Production of poplar containerized plants

- *Differences in cutting types and fertilization regimes*

Thomas Fransson
Supervisors: Henrik Böhlenius
Emma Holmström

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Examinator: Eric Agestam

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Abstract

Populus is one of the most economically important genuses in the world's temperate zones. They are known for their fast growth, easy propagation, many usages, aesthetic values and propensity to hybridize. Planting stock for poplar is usually divided into rooted and unrooted material. Unrooted can be divided into cuttings (2- 100 cm) and whips (1,5 to 6 m). Rooted can be divided into bare-rooted and containerized plants. The goals of this study were to investigate; (1) how different cutting types influenced survival and plant growth of containerized plants. (2) how fertilizer regimes influenced plants growth response to cutting types. The experiment consisted of 72 treatment combinations: eight cutting types, three clones (Rochester, Clone 15 and OP42), and three fertilizing treatments (a standard NPK solution, an amino acid solution and unfertilized control). 15 blocks, 1080 plants in total, were established in a greenhouse and grew for teen weeks before harvest.
Over all clones, treatments and cuttings, the survival rate was 79 %. Our results revealed that cutting type influenced height, diameter, biomass production and survival especially if plants were not fertilized. Fertilization lowered these differences although they were still present after fertilization. Plant growth (clones and cutting types) increased if fertilizer NPK or arGrow were used with NPK fertilization increasing plant growth the most. Plants fertilized with arGrow had a higher root to shoot ratio.

Keywords: Populus, Poplar, Cuttings, Containerized plants

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Introduction

Poplars

Populus is one of the most economically important genuses in the world's temperate zones. They are known for their fast growth, easy propagation, many usages, aesthetic values and propensity to hybridize (Isebrands & Richardson, 2014). 91 % of the poplar resources globally is growing in natural forests and woodlands, 6 % grows in plantations and 3 % in agroforestry systems (Balatinecz et al., 2014). The name "Populus" is derived from the Latin *arbor populi*, tree of the people.

FAO (2009) estimates the total area of poplars in the world to be 79,1 million ha and the total area of poplar plantations is 5,3 million hectares. The three countries with largest area of poplar plantations are China (4,3 million ha), France (236 000 ha) and Turkey (125 000). The largest area of natural *Populus* stands is found in Canada followed by Russia (Tsarev, 2005). China is the leading country in cultivating poplars for timber, fibre, pulp and paper (Isebrands & Richardson, 2014).

The genus *Populus* together with *Salix* belongs to the tribe *Saliceae*, which is a tribe of shade-intolerant pioneers that often colonize disturbed areas.

Populus is a deciduous broadleaved genus, with a natural distribution over the northern hemisphere. In general poplars are considered rather short-lived, compared to other tree species like (Quercus sp.) and pines (Pinus sp.). But the root system of *P. tremuloides* can persist for thousands of years, with many generations of stems. Poplars in nature occur either in early successional monotypic stands or in later successional mixed stands together with other broadleaves and conifers.

Populus species set lots of wind dispersed seeds and also propagate vegetative. Almost all species in the genus propagates well with stump shoots or root suckers or both (Isebrands & Richardson, 2014). A mature poplar can produce up to 50 million seeds, and they can travel with the wind for over 10 km. Seed production in poplar varies over the years as for most tree taxa (Wyckoff & Zasada, 2008). There are two sections of Populus that has the ability to root well from hardwood cuttings- Aigeiros and Tacamahaca. Aspens are lacking this ability and that makes the plant production much more labor intensive and expensive (Braatne *et al.*, 1996).

All Populus species are dioecious, which means that individual trees are either pollen-bearing (male) or seed-producing (female). Natural hybrids are also common, both interspecific hybrids (e.g. *P. alba* often interbreeds with aspens in areas where they grow together) and intersectional hybrids between taxonomical sections (e.g. members of the Aigeiros and Tacamahaca) (Dickmann & Kuzovkina, 2014). Most of these hybrids are fertile, so they can backcross with one of the parent species or in rare occasions hybridize again with a third specie, this has led to a complex taxonomy with two main camps. One group consists of mainly Russian and Chinese practitioners that claim that there are 85 species of poplars while Western taxonomists claim that the genus consists of 22 species (Dickmann, 2001).

When American poplars were brought to Europe and naturally hybridized with the European P. nigra they formed rapid growing hybrids. This was the start of the interest for poplar research.

First deliberate hybridization was made by A. Henry in 1912 and it was the start of numerous poplar hybridization programs throughout the world. The first large scale project started in 1925 in USA. In 1947 the International Poplar Commission was founded and started to register clones and gathered research on poplar cultivation.

In the 1960's the demand for matchwood lead to the introduction of poplar plantations on the southern hemisphere (Australia, Brazil, Chile, South Africa and New Zeeland) (Pryor & Willing, 1965; Isebrands & Richardson, 2014).

Sections

The *Populus* genus is divided into six taxonomic sections; Abaso (Mexican poplar), Turanga (Arid and tropical poplar), Leucoides (Swamp poplars), Aigeiros (Cottonwoods, black poplars), Tacamahaca (Balsam poplars) and Populus (White poplars and aspens). Three of the sections is of importance for the commercial forestry, two of the sections will be referred to as poplars (Aigeiros, Tacamahaca) and one section will be referred to as aspens (Populus). In table 1 a short overview of the different Populus sections (FAO, 1980; Eckenwalder, 1996; Dickmann & Kuzovkina, 2014) is presented.

Table 1. A short overview of the different Populus sections (FAO, 1980; Eckenwalder, 1996; Dickmann & Kuzovkina, 2014).

	Abaso	Aigeiros	Leucoides	Populus	Tacamahaca	Turanga
	Mexican poplar	Cottonwoods and black poplars	Swamp poplars	White poplars and aspen	Balsam poplars	Arid and tropical poplar
Number of taxa	1	3	3	10	12	3
Habitat	Riparian areas	Riparian areas, swaps and wetlands	Swamps and very wet bottomlands	Swamps, wetland borders, riparian areas and uplands	Riparian areas, swamps, wetland borders	Riparian areas
Geographical distribution	Mexico	Europe, North Africa, Middle East, Central Asia and North America	Eastern North America and Central Asia	Europe, North Africa, Middle East, Asia and North America	Asia and North America	North Africa, Central and East Asia
Suckering	Rare	Uncommon	Common	Profuse	Occasional	Common
Hardwood cuttings	Unknown	Well in general	Do not root well	Aspens not, white poplars variably	Root very well	Root variably
Silvicultural use	None	Very important	Little or no importance	Very important	Very important	Some importance
Important species		*P. nigra* *P. deltoides*		*P. tremula* *P. tremuloides*	*P. balsamifera* *P. maximowiczii* *P. trichocarpa*	

Populus deltoides has its natural distribution in southern, eastern and mid-western USA and southern Canada. It is a large tree that can grow taller than 45 m and with diameters exceeding 3 m. Growing in an open canopy it sometimes tends to get forked, but growing in a closed canopy it usually develop a straight bole with a small crown (Dickmann & Kuzovkina, 2014).

It is often seen as an invader on disturbed sites. It is regarded as the fastest growing native tree in North America. In the Mississippi delta where some of the best sites are found, height growth can exceed 4 m during the first five growing seasons (Knowe *et al.*, 1998). *P. deltoides* is used as mother in the most common hybrid, *P. xcanadensis*, it is also common in commercial hybrids together with *P. trichocarpa* (e.g. *P. xgenerosa*) and *P. balsamifera* (e.g. *P. xjackii*).

Populus nigra is native to most of Europe (except Scandinavia), North Africa and the western parts of Asia. Mature trees can reach 40 m in height and over 2 m in diameter. The stems are often crooked or swept with a branchy crown, and it frequently produces epicormic branches. It is common as an aggressive invader on exposed sites like river flood plains or wastelands. Shoots sprout vigorously from stumps as well as suckers from shallow roots. *P. nigra* is the father tree in the hybrid *P. xcanadensis* (Dickmann & Kuzovkina, 2014).

Populus balsamifera is present across the northern USA and Canada from the Atlantic to Alaska. It can grow further north than any other poplar specie in North America, growing as far north as the 69^{O}N latitude above the treeline (Bockheim *et al.*, 2003). It is a medium sized tree, with a height between 20 - 30 m and a diameter just below 2 m. Often it is found along streams, lakes and rivers, but also on drier sites. It is easy to propagate with hardwood cuttings. Pure *P. balsamifera* is not used for wood production, instead it is used as one parent in some hybrid clones like in the *P. xjackii* and in some hybrids together with P. *maximowiczii,* which are mainly used for forest planting in Canada (Dickmann & Kuzovkina, 2014).

Populus maximowiczii is native to northern China, Korea, eastern Russia and Japan. It is one of the largest poplars in Asia, up to 30 m in height and 2 m in diameter. Grows on gravel river bars and low terraces, and also on volcanic ashes in Japan (Haruki & Tsuyuzaki, 2001). The species is susceptible to stem canker when cultivated in North America but some hybrids with *P. nigra* have shown a high resistance. Pure stands has also shown to be brittle, getting damaged by wind, snow and ice. *P. maximowiczii* is the mother tree of the hybrid OP42.

Populus trichocarpa is under debate to be a unique specie or a subspecies to *P. balsamifera.* Their vegetative morphology is almost indistinguishable from each other but there are some differences in their reproductive structures. *P. trichocarpa* is growing along the Pacific coast from Baja to Alaska, and forms some of the largest poplar trees. Specimens over 50 m tall are not unusual and some even reaches over 60 m, with diameters up to 4 m. When grown in the coastal forests they develop long, clear boles. It is used extensively in different hybrids, and is the father tree in the hybrid OP42. Recent hybrids together with *P. nigra* is also showing very promising results (Dickmann & Kuzovkina, 2014).

P. tremula and *P. tremuloides* are genetically close species, and in some studies it has been proposed to regard them as one species with circumboreal distribution (Perala *et al.*, 1995).
The common aspen, *P. tremula* has one of the largest native distributions in the world, from the British Isles to the easternmost reaches of Russia and Japan. The American trembling aspen, *P. tremuloides* is present from the east coast to the west cost of the American continent and from Alaska to Mexico (Dickmann & Kuzovkina, 2014). In Russia alone the common aspen occupies 20,6 million ha (Tsarev, 2005). Common aspen can reach heights of 30 m and be up to 60 cm in diameter. On the best sites trembling aspen can reach 35 m in height and 1,3 m in diameter. Aspens do not propagate with hardwood cuttings but can produce an enormous amount (tens of thousands) of root suckers (Dickmann & Kuzovkina, 2014). The hybrid of *P. tremula* and *P. tremuloides* is commonly known as hybrid aspen (*P. wettsteinii*) and has shown faster growth and a higher biomass productivity than its parents (Tullus *et al.*, 2012).

Rytter *et al.*, (2011) explains this with the heterosis effect, a better pest resistance and the northerly transfer of P. tremuloides, which results in a longer growth period. Hybrid aspen is fertile and can produce viable seeds with both of its parent species.

The definition of a hybrid *is "an offspring of two animals or plants of different races, breeds, varieties, species, or genera".* A poplar hybrid is named with the seed-producing (female) parent first and the pollen-producing (male) last. The most common in commercial clones is *P. deltoides* (♀) x *P. nigra* (♂), called *P. xcanadensis* (Dickmann & Kuzovkina, 2014).

Swedish forest policy

In the Swedish forestry act common aspen (*P. tremula)* and the hybrid aspen (*P. wettsteinii)* are considered as the only native species from the Populus genus. By not being considered as a native species, there are limitations for how poplars can be planted on previously forested sites. All plantations larger then 0,5 ha needs to be confirmed by the Swedish Forest Agency (*Skogsvårdslagen*).

The use of non-native species is limited for owners certified with FSC or PEFC. The certifications only allows 5 % of the forest land to be planted with non-native species (if they were not planted with non-native species before 2009). (Forest Stewardship Council, 2010; Programme for the Endorsement of Forest Certification, 2012). Traditionally when establishing poplar plantations, herbicides are often used, however this is heavily restricted on forest land in Sweden (*Skogsvårdslagen*)

These limitations do not apply on agricultural land, if the rotations are kept shorter than 20 years, both poplars and aspens are considered as bioenergy crop. And for growing energy crops there is agricultural subsidies to be obtained from the Swedish Board of Agriculture, and in some occasions also subsidies for establishment and fencing. Growing energy crops like willow, poplars and aspen on agricultural land is considered as an alternation of the landscape and it requires consultation with the local County Administrative Board.

Wood properties and usages

Wood properties

Wood properties of poplar varies between the different sections and clones but there are some general features that defiance most of them. They have a rather high shrinkage, compared to other low density species, this is mainly due to their high polysaccharide content (Balatinecz *et al.*, 2014). The strength to density ratio is in line with most of the commercial softwoods like spruce (Boever *et al.*, 2007). Wood working properties for poplars are good, it machines well (i.e. good for planning, boring, shaping and sanding). It also finishes well, with a lot of different coatings like, lacquers, waxes and oils (Knudson & Brunette, 2015). For drying, starting with air drying for 6-8 weeks followed by a mild kiln-drying is a recommended regime. Poplar wood has a low natural durability against decay (Knudson & Brunette, 2015).

The wood is ring-diffuse which that means the pores are evenly distributed throughout the springwood and summerwood. It means that growth conditions and growth rate has rater little effect on wood density, the difference is larger between section and clones.

I-214 is a commonly used clone in Italy, it is considered as a low density clone (300 kg/m^3). On the other side on the density spectrum we find the clone "Robusta" (*P. deltoids x P. nigra*) with an average density around 550 kg/m^3 (Balatinecz *et al.*, 2014). Knudson & Brunette (2015) studied the

"Walker hybrid" (*P. deltoids x P. petrowskyana*) a commonly used hybrid in Canada and found that the average density was 370 kg/m^3 (330- 430 kg/m^3).

Usages

Poplar timber is an important raw material for the lumber, veneer and plywood industry. The growing use of poplars for producing oriented strand board and structural composite lumber in North America is an example of a promising future for added value products from poplars (Balatinecz *et al.*, 2001; Boever *et al.*, 2007). Poplars have been commercially used by sawmills in Canada and USA since the 1960's, and the average lumber recovery from the logs ranges between 45- 50 %. Plywood and veneer represents the largest product group made from poplar (59,9 % of the total production), followed by other wood panels (21,7 %) and pulp/paper (11,7 %) (FAO, 2009).

If poplars are managed with the aim of achieving the highest qualities, then their wood properties makes them very suitable for veneer and plywood manufacturing. The high green moist content lowers the need of preconditioning before being processed and wood has good machining and gluing characteristics. In Italy, a common end user of poplar is the furniture industry, mainly the lighter plywood from the low density clone "I-214" (Balatinecz *et al.*, 2014).

Poplars is often used in wood-based composite products like fibreboard, particleboards, wood-cement products. Since the wood is easy to defibrillate, it does not require large diameter logs and the stem form is not a critical factor (Balatinecz *et al.*, 2014). Geimer & Crist (1979) conducted a study in which they used juvenile wood from rapidly growing poplars (3-6 years) for making OSB (oriented stranded boards) with good results. The main disadvantage with poplars for these types of products is the amount of fine dust the fiber material contains (Balatinecz *et al.*, 2014). I-joist (both for the web and flange) and LVL beams is two products with an increasing popularity that creates a possibility to use poplar wood as material for building frames (Kurt *et al.*, 2012; Knudson & Brunette, 2015; Rahayu *et al.*, 2015).

It is the pulp industry that has been driving the development of hybrid poplars and aspens through the years. Poplar makes a short fiber pulp, the average fiber length is between 1,32 to 1,38 mm. It can be pulped with all commercial pulping methods (mechanical, semi-chemical and chemical) and especially aspens are well suited for making of fine papers thanks to its high opacity, good sheet formation and printability. It is often blended together with softwood pulp for making newspapers and other printing products (Balatinecz et al., 2014). Sulphate pulp yield is according to Balatinecz & Kretschmann (2001) between 52- 56 % in average.

Biomass is possible to convert into many forms of energy like heat, electricity and liquid fuels. Thanks to the rapid growth and good breading potential, poplars are often used in various ways for bioenergy. The most direct way to produce energy from wood is to burn it, and in some cases at the same time steam water to produce electricity. Heating values for poplar (dry weight) was estimated to 19,38 MJ/kg by Brown & Brown (2013), western red cedar was estimated to 20,56 MJ/kg and wheat straws to 17,51 MJ/kg.

When burning the wood, the energy must be used right away since it is technically very hard to store it, for storing and transportation of energy liquid fuels has a big advantage. There are some wood properties that makes poplar well suited for ethanol production, the major one is the high content of polysaccharides approximately 80 % (cellulose 50 % and hemicelluloses 30 %) and a low content of lignin (20 % or less) (Balatinecz & Kretschmann, 2001). The process of making ethanol from wood today includes a stage with enzymatic hydrolysis to split cellulose and hemicellulose into individual sugar molecules.

Lignin binds and inactivates these enzymes which requires a higher input and enables a lower grade of enzyme recycle for tree species with a high lignin content, increasing the costs substantially. Also the low amounts of extractives and ash has a positive influence on the possibility of making ethanol from poplars (Dinus, 2001). The author also sees a possibility to further lowering the amount of lignin in poplar wood trough classical breeding. *"All that can be made from oil can also be made from wood"* Christersson (2010).

Growth and Yield

The main factors influencing growth and yield of poplars are species or clones, site quality, climate and spacing (Zabek & Prescott, 2006; Christersson, 2010; Chandra, 2011).

Industrial plantations of poplars has some of the highest growth rates in the world (Dickmann, 2006). The highest reported growth from an operational, irrigated plantation in western USA had an MAI of 42 m^3/ha^{-1} (Stanton *et al.*, 2002). Even higher growth rates has been achieved in experimental and bioenergy plantations (Stanturf & Oosten, 2014). In table 2 are some examples of growth rates achieved in areas with fairly comparable growth conditions to Sweden.

Table 2. International comparison of growth rates for poplars

Location	Specie/clone	Age	MAI m^3/ha^{-1}	Source
Canada, prairie	Walker hyb.	25	8-15	(Knudson & Brunette, 2015)
Canada, with irrigation	Unspecified	11	30	(Carlson, 1998)
Ontario, Canada	Unspecified	12	29	(Zsuffa *et al.*, 1977)
Russia	Unspecified	21	20	(Stanturf & Oosten, 2014)
British Columbia, Canada	Unspecified	15	25	(Stanturf & Oosten, 2014)
Pacific Northwest, USA	Unspecified	8	25	(Stanturf & Oosten, 2014)
Midtjyllad, Denmark	OP42	13	28	(Nielsen *et al.*, 2014)
Midtjyllad, Denmark	*P. trichocarpa*	13	18	(Nielsen *et al.*, 2014)
Midtjyllad, Denmark	*P. maximowiczii x P. nigra*	13	16	(Nielsen *et al.*, 2014)
British Columbia, with irrigation	*P. trichocarpa x P. deltoides*	9	27,5	(Johnstone, 2008)

In Sweden, commercial plantations of poplars are rare, most estimates of production are based on well managed experiments, some examples are shown in table 3.

Table 3. Example of growth rates archived by poplars in Sweden

Location	Specie/clone	Age	MAI m^3/ha^{-1}	Source
Näsbyholm	OP42	18	23	(Christersson, 2010)
Kadesjö	OP42	18	22	(Christersson, 2010)
Karinslund (irrigated)	*P. trichocarpa*	19	28	(Christersson, 2010)
Innertavle (63^{O})	*P. trichocarpa*	14	8,5	(Karačić, 2005)

Management

Spacing

When considering the question of spacing in poplar plantations, Weih (2004) presents three important factors to consider: (i) the production objective, (ii) type and amount of weed control and (iii) cost of planting material and labor.

A close spacing will reduce the diameter of single trees, but total biomass production per unit area will increase (Bergkvist & Ledin, 1998). Johnstone (2008) could in his study see a mortality rate of 20 % after nine years in a medium dense spacing (>2000- 3000 stems/ha).

In very dense spacings (15 000 stems/ha) mortality rates can be even higher after a short period. In spacing trail with the clone *P. xrasumowskyana* (the origin of this hybrid is unknown) mortality was between 51 % and 81 % after six years (0,7 x 0,95 m, 15 000 stems/ha), depending on the fertilizing regime that was applied (Ferm *et al.*, 1989).

Johnstone (2008) studied the influence of different spacing regimes (ranging from 494 to 4 444 trees/ha) on growth in a hybrid between *P. trichocarpa x P. deltoides* in British Columbia. They found that after 9 years the highest total volume was in spacing 2,25 x 2,25 (1975 stems/ha) , but the highest merchantable volume was achieved with a 2,25 x 4,5 (988 stems/ha) spacing. In countries where mechanical or chemical weed control is used, spacing between the rows is recommended to be at least 3m (Stanturf *et al.*, 2001).

In Argentina and Chile a management system with 6x6 m spacing planted with 3-4 m long whips is used. The purpose with this is to have a silvopastoral system where they introduce cattle into the stand (Stanturf & Oosten, 2014).

When Stanturf & Oosten (2014) reviewed numerous spacing studies they considered a spacing of 3,7 x 3,7m to be a good compromise for producing pulpwood and saw logs. In table 4, there is a summary of their review, containing planting densities recommended for each purpose and different kinds of stock types.

Table 4. Recommended density and stock type depending on plantation purpose (Stanturf & Oosten, 2014)

Density/ha	Stock type	Purpose
>1500	Cuttings	Biomass
700- 1500	Cuttings/Rooted stock	Fibre and solid wood
< 400	Cuttings/ Rooted stock	Solid wood

Poplars are affected by competition through their whole life cycle, they require sufficient sunlight and good access to water and nutrients. But still, thinnings are uncommon in American poplar plantations since the final stand density is generally the same as the established density. The main reason for this is that their response to crown release is poor and that many poplar species doesn't tolerate side competition (Stanturf & Oosten, 2014).

Fertilization and irrigation

Schedules for fertilization and irrigation are specific for each region, depending on local conditions, but lack of nitrogen is the main limit to the growth of poplars in all regions (Stanturf *et al.*, 2001). Fertilisation of a poplar plantation is usually conducted in the establishment phase or just before canopy closure.

Fertilizing at the time of establishment can increase early growth and thereby help the trees to overtop competing vegetation (Miller, 1981). Either the fertilizer is applied into the planting hole or in an adjacent, smaller hole, this method has shown to further increase growth (van den Driessche, 1999; Stanturf & Oosten, 2014). Typically the fertilization is done at the same time as site preparation (Palmer, 1991), but some experiments have been conducted where the fertilization has been delayed for 1 or 2 years in order to maximize uptake by the crop tree and minimize the uptake from competing vegetation. The delayed system is primarily used together with cuttings.

Brown & van den Driessche (2002) saw a 34 % volume increase the first year after fertilization and three years after, the difference was 20 % for a hybrid between *P. trichocarpa x P. deltoides.* There was a similar trail nearby the following year, reported in van den Driessche (1999) where the highest volume after the first year was 329 % better than the control. (Brown & van den Driessche, 2002) explain the difference with the fivefold larger precipitation during June through August that year. This can be taken as an indicator for the importance of ensuring a sufficient water supply for these types of intensive management programs. When fertilizing at canopy closure there is usually smaller amount of undergrowth that can compete for nutrients, and it also shortens the period during which the investment is discounted (Palmer, 1991).

Coleman *et al.* (2006) studied growth in hybrid poplars fertilized at canopy closure in Minnesota, USA. They found that the above ground biomass increased with over 40 % in three years compared to the unfertilized control, other similar studies in USA had shown a growth increase between 21 % and 62 %.

Fertilizing has shown to have effect on growth in poplar plantations. In some dryer areas where fertilization alone has not been enough for an increase in production, fertilization together with irrigation have shown good results (van den Driessche, 1999). It can be discussed if stationary irrigation of tree plantations is sustainable, but in many areas outside the boreal zone it is practised with good growth results (Stanton *et al.*, 2002). There are also examples of gravity-fed systems like irrigation canals which could be considered as more sustainable.

Pruning

Pruning is a common practise to produce high quality logs for the veneer industry. How prone a stand is to develop sylleptic branches, is very dependent on what species or clones are planted, also spacing has an influence on amount of branches. It is recommended that pruning is done during the summer when the trees contain more leaf nitrogen and stomatal conductance, that will allow the trees to recover more rapidly (Maurin & DesRochers, 2013).

The pruning is recommended to start at the third growing season at the latest. All parts of the stem that are over 10 cm should be cleared from branches (Stanturf & Oosten, 2014). In Canada the recommendation is a clear bole of 6-7 m and this should be done in 3-5 lifts, where maximum a one-third of the living crown is removed in each lift (Maurin & DesRochers, 2013).

Management for bioenergy

Armstrong *et al.* (1999) made a large spacing and cutting cycle experiment with poplars for bioenergy use in United Kingdom. They achieved the highest yield with a 1x1 m spacing. It was compared with a 2x2 in both rotation cycles. And the 4 years rotation was more productive than the one over 2 years, so not only did they get a higher yield with the longer cycle, the cost for harvesting was also lower. In Italy the plant density depends on the cutting cycle, for a one year cycle a double row design is often used. It has 0,4 m distance between the twin rows, 0,75 m distance within the twin rows and 2,8 m between the sets of twin rows. This resulted in a total of 14 000 stems/ha (Stanturf & Oosten, 2014).

Plant establishment

Soil types

Poplars in general prefer alluvial soils with sufficient nutrients, a pH range of 5,0- 7,5, moist, well aerated and with a medium texture (sand/loam). Heavy soils, like clays are less preferable mainly due to the poorer aeration and drainage. Poplars are also intolerant to saline conditions and organic soils should be avoided, since they generally are waterlogged and very acidic (Stanturf *et al.*, 2001). Even if the establishment succeeds, Christersson (2010) warns for planting poplars on organic soils since the loose texture and the poplars shallow root system will make the trees sensitive to wind damages. Poplars can perform well on shallow soils, if there is a sufficient amount of water and nutrients but also on these sites there is a heightened risk for wind damages.

Factors influencing plant establishment

There are many factors influencing plant establishment and the development of new roots after being transplanted into field conditions. Factors like nursery treatments (e.g. short-day treatments, nutrient loading and root pruning) and field work (e.g. field storage, planting date, planting practices and site preparation) plays an important role. Their effect on plant performance is often summed up under the name "transplanting stress" and these are to some extent unavoidable. All of these factors has a large effect on plant performance immediately after planting and are important to consider in order to avoid planting stress (Ritchie G. A & Dunlap J. R, 1980; Rietveld, 1989; Grossnickle, 1999, 2012).

Among all tree species, root development is of fundamental importance for a successful establishment. The size and shape of a plant can't guarantee a good performance in the field, but optimizing some of the morphological characteristics can significantly increase the chances for successful establishment. A well balanced shoot to root ratio, large stem diameter, a large and fibrous (i.e. branchy) root mass are important universal factors for seedling survival and early growth (Carlson, 1986; Wilson & Jacobs, 2006; Grossnickle, 2012).

Planting stress usually occurs just after planting. If the plant is not coupled into the hydraulic cycle of the site, it risks to suffer from a lack of water (Grossnickle, 2005). In a number of studies regarding plant establishment, planting stress has been determined to be the cause of the greatest mortality (Vyse, 1981; Waters *et al.*, 1991). Even if the plant survives and is coupled in to the hydraulic cycle, it can still result in growth check that for conifers can last over several years during which the plants are unable to increase their height growth (Rietveld, 1989; Grossnickle, 2005).

Low soil temperatures are considered to be an obstacle for plantation establishment in parts of the boreal zone (Butt, 1988). Both Lopushinsky & Kaufmann (1984) and Grossnickle (1988) have seen a large reduction in root growth for jack pine, white spruce and douglas fir in low soil temperatures. Zalesny *et al.* (2005) found that higher soil temperature increased the number of roots, total and mean root length as well as root dry mass, in all studied genomic groups.

Landhausser (2003) studied the influence of soil temperature on establishment of poplar cuttings. After 6 weeks the cuttings had a 20 % mortality rate in a soil temperature of 5^{O}C, the ones still alive had a poor development of leafs and shoots and no root development.

He concludes that cuttings should be planted during the late spring for longest possible growth period, and in the same year as the previous stand was cut in order to give them a head start before grass and other competitors. For short rotation species, that is also sensitive to vegetative competition like poplars, a fast establishment early in the growth season is of extra importance.

Studies of the clone OP42 in Sweden has shown that 50 % of its annual growth occur during August (Ilstedt, 1996; Böhlenius & Övergaard, 2015b).

Even if mineral nutrients make up less than 5 % of the total dry weight for a conifer seedling, they are essential for all metabolic processes (Lavender, 1990). Studies on both conifers and broadleaves conclude that production of fine roots declines if plants are provided with an increased amount of nitrogen (Ingestad & Kähr, 1985; Gower et al., 1992; Ericsson, 1995; Hermans et al., 2006).

Juntunen & Rikala, (2001) reported that when plants in a nursery received a higher concentration of mineral nitrogen, their height growth increased and root development decreased.

(Kern *et al.*, 2004) couldn't find a linear relationship between increased nitrogen fertilization and a lower amount of fine roots in *P. deltoides.* They used three different fertilizing regimes with 0 kg/ha, 50kg/ha and 200 kg/ha of added nitrogen. The amount of fine roots where lower in the group that got 50 kg of nitrogen compared to the unfertilized control. But there was no difference in amount of fine roots between the unfertilized control and the group that received 200 kg.

Studies addressing the difference between organic and inorganic nitrogen forms (Öhlund & Näsholm, 2004; Miller & Cramer, 2005) show that uptake rates of organic nitrogen are comparable or higher than the uptake rates of inorganic nitrogen. Öhlund & Näsholm, (2001) and Schmidt *et al.*, (2014) could see a smaller shoot to root ration (due to a greater biomass allocation to the roots) in conifers seedlings when they were fertilized with arginine as the source of nitrogen. Bauer & Berntson (2001) found the same result in their study of *Betula alleghaniensis.*

Lindroth & Båth (1999) considers water availability to be a crucial factor for the growth of short rotation forestry species in southern Sweden, and stresses the importance of taking into account site hydrology before establishment. Plants are considered to be fully established when they are coupled into the hydrological cycle of a site and start to respond to silvicultural practices (Rietveld, 1989; Grossnickle, 1999).

Factors influencing plant growth

Competition for light and water between the newly planted plants and the existing vegetation are the main factors for limiting plant performance (Grossnickle, 1999). And this is especially valid for poplars that has a high demand for nutrients, light and water (Mitchell *et al.*, 1999).

Competition for light often comes from woody species (Balandier *et al.*, 2006) even though it depends on the size of the plant. Many studies has shown how sensitive poplars are to competition from surrounding vegetation and how removing competition can increase the growth. Böhlenius & Övergaard (2015) studied different types of vegetation control and could see that the best treatment (a 150 cm wide polypropylene plastic mulch) increased the height growth seven fold, compared with the control. They could also observe a difference between different widths of vegetation control. Seedlings grown with 50 cm of vegetation control was one year behind (in growth) compared to those with 150 cm after two growing seasons. In Quebec where the use of herbicides is prohibited practitioners have moved away from unrooted cuttings, also for field plantations, due to the heavy vegetative competition (DesRochers & Tremblay, 2009).

Grass has been shown to be a heavy competitor for water and nutrients below ground (Picon-Cochard *et al.*, 2006), it can also be a physical barrier and compete for space in the soil.
Some literature suggest it's enough to just mow the vegetation to reduce the competition (Czapowskyj & Safford, 1993), but Nilsson & Örlander (1995) saw that only mowing the grass didn't increase the soil water potential.

Soil preparation is influencing vegetative competition, soil temperature, soil aeration, soil moisture and nutrient availability (Sutton, 1993). Bilodeau-Gauthier *et al* (2011) studied four types of mechanical soil preparation on formerly forested sites in Quebec, Canada. They concluded that mounding was most efficient, followed by harrowing **>** heavy disk trenching **>** light disk trenching and last unprepared (control). The plots were planted with 1m tall cuttings of *P. maximowiczii × P. balsamifera.* In average for all different treatments, mortality was lower than 5 %, for unprepared plots mortality was 20 %. It was also possible to see an increase in height growth after 5 years on the treated plots compared to the untreated. On former agricultural land, in some cases there is a need of a deeper ploughing in order to break the plow pan (Stanturf *et al.*, 2001).

Previously forested sites provide a number of other challenges when it comes to dealing with vegetation competition, often the use of herbicides are regulated and uneven terrain, stones and logging debris makes mechanical vegetation control difficult. Poplars are also in general more sensitive to many herbicides and to mechanical damages, so vegetative control after planting is more complex, this makes the treatments pre-planting even more important.

Bilodeau-Gauthier *et al.* (2011) suggest that the priorities for establishing poplars on previously forested land should be mechanical soil preparation > aboveground vegetation control > fertilization.

Implications of choice of plant type on establishment

"Successful reforestation depends upon matching stock types with field site conditions" (Grossnickle & Blake, 1987)

Before the late 1960's there were only bare rooted seedlings available for establishment in the Nordic countries, then the containerized seedlings were introduced with the main goal to lower planting costs and extend the length of the planting season (Nilsson *et al.*, 2010).

According to Grossnickle (1999) & (2012) there is no clear consensus in studies comparing containerized and bare rooted plants over a broad range of site types.

However, under Swedish conditions Nilsson & Örlander (1995) found that containerized seedlings where less sensitive to moderate soil drought compared with bare rooted seedlings and one possible explanation could be that bare rooted seedlings need to establish a new root-soil contact. Becker *et al* (1987) also concludes that containerized seedlings had a better root growth during their first growing season compared with bare rooted seedlings.

The main advantage for bare rooted conifer seedlings in Sweden is that their size makes them more tolerant to damages from pine weevils and their later flushing reduces the risk of damages from spring frost (Örlander & Nilsson, 1999; Langvall, 2000).

Bare rooted seedlings are recommended for sites with low environmental stress but with rather high vegetative competition (Nilsson & Örlander, 1995).

Poplars have the capacity to develop advantageous roots from the stem. Therefore, dormant hardwood cuttings can be used as transplants in establishment of poplar plantations. Planting stock for poplar is usually divided into rooted and unrooted material. Unrooted can be divided into cuttings (2- 100 cm) and whips (1,5 to 6 m). And rooted into bare-rooted and containerized plants (Stanturf & Oosten, 2014).
On marginal agricultural land, rooted plants and cuttings display similar growth. However, on forest land in Sweden, containerized plants are superior to both bare-rooted plants and cuttings (Böhlenius & Övergaard, 2015a, 2016).

On agricultural land and other suitable sites where cuttings have shown a satisfying survival rate, they are preferred over plants since they are cheaper to produce. Using cuttings means that the size of the planting material can be reduced. Costs for handling, shipping and planting will thereby be lower. So in economic terms cuttings have an advantage over containerized plants, and the containerized plants has the same advantages over the bare rooted plants. Cuttings also have the advantage that they easily can be mechanically planted. There is large differences in rooting capabilities of cuttings between different Populus families, species and clones (Ying *et al.*, 1977)

DesRochers & Tremblay (2009) saw a significant difference in size between bare rooted seedlings and cuttings throughout the first and second growing season in Quebec. The survival was also higher for bare rooted (98 %) compared to cuttings (91 %).

Some studies have shown that the position on the branch from where the cutting is taken can affect the rooting ability. Many authors claim that the closer to the base, the better the cutting roots but the results are not consistent (Bloomberg, 1959; Smith & Wareing, 1972; Schroeder & Walker, 1990; Rossi, 1993). Fine roots, also known as feeder roots are small in diameter and short lived. These roots are thought to be the most important roots for taking up water and nutrients (Dickmann *et al.*, 2001). Rossi (1991) compared survival on 5 lengths (10, 20, 30, 40, 50 cm) of cuttings from one clone on agricultural land in Finland and could conclude that the tallest cuttings had the highest survival.

Cuttings collected during winter, when the trees are dormant, have shown to perform better then cuttings collected in the late autumn (Phipps *et al.*, 1981). DesRochers & Thomas (2003) performed a rooting trial, where they mainly looked at pre-planting treatments and clonal differences. They could see that there were significant differences between clones and lengths of cuttings.

Objectives

The goals of this study were to investigate;
(1) how different cutting types influenced survival and plant growth of containerized plants.
(2) how fertilizer regimes influenced plants growth response to cutting types.

Material and method

Plant materials, soil substrates, growth containers and planting

The experiment consisted of 72 treatment combinations: eight cutting types (fig 1), three clones (Rochester, Clone 15 and OP42 described below), and three fertilizing treatments (a standard NPK solution, an amino acid solution and unfertilized control). In total I planted 1080 cuttings.

Three poplar clones was selected for this study:
Rochester is a hybrid between *P. maximowiczii x P. nigra*, selected since it has a high rooting capacity hardwood cuttings.
Clone 15 is a pure *P. trichocarpa* clone that has shown poor rooting abilities from hardwood cuttings.
OP42 (*P. trichocarpa x P. maximowiczii*) is one of the most common hybrids in Sweden, and is known to have good rooting capability and growth performance.

The cutting types of the experiment were divided by the number of buds and and length of the cutting after the lowest bud (fig 1). These cutting types were used on both thin (average dimeter 4,3 mm) and thick (average diameter 10,1 mm) stems;
1) Cutting with one bud and 1 cm elongation;
2) Cutting with one bud and 2 cm elongation;
3) Cutting with two buds and 1 cm elongation;
4) Cutting with two buds and 2 cm elongation

The cutting were harvested in middle January form one year old sprouts from stole beds. After harvest the cuttings were stored in polyene bags at +4C until planting. Since positioning could have an effect, the cuttings were taken evenly from the whole sprouts.

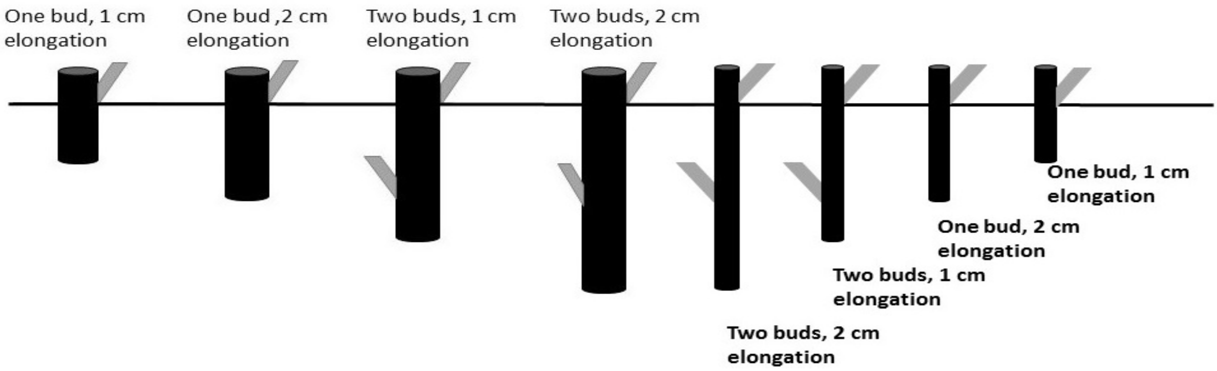

Figure 1. Schematic view of cutting types and their planting position

The soil substrate used consisted of Sphagnum moss (block peat 45 %, harrowed peat 25 %), peat humus (15 %) and perlite (15 %) it was also supplemented with Limestone (2 kg/m^3), Dolomite (2 kg/m^3), a solid NPK fertilizer (14-7-15, 1 kg/m^3) and micronutrients (FTE 36, 0.05 kg/m^3).
The soil pH was 5,7.

Prior to planting, fresh weight, length and diameter were registered and they got a unique id-number. A summery is shown in table 5 and clone specific values in appendix 1.
All cuttings were planted in soil up to the first bud, figure 1, in cylinder shaped plastic pots with a volume of 475 ml (diameter 67 mm and height 202 mm)

Table 5. Average diameter, length and fresh weight for each cutting type at planting. Means (n=135), ± indicate standard errors.

	One bud				Two buds			
	Thin, 2 cm	Thick, 2 cm	Thin, 1 cm	Thick, 1 cm	Thin, 2 cm	Thick, 2 cm	Thin, 1 cm	Thick, 1 cm
Diameter **(mm)**	4,1 ± **0,06**	9,8 ± **0,14**	4,4 ± **0,06**	10,2 ± **0,17**	4,2 ± **0,07**	10,1 ± **0,14**	4,6 ± **0,06**	10,2 ± **0,13**
Length **(mm)**	46,5 ± **0,47**	55,9 ± **0,53**	33,6 ± **0,37**	42,5 ± **0,62**	95,6 ± **1,35**	110,0 ± **1,10**	82,79 ± **1,11**	90,0 ± **0,86**
Weight **(g)**	0,7 ± **0,01**	4,1 ± **0,13**	0,6 ± **0,01**	3,4 ± **0,11**	2,2 ± **0,74**	8,7 ± **0,45**	3,0 ± **1,08**	6,9 ± **0,22**

Experimental design

15 blocks were established, each containing 9 plots (trays 22 cm x 35 cm) that were randomly distributed and assigned to the three fertilization treatments (Un-fertilized, NPK and arGrow) and the three poplar clones (OP42, Rochester, clone 15). In each of the 9 plots (trays) in each block, 8 cuttings of different types were randomly planted (fig 2). The distance between the plants were at minimum of 10 cm. Each week the tray (plots) were randomly rotated within the block.

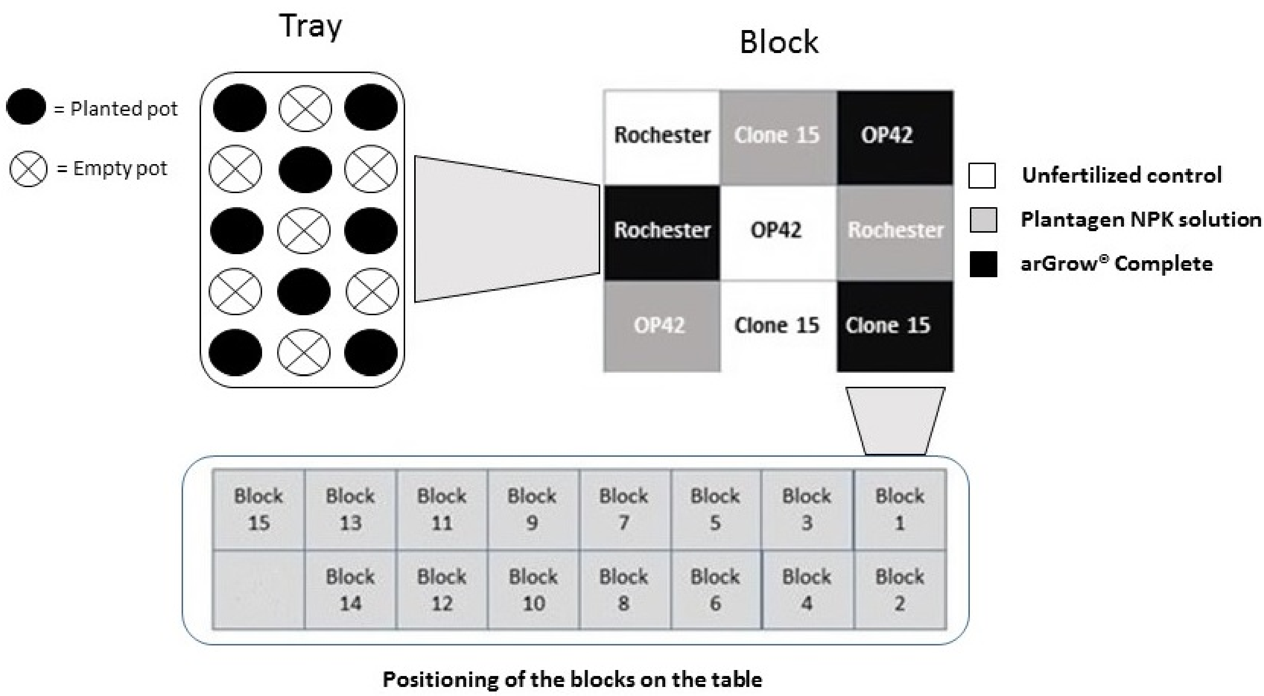

Figure 2. Schematic view of the experimental design

Growth conditions and fertilizers

The fertilizers used were selected based on their commercial availability and containing most of the important nutrients required for plant growth. Two types of liquid fertilizer were applied, Plantagen NPK solution, from Plantagen nursery Malmö, Sweden and arGrow® Complete, Swetree Nutrition AB, Umeå, Sweden. These fertilizers have different sources of nitrogen, in the Plantagen fertilizer nitrogen sources are urea ($CO(NH_2)_2$) 9 % and ammonia ($NH4+$) 1 %. In ArGrow the nitrogen source is

the amino acid arginine. Total nutrient content for both fertilizers is shown in table 6 and table 7. At the beginning of the growth period, week four to seven, 5 mg of total nitrogen of both fertilizers were applied every week. After week seven and until harvest, 10 mg of nitrogen were applied every week until the experiment were terminated teen weeks after planting.
Last fertilizing treatment was carried out 7 days before harvest.

Table 6. Nutrient content of arGrow

Nitrogen	6,8 %
Phosphorus	1,1 %
Potassium	4,5 %
Magnesium	0,4 %
Sulphur	0,9 %
Boron	0,022 %
Copper	0,003 %
Iron	0,11 %
Manganese	0,05 %
Molybdenum	0,004 %
Zinc	0,016 %

Table 7. Nutrient content of Plantagen NPK solution

Nitrogen	10 %
Phosphorus	3,9 %
Potassium	5,8 %
Boron	0,01 %
Copper	0,009 %
Iron	0,034 %
Manganese	0,016 %
Molybdenum	0,001 %
Zinc	0,018 %

The experiment was performed in a greenhouse with temperature of 20°C and 16 h of additional light supplied from fluorescent lamps with total photon flux of 130 µmol m^{-2} s^{-1}. All containers were watered daily if needed.

Measurements

All vital plants with an active growing shoot were classified as alive. All surviving plants were harvested and their roots were washed clean from soil. The shoots were separated from the cuttings, shoot heights and shoot diameters were measured. Stem, leaves and roots were separated and put in separate bags. The bags were dried for 48 hours before dry weights were recorded.

Statistical analysis

All analyses were conducted in R- studio, version 0.99.878. We did one way anova tests for analyzing survival and used Linear Mixed Effects Models for testing effects on growth. The data was normally distributed with homogenous variance, which was visually reviewed with residual plots and histograms. Significance levels were set at p=0.05 level.

Results

Survival

Over all clones, treatments and cuttings, the survival was 79 %. There was a difference in survival between the clones Rochester- 65 %, Clone 15 – 84 % and OP42- 87 %. The difference between Rochester and the two others is significant, not between Clone 15 and OP42 (fig 3 a). Fertilization with NPK or ArGrow resulted both in 81 % of survival for the planted cuttings, there was no difference between the fertilization treatments. Survival rate for the control was 76 %, the difference is not statistically significant (fig 3 b). There is not a statistical significance between the thick and thin cuttings over all clones treatments but the difference between one (71 %) and two (87 %) buds is significant (fig 4 a and b).

There is no significant difference between the one bud cutting types. The results are similar for cutting types with two buds. The lowest survival for any cutting type over all clones and treatments was for a thin cutting with one bud and 1 cm elongation (65 %), the thin cutting with two buds and 2 cm elongation had the highest survival (93 %). This difference is significant (fig 5). A table with the survival for each cutting type, treatment and clone is in appendix 2.

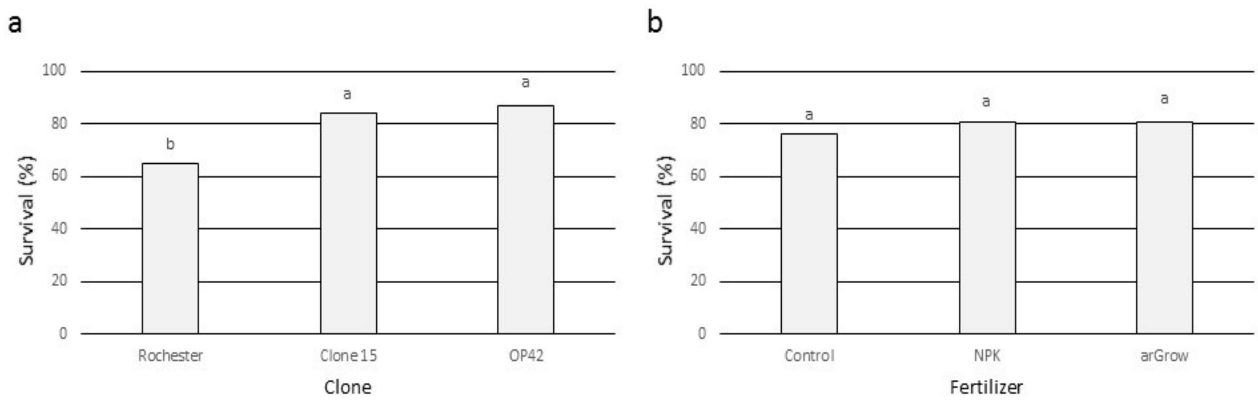

Figure 3. Survival for the different clones, regardless of fertilization treatment (fig a) and for the different fertilization treatments, regardless of clone (fig b). Values with the same letter are not significantly different at the *p=0.05* level: means (n=360).

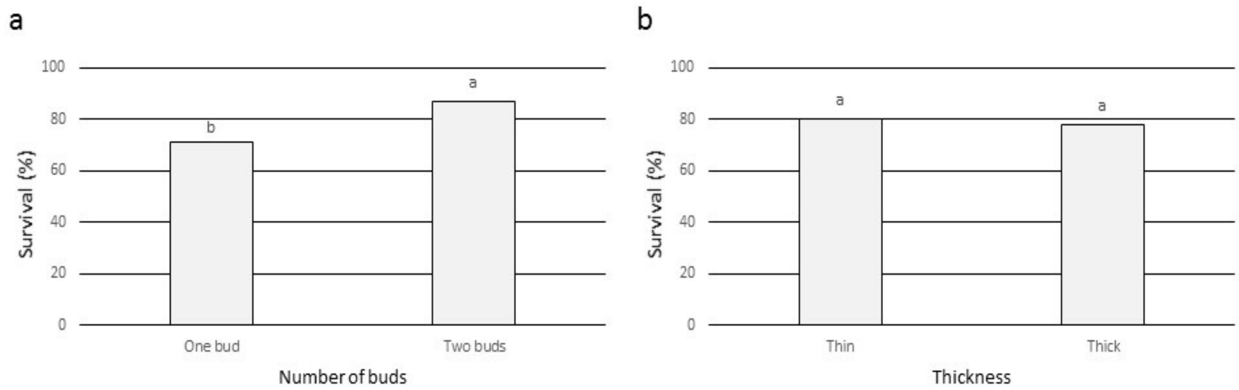

Figure 4. Survival for one and two bud cuttings, regardless of thickness (fig a). And survival for thin and thick types regardless of number of buds (fig b) Values with the same letter are not significantly different at the *p=0.05* level: means (n=540).

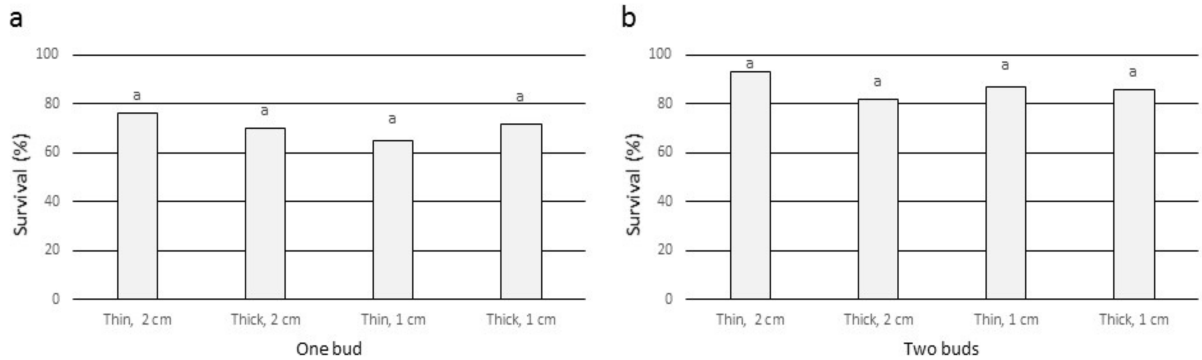

Figure 5. Survival for each cutting type, regardless of treatment and clone. X cm shows elongation length. Values with the same letter are not significantly different at the *p=0.05* level: means (n=135).

Growth

Clones

Clones were not a variable in the models, but total averages of height, diameter, below and above ground biomass is presented in fig 6. The largest difference is in root biomass where Clone 15 has a significantly lower root weight compared with Rochester and OP42.

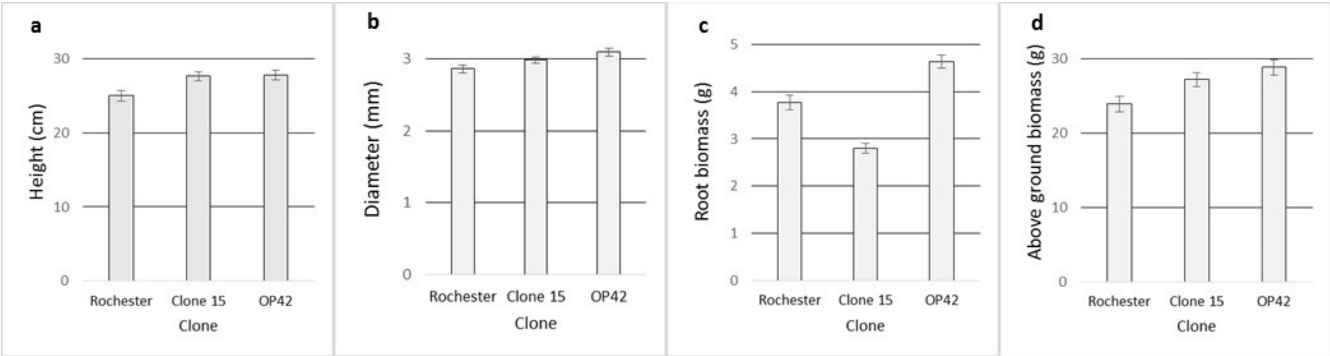

Figure 6. Clonal averages for height (fig a), diameter (fig b), root biomass (fig c) and above ground biomass (fig d). Means (n=360), error bars indicate standard errors.

General growth

Thicker cuttings were larger in diameter, below and above ground biomass, both with and without fertilizers, thick cuttings were taller than thin cuttings in the unfertilized control.
Two bud cuttings were larger in height, diameter, below and above ground biomass both with and without fertilizers.

Fertilized cuttings reacted different from the unfertilized ones, they grew more equal independent of cutting type in height, diameter and for thin and thick types in above ground biomass.
Elongation below lowest bud had a significance for diameter growth.

Unfertilized control

Height and diameter

Cuttings with two buds reached higher height and diameter compared to one bud cuttings (fig 7), reaching an average height of 161 mm and a diameter of 2.6 mm. The one-bud-cuttings were in average 119 mm in height and 1.9 mm in diameter.

Similar result was obtained when analyzing how cutting diameter influenced growth. Compared to thin-cuttings, thick-cuttings had an increased height and diameter growth reaching 196 mm in height and 2.9 mm in diameter. For thin cuttings height were 91 mm and 1.6 mm in diameter.

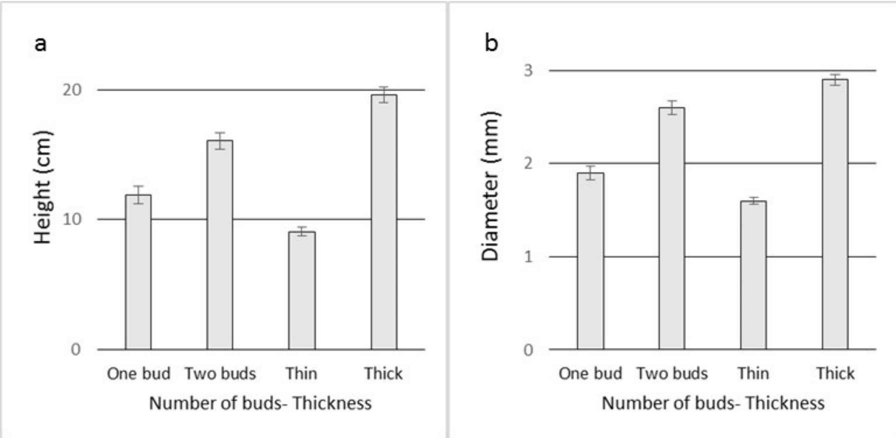

Figure 7. Height (fig a) and diameter (fig b) growth for unfertilized control, averages for one and two buds regardless of thickness. And averages for thin and thick types regardless of number of buds. Means (n=180), error bars indicate standard errors.

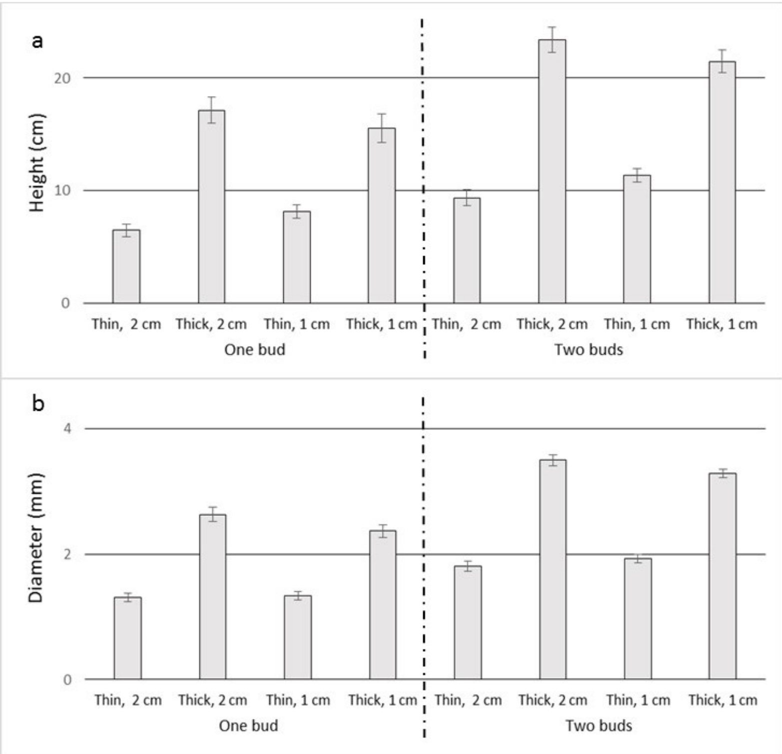

Figure 8. Height (fig a) and diameter (fig b) growth for unfertilized control, averages for each cutting type. X cm shows elongation length. Means (n=45), error bars indicate standard errors.

Root and above ground biomass

Cutting with two buds regardless of thickness, reached higher biomasses compared to one bud cuttings (fig 9), both in roots (2,9) and above ground (14,2 g). The one bud cuttings had average root biomass of 1,9 g and an average of 8,1 g in above ground biomass.

Similar result was obtained when analyzing how cutting diameter influenced growth. Compared to thin-cuttings, thick-cuttings had an increased root (3,2 g) and above ground biomass(17,7 g). For thin cuttings average root biomass was 1,8 g and above ground biomass 5,6 g.

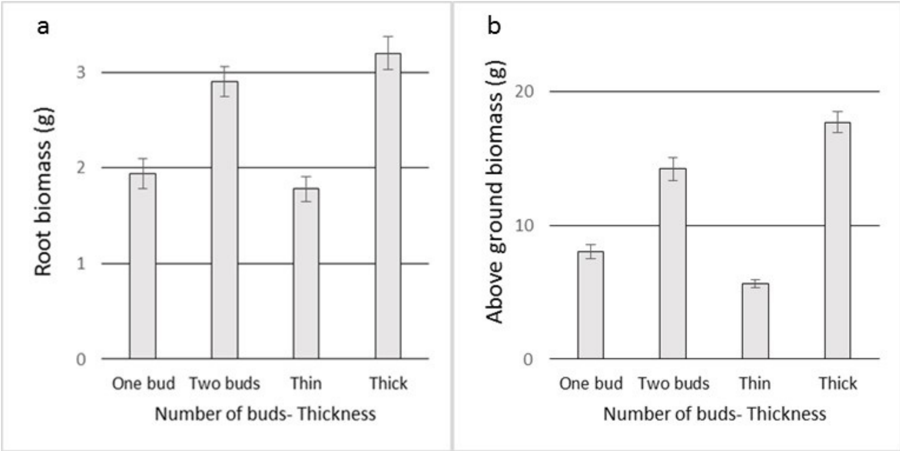

Figure 9. Root biomass (fig a) and above ground biomass (fig b) growth for unfertilized control, averages for one and two buds regardless of thickness. And averages for thin and thick types regardless of number of buds. Means (n=180), error bars indicate standard errors.

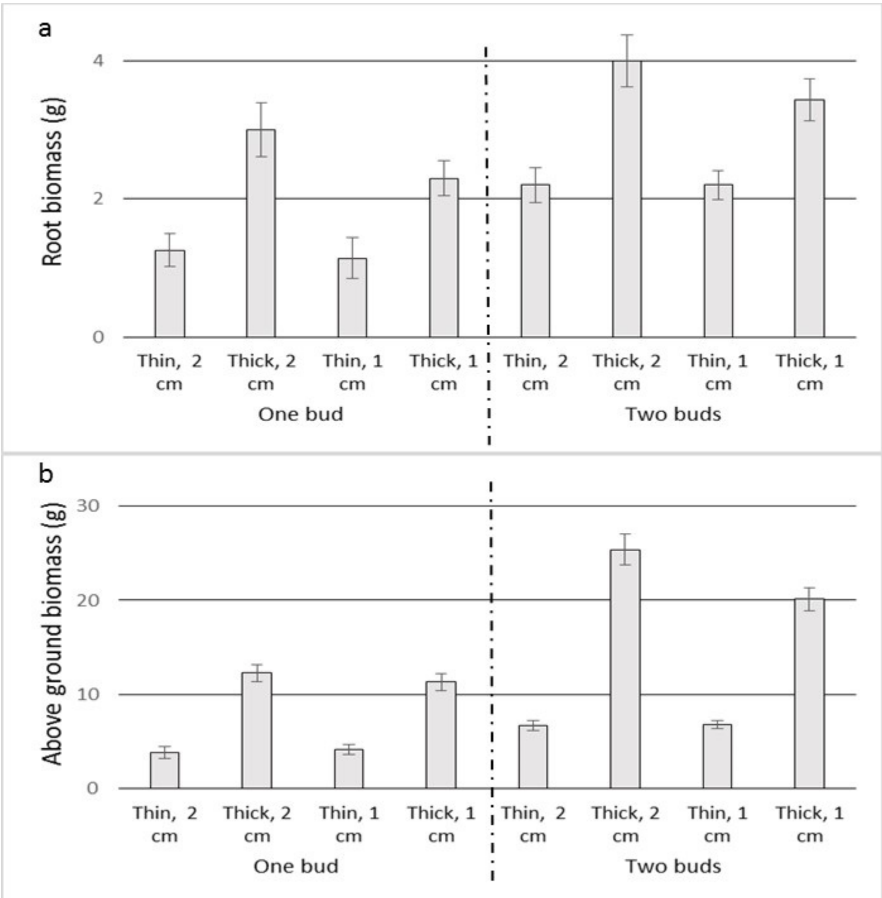

Figure 10. Root biomass (fig a) and above ground biomass (fig b) growth for unfertilized control, averages for each cutting type. X cm shows elongation length. Means (n=45), error bars indicate standard errors.

Fertilizers

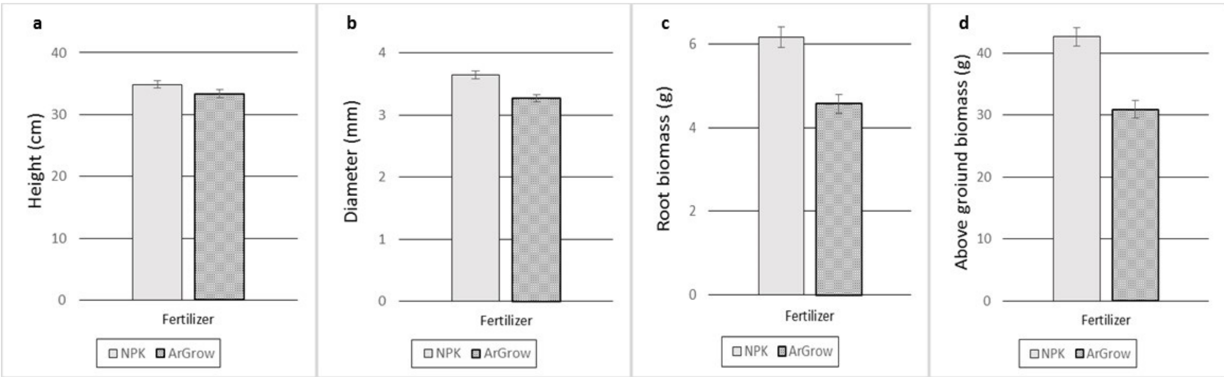

Figure 11. Average difference between the two fertilizers over all cutting types and clones. Height (a), diameter (b), root biomass (c), above ground biomass (d). Means (n=360), error bars indicate standard errors.

Across cutting types and clones, plants fertilized with the NPK fertilizer had higher height, diameter, root biomass and above ground biomass compared to plants fertilized with ArGrow.
This increment is significant but minor as height increased 1,8 cm, diameter 0,35 mm, root biomass 0,9 g and above ground biomass 9,7 g (fig 11).

Fertilization lowered the differences between the largest and smallest cutting types compared to the unfertilized control. As seen in table 10, what also should be observed is the larger values for fertilized plants which makes the proportional range even smaller. The values for each cutting type and fertilizer is found in supplementary graphs in appendix 4.

Table 10. Largest and smallest values for height, diameter, root biomass and above ground biomass for control and NPK fertilizer. And the range between them. Means (n=45), value for standard error ± in brackets.

	Control			NPK		
	Smallest	Largest	Range	Smallest	Largest	Range
Height (cm)	6,5 **(0,56)**	23,4 **(1,12)**	16,9	30,0 **(1,22)**	37,1 **(0,94)**	7,1
Diameter (mm)	1,3 **(0,07)**	3,5 **(0,09)**	2,2	2,9 **(0,09)**	4,1 **(0,07)**	1,2
Root biomass (g)	1,1 **(0,30)**	4,0 **(0,38)**	2,9	3,3 **(0,45)**	6,2 **(0,39)**	2,9
Above ground biomass (g)	3,9 **(0,62)**	25,3 **(1,6)**	21,4	26,2 **(1,84)**	55,5 **(1,88)**	29,3

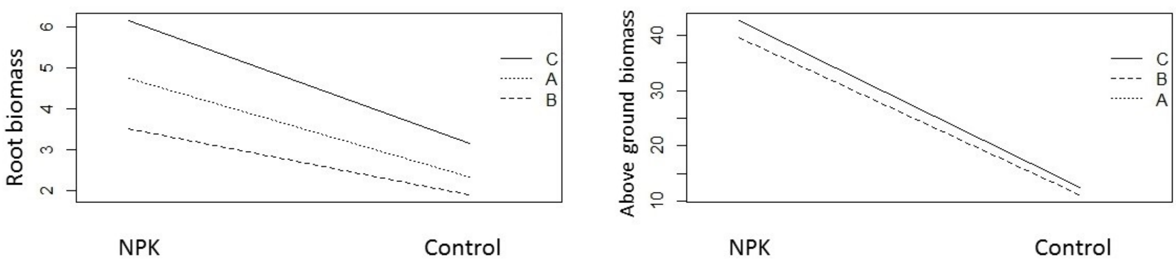

Figure 12. Interaction plot for mean root biomass (left) and above ground biomass (right) for fertilizing treatment (fertilized and control) and clone differences (A= Rochester, B= Clone 15, C= OP42)

Root to shoot ratio

There was no significant difference between one and two bud cuttings, or between thin and thick cuttings. Neither were there any significant difference between the different cutting types. The results were similar for both fertilizer treatments. But the root to shoot ratio was larger for arGrow compared to the NPK fertilizer. The values for each cutting type and fertilizer is found in supplementary graphs in appendix 5.

Discussion

In this study we investigated how different cutting types and fertilization treatments influenced plant survival and growth (height, diameter, root and above ground biomass) in the plant nursery. Our results revealed that cutting type influenced height, diameter, biomass production and survival especially if plants were not fertilized. Fertilization lowered these differences although they were still present after fertilization. Plant growth (clones and cutting types) increased if fertilizer NPK or arGrow were used, with NPK fertilization increasing plant growth the most. Plants fertilized with arGrow had a higher root to shoot ratio.

Our results are in line with the results of DesRochers & Thomas (2003), who found that cutting diameter didn't influenced survival in a greenhouse experiment. In studies that were conducted on agricultural land Ferm et al. (1989) saw a minor difference in survival of cuttings over and under 1 cm in diameter but Robison & Raffa (1996) did not detect an impact on survival for cuttings thicker than 6 mm. Similar to DesRochers & Thomas (2003) we found that longer (two buds) cuttings had higher survival than shorter (one bud) (fig 4). One possible explanation to this could be that the two bud cuttings are longer and therefore contain more root primordia or that buds produce root promoting hormones or a combination of both, more root primordia and root promoting hormones. However, DesRochers & Thomas (2003) were unable to detect differences in root numbers between 10 cm and 5 cm cuttings. A visual inspection of the number of roots in our study (data not shown) suggest that longer cuttings had a higher number of roots. Robison & Raffa (1996) suggested that cutting biomass could be used as an index instead of diameter to predict survival of a transplanted cutting. A thinner cutting should be longer compared to a thicker one and vice versa. Our results are that diameter doesn't influence survival, and does not support this theory in terms of survival. But when looking at height and diameter growth their results are similar to ours. Some studies have shown that the position on the branch from where the cutting is taken from, can affect the rooting ability, even if the results are not consistent (Bloomberg, 1959; Smith & Wareing, 1972; Schroeder & Walker, 1990; Rossi, 1993). We did not specifically study the effects of positioning, but we ensured that the cuttings were evenly distributed from the whole branch, in each cutting type.

We could not identify differences in survival between un-fertilized and the fertilized plants. This might suggest that fertilization treatments have no influence on survival or that fertilizers were applied after the transplanted cuttings were at risk for mortality.

When un-fertilized, longer (two bud) cuttings were taller, had a larger diameter (fig 7) and a larger biomass (fig 9). This is in line with previous studies; DesRochers & Thomas (2003) also saw that longer cuttings had a greater height and diameter, their explanation for this is that the carbohydrate reserves are larger in larger cuttings. (Dickmann et al., 1980) saw an effect from diameter on shoot length for larger cuttings and (Rossi, 1991) saw a clear positive influence on height growth from longer cuttings.

But DesRochers & Thomas (2003) couldn't see any difference between long (10 cm) and short (5 cm) cuttings in root biomass. This could be explained with results from Heilman et al. (1994) that callus/basal roots are heavier and shorter cuttings have proportionally more callus/basal roots. These tendencies were not found in our results, because two bud cuttings had a significant larger root biomass compared with one bud and a similar result was obtained for thickness (fig 9).

In the study of DesRochers & Thomas (2003) this resulted in a higher root to shoot ratio for the longer cuttings. In our experiment neither length nor diameter made a significant difference in root to shoot ratio (app 5). One factor to be observed when comparing root to shoot ratios on plants that are in active growth, is that there is a seasonal pattern in root to shoot value (Heilman et al., 1994).

The fact that our experiment had rather similar root to shoot ratio between the cutting types, could be explained by smaller cuttings in average compared to the other studies.

A low root to shoot ratio can be a warning sign for lower survival, especially in drier conditions, since the larger above ground biomass has a higher transpiration. Grossnickle (2012) recommends to use the shoot height, stem diameter, root mass and root to shoot ratio as indicators of plant quality. Even if not all of the previous studies have shown that morphological attributes can be a reliable indicator of future survival Rietveld (1989) concludes that "*some degree of transplanting stress is unavoidable even under ideal planting conditions*". But the duration, severity and outcome is determined by the plants performance potential and site characteristics. When a plant is planted in the field it needs to recover from the stress of handling and moving and get coupled into the hydro cycle of the site in order to overcome the planting stress and in other ways adapt to a more hostile environment. The plant must do this before the reserves of stored carbohydrate run out. A good size and shape of the plant does not guarantee a success but it has a major importance for limiting planting stress. Shoot height can work as a general measure for the photosynthetic and transpiration capacity, and give an advantage over existing vegetation in competition for light. Thompson (1985) and Johnson & Cline (1991) all suggest that root collar diameter is the best measurement for seedling size and has the best relation to future survival. Stem diameter can be a general measure for the root system size, root size means a large absorptive surface and in the end its drought resistance. Mexal & Landis (1990) saw that stem diameter correlated to water absorption in the roots and water transport in the stem. Fine roots, also known as feeder roots are small in diameter and short lived. These roots are thought to be the most important roots for taking up water and nutrients (Dickmann et al., 2001). A good and fast establishment is not only important on forest land, but also when poplars are planted as a short rotation energy crop (needs to be harvested within 20 years in Sweden). In these short rotations, one or two years with low growth make a substantial impact on the end result, compared with trees with longer rotation periods.

Application of fertilizers strongly increased the height, diameter and biomass growth for all cutting types and the differences between the fertilizers are minor (fig 11).

The most interesting result was how adding fertilization lowered the differences between cutting types. All fertilized plants got an equal amount of N. But the arGrow is known to be absorbed slower by the plants. If the experiment would be conducted over a longer period or longer time between last fertilizing and harvest, it is possible that the results would be different. In our study, plants fertilized with arGrow had a higher root to shoot ratio. And both Öhlund & Näsholm, (2001) and Schmidt et al., (2014) could see a larger root to shoot ration (due to a greater biomass allocation to the roots) in conifers seedlings when they used arginine as the source of nitrogen. Also Bauer & Berntson (2001) found the same result in their study of *Betula alleghaniensis*. However, these plants had developed mycorrhiza and it could be that mycorrhiza together with arGrow is the cause of the large increase in root growth. In our experiment plants were not inoculated with mycorrhiza so it is unlikely that they developed mycorrhiza during this experiment. Therefore it could be that arGrow in combination with mycorrhiza could increase the root growth of poplar plants. For getting a more precise picture of the differences in root development between the fertilizers, a more detailed study on the amount of fine roots should be conducted. Their low weight makes it troublesome to record the difference in fine roots only by weighting.

The objective of this study was not to study clonal growth differences but to investigate their growth responses to cutting types and fertilization treatments. However we could observe some clonal differences. The Rochester clone had a lower survival compared with the two other clones, especially in the thicker cutting types. There was not a significant difference in survival between thick and thin types. We could observe clonal growth differences with a gradual decline in height, diameter, and above ground biomass, from the highest values for OP42 - to lowest for Rochester.

Clone 15 had a surprisingly low root biomass, even if the number of roots were the same in a visual inspection (data not shown). These are examples of the large variations that exist between the different species and hybrids. All starts whit survival which is why breeding to enhance rooting abilities is and has always been a corner stone in poplar development (Zalesny Jr. & Zalesny, 2009). The material we used in this study is in commercial use today (Rochester, OP42) and includes the species that are the base for many more commercial clones, *P. trichocarpa, P. maximowiczii* and *P. nigra.*

Practical implications and future prospects

If poplar plantations would be introduced on a large scale on forest land a reliable source of plant material (cuttings or rooted plants) needs to be made available. The fact that poplar plants are made from cuttings and not from seeds could be a potential limiting factor. Large scale production of containerized plants out of cuttings can be limited by the amount of suitable material. Only the best material, preferably from the upper, most vigorous parts of the crown should be used (Stanton & Villar, 1996). So a stoolbed contains a rather large share of un-suitable material. Cuttings are cheaper to produce but it requires much more cutting material for a satisfying result. The use of smaller cuttings for making pre-rooted plants could also be a complement to larger cuttings that are used for field planting.(Dickmann et al., 1980) does not recommend cuttings with diameters below 6 mm to be used for field planting due to the harder establishment conditions. But those can be used to make pre-rooted plants according to the results of this study. A clone specific minimum cutting sizes could help optimize stoolbed use.

Judging by the results of this study, the most suitable cutting to use is a fertilized cutting independent of diameter, if a shorter cutting is going to be used, a thicker one is recommended in order to have an increase in growth.

Long cuttings also have an advantage in survival, but here is a potential trade- off between the costs of planting more of the smaller cuttings and cost for collecting and availability of cutting material. One observation in this study (data not shown) is that survival could be predicted with rather high accuracy after two weeks.

The fact that plants that developed the best in the green house will continue to have the lead after they are planted in the field is not guaranteed, even though it would be the most likely scenario. Plants need to be tested on a broad range of sites, since each site type provides a variety of challenges. Results from Böhlenius & Övergaard (2016) suggest that containerized and bare-rooted plant performance in field is highly site dependent.

One observation during the harvest that potentially could be a problem and needs to be tested in practice, is that all cuttings got the majority of their roots at the bottom of the cutting. For a long cutting that will be planted as a bare-rooted plant, this could make the planting process more troublesome. For the future it could be of interest to see how nursery treatments like long nights, top and root trimming or container surface manipulation can affect the plants. Another aspect that needs deeper research is how important is positioning on branch for the survival of small cuttings in greenhouses.

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Appendix

Appendix 1. Average diameter, length and fresh weight at planting

Table 1. Average diameter, length and fresh weight for each cutting type and clone at planting. Means (n=45), ± indicate standard errors.

	Cutting type	Cut below bud	Diameter ±SE	Length ±SE	Fresh weight ±SE
Clone 2	One bud/thin	20	**4,1** ± 0,1	**43,7** ± 0,8	**0,7** ± 0,0
	One bud/thick	20	**9,8** ± 0,2	**53,3** ± 0,9	**3,8** ± 0,1
	One bud/thin	10	**4,7** ± 0,1	**33,1** ± 0,5	**0,7** ± 0,0
	One bud/thick	10	**9,9** ± 0,2	**39,1** ± 0,7	**2,8** ± 0,1
	Two bud/thin	20	**4,2** ± 0,1	**96,4** ± 2,2	**1,5** ± 0,1
	Two bud/thick	20	**9,4** ± 0,2	**106,5** ± 1,6	**6,8** ± 0,3
	Two bud/thin	10	**4,5** ± 0,1	**89,5** ± 2,3	**1,4** ± 0,1
	Two bud/thick	10	**10,3** ± 0,2	**90,5** ± 1,7	**6,8** ± 0,4
Clone 15	One bud/thin	20	**3,9** ± 0,1	**47,3** ± 0,7	**0,7** ± 0,0
	One bud/thick	20	**9,2** ± 0,3	**55,2** ± 0,9	**3,7** ± 0,2
	One bud/thin	10	**4,3** ± 0,1	**35,6** ± 0,6	**0,7** ± 0,0
	One bud/thick	10	**9,2** ± 0,3	**41,0** ± 0,7	**2,7** ± 0,2
	Two bud/thin	20	**4,3** ± 0,1	**97,2** ± 2,8	**1,5** ± 0,1
	Two bud/thick	20	**10,2** ± 0,3	**105,5** ± 1,7	**8,4** ± 0,5
	Two bud/thin	10	**5,0** ± 0,1	**81,6** ± 1,3	**1,6** ± 0,1
	Two bud/thick	10	**9,8** ± 0,3	**86,4** ± 1,3	**6,3** ± 0,4
OP42	One bud /thin	20	**4,2** ± 0,1	**48,6** ± 0,8	**0,8** ± 0,0
	One bud /thick	20	**10,5** ± 0,2	**59,2** ± 0,8	**5,0** ± 0,2
	One bud /thin	10	**4,3** ± 0,1	**32,1** ± 0,7	**0,6** ± 0,0
	One bud /thick	10	**11,7** ± 0,3	**46,5** ± 0,8	**4,6** ± 0,2
	Two bud /thin	20	**4,3** ± 0,1	**93,2** ± 2,0	**1,5** ± 0,1
	Two bud /thick	20	**10,6** ± 0,2	**118,0** ± 1,9	**9,7** ± 0,4
	Two bud /thin	10	**4,4** ± 0,1	**77,3** ± 1,5	**1,3** ± 0,1
	Two bud /thick	10	**10,5** ± 0,2	**93** ± 1,3	**7,6** ± 0,4

Appendix 2. Survival for each cutting type and clone

Table 1. Survival for each cutting type and clone

Cutting type		Rochester NPK	Clone 15 NPK	OP42 NPK	Rochester arGrow	Clone 15 arGrow	OP42 arGrow	Rochester Control	Clone 15 Control	OP42 Control
One bud	Thin, 2 cm	60%	80%	87%	73%	73%	100%	60%	67%	87%
	Thick, 2 cm	**40%**	93%	80%	**47%**	87%	93%	**40%**	67%	80%
	Thin, 1 cm	60%	80%	60%	60%	73%	80%	**40%**	53%	80%
	Thick, 1 cm	**47%**	73%	93%	**47%**	80%	80%	60%	80%	87%
Two buds	Thin, 2 cm	80%	93%	93%	93%	100%	100%	100%	87%	87%
	Thick, 2 cm	**47%**	100%	87%	73%	100%	93%	73%	87%	80%
	Thin, 1 cm	87%	87%	93%	73%	80%	87%	93%	93%	87%
	Thick, 1 cm	87%	87%	93%	67%	93%	100%	60%	100%	87%

Appendix 3. Results mixed model

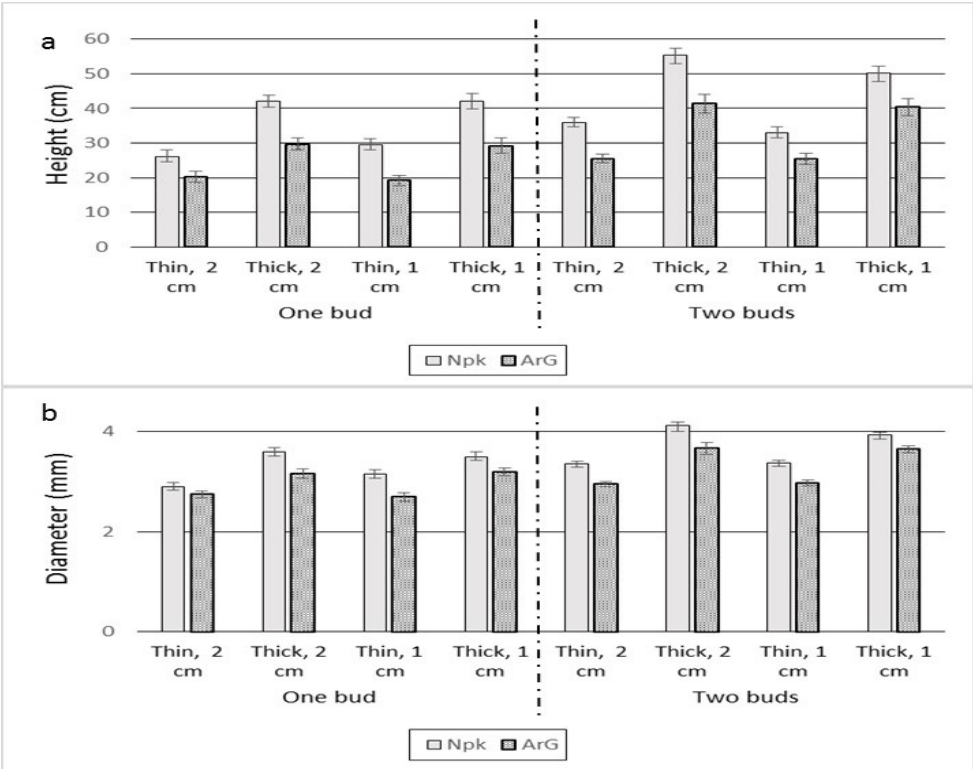
Random effects: Formula: ~1 | fbl					
	(Intercept)	Residual			
StdDev:	17.23034	55.06361			
Fixed effects: hoj ~ ffert * knopp + ffert * ts + ffert * luk + luk * ts + luk * knopp					
	Value	Std.Error	DF	t-value	p-value
(Intercept)	313.84303	8.933999	533	35.12906	0.0000
ffert3	-245.19454	9.817881	533	-24.97428	0.0000
knopp2	14.94768	8.116174	533	1.84171	0.0661
tstjock	38.52912	8.052516	533	4.78473	0.0000
luklång	-16.42240	9.641569	533	-1.70329	0.0891
ffert3:knopp2	29.46540	9.427396	533	3.12551	0.0019
ffert3:tstjock	61.61831	9.374143	533	6.57322	0.0000
ffert3:luklång	6.50489	9.365889	533	0.69453	0.4877
tstjock:luklång	17.62810	9.364965	533	1.88235	0.0603

Random effects: Formula: ~1 | fbl					
	(Intercept)	Residual			
StdDev:	0.1220102	0.4467328			
Fixed effects: dia ~ ffert * knopp + ffert * ts + ffert * luk + luk * ts + luk * knopp					
	Value	Std.Error	DF	t-value	p-value
(Intercept)	3.0679090	0.07029455	533	43.64363	0.0000
ffert3	-1.8021914	0.07964380	533	-22.62814	0.0000
knopp2	0.3822435	0.06583622	533	5.80598	0.0000
tstjock	0.4560471	0.06532155	533	6.98157	0.0000
luklång	-0.1554036	0.07819935	533	-1.98727	0.0474
ffert3:knopp2	0.3152817	0.07647392	533	4.12274	0.0000
ffert3:tstjock	0.7730238	0.07604044	533	10.16596	0.0000
ffert3:luklång	0.0711265	0.07597457	533	0.93619	0.3496
tstjock:luklång	0.2970197	0.07597036	533	3.90968	0.0001
knopp2:luklång	0.0394052	0.07651607	533	0.51499	0.6068

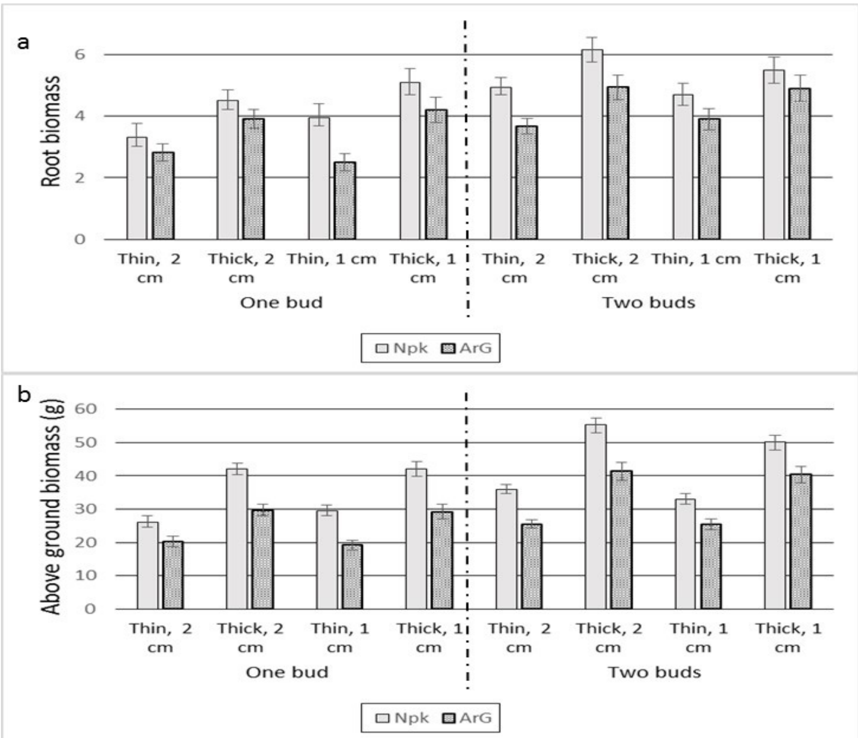
Random effects: Formula: ~1 | fbl					
	(Intercept)	Residual			
StdDev:	0.5859404	2.013141			
Fixed effects: vrot ~ ffert * knopp + ffert * ts + ffert * luk + luk * ts + luk * knopp					
	Value	Std.Error	DF	t-value	p-value
(Intercept)	3.994878	0.3210907	533	12.441588	0.0000
ffert3	-2.659655	0.3589238	533	-7.410083	0.0000
knopp2	0.787016	0.2967052	533	2.652517	0.0082
tstjock	0.871672	0.2943820	533	2.961024	0.0032
luklång	-0.571789	0.3524452	533	-1.622349	0.1053
ffert3:knopp2	-0.109170	0.3446431	533	-0.316762	0.7515
ffert3:tstjock	0.447028	0.3426929	533	1.304458	0.1926
ffert3:luklång	0.399479	0.3423936	533	1.166723	0.2438
tstjock:luklång	0.365026	0.3423675	533	1.066183	0.2868
knopp2:luklång	0.529745	0.3448386	533	1.536212	0.1251

Random effects: Formula: ~1 | fbl					
	(Intercept)	Residual			
StdDev:	0.5815457	8.899631			
Fixed effects: ojord ~ ffert * knopp + ffert * ts + ffert * luk + luk * ts + luk * knopp					
	Value	Std.Error	DF	t-value	p-value
(Intercept)	27.748338	1.257159	533	22.072258	0.0000
ffert3	-25.084903	1.584451	533	-15.831916	0.0000
knopp2	6.687064	1.308986	533	5.108582	0.0000
tstjock	15.006606	1.299245	533	11.550252	0.0000
luklång	-2.135706	1.552400	533	-1.375745	0.1695
ffert3:knopp2	-1.791322	1.521006	533	-1.177722	0.2394
ffert3:tstjock	-4.187689	1.511936	533	-2.769753	0.0058
ffert3:luklång	0.155930	1.510936	533	0.103201	0.9178
tstjock:luklång	3.157003	1.511593	533	2.088527	0.0372
knopp2:luklång	3.774895	1.521025	533	2.481809	0.0134

Appendix 4. Results fertilized plants



Height (Fig a) and diameter (Fig b) growth for NPK and arGrow, averages for each cutting type. Means (n=45), error bars indicate standard errors.



Height (Fig a) and diameter (Fig b) growth for NPK and arGrow, averages for each cutting type. Means (n=45), error bars indicate standard errors

Appendix 5. Root to shoot ratio

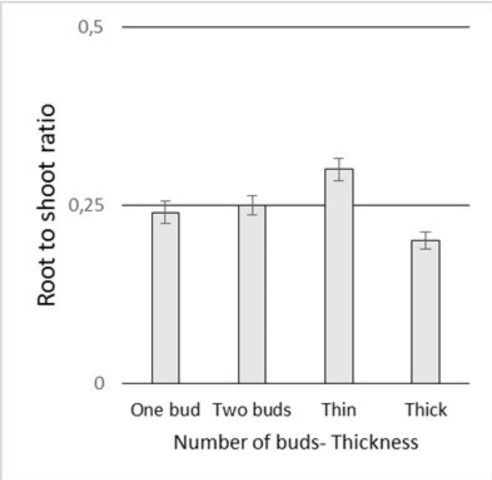


Figure 1. Root to shoot ratio for unfertilized control, averages for one and two buds regardless of thickness. And averages for thin and thick types regardless of number of buds. Means (n=180), error bars indicate standard errors.

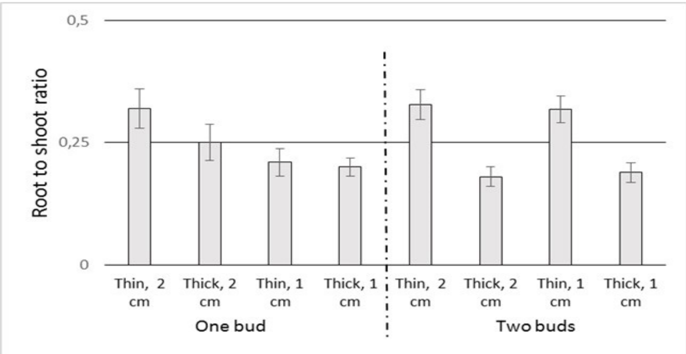


Figure 2. Root to shoot ratio for unfertilized control, averages for each cutting type. Means (n=45), error bars indicate standard errors.

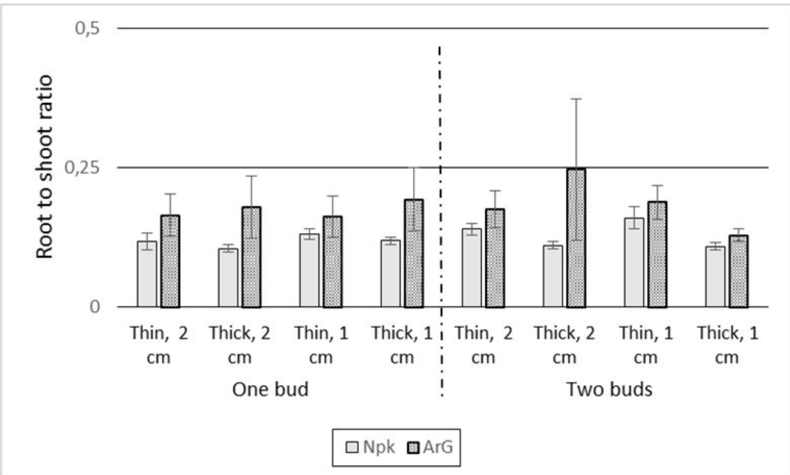


Figure 3. Root to shoot ratio averages in each cutting type of the two fertilizing treatments regardless of clone, NPK and arGrow. Means (n=45), error bars indicate standard errors.

Appendix 6. Photos

A photo from the day of the planting

After approximately four weeks of growing


After approximately eight weeks of growing


Harvested and washed plant