Production, Silviculture And Nutritional Aspects Of Hybrid Aspen Plantations – A Summary of Experiences in Sweden

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Abstract: Sweden currently concentrates on decreasing its oil dependency. Efforts are directed towards renewable sources, where biomass from agricultural and forest land is an important possibility. This synthesis deals with hybrid aspen (*Populus tremuloides* Michx. × *P. tremula* L.) as a source for wood and biofuels. Productivity, thinning effects and nutritional aspects were studied in stands in southern Sweden. Measurements indicate that the mean annual increment obtained without any artificial addition of fertilizers or irrigation, will exceed 20 m^3 of stem wood ha^{-1} yr^{-1} during the first generation, with a 20-25 year rotation period. This corresponds to a total average woody biomass production, including branches, of over 8 tonnes dry matter ha^{-1} yr^{-1}. These production levels show that hybrid aspen is a competitive alternative for short rotation forestry in Sweden. Thinning studies, with three different weights of thinning, resulted after five years in significantly higher current annual increment, but significantly smaller mean stem diameter where no thinning was applied compared with thinned alternatives.

A silviculture concept that combines early harvests of root suckers with conventional forestry is proposed for hybrid aspen in later generations. The large early biomass amounts could be exploited by corridor cleaning and used as biofuels, while the remaining stand could be treated with ordinary forestry measures to produce pulpwood and logs. Regenerating hybrid aspen rapidly produces a large number of suckers, and about 70 000 suckers ha^{-1} were found at a study site two years after clear felling. Standing biomass amounted to 38 tonnes of dry matter ha^{-1} after four years, corresponding to 9.5 tonnes ha^{-1} yr^{-1}.

The content of macro nutrients in stems of 4-15 year-old hybrid aspen was analysed, and nutrient removal at harvest operations was calculated. As expected, nutrient concentration decreased with age and increased with stem height. This means that a biofuel assortment of tops and branches will have higher concentrations of nutrients than merchantable wood, and puts the focus even more on growth sustainability and reapplication of nitrogen and ash.

Our results show that hybrid aspen is a strong contender as a biomass producer, but also for other wood assortments. Its significance has most probably increased with the new energy strategies declared in Sweden.

INTRODUCTION

The interest in fast-growing tree species in Sweden increased in connection with the oil crisis in the 1970's. It has stayed on the agenda since then although there have been some ups and downs. For example, around 1990 there was a conversion program with the intention to plant trees on surplus agricultural land, which raised the interest temporarily. Recently, however, a large push for biofuels including hardwoods occurred. A Commission for reducing the oil dependence was set up by the Swedish government in 2005, with the prime minister as chairman. The goals are to increase the energy use efficiency, to reduce oil consumption in the industry and transport sectors, and to remove oil as a means for heating houses. The Commission recently published a report (Anon. 2006), where strategies to reach the goals are presented. One important strategy is to use more biofuels from agricultural and forest land. Sweden is a sparse populated country with large available areas, especially of forest land. Moreover, it is said directly in the document that high-producing hardwoods are expected to be a useful tool in reaching the goal.

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Hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) has been studied almost continuously since the 1980's (Stener 2002) and can be regarded as a suitable alternative for producing large amounts of biomass, although there are still obvious gaps in our knowledge. This paper presents our experiences so far with hybrid aspen concerning productivity, silviculture effects and nutritional aspects.

MATERIAL

In total 13 research and demonstration sites in southern Sweden (latitudes c. 55° – c. 59°N) provide the base for the results presented here. These stands were established from the middle of the 1980's and forward. A large part of the results have been published in separate articles. For example, nutrient issues were handled in Rytter (2002) and Rytter & Stener (2003), production figures were presented in Rytter & Stener (2005), economy in Rytter et al. (2002), and breeding possibilities in Yu et al. (2001) and Stener & Karlsson (2004). For more information on the methods of the different studies, refer to these articles.

RESULTS AND DISCUSSION

Production

The growth capacity is of course of utmost importance for a tree species which should serve the biofuel sector. Measurements of first generation hybrid aspen stands on eleven different sites, with plant material from the breeding work during the 1980's, lead us to expect that a mean annual increment (MAI) of more than 20 m^3 of stemwood ha^{-1} yr^{-1} is within reach (Fig. 1). This corresponds to a biomass dry weight of almost 7 tons ha^{-1} yr^{-1}. Taken into account that this production is received at high latitudes (above 55°N) with no supplementary fertilization and irrigation, we argue that the production is high.

In addition to the stem volumes, the hybrid aspen will produce substantial amounts of branch wood. In our sparsely planted stands (1 100 – 1 600 stems ha^{-1}) we have found that twigs and branches constitute over 20% of the total aboveground woody biomass, which is generally higher than commonly found (eg. Rytter 2004a). A more complete picture of the first generation production should therefore include stem as well as twig and branch parts (Table 1). By doing this we get a total mean production in volume of about 25 m^3 ha^{-1} yr^{-1}, which corresponds to over 8 tons of dry matter. In comparison with fertilized energy forests of *Salix* species, the level is not far below (Willebrand et al. 1993, Larsson 2001).

Most of our experience with hybrid aspen forestry has come from the first tree generation, i.e. the planted generation. However, some information also exists from the second generation. It is obvious that the second generation, and also later generations, benefit from an existing root system which gives vigorous sprouting of mainly root suckers. This can be seen from two stands in Figure 1 and also in Table 2. Mean annual increment reaches a high level quickly (Fig. 1), and this can be explained both by a rapid development of the single sucker itself but also by the enormous number of suckers. After two years we have counted to between 50 000 and 100 000 suckers ha^{-1} (Table 2). The production of the sucker generation seems to be on about the same level as given by energy forests with willow, i.e. 9-10 tons of woody biomass ha^{-1} yr^{-1}.

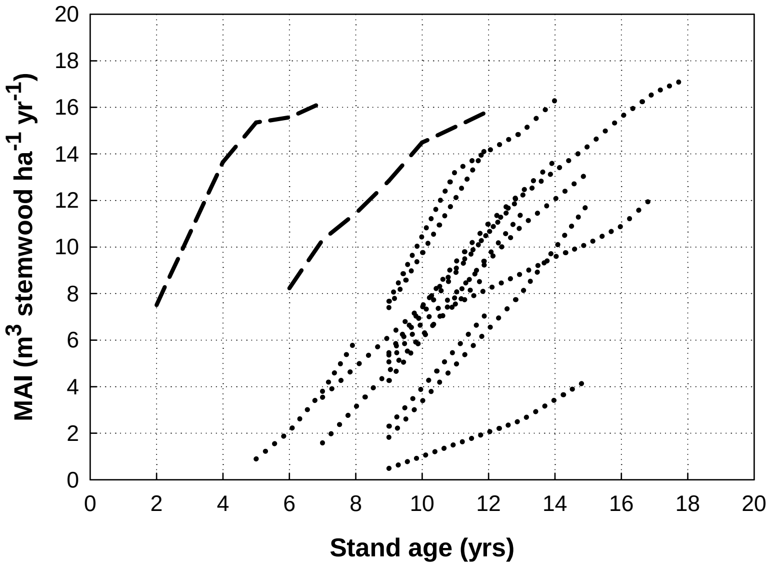

Figure 1. Mean annual increments (MAI) of stem volumes over bark for south Swedish hybrid aspen stands under standard thinning regimes. Planted stands of the first generation are shown with dotted lines, root sucker generated stands with broken lines. The stem volume removed in a clearing measure in the oldest sucker stand is unknown and therefore not included in the MAI estimate. Redrawn from Rytter & Stener (2005).

Table 1. Estimated total production above ground in a first generation hybrid stand in southern Sweden. It is assumed that the rotation period is 25 years and that twigs and branches constitute 20% of the total above-ground woody biomass of the tree.

Measure	**Stem** (m^3 ha^{-1})	**Branch** (m^3 ha^{-1})	**Stem biomass** (tons DM ha^{-1})	**Branch** (tons DM ha^{-1})
Thinnings	150-160	30-32	50-54	10-11
Final felling	360-370	72-74	121-124	24-25
TOTAL	510-530	102-106	171-178	34-36
TOTAL YR^{-1}	20-21	c. 4	6.8-7.1	c. 1.4

Table 2. Stem number and growth, expressed as standing biomass and mean annual increment (MAI) during four years, in a sucker-generated hybrid aspen stand on former agricultural land in southern Sweden. Two treatments are shown: 1) No cleaning, and 2) Corridor cleaning. In the second treatment two thirds of the area was cleaned after two years. Partly taken from Rytter (2004a).

Treatment	Years after harvest	Stem number (no ha^{-1})	Harvest (stems ha^{-1})	Standing biomass (tons DM ha^{-1})	Harvest (tons DM ha^{-1})	MAI (tons DM ha^{-1} yr^{-1})
1)	2	71 300	-	15.26	-	7.63
	4	55 200		38.02		9.50
2)	2	67 200 →	44 800[a]	13.06 →	8.71[a]	6.53
		↓		↓		
	4	24 400		18.91		6.90

[a] calculation based on even distribution of suckers over the area

Silviculture effects

The first tree generation is generally planted with a spacing of about 3 x 3 metres, which gives a density of 1 100 plants ha^{-1}. This is convenient because it leads directly into the commercial thinning phase without any prior cleaning measures. The biofuel harvest will thus mainly be directed only to lops and tops in this generation, because other more valuable assortments will most probably be sorted out. Calculations of economy have shown that the profitability strongly increases if saw logs can be produced (Rytter et al. 2002). Therefore, the thinning measures are important in that they transfer future production to fewer stems of higher quality and with probably better stem dimension development. We have tested this in our work.

On five sites different thinning strategies were applied: 1) no thinning but with cleaning in sucker stands, 2) standard thinning, and 3) strong thinning (more information can be found in Rytter & Stener 2005). Initially there were no statistical differences in current annual increment of stems between thinning treatments, but as expected the no thinning alternative grew better the next five years, and significant differences appeared (Rytter & Stener 2005). We could so far see no statistical differences between the two thinning treatments. A trend of diverging growth between treatments of different thinning strength was observed in the mean annual increment (Fig. 2).

On the other hand, the stem development, expressed as breast height diameter, was significantly better the stronger the thinning (Fig. 3). Also when the comparison was based on the 400 thickest trees ha^{-1} of each treatment (which represents a common density at the time of final felling and would roughly represent these future stems) a difference in stem development between the treatments was still present.

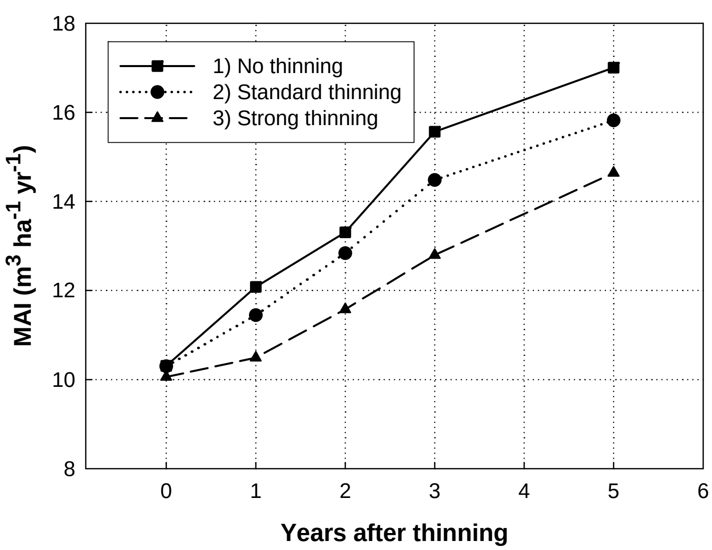

Figure 2. An example of mean annual increment (MAI) development in a stand where the three thinning strategies were applied. In this case the thinning was carried out at the age of 7 years.

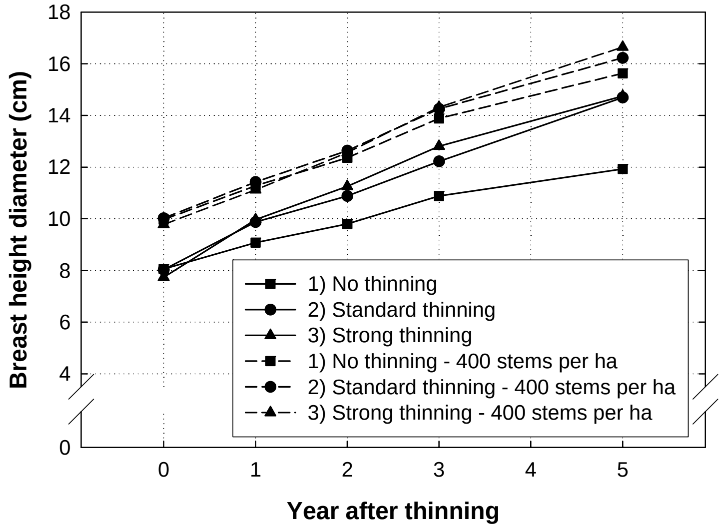

Figure 3. An example of the stem diameter development for the three thinning strategies. Continuous lines represent mean development for all trees on the plots, while the broken lines show the mean diameter development for the 400 thickest stems ha^{-1}. The thinning was carried out at the age of 7 years. Redrawn from Rytter & Stener (2005).

Plantation Systems

The high production level and the vigorous sprouting of root suckers after harvest give possibilities to choose different management directions and thus different end products.

In the first generation a conventional forestry aiming at pulpwood and lumber with possibilities to harvest lops and tops is the most obvious choice. The sparse number of plants is motivated by a high plant cost, but also the possibility to a premature harvest, with a new root sucker based generation afterwards, if plant survival should be low or the damage level high.

In the second generation, however, possibilities for different management strategies appear. In an ordinary forestry approach, heavy cleanings are necessary because of the dense root sucker generation (see above). The reduction of stem numbers should be accomplished early in the rotation to allow remaining stems to develop well, i.e. reach large dimensions.

Another approach is to carry on with coppice forestry. As can be seen, it is possible to obtain over 9 tons of dry matter ha^{-1} yr^{-1} during a four-year cycle (Table 2), which is about the level in fertilized energy forests (Willebrand et al. 1993, Larsson 2001). A corridor cleaning after two years reduces the amount after four years but may be advantageous if rotation time is stretched out. We currently do not know if this high production level will last in succeeding generations, but studies on this topic have been launched with support from the Swedish Energy Agency (Rytter 2004b).

It will also be possible to keep more stems than in the ordinary forestry alternative. With this direction the production will most probably be higher but the stem diameter smaller, which could be a management suitable for producing pulpwood.

An attractive way of management could be to combine conventional forestry with early biomass harvest. A corridor cleaning method should be useful. By cleaning 2 m broad zones between 1 m strips with trees (Fig. 4), two thirds of available biomass could be used as biofuels. The strips could then conveniently be cleaned manually. The biomass harvest would, according to table 2, amount to c. 9 tons DM ha^{-1} after two years and c. 25 tons after four years. Because cleaning is an early cost in forestry, an income or a low cost would greatly favour the profitability.

Figure 4. Corridor cleaning in a 2-year-old root sucker stand of hybrid aspen. Biomass harvest in the cleaning phase is a possibility to improve the economy. Picture taken from Rytter (2004a)

Damage and Harvest Consequences

There are obstacles for all kinds of tree species and forestry methods. A dense population of game (mainly moose (*Alces alces*) and roe deer (*Capreolus capreolus*) is the most apparent problem for establishing hybrid aspen and for the young forest. Fencing is recommended over large areas, and this cost will reduce profitability although a net gain could still be expected (Rytter et al. 2002). In the establishment phase damage from voles on stems and roots (especially water vole, *Arvicola terrestris*) may occur, and is more common when grass vegetation is abundant.

We have also recorded (Stener 2002) the existence of stem canker (*Entoleuca mammata*, former *Hypoxylon mammatum*) and branch canker (*Leucostoma niveum*). However, in the breeding work affected clones are continuously removed from the recommended plant material, so this problem seems to be under control.

Another serious issue in plantation forestry is sustainability of growth. We have obtained high production figures without any artificial supply of nutrients. Harvest of small-dimensioned stems and shoots implies that large amounts of nutrients per unit of biomass is removed from the stand

(Fig. 5). One reason for this is that the percentage of nutrient-rich bark is high in slender shoots but decreases with increasing stem size. Small dimensioned parts are removed both in lops and tops, and in harvest in the cleaning phase.

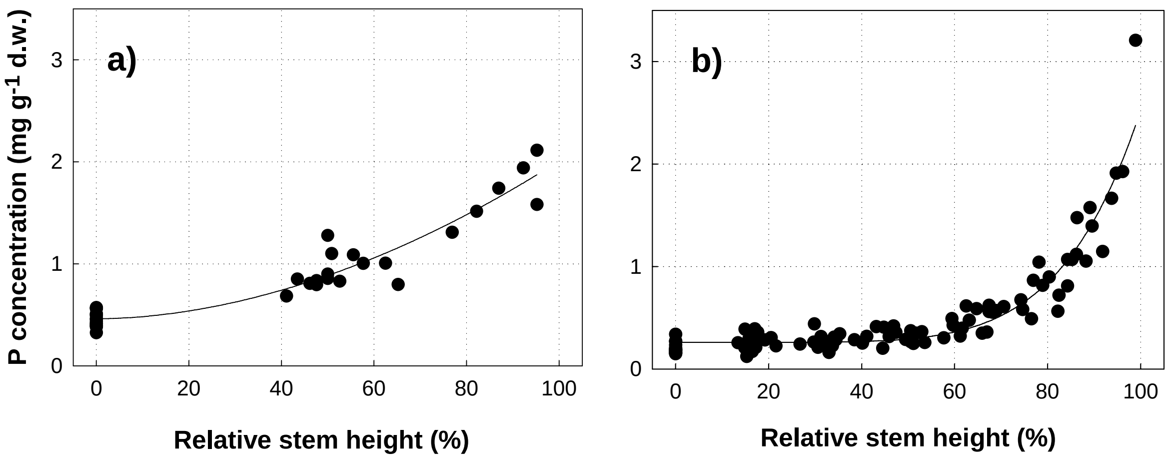

Figure 5. Examples of stem nutrient variation with tree height in a) 4-year-old small trees and b) 15-year-old larger trees. The figures show P concentration at different relative tree heights. The average tree heights were 5.8 and 18.0 m, respectively. Redrawn from Rytter (2002).

In energy forestry, with short rotations, a fertilization programme is recommended (eg. Ledin 1996). For a whole-tree system of hybrid aspen, Rytter (2002) concluded that most essential elements are removed at a faster rate than weathering and deposition can compensate for. This indicates that supplementary nutrient addition is necessary in the long run. Thus, it is important to get information on both the input and withdrawal of nutrients in plantation forestry in order to keep a favourable availability of nutrients, and this type of work continues.

CONCLUSIONS

Our results show that hybrid aspen is a strong contender as a biomass producer, but also for other wood assortments. Its significance has most probably increased with the new energy strategies in Sweden. Because Sweden is a conifer-dominated country, an introduction of hybrid aspen will also enhance the landscape variation, which is positive for biodiversity and recreation. The most easily defined obstacle is damage by a large game population. This necessitates fencing in many places, but profitability may still be good.

ACKNOWLEDGEMENTS

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