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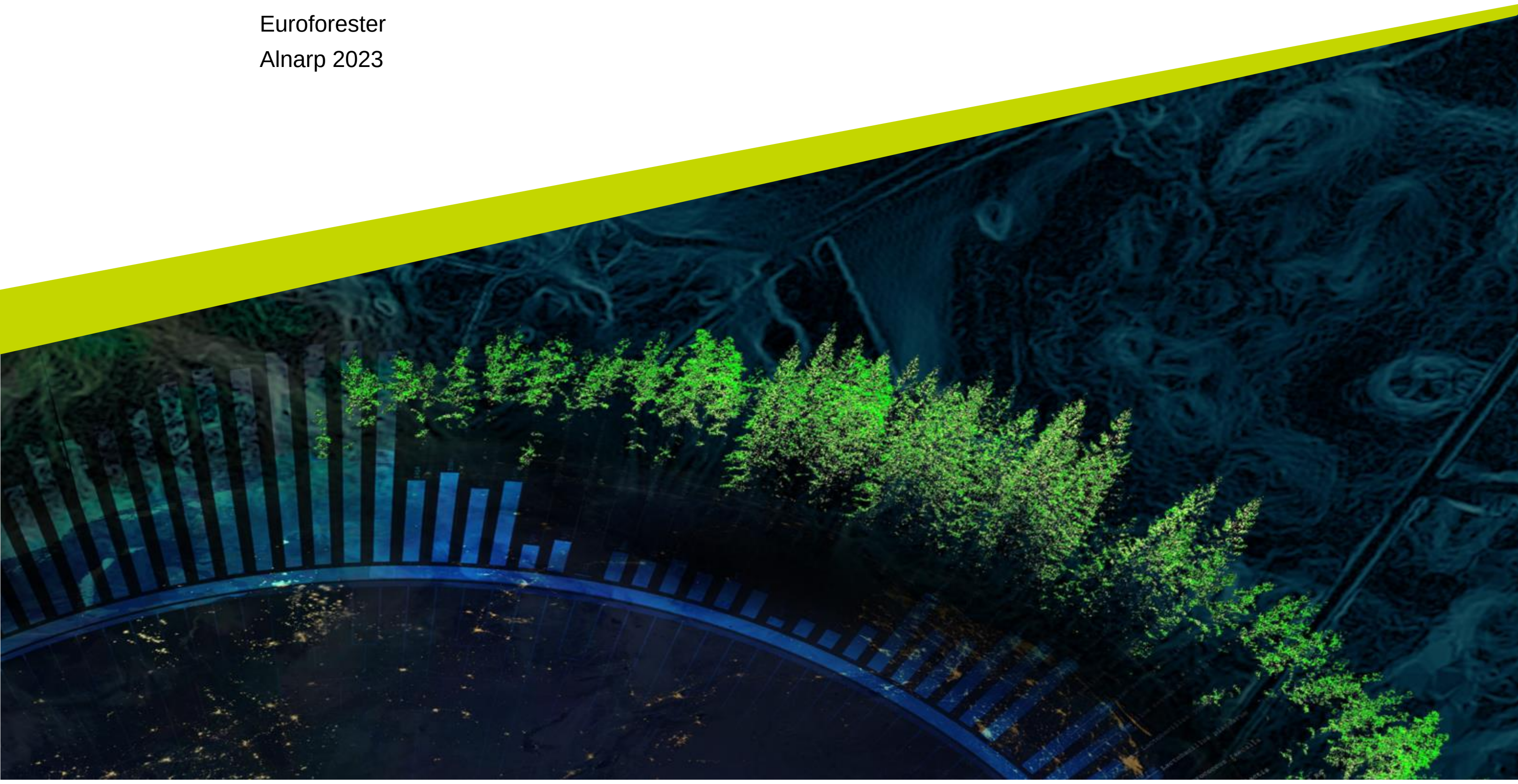

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Abstract

Silver birch is the most important broadleaf tree species in the context of wood production in Fennoscandia stating 12.9% of the total volume in Sweden (Nilsson et al., 2021). The issue is that birch wood currently available from Swedish forests is usually of low-quality classes and thereby is used mainly for pulp and fuelwood therefore its economic potential is not fully used and the willingness to invest in planting birch is low. Luckily tree breeding leads to the creation of fast-growing genotypes with higher quality. To increase interest in planting genetically improved silver birch (*Betula pendula* Roth.) further research is needed to assess the economic profit and popularize the knowledge about benefits coming from using genetically improved material.

In this study, data from two field trials (Remningstorp and Tagel) have been used where the same 10 material groups were planted. The material groups included 22 genotypes created in the elite populations (full-sib crossings), progenies of 14 selected +Trees, 50 comparison trees selected in proximity to +Trees, and 7 reference sorts. The planting design was randomized with a 2 x 2 m spacing in each trial. The measurements and assessment conducted in the field covered diameter at breast height (DBH), stem (SQ), and branches quality (BQ). The presence of damage meaning the occurrence of spike knots, double stems, and double tops were registered. The objective of this study was to examine the differences between different planting materials and to select the best individuals for future breeding.

The results showed that genetic improvement in silver birch brought improvement in diameter growth and quality characteristics compared to comparison trees. The offspring from the greenhouse plantation Ekebo 1 exhibited the largest diameter, showing a 22% increase. Improved material from Ekebo 4 seed orchard had the highest stem and branches quality with the lowest frequency of spike knots and double tops occurrence. Furthermore, the offspring of +Trees, selected based on phenotypic traits, outperformed comparison trees in diameter (4% increase), stem quality, and branches quality. The occurrence of damages was varied as the occurrence of spike knots and double tops was higher in +Trees but double stems were less frequent in this group. There was also some variability observed in the comparison on the stand level, where the advantage of +Trees was less pronounced. Due to the fact that phenotypic differences might be affected by many factors including the site, further research is needed on this topic. Lastly, the elite populations exhibited an average of 9% better diameter growth than comparison trees. The results showed high variability within Elite populations both in diameter and occurrence of damages.
These findings highlight the positive impact of genetic improvement in silver birch, emphasizing the potential for enhancing diameter growth and quality traits through breeding programs.

Keywords: Betula pendula Roth., genetic improvement, tree breeding, diameter growth, stem quality, branches quality

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1. Introduction

1.1. Birch ecology and its importance

Birch is the most common broadleaf tree species in Fennoscandia, with silver birch (*Betula pendula* Roth.) and downy birch (*Betula pubescens* Ehrh.) being the most commonly cultivated species (McAllister & Ashburner, 2016). Silver birch requires well-drained, sandy or silty till soils for optimal growth (Sutinen et al., 2002) whereas downy birch is less demanding and can grow in a wide range of conditions, including wet, poorly aerated soils and peatlands (Hynynen et al., 2010). Nevertheless, silver birch is more abundant as it is favoured in terms of production due to its better growth and higher stem quality on fertile sites (Heräjärvi, 2001, Hynynen et al. 2010).

There are multiple benefits related to the quality and diversity of the ecosystems coming from the presence of birch in species composition. It is a pioneer species with major capabilities for habitat restoration as it can establish efficiently in the early stages of succession after disturbances such as fire or clearfellings (Atkinson, 1992; Mitchell et al., 2007). Natural regeneration of birch is successful on various types of sites, particularly in canopy gaps created by thinnings or natural disturbances where gaps or strips are not wider than 60 m (Cameron, 1996). Moreover, birch provides important ecological functions, such as carbon sequestration, soil stabilization, and biodiversity conservation (Mitchell et al., 2007; Woś & Pietrzykowski, 2015). Birch stands and patches increase biodiversity richness and habitat availability for a wide range of organisms (Atkinson, 1992). It has been found that birch has a positive impact on soil nutrients and biological turnover. The decomposition of birch leaves is faster compared to conifer needles, leading to faster nutrient cycling and soil enrichment (Jonczak et al., 2020; Schua et al., 2015; Woś & Pietrzykowski, 2015). Birch has a positive effect on enzymatic activity and soil microorganisms (Woś & Pietrzykowski, 2015). Birch is also known for its phytoremediation potential for contaminated soils (Dmuchowski et al., 2014; Jonczak et al., 2020; Lewis et al., 2015).

1.2. Birch silviculture and timber market

Birch is the most important broadleaf tree species in northern temperate and boreal forests in the context of wood production (Hynynen et al., 2010). It is stating 12.9% of the total volume in Sweden (Nilsson et al., 2021).

Silver birch exhibits a sympodial height growth pattern (Heräjärvi, 2001; Heiskanen, 1957; Hynynen et al., 2010). On favourable sites, silver birch can reach heights of up to 24-25 m within 30 years, while on poor sites, the height increment remains modest, reaching only 6 meters in 30 years (Atkinson, 1992; Eriksson et al., 1997). Pure and managed silver birch stands in Finnish studies reach the culmination of height growth at stand ages of 10-20 years and of volume growth 5 years later (Oikarinen, 1983; Hynynen et al., 2010).

To ensure a high yield of good-quality timber in final fellings, high-intensity thinnings of 30-40% volume removal are applied with the aim of maintaining the living crown on 50% of the tree height to sustain a high growth rate (Cameron, 1996; Hynynen et al., 2010). Growth remains vigorous until the stand age of 40-50 years, with dominant height in a birch stand at the age of 50 years potentially reaching up to 30 meters (Oikarinen, 1983). Due to that, the usual rotation period of birch ranges from 30 to 60 years (Hynynen et al., 2010).

Birch can be grown in pure stands or with other tree species. In Sweden, birch resources usually come from spontaneous natural regeneration occurring in mixed stands dominated by planted coniferous species (Hynynen et al., 2010). Naturally regenerated birch in mixed stands is mostly of low value but with proper management practices, it can develop into profitable high-quality saw timber (Hynynen et al., 2010).

In managed, pure silver birch stands, the focus is on producing large-diameter, straight, and defect-free birch stems (Hynynen et al., 2010). The reason for this lies in the potential use of appropriately sized and high-quality sawlogs which are saw timber and plywood (Price & Macdonald, 2012). The presence of knots strongly influences the quality of birch wood and determines its utilization (Heiskanen, 1966; Karkkainen, 1984; Luostarinen & Verkasalo, 2000; Price & Macdonald, 2012). Therefore, pruning is recommended as pruned birch trees were found to provide logs of higher value (Skovsgaard et al., 2018; Skovsgaard et al., 2021). In the context of pure even-aged birch stands, planting is often necessary for their successful establishment, with typical planting densities within the range of 1600 to 2500 seedlings per hectare (Niemistö, 1995; Hynynen et al., 2010). Additionally, young birch plantations can suffer from ungulates and other herbivores (such as voles). This often requires intensive site preparation, weed control, and protective measures like individual tree shelters and fencing (Hynynen et al., 2010; Karlsson, 2002; Perala & Alm 1990).

The main issue is that birch wood sourced from Swedish forests is mainly used for pulp and fuelwood (Liziniewicz et al., 2022). This is primarily because of its poor quality which is shaped by insufficient silviculture practices mainly relying on spontaneous natural regeneration (Dubois et al., 2021; Liziniewicz et al., 2022). Since in most cases birch occurrence in the stand is not a forest owners' main target, conditions of growth are accidental and usually insufficient but also birch share in the stand usually declines over the rotation (Lidman, 2022). The removal usually starts during precommercial and commercial thinning to for example favour the growth of Norway spruce (*Picea abies* (L.) Karst) or Scots pine (*Pinus sylvestris* L.) dominating the stand (Götmark et al., 2005, Liziniewicz et al., 2022). It shows that birch is not properly valued by forest owners. One of the reasons is that there are many studies stating that birch production is low which results might not be fully representative. It is due to mentioned sub-optimal management practices that were often unchanged during the conduction of research. For example, in many studies inventory plots included spontaneously regenerated birch in coniferous stands that are lacking efforts aimed at growth maximization. Additionally, these plots usually do not contain improved material therefore are deprived of the potential genetic gain (Liziniewicz, 2022). The enlisted factors undoubtedly account for the low growth and poor stem quality of birch.

In addition, birch is a pioneer, light-demanding tree species that can fully utilize its growth potential only when it is a dominant tree in a stand of relatively wide spacing and low competition level (Atkinson, 1992; Dubois et al., 2021). Therefore, when the aim is to produce high-quality birch timber, monoculture plantations are often a more profitable, effective, and predictable choice (even though more expensive during the establishment phase) (Dubois et al., 2021; Liziniewicz 2022). Stener et al. (2005) stated that active management could balance the difference in production between birch and Norway spruce. Additionally, it is important to acknowledge that genetically improved material is expected to provide faster growth and better quality of the stem therefore its use has the potential to also cover the higher cost of the stand establishment by increasing the birch profitability (Stener & Jansson, 2005).

1.3. Tree breeding - current effort and state

For several years, reducing the use of non-renewable energy sources is extensively discussed. There are already many measures taken to decrease the reliance on fossil fuels burning as it is considered to be harmful on many levels - has a negative impact on the environment and contributes to global warming. Scandinavia set a goal to achieve a carbon-neutral energy system by 2050 (Seljom & Rosenberg, 2018). One of the possible ways to get close to achieving this goal is to promote the use of woody biomass (Haapanen et al., 2015). If this process is conducted successfully, it is expected that the need for timber will increase and put a bigger pressure on forestry. As land availability is another urging issue, it is favourable to use the area already designated for production purposes in the most efficient and extensive manner covering production, ecological and social needs (Ranius & Roberge, 2011). Currently, forest tree breeding is claimed to be one of the most productive and environmentally friendly ways to achieve this goal, therefore it has to be supported and developed further (Gailis et al., 2020; Jansson et al., 2017).

Additionally, breeding can accelerate the process of trees adapting to climate change and by that compensate for the lack of necessary time (Haapanen et al., 2015; Ruotsalainen, 2014). The Multiple Population Breeding Strategy (MPBS) is designed to ensure species preparedness for future climatic changes by dividing the breeding population into different sub-populations (Haapanen et al., 2015; Rosvall, 2019). Each subpopulation is bred for different adaptation targets defined by temperature and photoperiod. Another important ability of tree breeding is to create genotypes with higher adaptability and plasticity suitable across a range of sites (Jansson et al., 2017; Ruotsalainen, 2014). This is achieved by conducting field tests at several locations covering a wide range of climate conditions and selecting trees that perform well at all locations (Haapanen et al., 2015). Furthermore, breeding provides significant advantages at a minimal, additional cost, as the improved material is only slightly more expensive than unimproved material (Gailis et al., 2020; Liziniewicz et al., 2022). Using genetically improved forest plant material has a similar effect at the stand level to increasing the site index of the forest land, resulting in faster forest growth, earlier harvests, and the ability to shorten rotation time (Haapanen et al., 2015). The environmental impact is small, and improved material is also more vital, of better overall quality, and has better survival rates, which can be a significant benefit in harsh climates found in northern areas (Stener & Jansson, 2005). Improved survival rates provide opportunities to modify regeneration and silvicultural methods, such as reducing the number of plants per hectare. Haapanen et al. state that improved seedlings sourced from seed orchards had 11% higher survival than unimproved seedlings coming from local stand seed (2015). The choice of appropriate regeneration material is critical since it has significant silvicultural and economic consequences during the entire rotation period (Haapanen et al., 2015).

Silver birch is a good species to work with in genetics as it is abundant in the whole Fennoscandia plus has a relatively short rotation which gives a chance to collect the data covering the whole rotation period already within 30 years (Dubois et al., 2020). Various other birch species have been subject to field trials, including *B. papyrifera* Marsh., *B. pubescens* Ehrh., *B. lutea* Michx., and their hybrids, in southern Sweden and the results suggest that *B. pendula* Roth. is the most suitable option in the long term (Hynynen, et al. 2010).

The most extensive birch breeding program is being conducted in Finland, which has been ongoing since the 1960s (Koski & Rousi, 2005). There is also a long-term birch breeding program conducted in Sweden started in the late 1980s which led to substantial growth and stem quality improvement (Rosvall, 2011). A seed orchard for indoor cultivation in Sweden, located at Skogforsk Ekebo, has been projected to offer a 15% genetic improvement of both traits compared to unimproved material (Rosvall et al., 2001). According to the research conducted by Haapanen et al. genetic gain from improved material from seed orchards is expected to increase till 2050 to 15% in the north of Sweden, 35% in central Sweden, and 30% in the south of Sweden (2015).

Nevertheless, when undertaking long-term development projects that involve the use of improved material, it's crucial to take into account the potential changes in legislation that may restrict its use. Currently existing regulations are targeted for the use of improved reproductive material, including vegetatively propagated plants and non-native species. These regulations vary between countries and can affect the research progress and future growth potential of forests. It's important to note that regulations can change over time as our understanding of forests evolves (Hynynen et al., 2010).

In this master thesis, I aim to investigate the effects of different levels of genetic improvement on the growth and quality of birches. Specifically, phenotype parameters were measured and assessed such as the diameter, stem quality, branches quality, and damage occurrence. It was conducted based on 10 material groups representing different levels of genetic improvement: (i) overall comparison of material groups, (ii) comparison of +Trees and comparison trees, and (iii) comparison of full-sib families from the elite population. The study was done in two genetic field trials (in Tagel and Remningstorp) located in southern Sweden.

2. Materials and Methods

2.1. Site and experimental design

Two genetic field trials were established in 2014 in Tagel and Remningstorp in southern Sweden. Both trials were planted with a completely randomized tree-by-tree planting design in a 2 × 2 m spacing. Within each trial, the area was divided into plots (26 plots in Tagel and 23 plots in Remningstorp) with ca 120 seedlings planted in each plot. Within a plot the seedlings were planted in a pattern of 10 rows and 12 plant positions in a row. Each tree's ID code, genotype, and parent information was then associated with its location: tree number within a row, row number within a block, and block number. Not all genotypes were present in each plot due to the completely randomized design which is a common feature of genetic field trials.

Tagel is situated on latitude 57, with an average monthly temperature range from around -2°C in January to around 17°C in July, and the average monthly rainfall varies from around 39 to 80 mm. Remningstorp is situated on latitude 58, with an average monthly temperature range from around -2°C in January to around 17°C in July, and the average monthly rainfall varies from around 39 to 80 mm. Both trials were fenced before planting to eliminate browsing damage.

2.2. Material groups (i)

Ten material groups were planted in the trials (the same in both trials). The material groups included progenies of 22 genotypes from the elite populations of silver birch (full-sib crosses), progenies of 14 selected +Trees, progenies of 50 comparison trees that were selected in proximity of +Trees, and 7 reference sorts representing material from Swedish and Finnish plantations and seed sources. The reference material originated from seed orchards located in Ekebo (57°53'55.1"N 16°25'31.3"E) – Ekebo1, Ekebo2, Ekebo4, Asarum (56°12'12.8"N 14°50'01.2"E), LilaIstad (56°57'00.7"N 16°48'33.9"E), Oitti Finland (60°47'12.6"N 25°01'38.4"E), Visingsö (58°01'00.9"N 14°19'02.5"E).

2.3. +Trees (ii)

The experiment included progenies of 14 selected +Trees and 50 comparison trees. +Trees are the ones exhibiting superior phenotypic traits in comparison to their neighbouring trees (comparison trees). The progenies of 50 comparison trees were selected adjacent to the +Trees. +Trees and comparison trees were selected in eight stands in southern Sweden.

2.4. Elite populations (iii)

The elite material consisted of progenies of 22-full-sib families, which were produced by crossing trees in the Swedish elite birch population. The elite population comprised at the time of crossings with 30 clones of high growth and quality birch trees belonging to four southern Swedish populations (south from 59.5◦ latitude). The main objective of establishing the elite population was to enhance the genetic gain compared to the four existing birch breeding populations in southern Sweden by relaxing restrictions of genetic diversity.

2.5. Inventory

The data used in this study were collected in the first quarter of 2023 nine years after establishing the experiment. During the inventory, growth and external quality parameters were measured in all plots, including diameter at breast height (DBH), stem (SQ) and branch quality (BQ), and the presence of damage with the focus on double stems (DS) and tops (DT), and spike knots (SK) occurrence. Stem quality was evaluated based on a 9-point scale ranging from poor (1) to excellent (9) (Appendix 1). Branch quality considered angle size, and orientation of branches were evaluated on a 5-point scale ranging from poor (1) to excellent (5) (Appendix 2). The presence of damage such as spike knots, double top, and double stem was visually inspected and recorded. These assessments of growth and quality were conducted to find the distinction between genetic sources planted in the trials and aimed at selecting the best individuals for future breeding.

2.6. Data processing and statistical analysis

The results were analyzed for three different levels of genetic performance:

(i) The comparison of diameter, stem and branches quality and occurrence of damage of different material groups (based on the origin of the seed material) which were: +Tree, Asarum, Comparison Tree, Ekebo 1, Ekebo 2, Ekebo 4, Elite populations (Elitekorsn), LilaIstad, Oitti Finland, Sv Visingsö

(ii) The comparison of 14 +Trees and 50 comparison trees, where the effect of phenotypic selection was assessed by comparing diameter, stem and branches quality, and occurrence of damages between +Trees and comparison trees, both in general for each group and at the individual family level within stands.

(iii) The comparison of Elite population families which were the progenies of 22-full-sib families, which were produced by crossing trees in the Swedish elite birch population.

The data collected from the field was initially stored in an Excel spreadsheet. The first step was to inspect the data for any missing values and errors, The data analysis was conducted with RStudio using the readxl package (Wickham et al., 2019). Its processing was conducted through functions from tidyverse package (Wickham et al., 2019). The figures were generated using the ggplot2 package to facilitate interpretation and communication of the findings (Wickham, 2011). Bar charts were used to show the mean stem and branches quality ratings for various materials and the occurrence of damage like spike knots, double top, and double stem. Boxplots were used to show the distribution of diameter growth measurements for different planting materials. The statistical analysis provided insights into the impact of planting material on the stem and branches quality ratings, presence of damage and diameter growth.

The statistical analysis was performed to assess the impact of different materials on the measured parameter, specifically the diameter (could be also used for the % of class occurrence) of the trees. The experiments were subjectively divided into three blocks to control and minimize the influence of factors other than the materials being tested. Blocks contained a similar number of plots, and the mean value for each material within these blocks was calculated. An analysis of variance (ANOVA) was conducted to determine the significance between the various planting materials.

The statistical model used for the analysis was as follows:

$$Yijk = \mu + Block_i + Material_j + error_{ijk}$$

Here, Yijk represents the observed value for the diameter (or % of class occurrence) of the trees. The term μ represents the overall mean, Block accounts for the effect of different blocks i, Material represents the effect of different materials j, and error represents the random error component.

Additionally, a post-hoc test using the Tukey method was performed to assess pairwise comparisons between the materials. A significance level of $p < 0.05$ was considered statistically significant.

3. Results

3.1. Performance of material groups (i)

In this section, the performance of all material groups is presented. ANOVA test reveals a significant difference for diameter among the material groups. However, for the stem and branches quality, the difference among material groups is not statistically different (Table 1).

Table 1. The results of ANOVA test including factors: Experiment (representing the impact of difference between two trials – Tagel and Remningstorp), BLOCK (representing the impact of three blocks set for statistical analysis), and Material groups (representing the impact of different planting materials) on three key tree growth characteristics: Diameter, Stem Quality, and Branches Quality. The table displays degrees of freedom (df), F values, and associated p-values (Pr(>F)), providing insights into the statistical significance of these factors on the examined growth characteristics.

		Growth characteristics					
		Diameter		Stem quality		Branches quality	
	df	*F value*	*Pr(>F)*	*F value*	*Pr(>F)*	*F value*	*Pr(>F)*
Experiment	1	86.777	3.00E-12	3.406	0.07126	6.047	0.0177
BLOCK	2	0.672	0.51528	3.354	0.04349	1.706	0.1927
Material groups	9	4.783	0.00015	2.843	0.00931	0.968	0.478

The ANOVA results show that there is a lack of statistical significance for the material groups and the occurrence of damages (spike knots, double tops, and double stems) (Table 2). All of the results are presented, and their implications are examined in the discussion section.

Table 2. The results of ANOVA test including factors: Experiment (representing the impact of difference between two trials – Tagel and Remningstorp), BLOCK (representing the impact of three blocks set for statistical analysis), and Material groups (representing the impact of different planting materials) the occurence of damages: spike knots, double tops, and double stems. The table displays degrees of freedom (df), F values, and associated p-values (Pr(>F)), providing insights into the statistical significance of listed factors on the occurence of damages.

		Occurrence of damages					
		Spike knots		Double tops		Double stems	
	df	*F value*	*Pr(>F)*	*F value*	*Pr(>F)*	*F value*	*Pr(>F)*
Experiment	1	3.468	0.0688	0.224	0.639	1.088	0.302
BLOCK	2	0.881	0.4213	0.231	0.795	1.38	0.262
Material groups	9	0.842	0.5817	0.452	0.899	1.676	0.122

The results of the post-hoc analysis using the Tukey method for group comparisons revealed significant differences in the diameter among the various groups. Groups Ekebo 1, LilaIstad, and Elite populations displayed similar mean values. Likewise, groups Sv Visingsö, +Trees, and Asarum shared the comparable mean measurements. In contrast, comparison trees exhibited a distinct mean value, indicating its significant difference from the former groups. Furthermore, the Oitti group demonstrated the lowest mean value, which differed significantly from all other groups. (Table 3)

Table 3. The table displays mean diameter measurements for various material groups, with accompanying letters denoting the results of pairwise Tukey test. The letters (a, b, c) indicate statistically significant differences in mean diameter values between the corresponding material groups. Groups with the same letter are not significantly different, while different letters indicate significant distinctions in mean diameters.

Material groups	Mean diameter $^{\text{Tukey test results}}$
Ekebo 1	68^{a}
LilaIstad	65^{ab}
Elitkorsn	63^{ab}
Ekebo 2	61^{ab}
Ekebo 4	60^{ab}
Sv Visingsö	59^{abc}
+Tree	59^{abc}
Asarum	59^{abc}
Comparison Tree	56^{bc}
Oitti Finland	48^{c}

Almost all improved materials performed better than comparison trees in terms of diameter (Fig. 2). The largest mean diameter 68 mm was observed in the material from greenhouse plantation Ekebo 1 which had a 22% greater diameter than comparison trees. The second best growth was in the offspring coming from open field plantation in LilaIstad which had 16% higher diameter. The slightly higher diameter than comparison trees had material coming from the old outdoor plantation Asarum which gave an improvement of 2%. The offspring coming from the Finnish Oitti plantation had 16% lower diameter than comparison trees. Elite crosses showed a significant improvement of 9%. (Fig. 2)

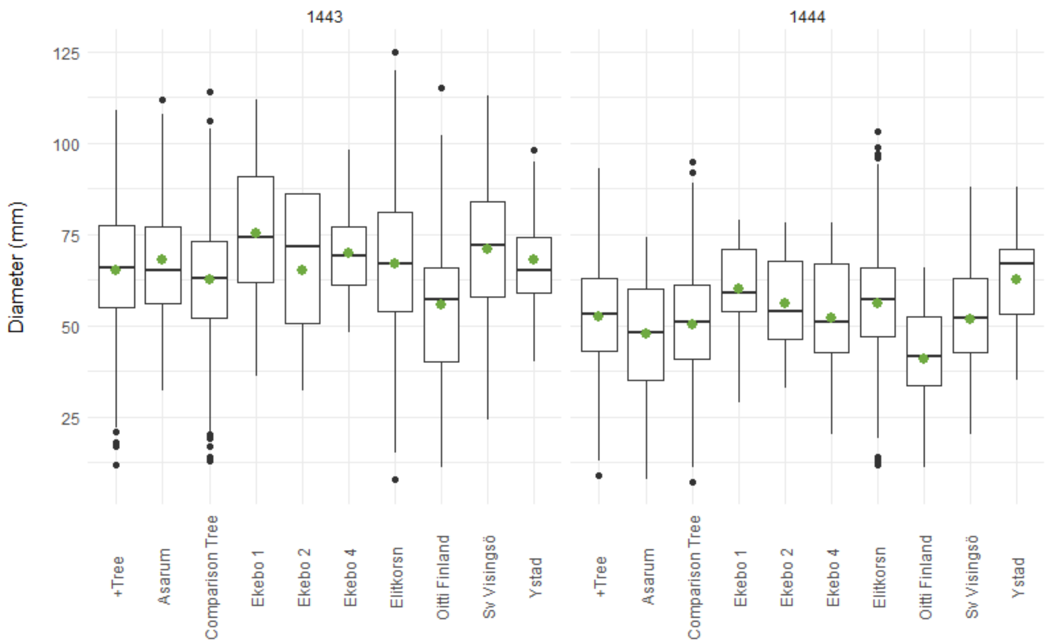

Figure 2. Stem diameter (mm) at 1.3 m height, in Tagel (1443) and Remningstorp (1444).

Ekebo 4 had the highest value both in stem (5.9) and branches (3.9). Ekebo 2 had the worst stem quality (4.2). When it comes to branches Ekebo 2 and LilaIstad performed the worst (2.6). The occurrence of spike knots was the highest in LilaIstad material group (36%) and the lowest in Ekebo 4 (19%). The occurrence of double top was the highest in Ekebo 1 (31%) and the lowest in Ekebo 4 (14%). The occurrence of double stem was most frequent in Sv Visingsö (26%) and least frequent in Ekebo 4 and Asarum. (Fig. 3-7)

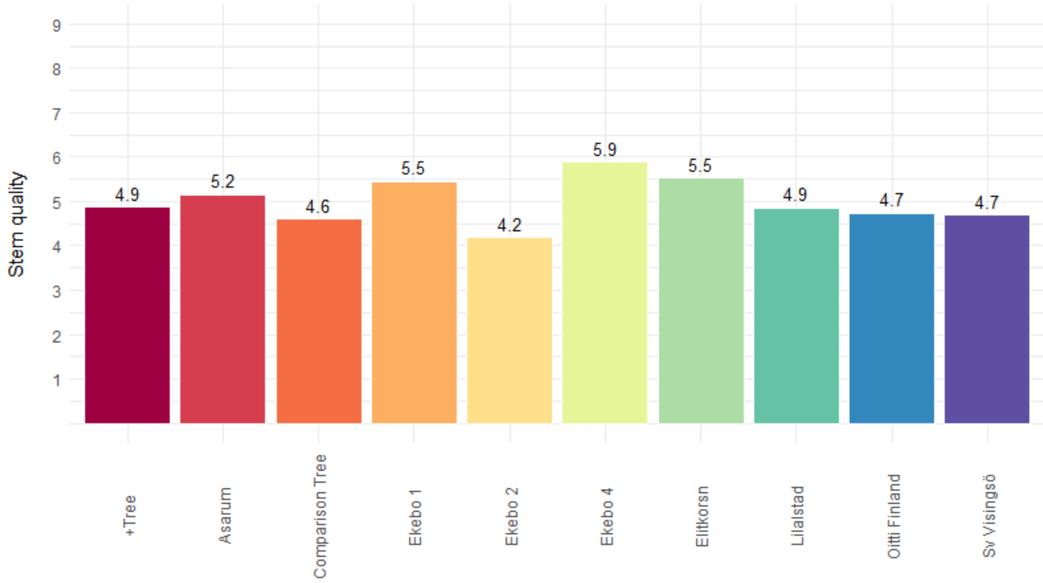

Figure 3. Average stem quality presented in the quality index ranging from 1 to 9.

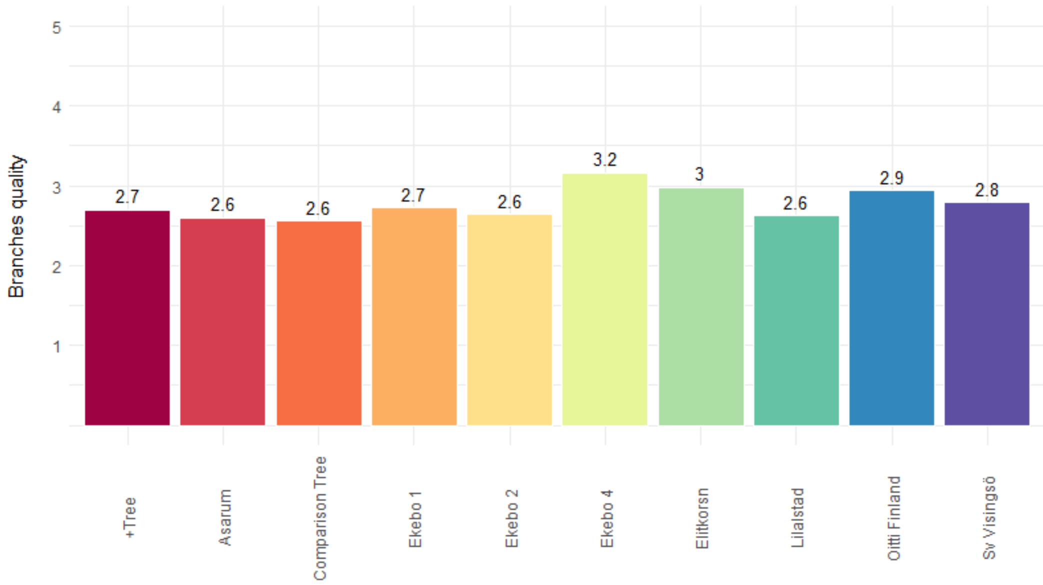

Figure 4. Average branches quality presented in the quality index ranging from 1 to 5.

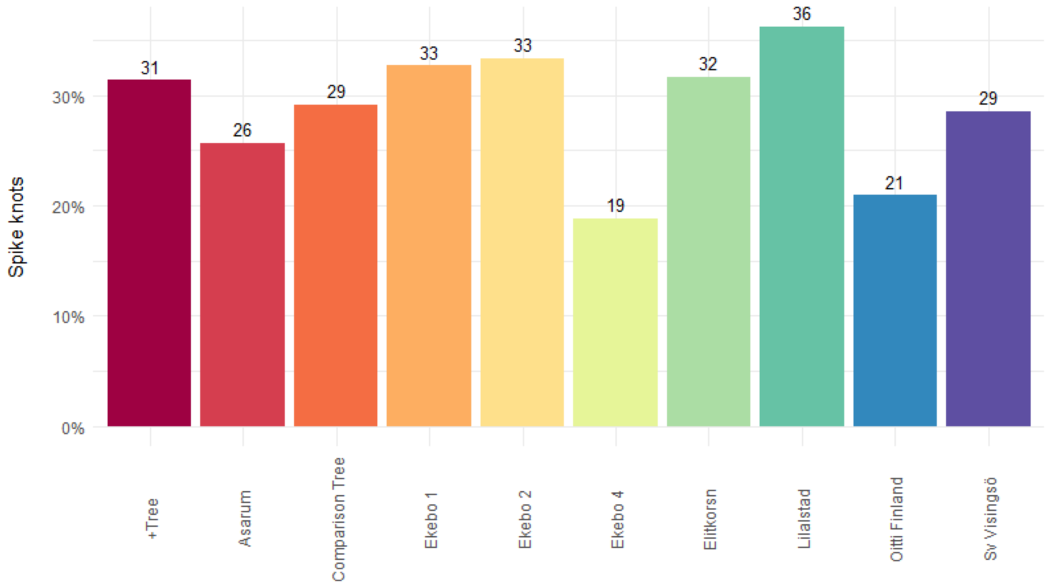

Figure 5. The frequency of spike knots occurrence within different material groups.

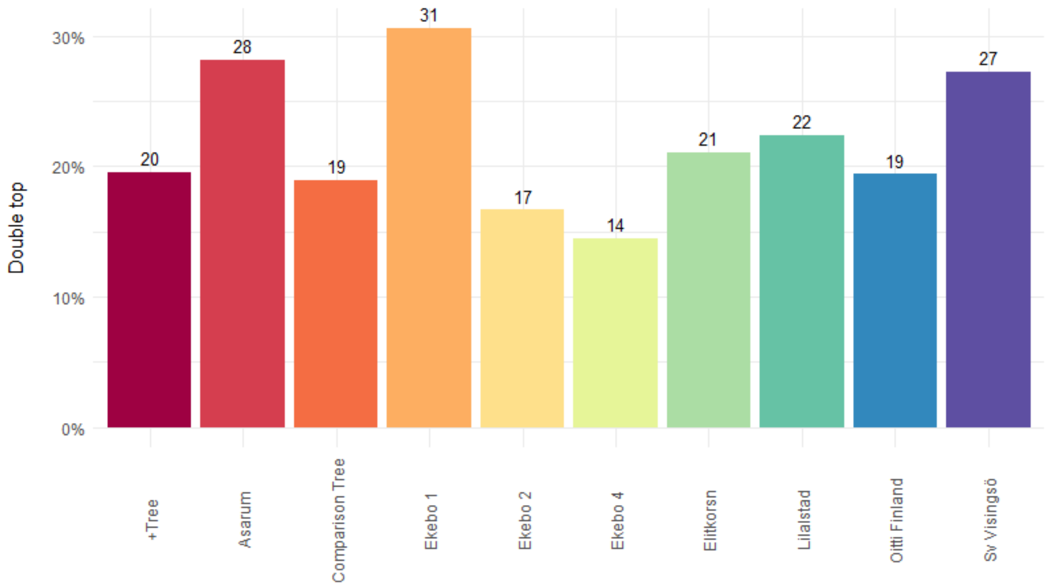

Figure 6. The frequency of double tops occurrence within different material groups.

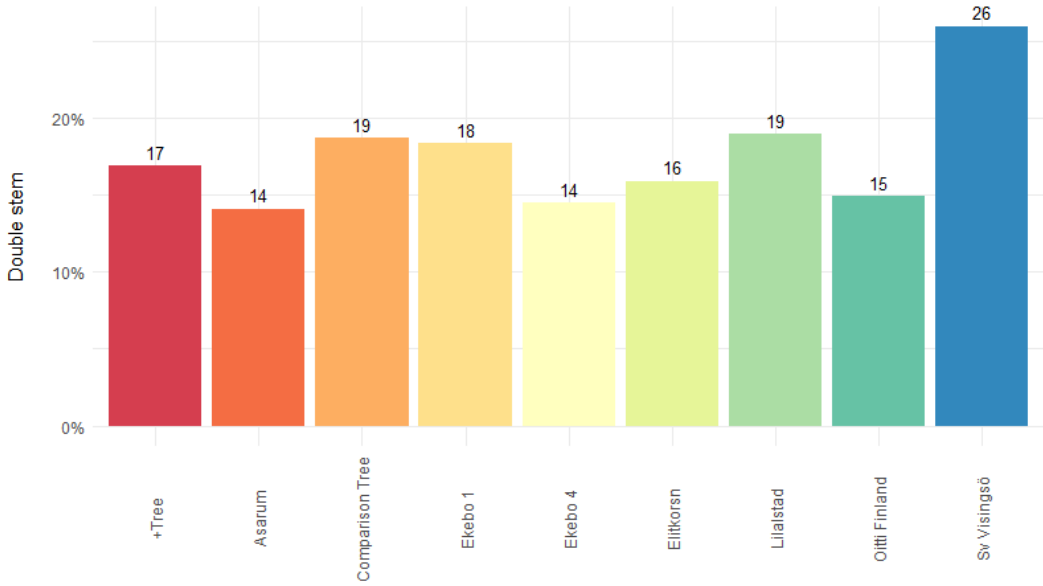

Figure 7. The frequency of double stems occurrence within different material groups.

3.2. Performance comparison of +Trees and comparison trees (ii)

The results showed that +Trees exhibited superior growth in terms of diameter (Fig. 8), stem quality (Fig. 9), and branches quality (Fig. 10), but had varied levels of damage (Fig. 11 & 12). On average, +Tree offspring had 4% higher diameter than comparison trees. +Trees had better stem and branches quality. The occurrence of spike knots and double tops was higher. The occurrence of double stems was lower in +Trees group (Fig. 13).

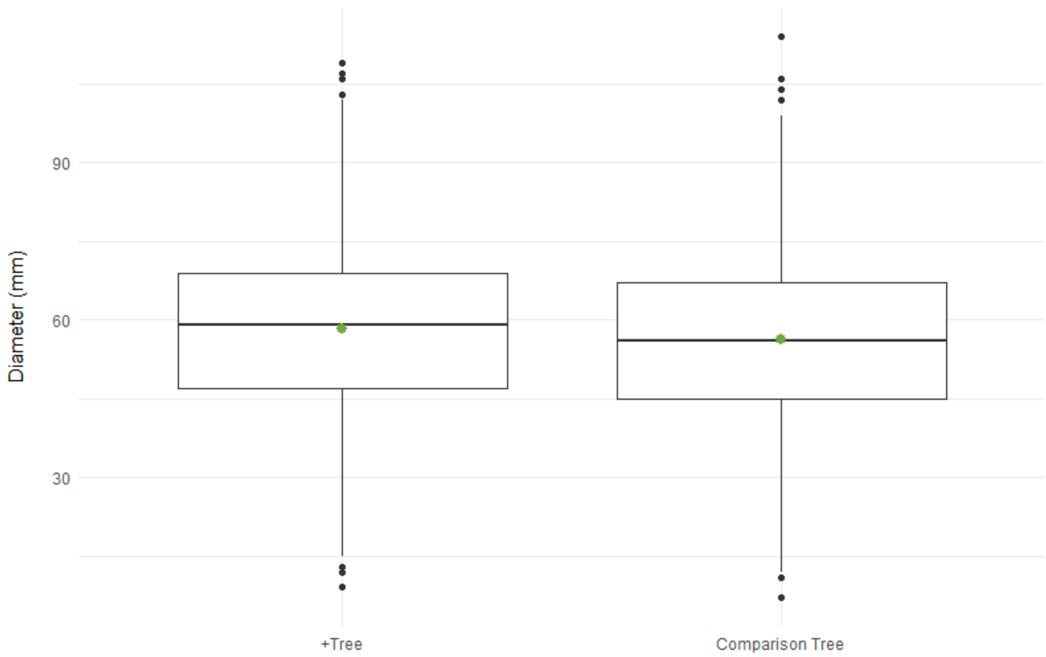

Figure 8. Stem diameter (mm) at 1.3 m height of +Trees and comparison trees.

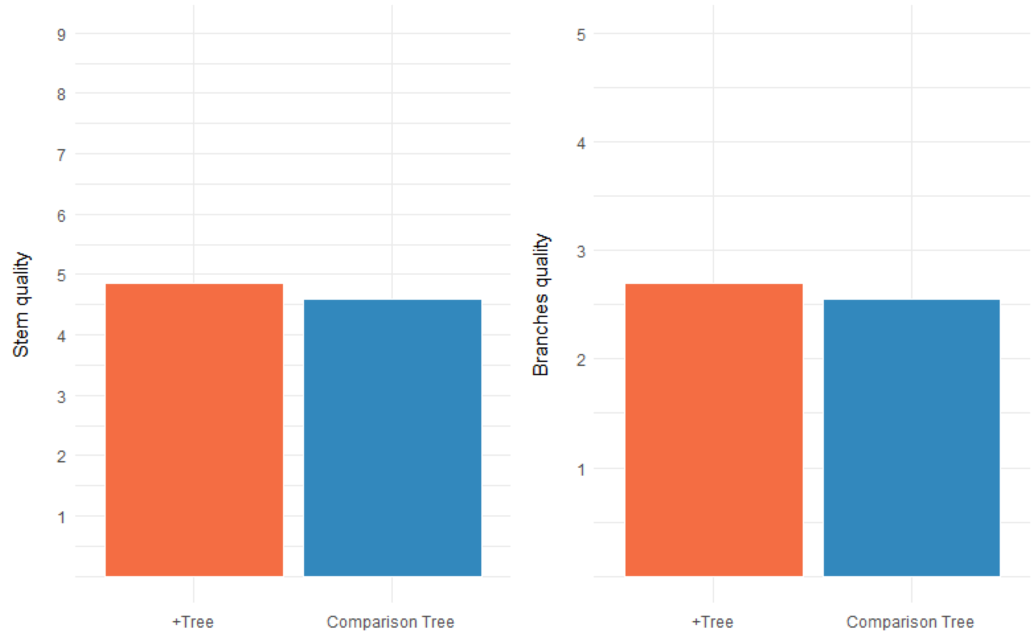

Figure 9 & 10. Stem and branches quality of +Trees and comparison trees.

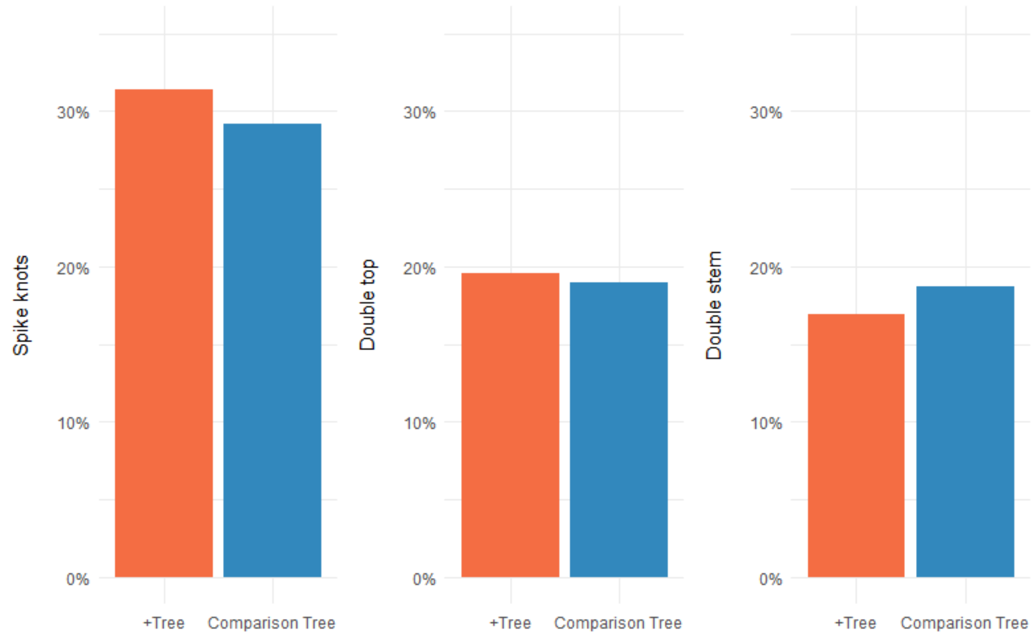

Figure 11, 12 & 13. The occurrence of spike knots, double tops and double stems in +Trees and comparison trees.

While the growth and quality improvement between +Trees and comparison trees was found to be relatively stable and consistent, there was a noticeable variability observed at the stand level. On the stand level, the advantage of +Trees over comparison trees was not as pronounced (Fig. 14).

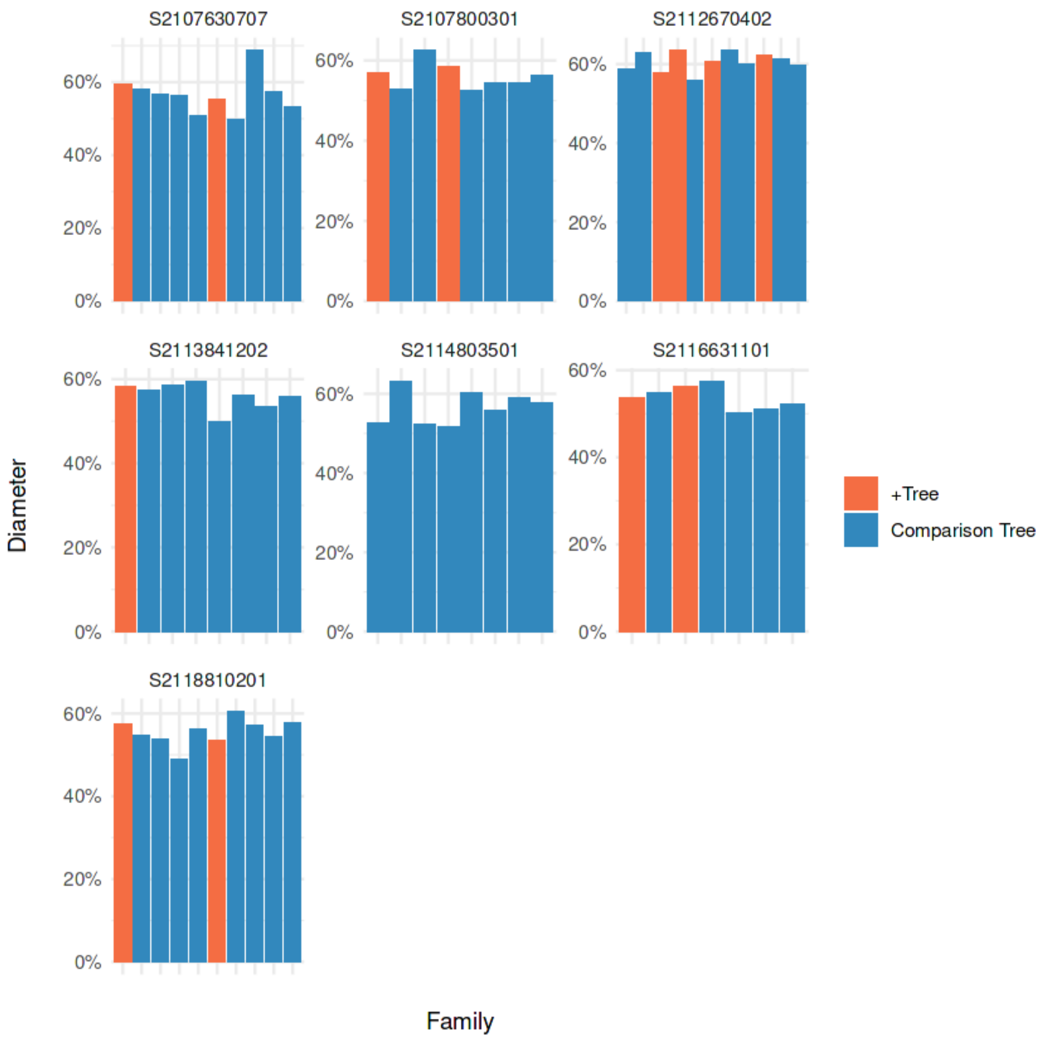

Figure 14. Average diameter of the progenies of selected +Trees (orange) and comparison trees (blue) growing in a proximity of that +Trees in seven stands (top number).

Table 4. The column named Diameter growth difference represents the extent of improvement in terms of larger diameter between +Trees and comparison trees at the stand level. The table includes the Best +Tree column, which indicates the highest diameter value of a +Tree measured in a particular stand, and the worst comparison tree column, which shows the lowest diameter value of a comparison tree measured in the same

	Stand average			Family per stand average		
STAND	+Tree	Comparison Tree	Diameter growth difference	Best +Tree Family	Worst Comparison Tree Family	Diameter relative difference
	58.3	56.0	4.1 %	65.8	47.1	39.8 %
S2107630707	56.3	54.8	2.8 %	78.0	21.0	271.4 %
S2107800301	55.6	54.6	1.8 %	71.5	33.5	113.4 %
S2112670402	58.4	57.5	1.5 %	71.3	18.0	296.1 %
S2113841202	60.0	55.9	7.3 %	71.0	26.0	173.1 %
S2114803501	59.2	57.5	2.8 %	72.5	17.0	326.5 %
S2116631101	58.9	57.1	3.1 %	70.8	27.5	157.3 %
S2118810201	59.8	56.6	5.6 %	78.5	24.0	227.1 %
Average	**58.3**	**56.2**	**3.8 %**	**72.4**	**26.8**	**170.6 %**

3.3. Performance comparison of Elite populations (iii)

On average, elite offspring had 9% better diameter growth than comparison trees. Additionally, the results show high variability within Elite populations. The best family had 28% higher diameter than the average family and 57% higher diameter than the worst family (Fig. 15). The occurrence of spike knots in the best family was 23% and in the worst family was 57%. The occurrence of double tops in the best families was 8% and in the worst families was 43%. The occurrence of double stems in the best family was 8% and in the worst family was 43%. (Fig. 16-18)

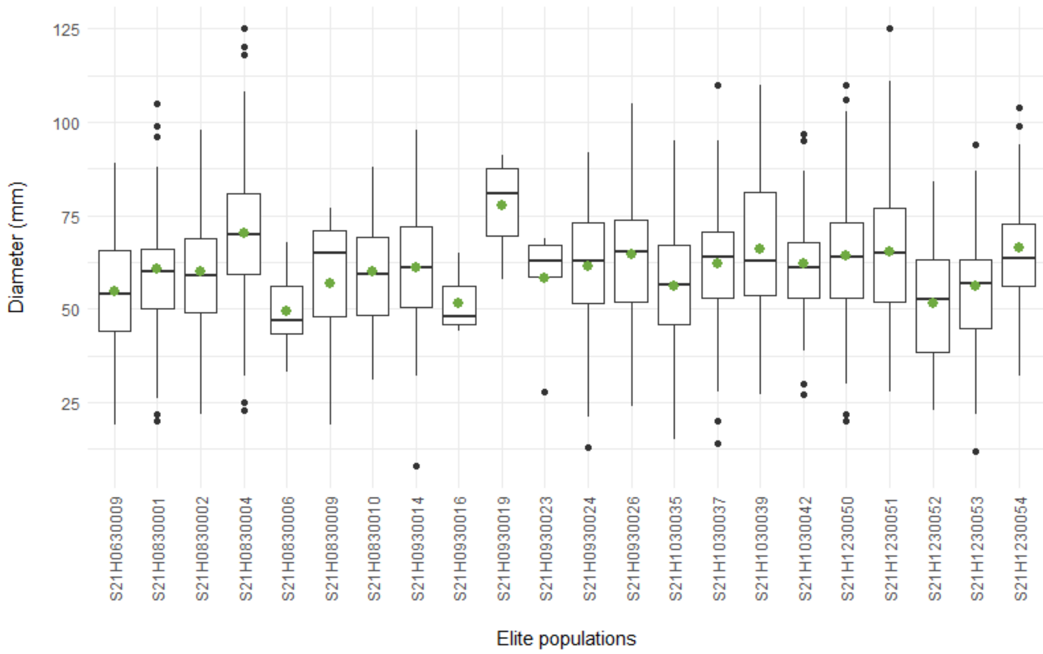

Fig 15. Stem diameter (mm) at 1.3 m height of 22-full sib families from the Elite populations.

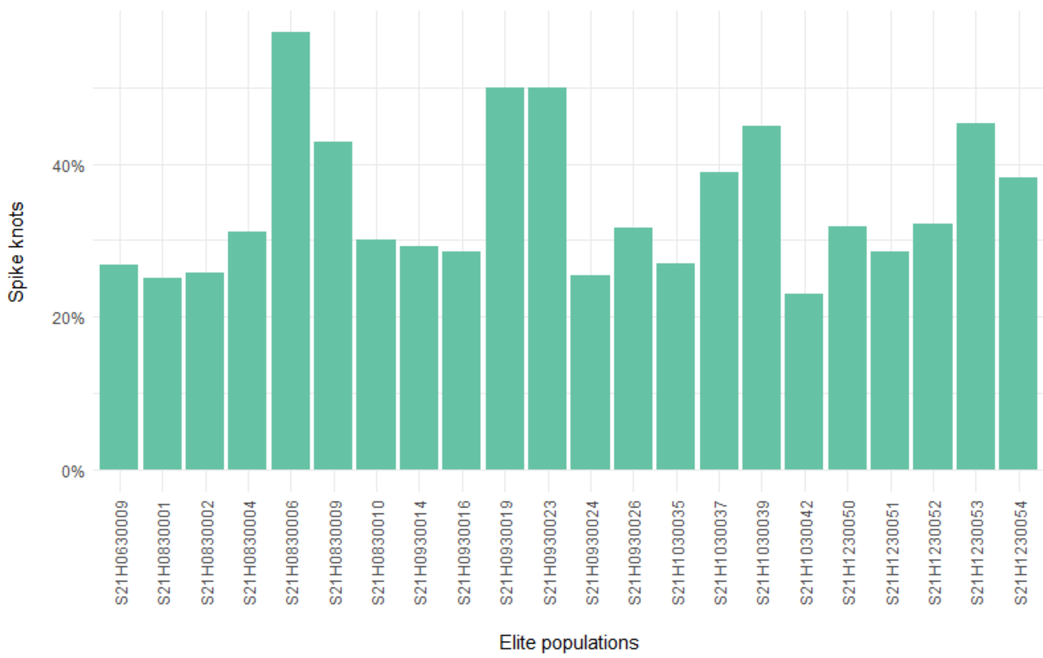

Fig 16. The occurrence of spike knots in 22-full sib families from the Elite populations.

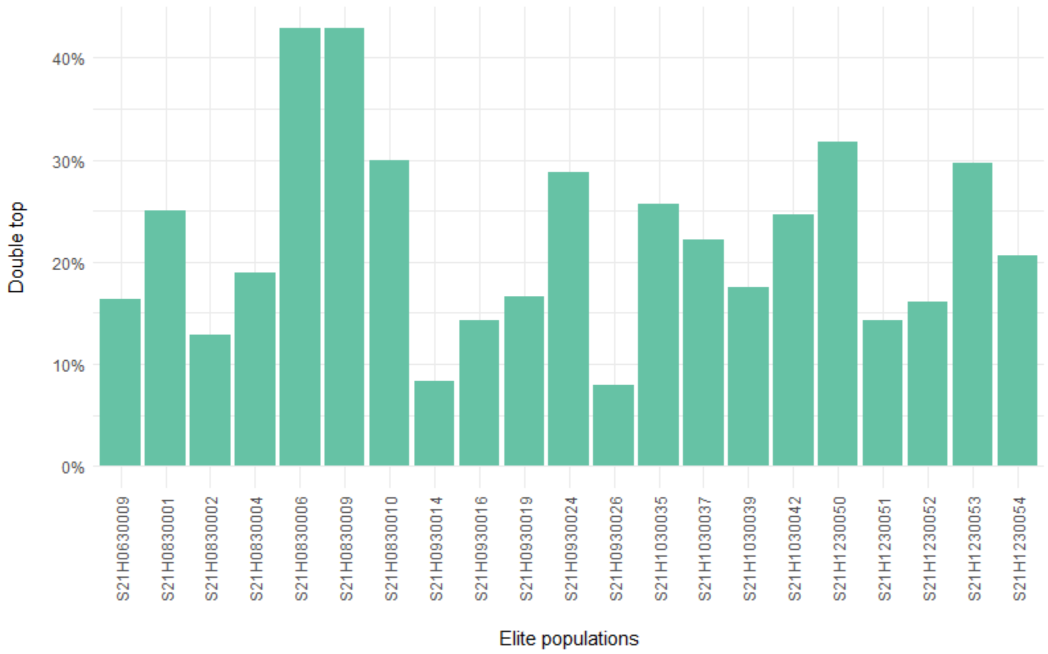

Fig 17. The occurrence of double tops in 22-full sib families from the Elite populations.

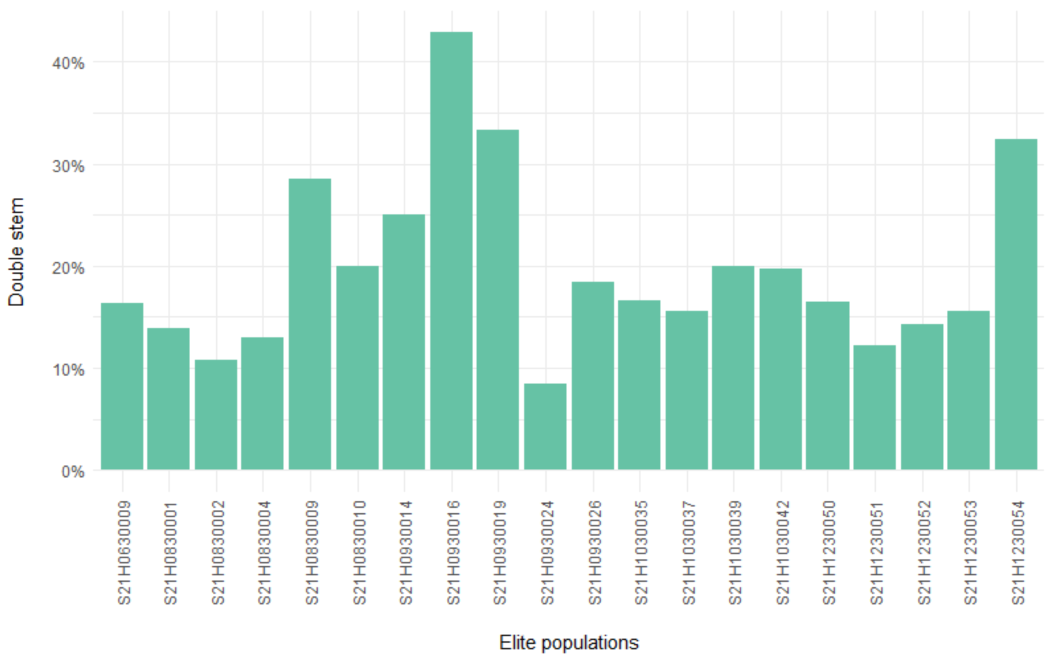

Fig 18. The occurrence of double stems in 22-full sib families from the Elite populations.

4. Discussion

Firstly, I will discuss the possible reasons for the statistically not significant results in the correlation of material groups with branch and stem quality, as well as with the occurrence of damages. Additionally, I will emphasize the importance of reporting these results and their implications for research.

The statistically not significant results can be caused by many factors for example the sample size, human bias, environmental factors, etc. (Wasserstein & Lazar, 2016; Yaddanapudi, 2016). For instance, there was a notable difference in results between experiments in Tagel and Remningstorp. Increasing the size and amount of trials can often enhance the ability to detect significant patterns. Additionally, engaging multiple individuals in data collection can enhance reliability. Consistency among multiple observers provides greater confidence in the accuracy of the measurements and reduces the risk of systematic errors associated with a single data collector's perspective. I would like to note that the results coming from the data based on measurements (diameter) showed a statistical significance between material groups and the examined trait. At the same time the stem, and branches quality, and the occurrence of damages that were based on subjective assessment and observations, resulted in a lack of statistical clarity. Human error and subjectivity could have a strong impact on the conduction of the project. Another possible reason is the impact of environmental factors and site-dependent effects as forestry research operates within a dynamic ecological context characterized by natural variability. Therefore, statistically not significant findings should be interpreted with an understanding of this influence.

Forestry research heavily relies on sound statistical analysis to derive meaningful conclusions from data. The ASA's clarification reinforces the importance of employing statistical tests accurately in forestry studies, but at the same time warns against selective data reporting (2016). To support that, Wasserstein & Lazar based on ASA’s report claims that transparency is the key and all results should be reported (2016). Apart from that, a nuanced approach to p-values is suggested, namely to not rely extensively on a single statistical index and to not ignore the statistically not significant results (Dushoff, 2019; Grabowski, 2016; Wasserstein et al., 2019). Therefore, all results are included in the thesis because not meeting the threshold of $p < 0.05$ does not necessarily imply their absence but rather point towards further exploration and provide insights for future research directions.

Statistically not significant findings guide further exploration by emphasizing the need for refining study design, expanding sample sizes, and considering broader analyses. They play an integral role in advancing our knowledge base and their reporting should not be understated (Wasserstein & Lazar, 2016).

Now, in light of the results, I would like to analyze how certain material groups performed and explore the potential factors influencing their performance. Majority of improved material groups outperformed comparison trees in terms of diameter (correlation of high statistical clarity), but also stem quality, branches quality and occurrence of damages (without a statistically clear correlation). The offspring from the greenhouse plantation Ekebo 1 exhibited the largest mean diameter of 68 mm, representing a 22% increase compared to comparison trees. It is consistent with the claim that greenhouses can accelerate birch breeding and increase the effectiveness of the whole process by providing a controlled setting for data collection, reducing environmental factors, giving a possibility of growth acceleration and stating a stable base for disease and risk management (Alves et al., 2020; Lepisto 1973).

Asarum had the lowest improvement level in diameter and is stating the first birch open-air seed plantation established in the 1960's. Trees at Asarum were not tested +Trees selected based on growth and quality properties when the plantation was established. The trees were tested later on and most of them were considered as not proper for further improvement. The progenies of Asarum were just 2% better in diameter than comparison trees. Therefore, the results from Asarum can support the claim that relying on phenotypic observations to establish seed orchards may not guarantee a genetic gain. The study that addresses the effectiveness of phenotypic selection is the one of Cornelius, in which he claims that in some cases phenotypic selection can give a satisfying increase in the diameter growth but the issue is that the predictability of the outcome is low (1994). He states that the effect depends on many factors including heritability, genetic variance, and selection intensity, and in unfavorable cases, the gain can be non-existent or very slight (Cornelius, 1994). Additionally, Asarum's plantation is quite small, and one can assume that there is quite large background pollination from surrounding birch stands. Ruotsalainen and Lindgren claim that unimproved pollen coming from background pollination can be the main drawback when using open-pollinated material and can significantly reduce genetic gain (1998).

The LilaIstad plantation is also an open-air plantation but it is located on Öland island where the background pollination can be expected to be significantly lower. However, the choice of the mother clone remains crucial and the results from this plantation can vary notably between years, reflecting fluctuations in pollen quality and quantity which, as the study of Di-Giovanni & Kevan supports, impact the genetic diversity of the seeds produced (1991).

Ekebo 1 material had on average 22% higher diameter than comparison trees while offspring from Ekebo2 and Ekebo4 were respectively 5% and 6% better. One would expect Ekebo4 to perform better than Ekebo1 and Ekebo2 as it states the most advanced seed plantation and consists of tested +Trees. Smaller Ekebo4 offspring may be due to differences in flowering frequency between clones in an annual harvest and different number of clones in the orchard.

The Finnish seed orchard Oitti had the worst growth which was lower than the comparison Trees by 16%. It was possible to predict as according to Viherä-Aarnio et al. latitudinal seed transfer has a significant effect on its growth and survival (2005). The Finnish material, which is intended to be used in southern Finland, has been moved more than 3 latitude degrees in the Tagel experiment and based on the claim of Stener and Jansson birch is recommended to be moved max 25 miles in a north-south direction without tangible effects on survival, growth and quality (2005).

The differences in diameter growth between comparison trees and +Trees were 4%. The figure is quite in line with the theoretical assumptions that when estimating the genetic breeding gain for birch the +Tree effect, i.e. the gain in the phenotypic selection of +Trees, is 5%, which is half that of spruce and pine (Rosvall et al., 2001). The lower +Tree effect is mainly due to the fact that there were few well-managed birch cultural stands, which meant that many +Trees were selected in small, unpolluted, and unevenly emerging natural stands.

Also, the lack of a clear and consistent positive trend within individual stands can be attributed to the selection strategy employed in +Tree selection. This strategy considered not only growth but also quality characteristics like straightness and branchiness. This selection approach likely contributed to the observed variability of results. In their study, Egbäck et al. discussed the potential trade-offs involved in breeding decisions that are focused on specific traits (2018). They emphasized that prioritizing one trait may unintentionally impact other aspects of tree morphology, therefore the attempts to improve few traits at once can be difficult to predict and may result in a broad range of breeding outcomes (Egbäck et al., 2018).

The study is limited by the sample size and the geographic location of the study area mostly due to the limited resources spent on birch breeding. The annual variation in the performance of seedlings coming from seed orchards has not been considered and can be studied in the future. The results may not be generalizable to other forests or regions. Additionally, the performance of improved materials should be monitored throughout the entire rotation period, including silvicultural measures such as spacing, thinnings (pre-commercial and commercial), and fertilization, ideally using larger experimental plots. Also, Wu emphasizes that if the utilization of individual clones becomes a future consideration, it should be approached cautiously, given the significant variation in their performance (2018). Therefore, in forestry practice, it is recommended to use a mixture of clones as this approach, according to Rosvall, enhances genetic diversity, reduces vulnerability to pests and diseases, ensures greater adaptability to changing environmental conditions, and ultimately contributes to the overall health and resilience of forest ecosystems (1999).

Nevertheless, enlisted ecological benefits suggest that the Swedish forestry industry and forest owners should expand their focus beyond the two conifer species. Understanding the current status and future potential of birch in Swedish forestry is crucial for sustainable forest management. Additionally, birch has a strong potential for climate change threats mitigation, making it a promising tree species for the future.

5. Conclusion

In this study, I examined birch material groups with different improvement levels coming from the silver birch breeding program in Sweden. My findings indicated that the majority of improved materials demonstrated better performance in terms of diameter growth represented by progenies of trees selected in proximity to +Trees. The differences in diameter growth between +Trees and comparison trees showed in general a positive effect of +Trees selection. It also showed a high variation within trials level and between the two trials. This underscores the potential influence of site-specific factors on phenotypic selection outcomes therefore there is a need for further genetic tests. Variation within families secure sustainable selection possibilities, as there was higher variation within families than between families which is good for breeding and selection.

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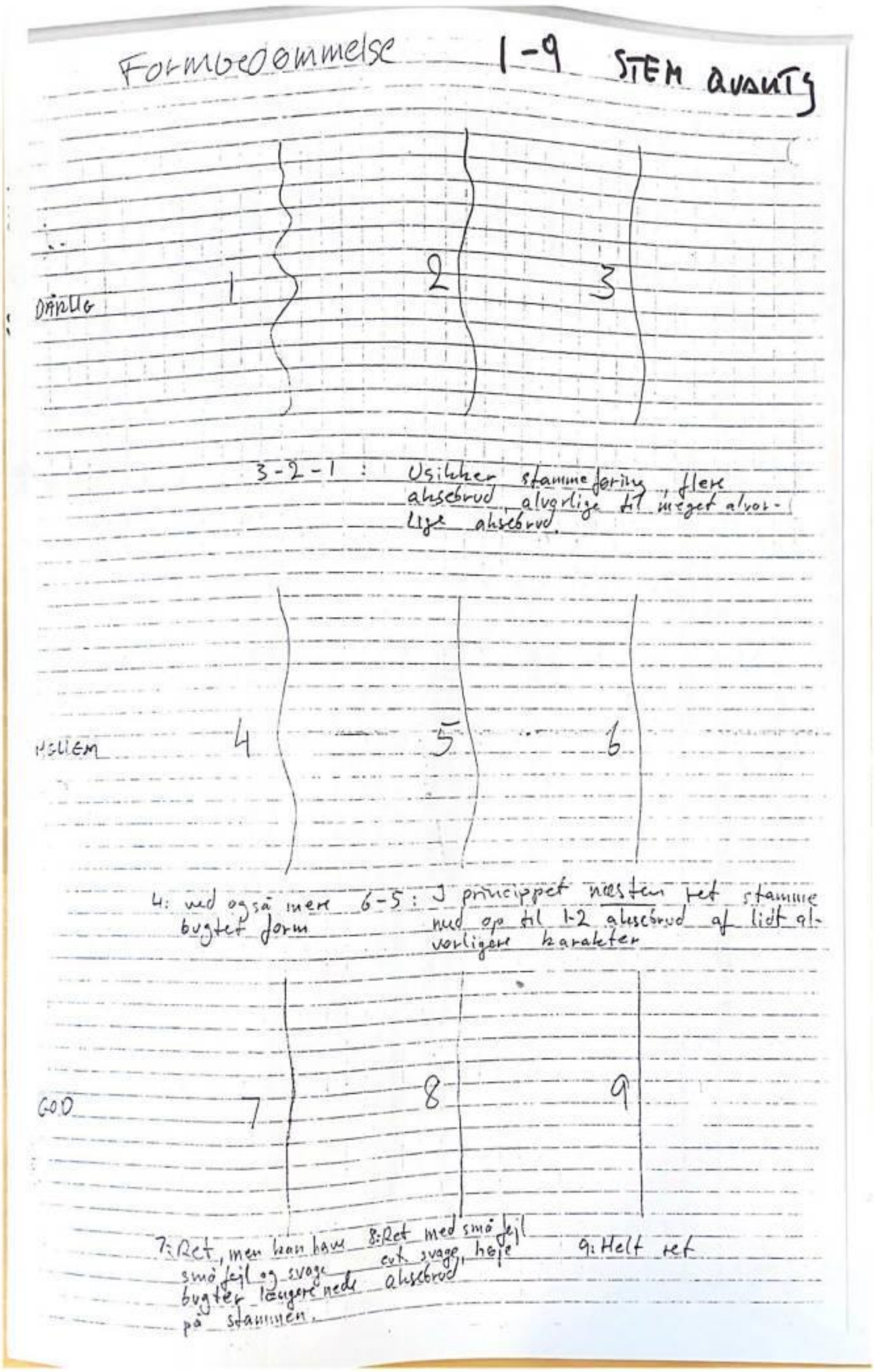
Appendix 1


Formbedømmelse 1-9 STEM QUALITY
DÅRLIG
1
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3-2-1 : Usikker stammeføring, flere aksebrud, alvorlige til meget alvorlige aksebrud.
MELLEM
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4: med også mere bugtet form
6-5: I princippet næsten ret stamme med op til 1-2 aksebrud af lidt alvorligere karakter
GOD
7
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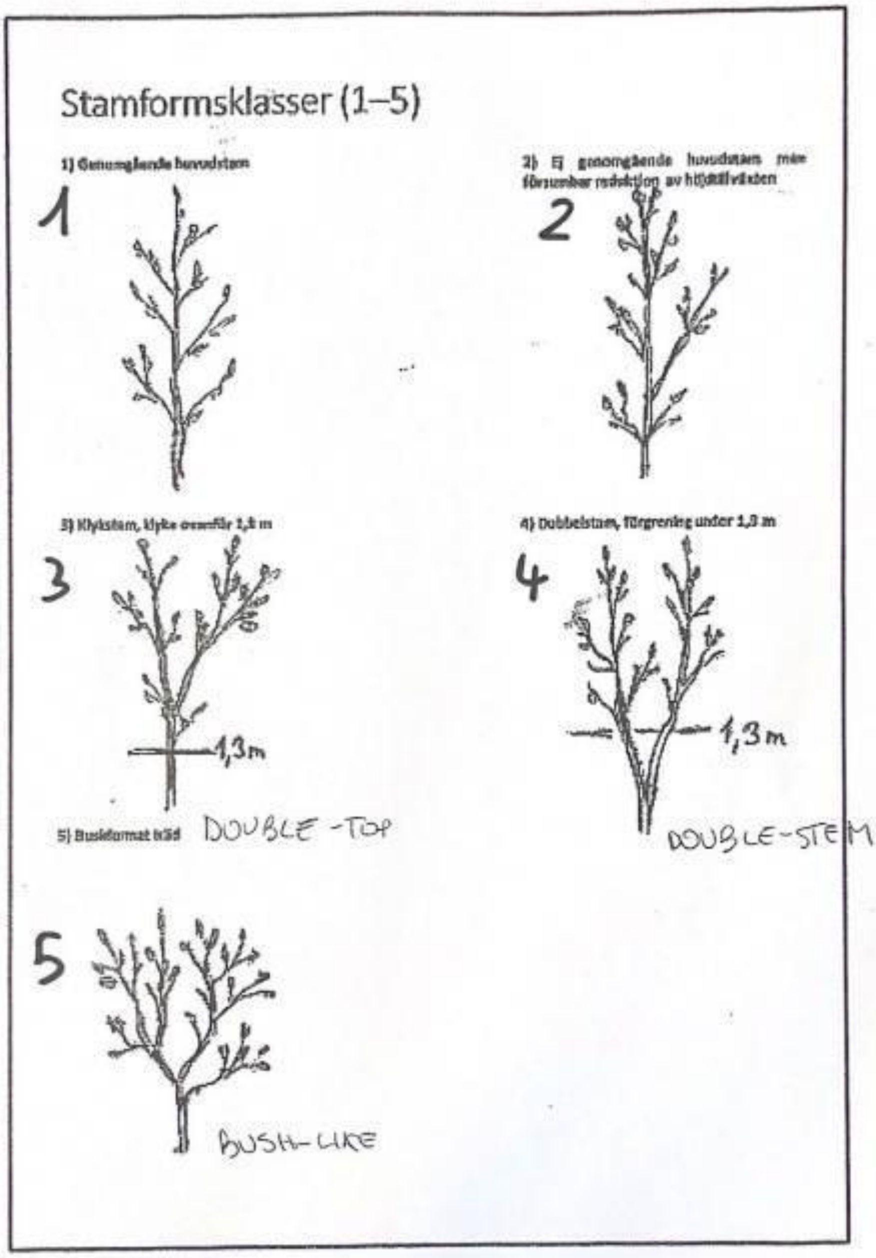
9
7: Ret, men kan have små fejl og svage bugter længere nede på stammen.
8: Ret med små fejl evt. svage, høje aksebrud
9: Helt ret

Appendix 2



Figur 4. Typträd som representerar de olika klasserna för bedömning av stamform. Illustration av Lars Rytter.

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