Poplar plantations in southern Sweden: A comparison of growth and production on former farmland and forest land

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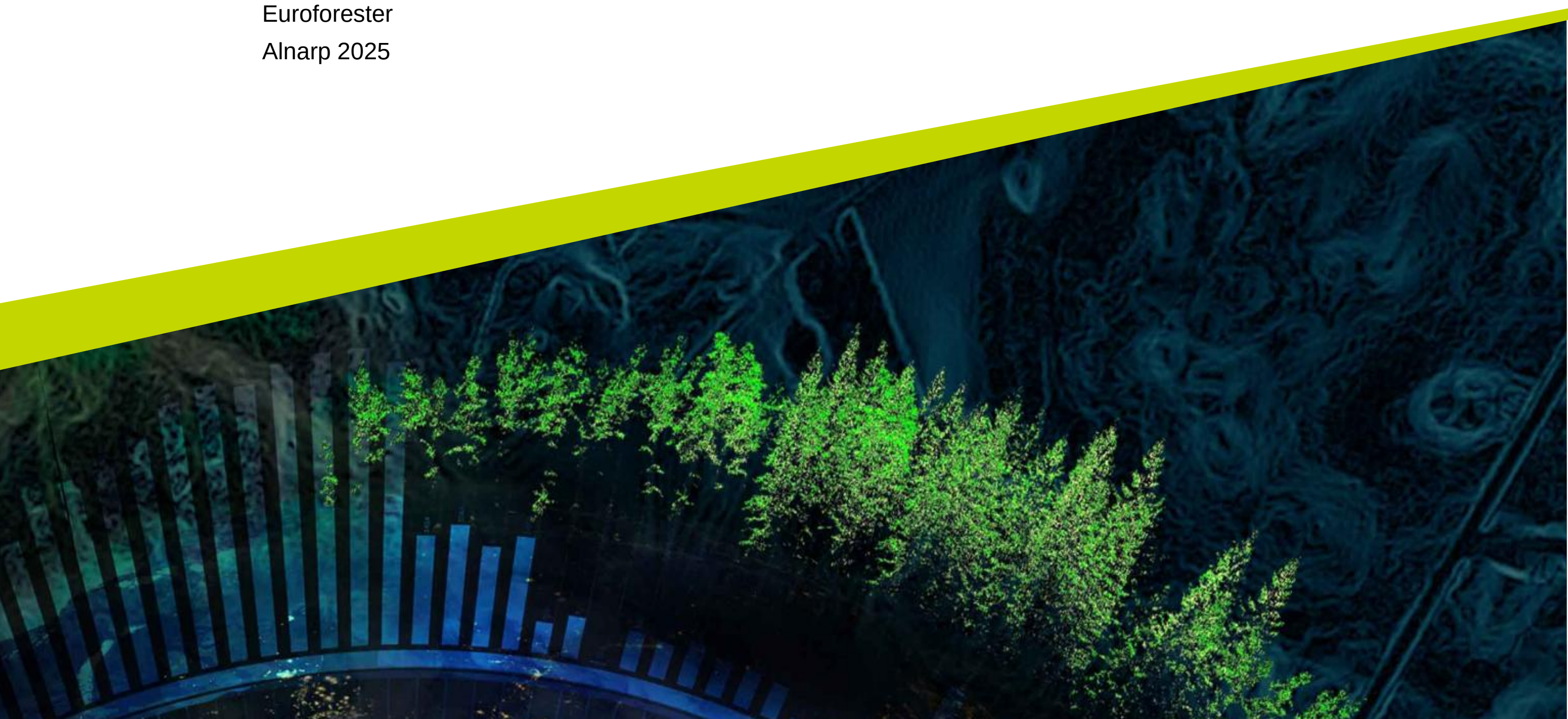

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Abstract

In recent years, there has been growing interest in Sweden in utilizing biomass from short-rotation forestry with fast-growing tree species, as well as increasing interest in storing more carbon in standing forests. This is part of Sweden's aim of becoming a fossil-free country until 2045. In short-rotation forestry, poplars play an important role and are widely used due to their high productivity over short rotation periods. Considering the available agricultural land and the vulnerability of spruce plantations to bark beetles in southern Sweden, poplars could be considered a viable alternative.

Data for this study were collected in the winter of 2025 from 23 poplar stands across southern Sweden, in the Götaland region, and represent two types of land that were used differently in the past: forest arable land and arable land. All sites were planted using poplar clone OP42. The study covers sites in the counties of Skåne, Halland, Kalmar, Kronoberg, and Västra Götaland. The objectives of the study are to compare growth parameters between arable and forest arable land types, evaluate the potential of poplar as an alternative to spruce, analyze variations in site conditions and geographic locations, and examine the differences in productivity and diameter distribution among stands.

Poplar stands age distribution range is between 11 and 20 years on forest arable land and between 12 and 18 years on arable land. Stem densities range from 480 to 1.728 stems per hectare on forest arable land and from 752 to 2.224 stems per hectare on arable land.

The results show that in a comparison of growing parameters between arable and forest arable lands, the mean diameters of the stands don't differ significantly between land types but the mean height tends to be higher for the stands on arable land. This suggests that stands on arable land tend to have a higher productivity, and this can be seen from the volume distribution on age, where stands on arable land have in most of the cases, a higher volume per hectare than in forest arable land case.

Despite the differences in age, density, and plots number, stands on arable land also showed a higher mean annual increment (21.3 m^3/ha/year) compared to forest arable land (15.8 m^3/ha/year), indicating approximately 35% greater increment yearly. Regional comparisons showed higher mean annual increment (MAI) on arable land in both Skåne and Västra Götaland regions, with differences of 2.5 and 9.3 m^3/ha/year, respectively. The highest MAI was recorded in Kalmar on arable land (27 m^3/ha/year). From a general observation, stands on forest arable land showed greater variation in tree diameter compared to arable land. Diameter class distribution was more regular across sites on arable land, indicating more uniform growth. These findings offer valuable insights for landowners, showing that although productivity can be lower on forest arable land compared to arable land, poplar still demonstrates relatively high growth and can be considered a viable alternative for spruce.

Keywords: Poplar, arable land, forest arable land, productivity, density, rotation, Götaland, volume, mean annual increment.

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Abbreviations

GHG	Greenhouse gas
MAI	Mean annual increment
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1 Biomass usage in Sweden

Forests and forest management are important patterns in mitigation of climate change, especially when we talk about carbon storage and sequestration. In this context, a target of the Swedish forest policy has been to maintain a long-term production of timber (Bravo et al., 2017). In the same time, Sweden's aim is to become a fossil-free society until 2045, with net zero greenhouse gas emissions (GHG) and with negative GHG afterwards (Petersson et al., 2022).

For the last few years in Sweden, the energy supply has depended more and more on biofuels. For example, the share of biofuels in the total energy supply in 2013 was 23% (Bravo et al., 2017), in 2019 was 26.4% (The Swedish Energy Agency, 2022) and in 2020 was 27.7% (The Swedish Energy Agency, 2023). This suggests an increasing tendency of the value in the last years with more than one percent per year.

Regarding Sweden's imports, a report made in 2024 concludes that the country's overall energy import dependency is 21% where bioenergy carriers and waste import is around 10%, which makes an important contribution to Sweden's energy security (Malmström et al., 2024).

The Swedish Energy Agency assumed that the total biomass supply for energy tripled over the last 40 years. Most of the biomass is expected to come from forests, which can support the mitigation of climate change through enhanced forest carbon storage and the industry is expecting more wood products such as timber and other bio-based products (Petersson et al., 2022).

To fulfill the necessities of the swedish industry, a suitable solution would be the use of existing poplar plantations and the introduction of poplars on the previous spruce lands and agricultural fields as biomass producers. Poplar plantations are well known for their fast growth and for their important role in biomass production, but there are not many studies which are showing their potential on previous forest sites, compared to the agricultural fields, where are considered energy crops.

In Southern Sweden, spruce trees are massively damaged or killed by pests and pathogens as an effect of climate change and poplars could be considered an attractive alternative for over 1 million ha of forested arable land, when the current plantations of Norway spruce reach their rotation (Böhlenius et al., 2023). Besides this, we can add the available abandoned agriculture arable land, which is between 88,000 and 466,000 ha, mainly arable land suitable for fast-growing trees (Böhlenius et al., 2023). An earlier study suggests that forest management with a circular forest-based bioeconomy and a constant use of wood materials would be a better solution to store the carbon in long term perspective. Either way, storing carbon in standing forests can clearly contribute to climate change mitigation and the carbon sequestered in forests with long rotation period (around 100 years) have better results but in a short term perspective and without taking into consideration the opportunity cost (Petersson et al., 2022).

1.2 Available land and biomass production

In Sweden, for the last 30 years, short rotation plantations of willow on former agriculture lands have been practiced. But in the last 20 years, the area which is around 12,000-15,000 hectares has not increased. Nowadays, plantations of hybrid aspen and other poplar hybrids have increased because of their fast-growing rate and multiple uses. By taking into consideration the increasing tendency of cereals prices and the political view regarding the use of fast-growing trees as a way to balance CO2 emissions, farmers might choose to plant fast-growing trees instead (Bravo et al., 2017).
The availability of land for the use of fast-growing broadleaves species in Götaland is around 1.8 million hectares, from which 1.3 million hectares of forest arable land and around 0.5 million hectares of abandoned arable land, and includes areas not considered as forest or arable land. With this opportunity comes the interest in accumulating more knowledge about poplars and how are they actually growing on a specific geographical site. The current situation in Sweden’s industry would also be helpful, which includes already developed logistics like transportation and harvesting operations for woody biomass (Böhlenius et al., 2023).

With a shorter rotation period in comparison with other tree species used for wood production in Sweden, usually, poplar stands harvesting age is between 15 and 20 years. This is strictly dependent on the production goals, with saw log and veneer rotations the longest and pulpwood and bioenergy the shortest. Also poplars are well known for their fast wood increment, with the mean annual volume increment which can reach 30 m^3 per hectare per year (Isebrands, 2014). Poplar plantations are often planted as monocultures or as mixtures in rare cases.

The poplar OP42 clone is the most used in Sweden and has been used in the southern and middle parts of Sweden for its sustainable production and high vitality in various site conditions (Böhlenius et al., 2023).
However, there is a lack of research that estimates the biomass potential of poplar stands for a specific geographical area in Sweden which are planted on previous spruce forests. Also, an evaluation of the poplar biomass produced from long rotation periods wasn't researched previously. Especially there is a need for research that shows values in accordance to meet the Sweden's targets for mitigating climate change and becoming a fossil-free country until 2045 (Böhlenius et al., 2023).

1.3 Aim and objectives

The aim of the study is to show what growth can be expected from the poplar trees and the potential of poplar stands in the southern part of Sweden, both as a substitute for the spruce forests and for new plantations on arable lands.

The first objective of this study is:

- To observe the differences between growing parameters for these two types of land (arable and forest arable land), which historically had different uses, and to verify the potential of poplar as a potential alternative for spruce.

The second objective of this study is:

- To provide insight into the variations in site conditions and geographic locations of the stands.

The third objective of this study is:

- To examine the expected variations in productivity and diameter distribution between stands on a specific type of land.

2. Material and methods

2.1 Site description

Data collection was performed in the winter of 2025, with 23 poplar stands visited and measured in Southern Sweden. Data was collected in particular from Götaland region, where are the most concerns regarding the future of spruce forests, affected in high proportions by bark beetle and drought. Of the total inventoried stands, 13 of them were on forest arable land and the rest of 10 were on arable land. The counties encountered were Skåne, Halland, Kalmar, Kronoberg and Västra Götaland. The largest number of stands counted (16) were located in Skåne. The rest of the inventoried stands counted 3 in Västra Götaland, 2 in Kalmar, 1 in Halland and 1 in Kronoberg. From the poplar stands which were measured on the forest arable land, 10 of them were situated in Skåne, 2 in Västra Götaland, and one in Halland. From the sites measured on arable land, 6 of them were situated in Skåne, 2 of them were in Kalmar, one site in Västra Götaland, and one in Kronoberg.

In this study, two types of land use history were investigated, which are "previous spruce forests", named forest arable land, and "abandoned agricultural lands" – named arable land. The definition of forest arable land is land that had a generation of spruce on a former arable land. The definition of arable land consists of both pasture and agricultural land. The land type considered abandoned agricultural land can be either pasture or traditional agricultural land which is no longer used for any purpose. What the pasture and the agricultural land have in common is that it has been worked or influenced by man and his cattle in some way, and that no forest cultivation has occurred in the last century. In this study both land types were considered but only if poplar clone OP42 was used as plant material for removing clonal growth effects on biomass production.

2.2 Data collection and experimental design

In the collection of data and information, various tools and aids have been used. For the tree measuration and data collection, the following has been used:

- Caliper

- Vertex 5 (height measuring)
- Tape measure (25 m)
- Corner posts for surface
- Stamp color

A caliper has been used to measure the diameter of the trees, each tree has been measured 130 centimeters from the ground up to the trunk (breast height). The height of the trees was measured using Vertex 5. A tape measure was used to mark out the surface of the stands where each corner of the surface has been marked with a post painted with colored paint. After the trees have been split into plots, each tree has been marked and numbered with paint. The data has been entered through a table made in Microsoft Word. For further data calculations and analysis, data was introduced and analyzed in Microsoft Excel and the report was written with Microsoft Word.

The inventoried stands meet the following criteria:

- Clone: OP42
- Age: 11-20 years
- Density: 480-2224 stems per hectare

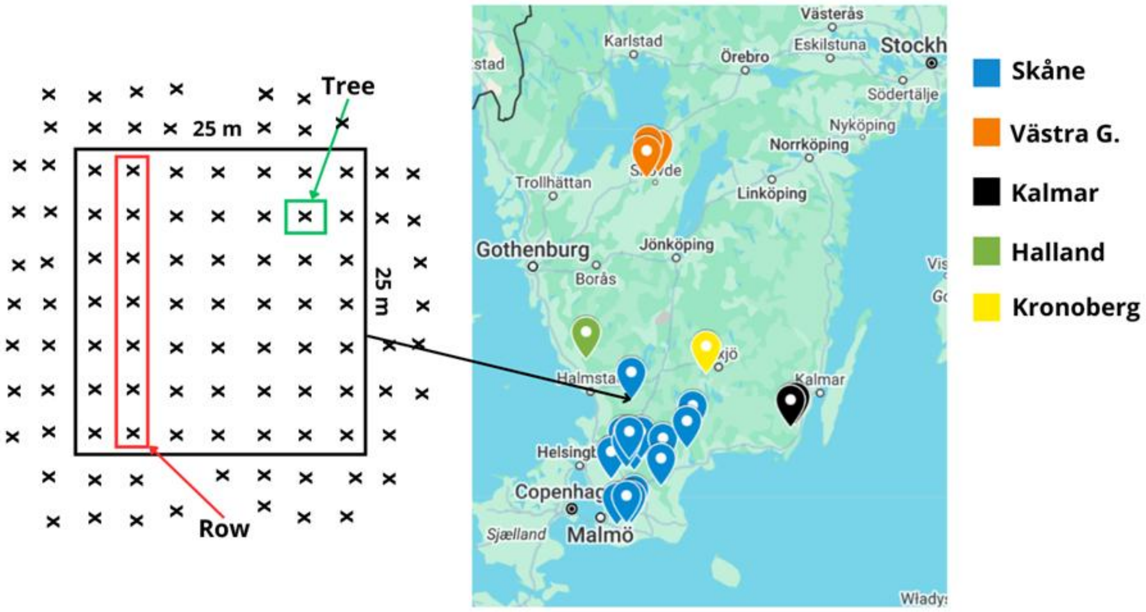

Figure 1.Localization and description of the measured sites with differentiation of lands and an example of the imaginary plot.

Each plot measured 0.0625 hectares (25m by 25m) and consisted of about seven tree rows. The plots were selected and established approximately in the middle of each stand or some meters inside the stand to avoid the edges and buffer zones. The overlapping with forest roads, ditches, and other factors that might affect the normal condition of a plot was also avoided. Trees were numbered and painted with each tree's ordinary number from the beginning of the plot through each row (Zigzag).

Inside each plot, all trees were measured. The height and diameter differences corresponded to each tree's vitality and growth. At the same time, no severe damages like browsing or pathogens damage were observed on the trees for all the plots. The range of measured trees diameter was between 40 and 400 millimeters and for measured height was between 70 and 310 decimeters.

The age range of the measured plots is between 11 to 20 years, distributed through different regions and site types.

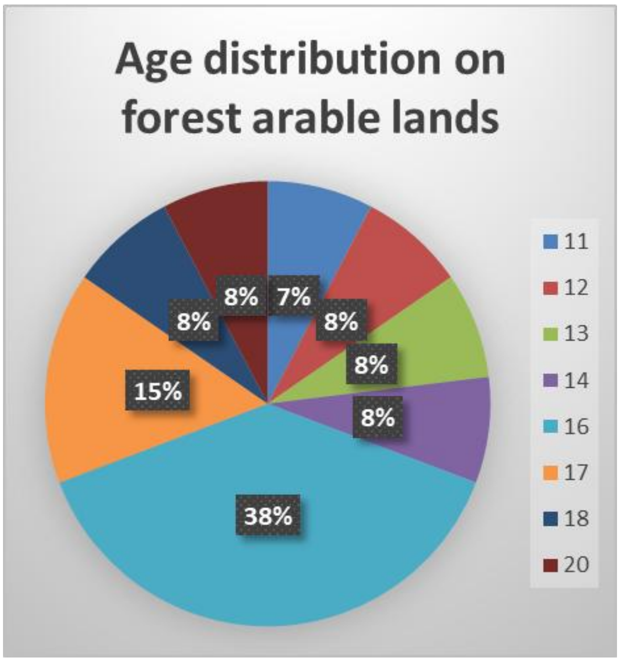

Figure 2. Age distribution of stands on forest arable land.

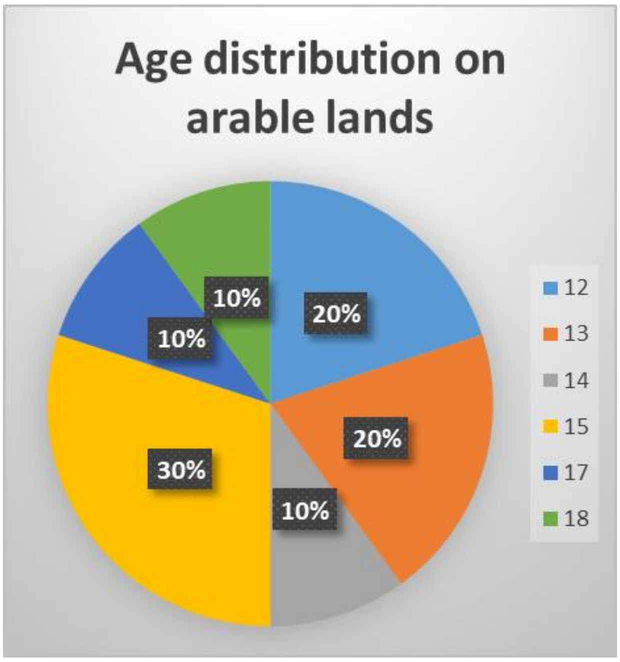

Figure 3.Age distribution of stands on arable land.

For the sites on the forest arable land (Figure 2), plots were between 11 and 20 years old. More than half of the plots, 69% were between 16 and 20 years. For the sites on the arable land (Figure 3), the range is between 12 and 18 years, with the distribution relatively equal, with more exactly 50% of plots between 15 and 18 years and the other half between 12 and 14 years.

2.3 Calculations

2.3.1 Height calculation

For each plot with more than 50 trees, height was measured for 10% of the trees, more exactly each tenth tree's height was measured. For the plots with less than 50 trees, each fifth tree's height was measured, to have enough data for a more realistic analysis. After the introduction of data in Microsoft Excel, a file was created with all the trees that have been height measured for the forest arable land and one file for all the trees from arable land. Then was created a correlation between diameter and height from where we took the formula of height which uses diameter. Two height formulas were deduced for the arable land and forest arable land. The height was calculated for each tree using the formula for each type of land.

2.3.2 Volume calculation

To calculate the volume of the different stands and trees, a volume formula is used for hybrid aspen. This function was chosen as it was judged to represent poplar on both arable land and forest arable land. V stands for the volume of the tree and the result is reported in dm^3. D stands for the diameter of the tree in centimeters and H stands for the height of the tree in meters. The result for each tree was divided by 1000 to get the volume values in m^3. The volume formula is taken from Skogskunskap (2024).

Hybridasp	**$V = 0,03186D^2H + 0,43H + 0,0551D^2 - 0,4148D$**	

Figure 4.Volume formula used for calculations. The formula is originally applied for hybrid aspen but in practice, it is also for hybrid poplars in Sweden.

2.3.3 Calculations of thinned stands

For four of the plots that were thinned before data collection, a correction was needed to be able to see the potential of the unthinned stands for their age and for correct comparison of the results with other stands. The stands were thinned in the last year which means that there isn’t a significant effect on the standing trees.

The correction calculation procedure began already when the data was collected. All stumps within the thinned plots were measured in diameter and recorded. Furthermore, all standing trees were measured in diameter at breast height (1.3 meters above the ground) and at approximately 20 centimeters above the ground to get the diameter of the imaginary stump. The average diameter is calculated for the stumps and standing trees, both at breast height and stump height. Then the ratio was calculated, between stump and breast height diameter, the average value of this ratio became the chosen factor to calculate the breast height diameter of the harvested trees. The standing trees will be the answer to how much the diameter decreases from the diameter of the stump to the diameter of the tree's breast height. The average decrease from stump to chest height was 15 percent. The given factor was multiplied by all stump’s diameters to get the non-existent breast height diameters. The value that was multiplied was 0.85.

3. Results

In table 1 are described age, stem density and geographical coordinates for each site and growth parameters as diameter, height, volume per plot, volume per hectare, MAI and mean annual height increment. The units of measurement shown are millimeters for diameter, decimeters for height, and cubic meters for volume.

For the poplar stands on forest arable land, the age is between 11 and 20 years with the both youngest and oldest stands in Skåne land. As for the stands on arable land, age varied between 12 and 18 years, with the youngest stand in Skåne and the oldest in Kronoberg. Regarding stem density on forest arable land, the lowest density recorded was 480 stems per hectare on 20 years old stand and the highest density numbered 1728 stems per hectare on 16 years old stand, both localized in the Skåne region. For the arable land, both the lowest and highest density values were in Skåne and counted 752 stems per hectare on 17 years old stand respectively 2224 trees on 12 years old stand (Table 1).

In the following part of our study, an examination will be made on the differences in growing parameters between arable and forest arable land. Another analysis will include the differentiation of mean annual increment (MAI) of the measured stands, separate between poplar stands planted on arable land and those planted on forest arable land, as well as the MAI effect on regions. This will show us how much is the mean increment, in cubic meters per hectare per year of the stands on these two different site types.

Table 1.Centralized data of the measured stands with the further calculations, separated between land type.

Forest arable land									
Name	**Coordinates**	**Age**	**Density**	**Mean diameter (mm)**	**Mean height(dm)**	**Volume (plot)**	**Volume (ha)**	**MAI (m3/year)**	**Mean annual height increment (dm/year)**
Mean		**15.5**	**1024**	**184**	**191**	**15.4**	**246.2**	**15.8**	**12.4**
Skåne 1	56.10791 13.600412	11	1648	114	139	7.7	122.5	11.1	12.6
Skåne 2	55.93233 13.14730	12	1600	136	157	12.5	199.8	16.7	13.1
Skåne 3	55.87900 13.91543	13	1168	159	174	14.2	227.5	17.5	13.4
Skåne 4	56.10357 13.32319	14	544	189	189	8.4	134.4	9.6	13.5
Skåne 5	55.93173 13.14816	16	1440	157	174	17.2	274.7	17.2	10.9
Skåne 6	55.53902 13.23184	16	1168	179	189	20.6	329.0	20.6	11.8
Skåne 7	55.59747 13.48038	16	816	225	223	25.1	402.1	25.1	14.0
Skåne 8	56.19360 14.30763	16	1728	143	164	14.0	224.5	14.0	10.2
Skåne 9	56.04787 13.93582	18	560	306	281	32.4	518.5	28.8	15.6
Skåne 10	56.10848 13.41317	20	480	176	182	6.1	97.0	4.9	9.1
Vastra G. 1	58.42092 13.68821	16	736	179	189	10.5	168.2	10.5	11.8
Vastra G. 2	58.50944 13.70149	17	896	198	202	16.8	268.2	15.8	11.9
Halland	56.94877 12.76261	17	528	232	225	14.6	234.3	13.8	13.3

Arable land									
Name	**Coordinates**	**Age**	**Density**	**Mean diameter (mm)**	**Mean height(dm)**	**Volume (plot)**	**Volume (ha)**	**MAI (m3/year)**	**Mean annual height increment (dm/year)**
Mean		**14.4**	**1260.8**	**177**	**204**	**19.3**	**309.3**	**21.3**	**14.2**
Skåne 1	56.11064 13.42120	12	2224	128	163	14.3	228.6	19.0	13.6
Skåne 2	55.55162 13.45545	12	1056	171	198	14.7	234.6	19.6	16.5
Skåne 3	56.04049 13.38016	13	1296	139	170	10.8	172.1	13.2	13.1
Skåne 4	55.60301 13.44454	14	1248	173	201	18.3	293.5	21.0	14.4
Skåne 5	56.32562 14.39669	15	1216	176	205	19.0	303.5	20.2	13.6
Skåne 6	56.01474 13.48787	17	752	228	246	22.3	357.3	21.0	14.4
Kalmar 1	56.40567 15.95121	13	1440	173	201	20.8	333.3	25.6	15.5
Kalmar 2	56.38220 15.88021	15	1088	196	220	27.4	438.6	29.2	14.7
Vastra G.	58.46787 13.86192	15	960	204	226	21.0	336.5	22.4	15.0
Kronoberg	56.83085 14.58704	18	1328	178	207	24.7	395.0	21.9	11.5

From the results shown in Table 1 which contains our centralized data, we could observe that the largest mean diameter was 306 mm in site named Skåne 9 on forest arable land, with the age of 18 years and a density of 560 stems per hectare. The second largest mean diameter can be seen in site Halland (232 mm) at a density of 528 stems per hectare and stand age 17.

On the other side, the smallest mean diameter from all 23 measured sites was observed in site Skåne 1 on forest arable land, which had 11 years old, a stand density of 1648 stems per hectare, and measured 114 mm. The reasons for the small diameters can be stand density (1648 stems per hectare) and stand age (11). The second smallest mean diameter was found in site Skåne 1 on arable land, with 128 mm where the stand density was 2224 stems per hectare and the stand age was 12 years.

Also in Table 1 is shown that for the largest value, mean height is correlated to mean diameter, so the tallest mean height corresponds to site Skåne 9 on forest arable land and measured 281 dm. In contrast, the smallest mean height is in site Skåne 1 on forest arable land measuring 139 dm, which is also the site with the smallest mean diameter.

The greatest volume per hectare recorded in our study is 518.5 m^3 in site Skåne 9 (18 years) on forest arable land (Table 1) with a mean annual increment of 28.8 m^3/ha/year. As mentioned above, the same site has also the largest mean diameter (306 mm) and the tallest mean height (281 dm). On the other hand, for the arable land, the greatest volume per hectare is in site Kalmar 2 (15 years) and measured 438.6 m^3/ha. For the same site, the mean annual increment is 29.2 m^3/ha/year.

3.1 Growth

Further in this study (Figures 5,6 and 7) there is a representation of how growth through different parameters (diameter, height, and volume) is affected by different site types: arable land and forest arable land. This comparison offers a better understanding if there is a difference between previous use of the land that will affect a potential poplar forest in Southern Sweden.

3.1.1 Diameter

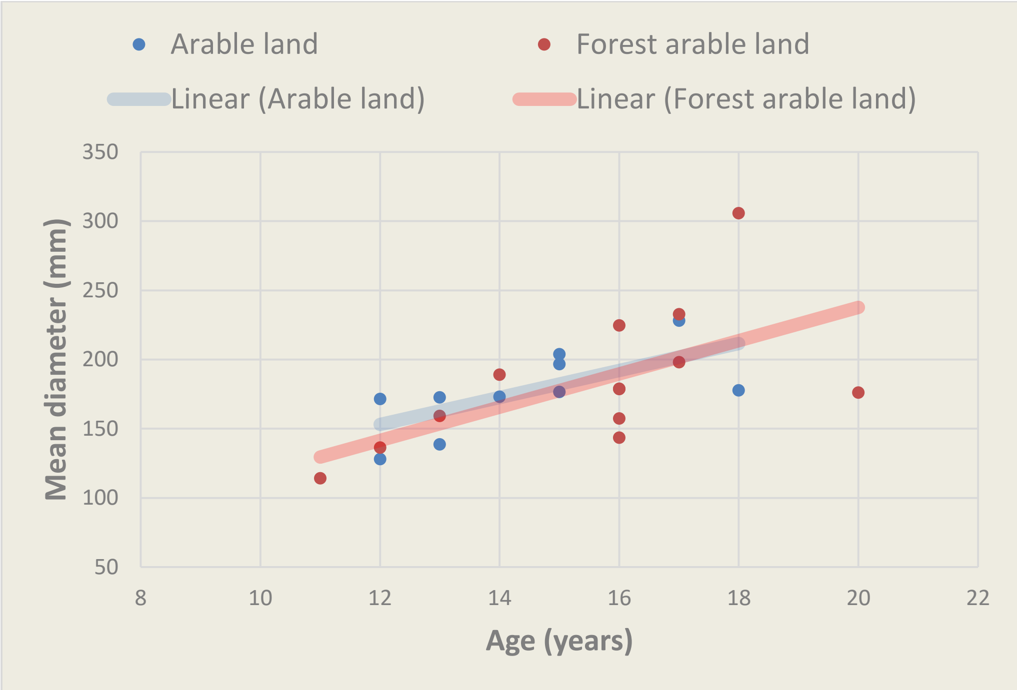

Figure 5.Diameter distribution on age for arable and forest arable land.

For diameter growth distribution (Figure 5), trendlines are overlapping for both site types suggesting that the mean diameter has more or less the same increment. For the stands over 16 years, we see a tendency for stands situated on forest arable land to overcome in mean diameter the stands on arable land. In principle, this is related to stands which have a higher productivity. For example, in this representation, the stand Skåne 9 (Table 1) with around 300 mm mean diameter at 18 years is responsible for the forest arable land growing tendency. Except for this case, a relatively equal distribution of mean diameters is observed in this example. The largest concentration of values is between 150 mm and 250 mm.

3.1.2 Height

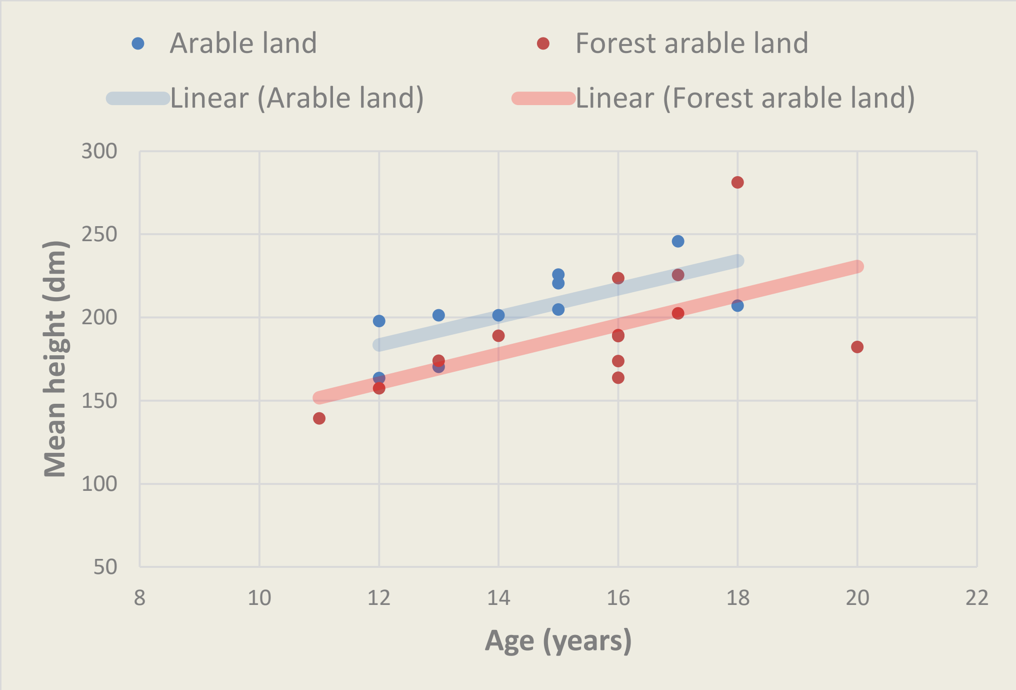

Figure 6. Mean height distribution on age for arable and forest arable land.

In Figure 6 is presented height growth on stand age with trendlines showing a positive correlation between height and age. However, they are not overlapping, with the blue line (Arable land) above the red line (Forest arable land), suggesting that there is a tendency for trees on arable land to grow taller, and faster, compared to those on forest arable land. Some exceptions have been seen, where the red dots (stands on forest arable land) are overcoming the blue dots (stands on arable land) at certain ages. For example, site Skåne 9 (18 years – 281 dm), site Skåne 7 (16 years – 223 dm), and site Halland (17 years – 225 dm), all three on forest arable land, have taller mean height than most of the sites on arable land. Anyway, in general, across most of the stand ages, the mean height for stands on arable land tends to be higher than for stands on forest arable land which supports the observation of higher growth. Moreover, arable land seems to have also a tighter variation of the mean value (Trendline) which can possibly indicate more uniform growth conditions. Of 23 inventoried sites, 21 have a mean height between 150 and 250 dm.

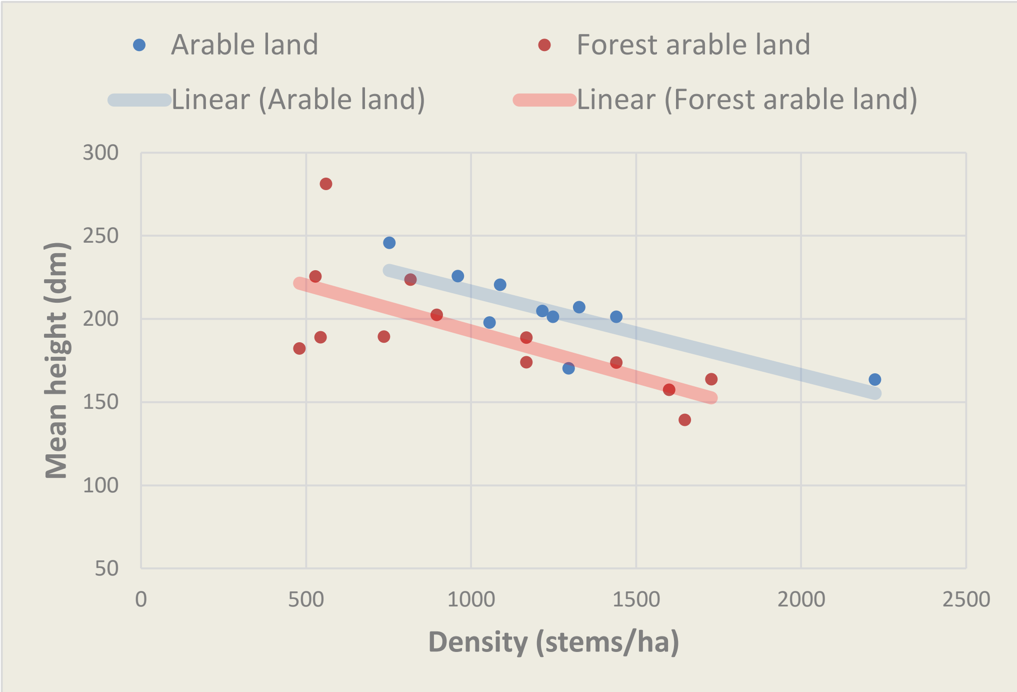

Figure 7. Mean height distribution on stand density for arable and forest arable land.

From the distribution of stand density and mean stand height (Figure 7), it can be seen that at higher stand densities, both stand on arable and forest arable land are decreasing in mean height. The blue trendline (Arable land) and red line (Forest arable land) are parallel which indicates that there are no differences in the decreasing trend. Either way, on the stand at the same density, arable land shows higher mean height compared with forest arable land. As it was shown in the previous distribution of mean height (Figure 6), the higher variability of the stand's mean height in this case is also on forest arable land. The stand density range on forest arable land is from 480 to 1728 stems per hectare, while on arable land is from 752 to 2224 stems per hectare. On forest arable land, especially at lower densities, there are high variations among stand's mean height, from 182 to 281 dm on stand with a density of around 500 stems per hectare.

3.1.3 Volume

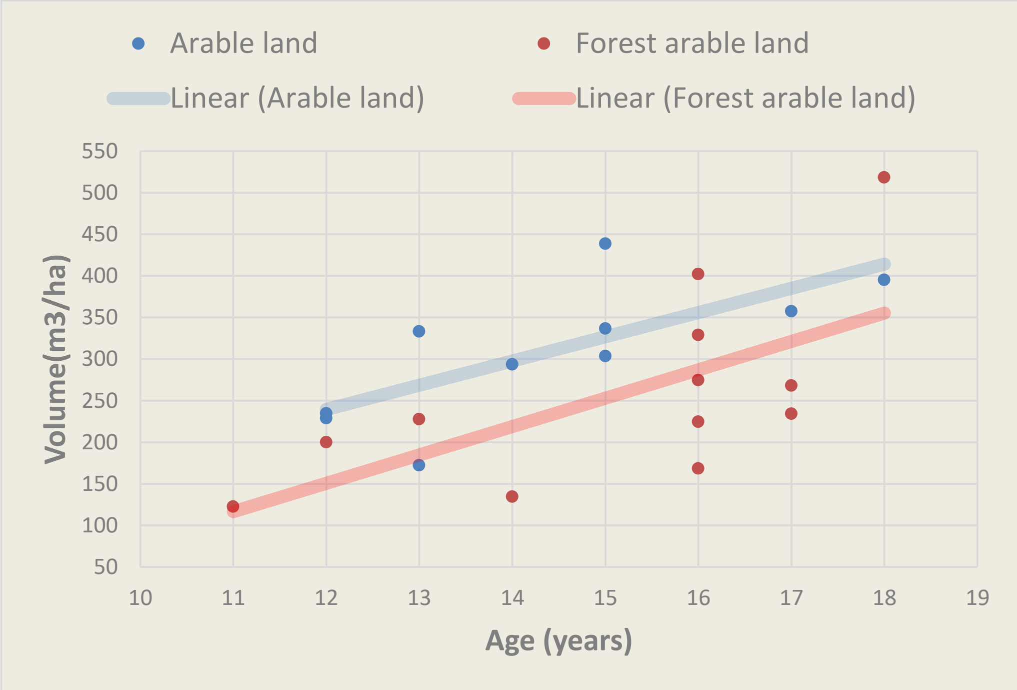

Figure 8.Volume per hectare distribution on age for arable and forest arable land. Site Skåne 10 (20 years) was taken out from this distribution because of the uncertainty regarding the clone used and this could affect the credibility of our results.

Figure 8 shows the relationship between stand age and volume (m^3/ha) for the two types of land where data was gathered: arable and forest arable land. At a first look, a positive correlation between volume and age is observed for both sites. It is also indicated that the blue trendline (Arable land) is higher than the red line (Forest arable land), which suggests an overall higher volume increment for the poplar stands on arable land than for poplar stands on forest arable land. Either way, with age there is a tendency for the stands on forest arable land to reduce the difference in volume increment, which is related to the high productive stand (Skåne 9 on forest arable land) with more than 500 m^3 per hectare. Despite the tendency to get closer to arable land in growth performance, there is high variability of volume for the poplar stands on forest arable land, especially in the 16-year category, where volumes range from 168 to 402 m^3/ha (Table 1). This indicates that in some cases the volume per hectare for stands on forest arable land is larger than on arable land but also that they have a greater variability in growth performance.

3.2 Mean annual increment

In the figure below (Figure 9), for each site type there was calculated the average MAI of all stands on the respective site. The values are calculated in cubic meters per hectare per year.

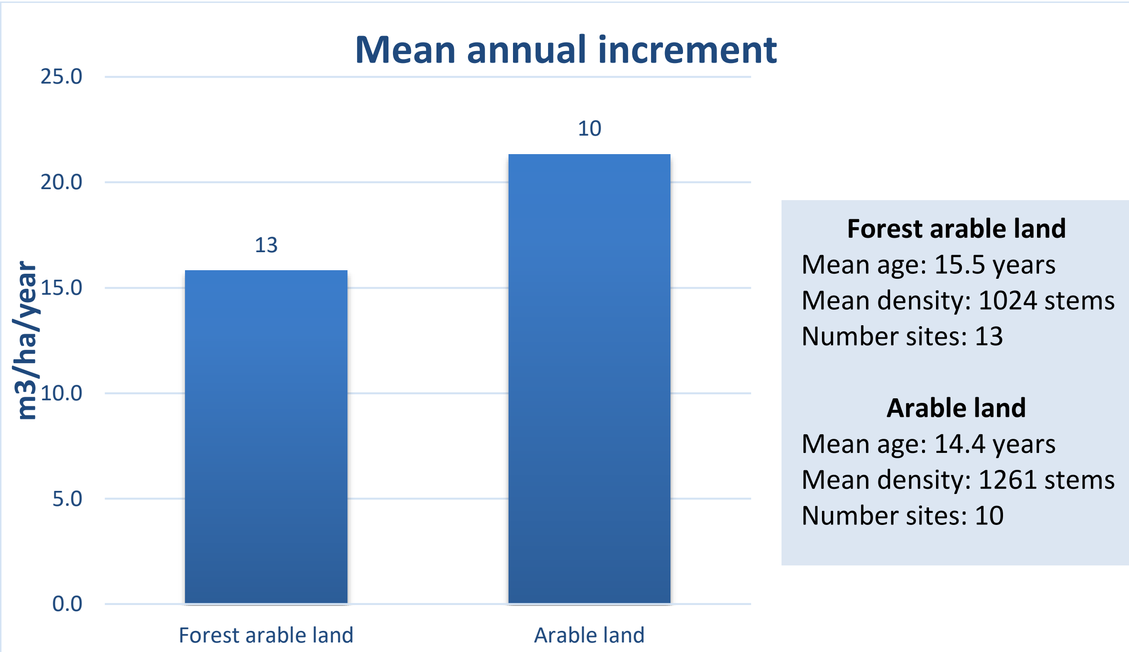

Figure 9.Mean annual increment comparison between arable and forest arable land. On top of each column is specified the number of measured sites for the respective type of land (forest arable land – 13 sites; arable land – 10 sites).

In the comparison between the mean annual increment (MAI) between the stands on arable land and stands on forest arable land, the arable land type has an average higher annual increment compared with other site type. It is important to note that in this situation, the two site types (Arable and forest arable) differ in terms of age, density and the number of sites inventoried, and therefore cannot be considered to have the same conditions. In a study conducted by Karacic et. al (2006), the maximum MAI for poplar OP42 was shown at the stand age of 11 years. In this study, the plantations on forest arable land have a mean age of 15.5 years, while those on arable land have a mean age of 14.4 years, corresponding to a growth difference of 1.1 years. At the same time, the mean stem density of forest arable land plantations is 1024 stems per hectare, and in the case of arable land, the mean density is 1261 stems per hectare, with a difference of 237 stems per hectare. There are also 3 more inventoried sites for the forest arable land compared with the other site type. However, reporting only to the mean annual increment which is compared in Figure 9 and at specified conditions, it can be observed that overall for our set of data, poplar plantations on forest arable land are growing with 15.8 m^3/ha/year, and poplar plantations on arable land with 21.3 m^3/ha/year. This corresponds to better growth for the plantations on arable land with 5.5 m^3/ha/year or approximately 35%.

To gain further insight into growth patterns, the mean annual increment was calculated for stands in each region, and an average value was determined for each region to compare the mean annual growth across poplar plantations in southern Sweden.

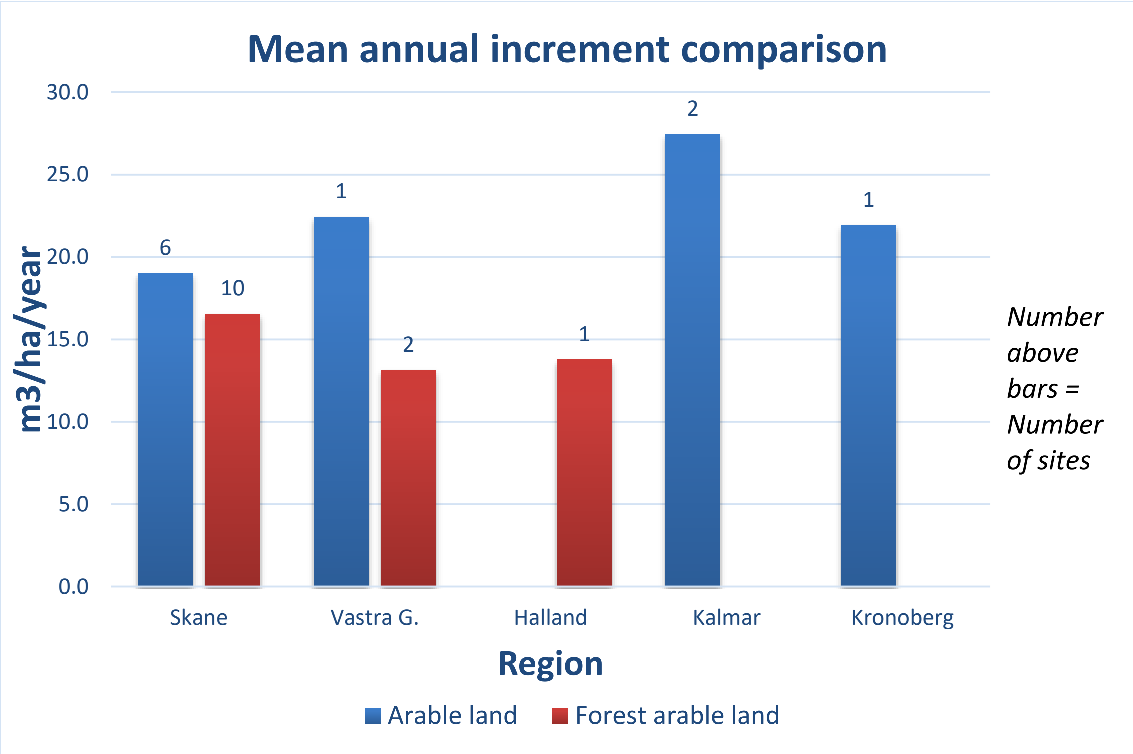

Figure 10.Mean annual increment comparison between arable and forest arable land in different regions. On top of each column, the number of sites that have been measured in each region is specified.

On a first look at Figure 10, it is observed that only for two regions (Skåne and Västra Götaland) there are sites on both land types. In both situations there is a higher MAI for the arable land. In Skåne, with an MAI of 16.5 m^3/ha/year on forest arable land and 19 m^3/ha/year on arable land, resulted in a difference of 2.5 m^3/ha/year in growth. In the case of Västra Götaland region, the difference is bigger, around 9 m^3/ha/year, with a mean annual increment of 13.1 m^3/ha/year on

forest arable land and 22.4 m^3/ha/year on arable land. In comparison with other regions, Skåne benefits from a larger amount of data, respective 10 sites measured on forest arable land and 6 sites on arable land, where in Västra Götaland there are 2 sites on forest arable land and only one sites on arable land. The mean age in Skåne region is 15.2 years for forest arable land and 13.8 years for arable land, while in Västra Götaland the mean age is 16.5 years for forest arable land and 15 years for arable land case.
For the regions Halland, Kalmar, and Kronoberg, there is only one type of land in each region, so a comparison between land types in these regions was not possible. By comparing the MAI of existing site types for all five regions, the greatest value is in Kalmar, where 2 sites on arable land were measured, and the average MAI is around 27 m^3/ha/year. The other two regions where resulted a relatively high MAI are Kronoberg and Västra Götaland, with both sites situated on arable land and an MAI of around 22 m^3/ha/year in both cases.

3.3 Diameter distribution

This part of the results focuses on showing the diameter distribution for each measured site, separated between forest arable and arable land. The distribution is made on diameter classes. Each class means 20 millimeters or 2 centimeters, so for example, class 5 will be 100 millimeters, class 10 will be 200 millimeters, and so on. These diagrams will help us to have a better understanding of tree size variation in each site.

From data analyses, in a comparison of a site on arable land with another on forest arable land, some homogeneity was observed for the dimensions of the trees on the arable land and more diversification of dimensions for the site on the forest arable land.

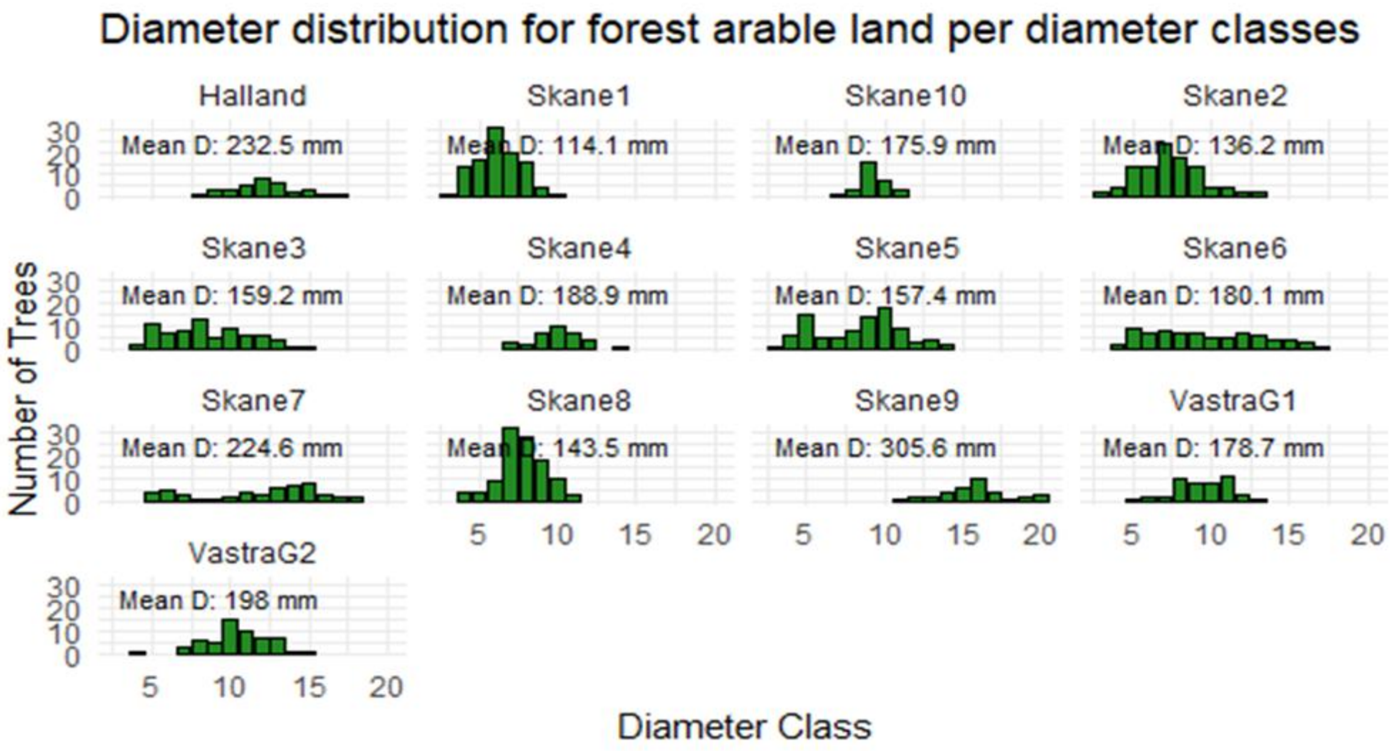

Figure 11.Diameter distribution on classes for the sites on forest arable land.

Figure 11 presents the diameter distribution for the sites on forest arable land and indicates that the variation of tree size depends on each site. It can be highlighted that for sites Skåne 1, Skåne 2, and Skåne 8, there is a concentration of trees in certain diameter classes, and for sites Skåne 3, Skåne 6, and Skåne 7 there is a larger distribution of diameters through more classes. Considering for example site Skåne 6, the data show that diameter ranges from class 4 to class 17, which means from 80 to 340 millimeters, with a relatively equal number of trees in each class. The mean diameter for site Skåne 6 is 180 mm.

As for the sites with tree numbers concentrated in some classes, it can be seen for example site Skåne 8 with most of the tree diameters between class 7 and 9, which is translated to 140 and 180 millimeters. The mean diameter for site Skåne 8 is 143 mm.

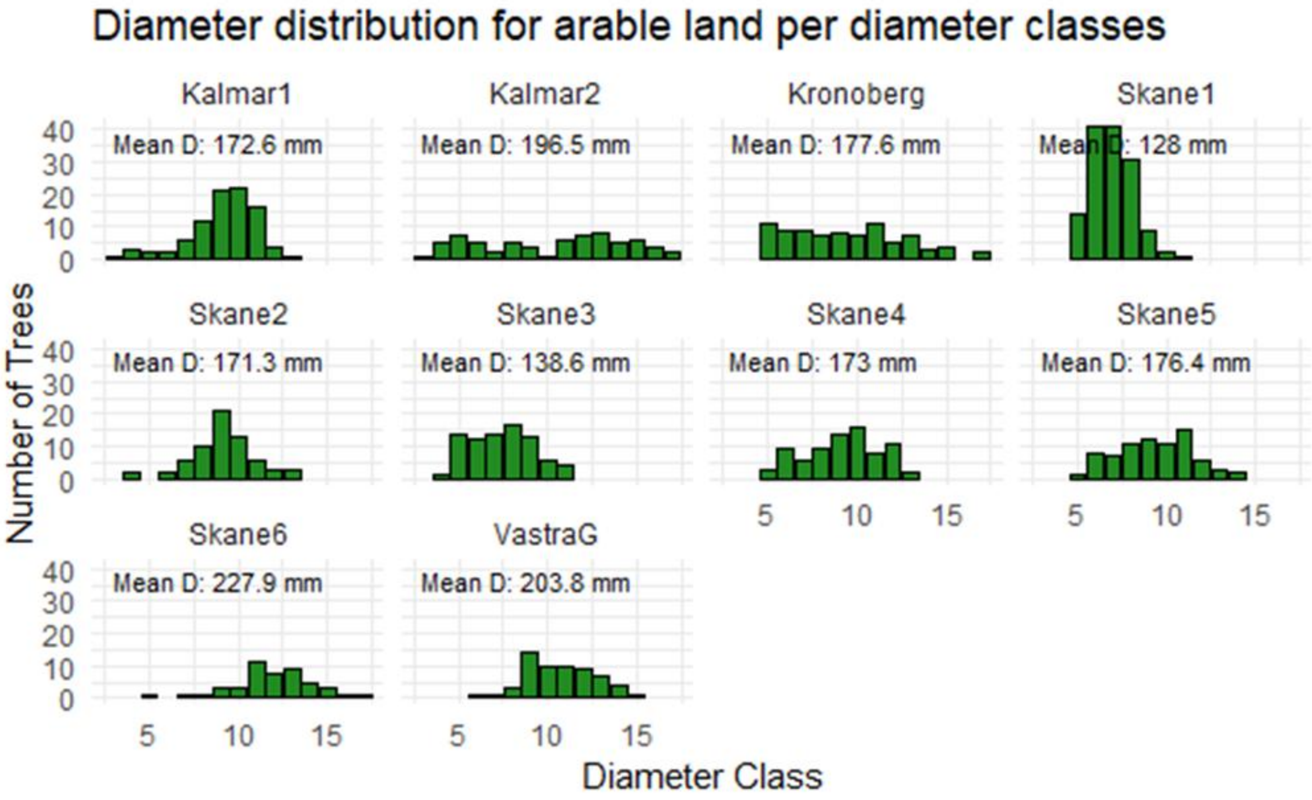

Figure 12.Diameter distribution on classes for the sites on arable land.

In the figure above (Figure 12), which illustrates the same distribution of trees in diameter classes but for the sites on arable land, it can be observed that each site differs when it comes to a number of trees and the range of them among classes. For instance, at sites Kalmar 1, Skåne 1, and Skåne 2 is indicated a more concentrated tree number in certain classes, and in second case the sites are Kalmar 2, Kronoberg and Skåne 5 which have a wider distribution through diameter classes.

An example is site Skåne 1, which has a big number of trees between classes 5 and 8, or between 100 and 160 mm, with the biggest number of trees in classes 6 and 7 (120 mm - 140 mm) and a mean diameter of 128 mm. The other example is site Kalmar 2 where the diameter range is from class 4 which is equal to 80 mm to class 17 which means 340 mm. The biggest number of trees are in classes 12 and 13 (240 mm - 260 mm) and the site has a mean diameter of 196 mm.

4. Discussion

In accordance to fulfill Sweden's aim of becoming a fossil-free country by 2045 (Petersson et al., 2022) and using poplar species for biomass production as a replacement for spruce or to use the available land for planting, we analyzed the growth of 23 sites of poplar OP42, located on two types of land available for planting, which are arable land and forest arable land. And because of the intensive use in the southern part of Sweden of poplars on arable land as a crop trees, there is a need for a study investigating the differences between poplar stands that were planted on forest arable land with stands planted on land previously used for agricultural activities (arable land).

Our results present growth parameters including mean height, mean diameter, and volume. The results suggest that in the mean diameter, forest arable land and arable land don't differ and our data suggest that it is not possible to conclude which site is more productive than another based on diameter measurements. However, for mean height, we observed that the mean stand heights on arable land tend to be higher than those on forest arable land.

The age distribution that our stands have on both land types helped us to have a better view of the production potential through parameters like volume, mean annual increment, and mean height increment at different stages and had the advantage of covering the main rotation periods of hybrid poplar in Sweden. It can also be considered that, regarding production purposes, we have covered also the main uses of poplars in Sweden: younger stands suitable for biomass production and older stands for timber production.

4.1 Volume potential for both arable and forest arable land at different age

From the tendency of higher mean height for the sites on arable land, it is indicated that the same sites on arable land tend to have also a higher volume in comparison with stands planted on forest arable land. This can be seen also from volume projections for both types of land, where at the same age, poplar plantations on forest arable show less productivity than poplar plantations on arable land. The mean volume production per hectare on forest arable land reaches 246.2 m^3 compared with 309.3 m^3 for arable land (approximately 25% more productive).

However, we could also observe a higher variation in volume for the stands on forest arable land. For these sites, the volumes per hectare range between 122 m^3 after 11 years after planting and it can reach 518 m^3 at 18 years. In the case of stands reaching 16 years after planting, where we collected data from 5 sites, there are variations in volume. The lowest volume per hectare calculated was 168 m^3, then the medium values are 224 m^3, 274 m^3, and 328 m^3, and the largest volume per hectare is 402 m^3 at 16 years. In contrast, on the two stands reaching 17 years, volumes per hectare are 234 and 268 m^3. The largest volume on forest arable land from our data is 518 m^3 per hectare at 18 years.

One of the reasons regarding the growth variability for the stands on forest arable land can be the decreasing volume increment for the stands over certain age, as well as soil characteristics. For example, soils with a lower pH value can lead to low tree growth for poplars. Another reason can be attributed to the competing vegetation. In combination with poor soil conditions, the existence of ground vegetation can cause troubles in the establishment of poplar stands. Another aspect that needs to be taken into consideration is that the conversion of the arable land into forest arable land by planting spruce might be related to the unproductivity of the arable sites at that time, considered unsuitable for food production. This can be considered a disadvantage for the forest arable land in this study from the beginning.

On the other hand, the volume range for the stands planted on arable land is from 172 to 438 m^3 per hectare. At 15 years, where we had inventoried 3 stands, the volumes were 303, 336 and 438 m^3. If we compare, we can see that at 15 years, these stands are more productive than some of the stands at 16 years planted on forest arable land. Further, on the stand reaching 17 years after plantation, volume is 357 m^3 per hectare. On the 18-years stand, volume is 394 m^3 per hectare, which is lower in this case by comparing with the stand on forest arable land at same age (518 m^3). This can be related to different site conditions, with the stand on arable land being situated in Kronoberg and the stand on forest arable land in Skåne (Table 1).

4.2 The mean annual increment comparison on regions

In a general view, the mean annual increment comparison between arable and forest arable land shows that stands on arable land grow with around 5 m^3/ha/year more but in a comparison between regions there are differences among them.
In both cases where we were able to compare the mean annual increment between regions, which are Skåne and Västra Götaland, we have seen a better performance in mean annual increment for the arable land type. The mean age for the stands in the Skåne region is 15.2 years on forest arable land and 13.8 on arable land, while in Västra Götaland the mean age for the stands on forest arable land is 16.5 years and 15 years on arable land. As we can see, for both regions, the mean age on arable land is lower than on forest arable land. Increment differences are 2.5 m^3/ha/year for Skåne, respectively 9.3 m^3/ha/year for Västra Götaland. It is important to mention that in the case of Skåne, we had also more data, which numbered 10 sites on forest arable land and 6 sites on arable land. In this situation, the Skåne region benefited from different sites which combined different growing performances, making the results more reasonable.

Considering forest arable land, Skåne region has the biggest mean annual increment (16 m^3/ha/year) with the mean age of 15.2 years, followed by Halland with 13.8 m^3/ha/year and mean age of 17 years and the lowest MAI on forest arable land is in Västra Götaland with 13.1 m^3/ha/year and 16.5 years mean age. Based on the number of measured sites – 10 in Skåne, 2 in Västra Götaland, and 1 in Halland – it can be stated that the MAI value for Skåne reflects a wider range of growth conditions due to the larger sample size. Taking this into account, forest arable land in Skåne region appears to demonstrate better productivity compared to Halland and Västra Götaland. However, general assumptions about productivity in Halland and Västra Götaland cannot be made due to the limited amount of sites.

As for the arable land, in all four regions where we have measured the mean annual increment, the values show a relatively high productivity. Comparing the sites on arable land, the Skåne region (13.8 years) has the lowest MAI with 19 m^3/ha/year, followed by Kronoberg (18 years) and Västra Götaland (15 years), first one with 21.9 m^3/ha/year and the second one with 22.4 m^3/ha/year. The best productivity is in Kalmar (14 years) with 27.4 m^3/ha/year. We can justify the high productivity of the Kalmar region by the standing volume of the sites at their age, which at 15 and 13 years is 438.6 m^3/ha respectively 333.3 m^3/ha. In comparison with other stands, this high volume is reached at a stand age of 17 or 18.

In a study by Christersson (2010) made in Sweden, it was found that at 18 years after plantation, the mean annual increment of poplar OP42 for two inventoried stands is 22 m^3/ha/year respectively 23 m^3/ha/year. In a comparison with our study, only the Kalmar region (arable land) has a better increment, at a younger mean age (14 years). Kronoberg (18 years) and Västra Götaland (15 years) have similar increments, both regions being on arable land. The stands on forest arable land have noticeably lower increments.

4.3 Difference among tree dimensions between land types (arable and forest arable)

The variability of tree size between different stands can be related to stem density. We know already that for stands whose goal is to produce timber out of trees with large diameters, density is an important parameter which influence the completion for light, water, and nutrients. The lower density will increase tree diameter, offering more light and more nutrients compared with stands with higher density. In accordance with production goals, landowners choose the stand density when planting.

A difference that we have observed among stands between those on arable land and the ones on forest arable land is a greater variation of tree diameters for the forest arable land type. In Figure 11 our results show that the mean diameter range for the stands on arable land is from 128 mm to 227 mm and for the stands on forest arable land type range is from 114 mm to 305 mm. The difference is 99 mm for the first land type and 191 mm for the second land type. From the tree diameters distribution on diameter classes, we saw that for both land types, the number of trees per class varies from site to site, but between land types, we observed a more regular distribution for the sites on arable land.

One possibility for the observed variability in tree size between the sites on the two types of land can be related to the establishment issues. The competition with already existing ground flora in the stand establishment stage can cause a higher variability between sizes of the trees on the forest arable land. Another argument which supports our hypothesis is the soil condition on the forest arable land. Böhlenius et al. (2020) found that spruce has the possibility to lower soil pH and that spruce forests are characterized by acidic podzol soils with pH between 3.7 and 6.4. Therefore, because forested arable land in southern Sweden often has one generation of spruce, soil properties might be changed to be unsuitable for poplars. In fact, since most of the forested arable land in our study was planted with Norway spruce, there is a high possibility that spruce cultivation contributed to the acidification of the soil, making it not suitable for poplar growth potential, poplar trees being sensitive to low soil pH. However, there might be differences in how sites are influenced by spruce cultivation and as result, we have a higher variability of tree sizes on forest arable land. This suggests that stand productivity on such sites can be unpredictable, which may cause challenges for forest management and planning by landowners.

4.4 The potential of poplar stands on the available land

The results in this study suggest that arable land or forest arable land is suitable for fast-growing tree species where poplar might be a new alternative for replacement of spruce. We have analyzed both situations and concluded that in general, on the arable land, poplars can show a higher productivity. As for the forest arable land, our study shows that productivity depends more on region and density but these sites still reach a high production (Figure 7).

The high productivity of poplar on arable land can show an increasing tendency of farmers to convert the arable land to forest arable land by planting poplar over the use of land for food production. If we are comparing the use of arable land for the production of food and for growing poplars, the main difference is that food production has a significant shorter rotation period which comes with rapid economic revenue after harvesting. On the other side, depending on the production goals, poplar stands in Sweden are harvested in general between 15 and 20 years (Isebrands, 2014). We could see from our results that poplar stands on arable land can reach a high standing volume even at a lower age, so at 13 years we can have around 330 m^3 per hectare and around 250 m^3 at the age of 12. The high productivity at a lower stand age can represent a reduction of the rotation period on arable land in Sweden for the production of pulpwood and biomass. As for the veneer and timber production, we could see that at the age of 18, the standing volume on arable land can be 400 m^3 on 18 years stand. The increasing interest in biomass production, carbon sequestration, and the high productivity in short rotation periods can be considered as strong arguments in motivating farmers to orient themselves into changing land use and to choose a bigger economic revenue after a longer rotation period compared with food production and also to be an important actor in reaching country's climate goals.

At the same time, because hybrid poplar is considered one of the exotic tree species in Sweden, the certification systems like the Forest Stewardship Council (FSC) or Programme for the Endorsement of Forest Certification (PEFC) already have in their process of certifying forests, regulations on the planting location and its surface, dispersal method (The FSC National Forest Stewardship Standard of Sweden, 2020), as well as extra bureaucracies (Pefc.se, 2023). These regulations apply for the forested arable lands and can be one of the impediments which stands against the use of poplars instead of other species in Sweden. Finally, the hesitation of land owners to use poplar as a major production may be caused by the unpredictability of using species considered exotic in Sweden which requires more research on the ecological and biodiversity benefits side.

References

Böhlenius, H., Nilsson, U. and Salk, C. (2020). Liming increases early growth of poplars on forest sites with low soil pH. Biomass and Bioenergy, 138, p.105572. doi:https://doi.org/10.1016/j.biombioe.2020.105572.

Böhlenius, H., Öhman, M., Granberg, F. and Persson, P.-O. (2023). Biomass production and fuel characteristics from long rotation poplar plantations. Biomass and Bioenergy, [online] 178(106940), p.106940. doi:https://doi.org/10.1016/j.biombioe.2023.106940.

Bravo, F., Lemay, V., R Jandl and Springerlink (Online Service (2017). Managing Forest Ecosystems: The Challenge of Climate Change. Cham: Springer International Publishing.

Christersson, L. (2010). Wood production potential in poplar plantations in Sweden. Biomass and Bioenergy, 34(9), pp.1289–1299. doi:https://doi.org/10.1016/j.biombioe.2010.03.021.

Isebrands, J.G. (2014). Poplars and willows : trees for society and the environment. Wallingford: Cabi.

KARACIC, A. and WEIH, M. (2006). Variation in growth and resource utilisation among eight poplar clones grown under different irrigation and fertilisation regimes in Sweden. Biomass and Bioenergy, 30(2), pp.115–124. doi:https://doi.org/10.1016/j.biombioe.2005.11.007.

Malmström, A., Thorsell, A., Carlsson, D., Fogelberg, F., Gustafsson Ismodes, I., Vinterbäck, J., Svensson, K., Larsson, M., Westerberg, N., Andersson, S., Söderholm, S., Nemanova, V., Pettersson, K. and Torén, J. (2024). Implementation of Bioenergy in Sweden – 2024 Update.

Pefc.se. (2023). Swedish PEFC standard in English - Svenska PEFC. [online] Available at: https://pefc.se/vara-standarder/svenska-pefc-standarden/swedish-pefc-standard-in-english [Accessed 24 Apr. 2025].

Petersson, H., Ellison, D., Appiah Mensah, A., Berndes, G., Egnell, G., Lundblad, M., Lundmark, T., Lundström, A., Stendahl, J. and Wikberg, P. (2022). On the role of forests and the forest sector for climate change mitigation in Sweden. GCB Bioenergy, 14(7), pp.793–813. doi:https://doi.org/10.1111/gcbb.12943.

Skogskunskap (2024). Volymfunktioner. [online] Skogskunskap.se. Available at: https://www.skogskunskap.se/rakna-med-verktyg/mata-skogen/volymberakning/volymfunktioner/.

The FSC National Forest Stewardship Standard of Sweden. (2020).

The Swedish Energy Agency, (2022). Energy in Sweden 2021 An overview.

The Swedish Energy Agency (2023). Energy in Sweden 2022 an Overview.

Popular science summary

Are poplars a suitable option for the available land in southern Sweden, and can they serve as a substitute for spruce?

Eduard-Andrei Cruț

Sweden aims to become fossil-free country by 2045, and as strategy involves using fast-growing trees to produce biomass and store more carbon in forests. Poplars are one of these fast-growing tree species and are especially well known for short rotation forestry practice, where trees are harvested after a relatively short time. In southern Sweden, spruce forests face threats from pests like bark beetles, so poplars could be a useful alternative.

This study looked at how well poplars grow on two types of land in Götaland: forest arable land and arable land. A number of 23 poplar plantations across five counties were measured, all planted with the same poplar clone (OP42). The study areas were spread across the counties of Skåne, Halland, Kalmar, Kronoberg and Västra Götaland.

The findings show that poplars tend to grow better on arable land than on forest arable land. Although the average tree diameters were similar across both land types, trees on arable land were in some cases taller and therefore stands on arable land showed in most of cases higher volume per hectare. In fact, the mean annual increment (MAI) of stands on arable land was about 35% higher compared to forest arable land, producing an average of 21.3 cubic meters per hectare per year compared with 15.8 on arable land. Regional differences were also observed, with the highest growth rates on arable land recorded in Kalmar county.

The study also found that trees on forest arable land had more variation in their sizes, while trees on arable land grew more uniformly. This variation on forest arable land might be related to the spruce cultivations influence on soils and the competing vegetation and may make the forest management harder for landowners.

Overall, the findings suggest that poplars are a promising option for the available land in southern Sweden. Even though our study indicate a better growth on arable land, poplars still show a high growth on forest arable land. This means that poplar clone OP42 could be a valuable alternative to spruce, helping to reduce the risk from pests, and contribute to Sweden’s goals of increasing biomass production and carbon storage.

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