Slutrapport

Pilot study of growth in different planting densities and the rotation period of poplar plantations.

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Del 1: Utförlig sammanfattning

Det finns stora behov av ny kunskap om lämpliga planteringsförband och skördetidpunkter för poppelodling i Sverige för att optimera det ekonomiska utbytet. Syftet med studien var att utveckla en beräkningsmodell som predikterade biomassaskörd som funktion av planteringstäthet och omloppstid. Data samlades in från befintliga odlingar för att utveckla en modell som beräknar biomassaskörd från täthet och omloppstid. Nya odlingar etablerades med tre olika planteringstätheter. Vi beräknade det ekonomiska utbytet för de olika skötselsystemen. Genom att koppla biomassaproduktionsmodellen till ekonomisk information har vi fått ett kraftfullt verktyg som kan ge svar på hur många träd vi ska plantera per hektar och efter hur många år vi ska avverka dessa, allt för att bäst möjliga ekonomi på våra poppelodlingar. Vi drog slutsatsen att hybridpoppel har en stor produktionspotential. I början är biomassaproduktionen oberoende av den initiala tätheten och biomassaproduktionen är proportionell till densiteten. Poppelodling är lönsam för en rad olika kombinationer av omloppstider och planteringstätheter. När en medelhög planteringstäthet användes (1000 stammar/ha) ökade lönsamheten när omloppstider på mer än 20 år användes.

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Introduction

The interest in the cultivation of fast-growing deciduous tree species and their hybrids on abandoned cropland is increasing in Sweden. Among the employed fast-growing species (hybrid aspen, hybrid poplar, and willow), hybrid poplar is considered to have the greatest production potential. A renewed interest in the cultivation of poplar started in the late 1980s due to political decisions to reduce the area of arable land in Sweden. Hybrid poplar was included as a group of species, among others, in trial plantations intended to be the basis for the acquisition of knowledge about the production and performance of various tree species on arable land. The initial interest in woody crops on agricultural soil was mainly because their potential as a future supplier of bioenergy. However, poplars are also suitable for other assortments such as pulp and timber (veneer, plywood and matches). Poplar plantations aiming to produce other assortments than bioenergy need to take into account the size requirements for pulp and timber production and need to be managed to enable trees to grow into larger diameters. For the latter reason, knowledge of growth dynamics and diameter development under different planting densities is crucial. Production of other assortments than material for bioenergy may be an important economic incentive for the individual landowner to invest in and establish poplar plantations.

To date, the area of mature poplar plantations in Sweden is less than 1 000 ha (Nordh et al. 2014) but during the last ten years new plantations have been established. The majority of the plantations, older as well as younger ones, are planted with the clone OP 42 (*P. maximowiczii* Henry *x P. trichocarpa* Torr. & Gray) with a rather similar planting density (1000 -1200 plants per hectare). Data from several of these poplar plantations are part of our research studies. Most of the plantations established in the late 80s and early 90s are still growing, and the landowners are demanding practical management advice. Recently a practical manual by the Swedish Board of Agriculture for cultivation and management of poplar- and hybrid aspen plantations in Sweden was published (Persson et al., 2015). It is essential for landowners, forest- and energy companies and other actors who are interested in establishing poplar plantations with short rotations that there are tools available to calculate / predict the outcome in volume and / or biomass. In recent years studies of poplars volume, growth and biomass of individual poplar trees have been published (Hjelm, 2013; Hjelm and Johansson, 2012; Johansson and Hjelm 2012; Johansson, 2011; Johansson and Karacic, 2011; Rytter et al., 2011; Hjelm 2015). Knowledge of the rotation period of poplar and production under different planting densities under Swedish conditions is however scarce. Few or no studies on the optimal rotation period of poplar plantations for Swedish conditions are available. Yield studies dealing with rotation aspects for poplar plantations from other countries /regions (Fang et al., 2007; Labrecque & Teodorescu, 2005 and Miller and bender, 2008) are available, but the applicability is speculative or likely to be small to Swedish conditions. Landowners who are ready to establish new poplar plantations also ask for advice and knowledge about planting density and management of young plantations, including if the plantations should be thinned and what thinning regime to be applied. In order to provide better guidance on these issues, more knowledge is needed regarding the growth pattern of poplar under different planting densities and the physiological optimal rotation period.

This pilot study was initiated and conducted by the project participants 2016-2018 to assess the mean and current annual production in order to derive conclusions and guidelines on the optimal rotation length. During three years, an annual monitoring of production and yield was performed in 12 poplar plantations with clone OP 42 (*P. maximowiczii* Henry *x P. trichocarpa* Torr. & Gray), ranging in age from 7 to 23 years, in south and middle of Sweden. Due to the small variation in planting density in Swedish commercial poplar plantations we also established research trials with three planting densities, representing 625; 1111 and 2 500 plants per hectare. An essential purpose of having knowledge about the effects of rotation period and planting density on biomass production is to gear management systems towards an optimization of the financial outcome.

We anticipate that poplars in short rotation systems (10-12 year) will produce stems with smaller dimensions than those in longer rotations and thereby biomass primarily used for the energy market. If the rotation periods are longer (20-30 year), management systems also can produce pulpwood and other assortments with larger diameter requirements. Beside knowledge of appropriate rotation period, it is also essential to know how the growth dynamics and biomass production develops under different planting densities and how planting density and length of the rotation period interact with each other (individual trees will grow slower at high densities, while production per unit area will converge, the Yield-Density effect). With such knowledge, stakeholders can provide forecasts about the yield production on an area depending on site conditions and management method. (i.e. planting density, thinning regimes and rotation periods). The models are tools to select appropriate management regimes and to predict and optimize the financial outcome better than today. The latter is especially important if a harvest date is significantly different (early or late) from the optimally productive rotation date, which means that the landowner would be deprived of potential biomass yield and logging revenues.

The specific objective of the project was to develop a model that predicts biomass yields as a function of planting density and length of rotation period. To reach the objective, we performed two sub-studies: (1) Data were collected from existing older plantations to develop a model that predicts biomass yield as a function of planting density and rotation length. As there was a low variation in the planting density of these older plantations, we also (2) established new plantations with three different planting densities and monitored their early growth. Based on the results of these studies we (3) calculated the economic outcomes for specific management options in terms of planting density and length of rotation period.

Materials and Methods

(1) Existing older plantations.

Altogether, the study was conducted on 50-200 trees in permanent sample plots for each of 12 poplar stands in three regions (Skåne incl. southern Halland, Västra Götaland and Uppland /Östergötland). The plantations were 7 - 25 years old when the project started. All plantations and the density trials are located on former farmland. The water table was within one meter from ground and the soil type consisted of clay sediments ranging from light to heavy clay, with a couple of exceptions where the soil type were silty tills.

Revision of the plantations was performed in spring 2016 and after each growing season i.e. autumn 2016 and 2017 and included measurements of mean and dominant height in the sample plots, diameter measurements to assess basal area. The latter was also measured with a relascope. A final revision in autumn 2018 included stem diameter measurements, mean and dominant height of the sample plots and of the plantations area as well as the basal area. We also felled two to three sample trees per plantation. These sample trees were subject to detailed and accurate measurements of the total height, volume and the last years shoot length, the latter to describe the annual height development of the poplars. These measurements are essential and necessary for the calculation of the mean annual increment (MAI) and the current annual increment (CAI), the latter for the five last year increment. Some additional allometric tree data were recorded to detect and describe stem form variations within and between plantations, which may influence the biomass and volume estimations. Compatible data from the existing older plantations, collected prior to the project period, were included as far as possible in the subsequent analyses. Mean- and Current Annual Increment (MAI & CAI) was calculated and interpreted into indications and guidelines of the growth trends.

(2) Plantations established in the project period.

Two research trials, one in Västra Götaland and one in Uppland, were established on farmland provided by the Agricultural Society (Hushållningssällskapet). Three different densities (625, 1 111 and 2 500 plants per hectare) were used, equal to 2, 3 and 4 m squared plant spacing respectively. The plant material consisted of bare-root cuttings planted in individual plots (of 900 m^2) with respective density planted within the plots. Each density had three replications, altogether nine plots with a total area of 8100 m^2.

Fig 1. Location of the poplar plantations- and research trials in the pilot-substudy I; □ = rotation period and pilot-substudy II □ = plant density trials

Fig 2. Aerial photos of the two research trials. On top the Uppland trial and on the bottom the trial in Västra Götaland, with plots labelled with each plant spacing (m).

Establishment of the new research trials was carried out spring 2016, and the following activities were undertaken the first year.

- Mechanical soil preparation and scarification by tractor with Plough and harrow.
- Measurement and mark out the research trial, including demarcation lines between the trial plots and establish plot reference poles and trial corners.
- Plantation, i.e. digging holes and planting of 40 cm long rooted cuttings.
- Plant a 5 m wide border zone around the trial (to eradicate border effects).
- Fencing of the trials.
- Mechanical weed control (essential to avoid weed competition and ensure vital and healthy plants during establishment).

Revisions where conducted in autumn 2017 and finally autumn 2018 and included survival and average height for each plot in the trials. In addition, damages and diseases were recorded and a course estimate of average DBH was made by eye. A systematic random sampling of 10 plants per plot was made for height measurements in spring 2019. A more extensive analysis of production and growth dynamics, including diameter measurements, will be carried out ca 6 years after planting when the trees have developed their diameters and can be expected to reach a state of crown closure.

(3) Economic calculations

We used conservative production estimates as input for the economic calculations by truncating maximum MAI to 26 m^3sk, see table 2 in Appendix 1. Cost prices used in the economic model are given in table 3 in Appendix 1. Other prerequisites used in the calculations are specified and discussed in Appendix 1.

Results and discussion

(1) Existing older plantations.

The production in the 12 monitored commercial poplar plantations is high with a mean annual increment (MAI) up to 25 m^3 (figure 3) and current annual increment (CAI) over 25 m^3 for the two plantations over 20 years.

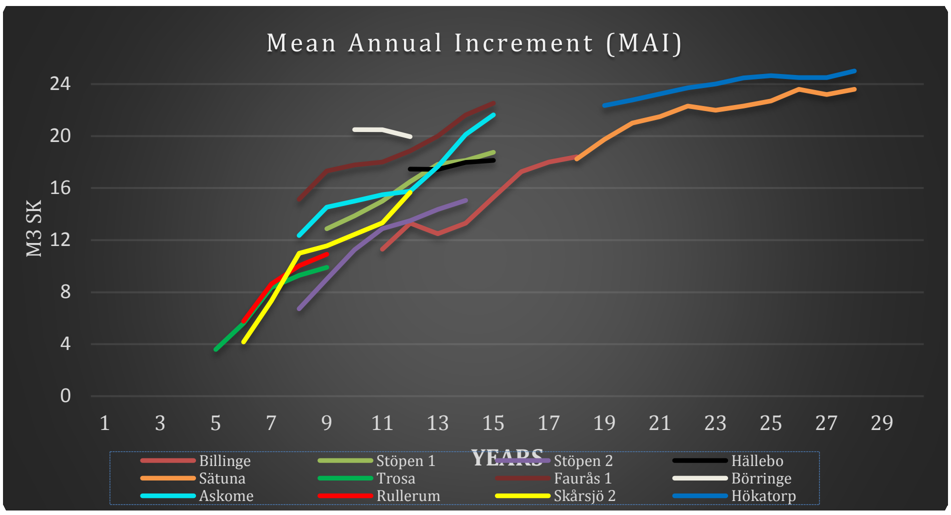

Fig. 3. Graph of the Mean Annual Increment (m^3sk) over age for the 12 monitored plantations.

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The two plantations older than 20 years show a tendency to stabilize and plane out the increment after 23 ca years of growth. Three other plantations have reached a mean annual production of 20 m^3 or higher, but at earlier rotation age. These three plantations are located in the southern provinces of Halland (Fauràs 1 & Askome) and Skåne (Börringe). The Billinge plantation is also located in Skåne and shows initial high production when the surveys started but was damaged by a wind-throw after a storm 2013 that created a sudden decline in MAI trend-line. The other plantations are located in the provinces of Västra Götaland, Östergötland, and Uppland of which Sätuna has the northernmost longitude. However, as there are strong correlations between latitude and stand age on the one side, and between increment and stand age on the other side, we cannot conclude that poplar grows faster in the more southern latitudes. Despite the low variation in planting density, we found significant positive effects of both age and density on MAI, showing that denser stands initially have a higher increment (Fig. 4).

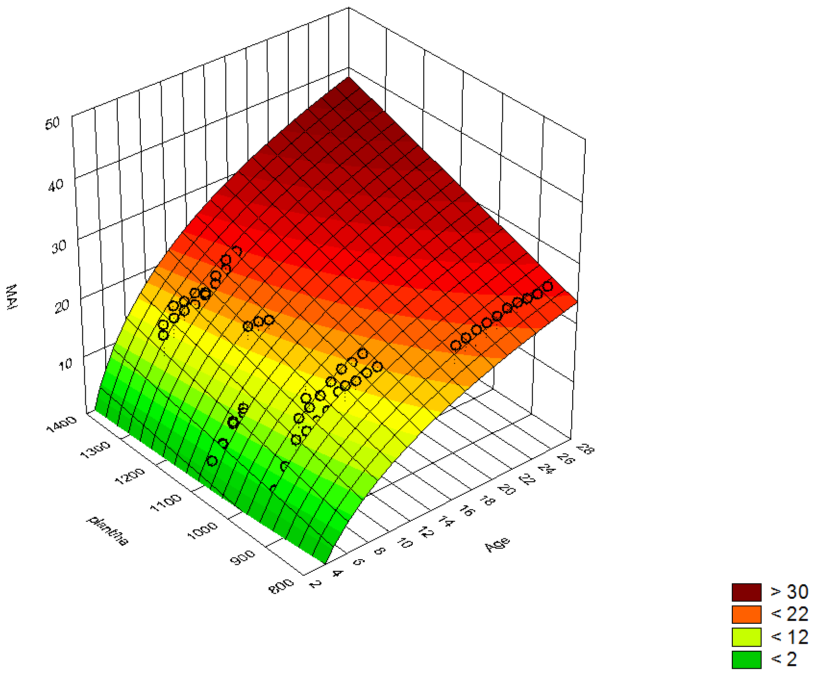

Fig. 4. Modelled MAI as a function of stand-age and planting density.

As the MAI has not levelled out in our data, the model should be used with care and not be extrapolated beyond the actual data range. For the economic calculations we have truncated the maximum MAI to 26 m^3sk, see below.

(2) Plantations established in the project period

The establishment of the two planting density research trials was successful. A survival inventory in the end of the first growing season showed a 99% survival rate and all the plants had a good vitality at the end of the first growing season. In the final revision for the trial in Västra Götaland, the high survival was maintained at a level of 98%. For the density trial in Uppland, there were about 60 plants that died, mainly due to attack by browsing voles, but also during weed pressure, which was relieved by manual weed control in 2017. In spite of this, we still have a survival rate of 95 %. After the last survival assessment, and due to the vole attack an enrichment planting was done in autumn 2018. The diameter at breast height (DBH) is in general around 20 mm and no differences in DBH between the densities nor locations could be observed. The height increment after three growing seasons is for the Uppland trial in general 25 dm and for the southern trial in province of Västra Götaland 27 dm. Height increment after three growing seasons did not differ significantly between densities nor sites (Fig. 5).

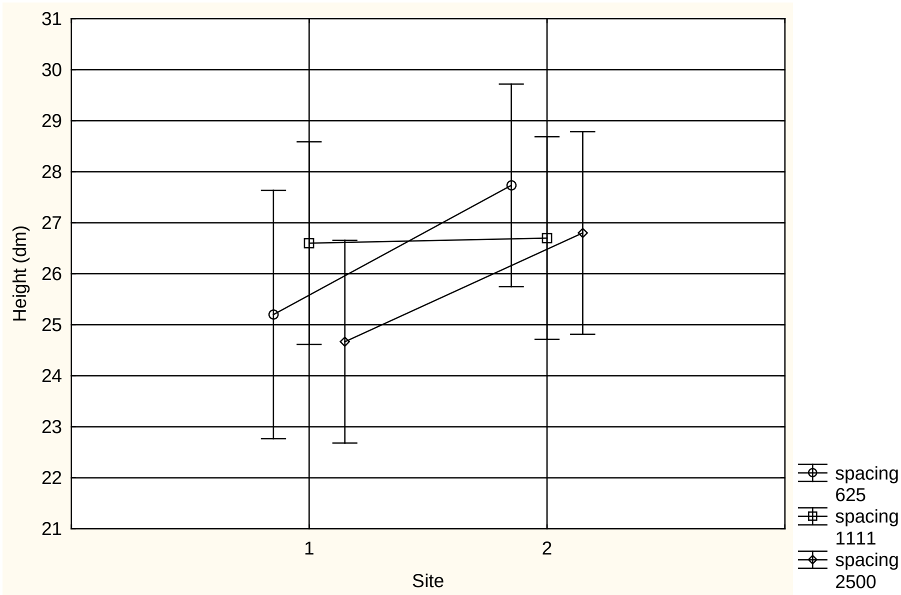

Fig. 5. Tree height at three spacings and two sites (1=Uppland, 2=Västra Götaland), bars indicate 95% confidence intervals.

This shows that biomass production per unit area is proportional to planting density and that no yield-density effect could be detected in the early stage, meaning that individual trees not yet are restricted in growth by means of competition with each other.

(3) Economic calculations

For a complete account of the economic calculations, see Appendix 1. The predicted financial revenues for the various planting densities and rotation periods are given in Table 1 below. Since the calculations for the denser units, 1600 and 2500 plants per hectare were judged to be too uncertain for the longer rotation periods, these are omitted. There is also some uncertainty for the financial results for 30 years. Compared to a practical after-calculation, which is reported in Energiskogspoppel's final report (Persson 2014) for 816 plants and production period of 20 years (which showed a positive result before support of SEK 1817 per hectare and year) our model predicts a result of 1665 SEK per hectare and year. The economic calculation indicates that the production economy can be improved at somewhat longer rotation times than 20 years.

The model suggests that in order to receive a positive result for 2500 plants per hectare and the production period of 20 years, a production of at least 30 m3sk, MAI, per hectare per year is needed. Future revisions of the newly planted denser stands will show if such a high level of production can be realized in practice.

Rotation period:	**15 years**	**20 years**	**25 years**	**30 years**
Tree densities	**NET ha Year**	**NET ha Year**	**NET ha Year**	**NET ha Year**
625	666	1566	2195	*3234*
816	574	1665	2385	*3566*
952	510	1707	2505	*3324*
1111	434	1733	2268	*3084*
1600	-96	957		
2500	-1839	-486		

Table 1. Net revenue in SEK per hectare and year for different plant densities per hectare and Rotation period in years. Values written in italics are more uncertain than the others.

Conclusions

Despite limitations of this pilot project (few monitored plantations of which only two were older than 20 years, a small variation in planting density of older stands, the use of only one clone and finally the lack of objects with a declining MAI), we can conclude the following:

- Over the geographical range from Skåne to Uppland, hybrid poplars have a large production potential (MAI> 25 m^3sk).
- Attainable MAI can not yet be assessed exactly due to lack of older stands with a declining MAI: Attainable production is likely to be higher than derived from currently available MAI-values.
- During the first years, biomass production is independent of initial density and biomass yield is proportional to planting density. Short rotations (10-12 yr) at high planting densities may become profitable if plant material costs can be lowered.
- Hybrid poplar cultivation is or can be made profitable over a relatively wide range of rotation period lengths and planting densities.
- At intermediate planting densities (1000 stems/ha), profitability increases when using rotations longer than 20 years.

Benefits and advice for the industry

An essential purpose of having knowledge of optimal rotation period is to design better management systems and optimize their financial outcome. This study showed that hybrid poplar can be grown under a wide range of planting densities and rotation periods on agricultural land in Sweden and that there are large differences in economic revenues depending on the employed spacing and rotation periods. However, knowledge about the effects of spacing and rotation time for poplar in Sweden on biomass yield has been scarce and few objects in Sweden have been available to quantify these effects and their consequences for the stakeholders to optimize profit.

On basis of the objects analyzed within the framework of this pilot study, we now have reliable estimates of biomass yields and economic profits for poplar stands grown at intermediate densities and rotation periods of 15-25 years. This knowledge can be used by present stakeholders for the optimization of yields within delineated ranges. Uncertainty still remains about the financial outcome of denser plantings and longer rotations. The former ones could be developed towards production of biomass for energy purposes while the latter also may provide pulpwood and timber. The results from this pilot study give some indication that with the standard planting density today the optimal rotation could be longer.

What has been presented in this pilot-study is of high interest and importance and shows the possibilities for a better economic output of poplar plantations. But as mentioned at several places, we are lacking data to draw firm conclusions that would hold for plantations of higher densities. We also need data over a longer time span to be able capture a MAI-decline. Once we have those, we would be able to use asymptotic production models that are more robust that what we used now. Therefore it is strongly desirable and recommended to prolong the project and/or to set up a larger project that continues to follow up the established density research trials and the twelve monitored plantations, but preferably also includes more plantations, especially in the older age-classes, to detect the important point of decline in annual production. Furthermore, it would be possible to capture the effects of thinning and their consequences for the economic output. It is also desirable and recommended that planting density research plots will be established with higher densities than those in the two trials in this study. Higher densities up to 6 000 plants per hectare or higher are used in other European countries such as France and Italy with a long tradition and successful practice of growing poplar plantations. These higher planting densities likely can be used in the Nordic countries, but they need to be tested and studied.

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Del 3: Resultatförmedling

Vetenskapliga publiceringar	IPC/FAO (International Poplar Commission) conference in Berlin September 14, 2016, oral presentation and abstracts published in conference compendium, se link and attachment https://ipc25berlin2016.com/program-presentations/
	Journadas de Salicaceas 2017, V Congreso Internacional de Salicaceas, Talca, Chile, 13-17 noviembre 2017, Abstract and conference paper, se attachment
	IUFRO (International Union of Forest Research Organizations) Conference; Seventh International Poplar Symposium: New bioeconomies: exploring the potential role of Salicacea: October 28-November 4, 2018-Buenos Aires, Argentina. Poster and abstract. Se link and attachment https://poplarsymposium.blogspot.com/
Muntlig kommunikation	Presentation (powerpoint and general discussion) to visitors to SLU from an official Lithuanian bioenergy group, 7 april 2017
Övrigt	Three field excursions (Skara /Götene, Björklinge and Valdemarsvik) during September and October. funded by the Swedish Board of Agriculture (JV) and organized by the Agricultural Society in Skaraborg. At the excursions some project's plots were visited and demonstrated, see attachments