the selection criteria (Stener & Karlsson, 2004). Based on the results of short-term experiments, the genetic gain in each of the traits can be estimated at a particular age and, using the assumptions on age-age genetic correlation and increment, also at the rotation age. However, to test the assumptions as well as to control solid data for land owners interested in the establishment of the plantations, it is essential to obtain data also from trials at harvesting age. The oldest hybrid aspen properly replicated trials in Latvia had recently reached this age; therefore the aim of our study was to assess the productivity and quality of hybrid aspen clones and assortment structure at the final felling.

Materials and Methods

Material was collected in the clonal trial (experiment No 62 – Baumanis, Jansons, & Gaile, 2005), established on a former agricultural land (drained fertile soil) using one-year old micro-propagated containerized plants, with initial spacing 2 × 2 m (2500 trees ha^{-1}). Altogether 31 clones were used – 24 hybrid aspen, 5 diploid common aspen and 2 triploid common aspen – placed in 15 tree block plots in 4 replications. Extensive beaver damages occurred during the trial; only clones represented in at least 2 replications outside the area affected by beaver were used for analysis. Systematic thinning, removing every second tree (by diagonals of the trail) was carried out at the age of 12 years. All trees were assessed at the age of 8, 10, 12 (before and after thinning) and 18 years; from the first inventory only mean values of clone were available. During each assessment the tree height and breast height diameter were measured, presence of spike knots, browsing damages or signs of cancer (*Entoleuca mammata*) was noted. Branch thickness was visually assessed relative to that of similar diameter trees in the trial in 3 grades: grade 1 – thin, grade 2 – average, and grade 3 – thick. Branch angle in the middle part of crown was assessed using 3 grade scale, where grade 1 – angle with stem axis ≥ 85°, grade 2 – 75°≥ angle > 85°, grade 3 – angle < 75°. Stem straightness was assessed using 3 grade scale, where grade 1 – straight, grade 2 – slightly bent (one curve deviating from vertical axis of the stem at least 5 cm), grade 3 – bent (more than one curve). Stem volume was calculated using equation elaborated by Liepa (1996), developed for common aspen, since the height – diameter relationships in the trial did not suggested notable differences in stem form between common and hybrid aspen. The yield was calculated as the sum of stem volumes divided by the area of the plot, i.e. survival differences were included in the result. Broad sense heritability (H^2) of traits was calculated based on variance components derived from additive linear model using SAS PROC

Table 1

Yield and survival of hybrid aspen clones at different age

Clone	Yield (m^3 ha^{-1}) at the age of					Survival (%) at the age of		
	18	12		10	8	18	12	10
		harvested	standing*					
3	242	60	163	130	81	38	69	71
4	507	149	298	257	137	47	90	97
6	318	79	187	160	90	43	80	83
9	608	96	275	228	134	57	90	97
10	293	48	167	129	81	37	50	50
12	349	84	182	135	64	43	80	83
15	349	45	159	138	71	43	60	63
16	447	102	255	215	106	47	80	83
19	454	92	252	218	129	50	83	90
20	381	100	222	181	89	40	73	80
24	274	66	144	126	69	37	70	73
23	284	69	150	120	51	42	93	96
30	447	83	222	174	102	44	71	78
34	396	86	216	163	92	43	82	83
36	212	70	164	120	72	47	90	90
39	269	60	145	102	51	42	80	82
41	521	103	281	250	150	50	80	90
46	482	71	187	144	97	50	90	97
49	117	27	66	50	49	29	58	69

*standing –before thinning

MIXED function, as defined by Falconer & Mackay (1996). Assortment structure was calculated based on formulas developed by Ozolins (2002). Minimal top diameter for HQS logs is 18 cm, length 3.1 m; for SDS logs the respective figures were: 12 cm and 2.5 m, for pulp wood: 6 cm and 3 m, for fire wood 3 cm and 3 m. Quality was not considered when dividing stems into assortments.

Results and Discussion

Survival (before thinning) of hybrid aspen clones was 82 ± 6.0% (mean ± 95% confidence interval), but for common aspen clones it was significantly lower: 68 ± 7.3% (Table 1). Survival of hybrid aspen was similar to that found in Estonia at the age of 5 years – 81% (Tullus *et al*., 2007) and slightly lower than reported in Sweden – 96% (Stener & Karlson, 2004). Lower survival in our trial could be a result of insufficient weed control (resulting in competition for moisture) or browsing damages caused by rodents, which are mentioned as the main causes of tree death in plantations on former arable land during the first years after their establishment (Melchior & Seitz, 1966). A significant clonal difference in early survival was found in plantations in Germany, mainly linked to differences in resistance against prolonged periods without precipitation (Ilstedt & Gullberg, 1993). In our trial differences between clones were notable too (at the age of 10 years – from 50 to 97%), however, the small number of replications limit the possibility to estimate the statistical significance of the observed differences. Genetically determined differences (H^2 = 0.25) in survival had been found also in 14-16 years old plantations, linked to browsing damages by cervids and the influence of diseases (Ilstedt & Gullberg, 1993). The major diseases affecting plantations of hybrid aspen are cancers (*Hypoxylon mammatum* and *Leucostoma niveum*). In our experiment the occurrence of cancers was very limited (only a few cases), therefore, it was not possible to draw any conclusions on differences among clones in this respect.

Mean standing volume in the experimental plantation at the age of 18 years was 366 ± 59.2m^3 ha^{-1} and it was close to that expected or found at harvesting age in other studies of this hybrid (Hynynen, Ahtikoski, & Eskelinen, 2004; Rytter & Stener, 2005; Tullus *et al*., 2011, Tullus *et al*., 2012). Very large variation in this trait between clones was caused both by growth and survival, but part of it, presumably, also by random error due to the small size of plot and limited number of replications. The mean annual increment (MAI) of the hybrid aspen clones at the age of 8 years was 11.3 ± 1.8 m^3 ha^{-1} year^{-1}, but for the common aspen 4 m^3 ha^{-1} year^{-1}; at the age of 10 years the respective figures were16.0 ± 2.6 m^3 ha^{-1} year^{-1} and 7.1 m^3 ha^{-1} year^{-1}; at the age of 12 years (before thinning) 16.4 ± 2.4 m^3 ha^{-1} year^{-1} and 7.3 m^3 ha^{-1} year^{-1}; but at the age of 18 years: 20.3 ± 3.3 m^3 ha^{-1} year^{-1} and 10.0 m^3 ha^{-1} year^{-1}. The mean productivity of the hybrid aspen was more than double that of European aspen; this observation is in line with results found in other studies (Hynynen, Ahtikoski, & Eskelinen, 2004). The current annual increment between the age of 8 and 10 years was 35 ± 6.6 m^3 ha^{-1}year^{-1}, in the next two years decreased to 18 ± 2.6 m^3 ha^{-1} year^{-1}, but after the thinning from age 12 to 18 years, the increment was 28 ± 6.0 m^3 ha^{-1} year^{-1}. These results demonstrate a notable response of hybrid aspen to changes (optimum) of environmental conditions and suggest a strong impact of competition between the trees and a negative effect of delayed thinning. It is in accordance with the results obtained in other countries, suggesting the use of high density (2500 trees ha^{-1}) plantations for energy wood production with no thinning and rotation age of 10 years (Liesebach *et al*., 1999, Karačić, Verwijst, & Weih, 2003). In plantations for saw log production, a lower initial density (1100-1600 trees ha^{-1}) and one or two thinnings (depending on the length of rotation – 20 or 25 years) have been recommended (Rytter & Stener, 2005; Tullus *et al*., 2007; Tullus *et al*., 2012). Prompt reaction to the thinning can be seen also from changes in basal area: before thinning it was 25 m^2 ha^{-1} for hybrid aspen and 15 m^2 ha^{-1} for European aspen, as a result of thinning it decreased to 11 m^2 ha^{-1} and 9 m^2 ha^{-1}, respectively, but already within 6 years it reached 32 m^2 ha^{-1} and 16 m^2 ha^{-1}, respectively.

The total increment (including the volume extracted in thinning) at the age of 18 years for best hybrid aspen clone reached 39.1 m^3 ha^{-1} year^{-1}, exceeding the figures reported in other studies (Rytter *et al*., 2002; Stener & Karlsson, 2004; Tullus *et al*., 2012; Rytter & Stener, 2005), not exceeding 25.8 m^3 ha^{-1} year^{-1} at the age of 23 years (Johnsson, 1976, Tullus *et al*., 2012). Even if only the mean annual increment was considered, it was higher than described by growth curve developed for hybrid aspen in southern Sweden and Denmark – areas with a longer vegetation period than in Latvia (Jakobsen, 1976). MAI differed notably and significantly ($p<0.05$, $\alpha = 0.05$) between hybrid aspen clones, at the age of 18 years ranging from 7 to 34 m^3 ha^{-1} year^{-1} (Fig. 1).

Ranking of clones based on their MAI remains relatively stable at different ages of assessment: correlation ranges from 0.89 to 0.95 ($p<0.05$, $\alpha = 0.05$), indicating that relatively early selection for this trait ensures accurate results. It conforms to a study in Sweden, where strong genetic correlations between values of traits at the age of 4 years and at the age of 9 years were found: for tree diameter – 0.9 and for tree height - 0.87 (Stener & Karlsson, 2004).

Mean height of hybrid aspen at the age of 8 years reached 11.5 ± 0.43 m, at 10 years: 13.9 ± 0.50 m,

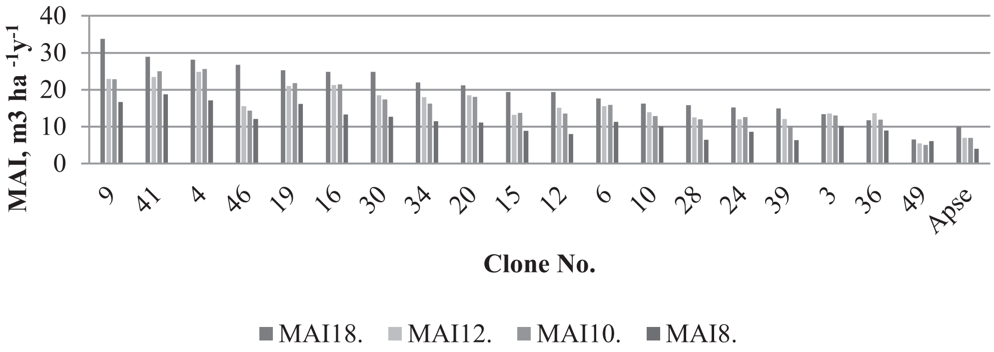

Figure 1. Mean annual increment (MAI) of hybrid and European aspen at 8, 10, 12 and 18 years.

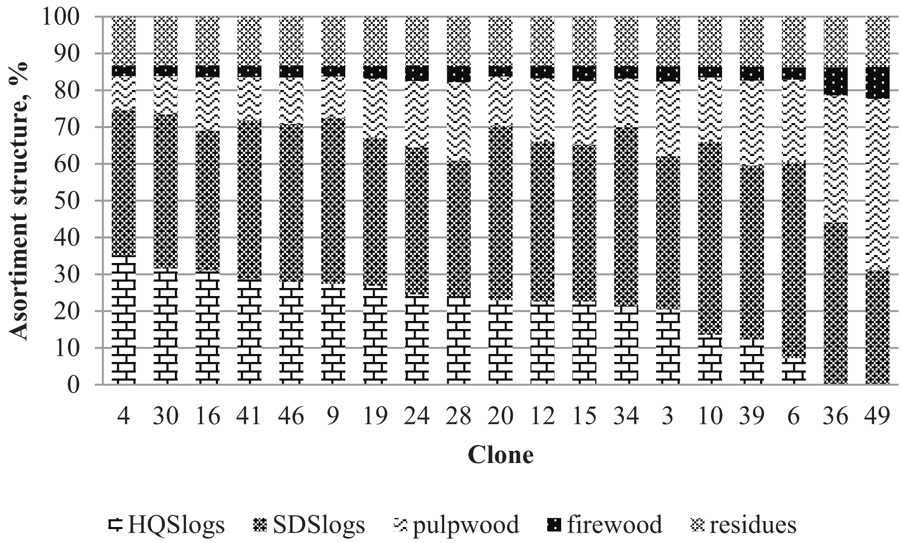

Figure 2. Hybrid and European aspen clone assortment structure
HQSlogs - high quality saw-logs; SDSlogs - small dimension saw-logs.

at 12: 15.5 ± 0.50 m and at 18 years: 21.6 ± 0.84 m. Annual height increment remains relative stable over the observed period, ranging from 1.44 m at the age of 8 years to 1.20 m at the age of 18 years.

Assortment structure of hybrid aspen at the age of 18 years was the following: 43 ± 4.86% of SDSlogs, 21 ± 4.86% of HQSlogs, 18 ± 4.33% of pulpwood, 4 ± 0.77% of firewood and 13 ± 0.08% of logging residues (tops). Notable differences between clones in the proportion of HQSlogs (from 0 to 35%, i.e. from 0 to 174 m^3 ha^{-1}) and SDSlogs (from 31 to 53%, i.e. from 26 to 277 m^3 ha^{-1}) were found, emphasizing the importance of breeding and selection of proper clone to maximize the productivity of plantation (Fig. 2.).

Additional volume, mostly pulpwood and firewood, was extracted in thinning. Since the systematic thinning was used, the mean stem volume of cut and remaining trees did not differ significantly (Table 2), but harvested volume (i.e. income for the plantation owner) differed notably between clones: from 27 to 149 m^3 ha^{-1} (mean: 78.3 ± 12.9 m^3 ha^{-1}). Since the yield before thinning was 197 m^3 ha^{-1} on average, the decision to harvest the plantation at that time could also be considered.

To ensure high genetic gain, not only differences between clones and stability of ranking between selection and target age is important, but also heritability of traits. In our study the highest heritability was found for tree height (H^2 = 0.47), stem straightness (H^2 = 0.73) and branch angle (H^2 = 0.60); heritability of other traits was moderate: for stem diameter H^2 = 0.27, stem volume H^2 = 0.32, presence of spike knots H^2 = 0.21. Relative high heritability (H^2 = 0.38 - 0.39) for tree height, stem diameter and volume had been found also in the analysis of hybrid aspen trials in Sweden (Stener & Karlson, 2004); even higher – H^2 = 0.60 for tree height and H^2 = 0.51 for stem diameter – in Finland (Yu & Pulkkinen, 2003). Differences in heritability between the studies may to some extent be affected by the age of trees: it was found, that heritability for tree height is gradually decreasing with age, but for stem diameter – increasing

Table 2

Mean stem volume of hybrid aspen clones at different age

Clone	Mean stem volume (m^3) at the age of				
	18	12		10	8
		harvested	standing*		
4	0.43 ± 0.08	0.14 ± 0.02	0.13 ± 0.02	0.11 ± 0.01	0.06
9	0.43 ± 0.06	0.12 ± 0.02	0.12 ± 0.01	0.09 ± 0.01	0.06
41	0.42 ± 0.06	0.14 ± 0.04	0.14 ± 0.02	0.11 ± 0.01	0.07
30	0.40 ± 0.06	0.12 ± 0.03	0.12 ± 0.01	0.09 ± 0.01	0.05
46	0.39 ± 0.08	0.07 ± 0.02	0.08 ± 0.01	0.06 ± 0.01	0.04
16	0.38 ± 0.09	0.12 ± 0.02	0.13 ± 0.02	0.10 ± 0.01	0.05
20	0.38 ± 0.09	0.12 ± 0.02	0.12 ± 0.02	0.09 ± 0.01	0.04
34	0.37 ± 0.05	0.09 ± 0.02	0.11 ± 0.01	0.08 ± 0.01	0.04
19	0.36 ± 0.09	0.11 ± 0.02	0.12 ± 0.02	0.10 ± 0.01	0.06
15	0.32 ± 0.09	0.11 ± 0.03	0.11 ± 0.02	0.09 ± 0.01	0.04
12	0.32 ± 0.07	0.09 ± 0.03	0.09 ± 0.01	0.06 ± 0.01	0.03
10	0.32 ± 0.07	0.14 ± 0.03	0.13 ± 0.02	0.10 ± 0.02	0.06
24	0.3 ± 0.10	0.08 ± 0.3	0.08 ± 0.02	0.07 ± 0.01	0.04
6	0.29 ± 0.07	0.09 ± 0.01	0.09 ± 0.01	0.08 ± 0.01	0.04
28	0.27 ± 0.09	0.07 ± 0.02	0.09 ± 0.01	0.07 ± 0.01	0.03
39	0.26 ± 0.05	0.06 ± 0.01	0.07 ± 0.01	0.05 ± 0.00	0.03
3	0.26 ± 0.07	0.08 ± 0.02	0.09 ± 0.02	0.07 ± 0.01	0.05
36	0.18 ± 0.03	0.06 ± 0.02	0.07 ± 0.01	0.05 ± 0.01	0.03
49	0.16 ± 0.06	0.04 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	0.03

*standing –before thinning

(Stener & Hedberg, 2003). The value of heritability is also affected by a specific set of clones and design of experiment: it is usually higher in trials where single-tree plots are used in many replications (Stener & Karlson, 2004; Zeps *et al*., 2008). Heritability of stem quality traits is usually lower than growth traits – it has been found in our study as well as in the analysis of the hybrid aspen trials in Sweden, where $H^2 = 0.27$ for branch angle and $H^2 = 0.29$ for number of branches (Stener & Karlson, 2004). However, other approaches to improve stem quality (like pruning) are costly; therefore, these traits are considered in tree breeding. In our study, significant differences between clones were found in branch thickness, branch angle, as well as frequency of spike knots. On average 32% of trees had thin branches, 10% - narrow branch angle, 23% - spike knots. Genetic correlation between the quality traits was weak, indicating, that they are controlled by different set of genes. Significant moderate negative genetic correlation was found between branch thickness and stem diameter ($r = -0.52$; $\alpha = 0.05$), demonstrating the difficulties to select trees based on multiple traits. Complexity of selection is further increased by negative genetic correlation between productivity traits and stem straightness (Stener & Karlson, 2004). This trait also was significantly affected by clone, but the reason for curves at any particular case might vary – apical dominance can be affected by drought stress, insects etc.

Conclusions

1. Survival of hybrid aspen at the age of 12 years differed between clones and was on average 82%, notably and significantly exceeding that of European aspen (68%).
2. Notable decrease of current annual increment at the age 10 to 12 years, as well as the positive reaction of trees (increase of increment) after the thinning at age 12 years proves the necessity of thinning in hybrid aspen stands with a relative high density (2500 trees ha^{-1}) and survival, if the intended rotation period exceeds 10 years.
3. The mean annual increment (MAI) of the hybrid aspen clones at the age of 8 years was 11.3 ± 1.8

m^3 ha^{-1} $year^{-1}$, but for European aspen 4 m^3 ha^{-1} $year^{-1}$; at the age of 18 years: 20.3 ± 3.3 m^3 ha^{-1} $year^{-1}$ and 10.0 m^3 ha^{-1} $year^{-1}$, respectively. The height of hybrid aspen at the age of 18 years was 21.6 ± 0.84 m. Both stem volume and height had a high heritability and large differences between clones, indicating notable possibilities to improve the productivity of plantations via selection of best-growing genetic material.
4. Notable differences between clones were found both in the mean annual increment, ranging from 7 to 34 m^3 ha^{-1} $year^{-1}$, and proportion of HQSlogs, ranging from 0 to 35%, i.e. from 0 to 174 m^3 ha^{-1}.

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