NORTH KARELIA UNIVERSITY OF APPLIED SCIENCES
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ESTABLISHMENT OF SHORT ROTATION WOODY CROP TRIALS IN ATLANTIC CANADA

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Establishment of Short Rotation Woody Crop Trials in Atlantic Canada

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Abstract

The purpose of this study was to analyze the establishment of short rotation plantations in the province of New Brunswick, in Atlantic Canada. Two bioenergy crops, willow and *Miscanthus* and their six clones (*Salix Viminalis, Salix Eriocephala, Salix Miyabeana*, *Miscanthus* M114, M115 and M116) were selected to this thesis and their survivals and costs were examined.

The method in this study is a field test conducted in summer 2011. Materials include survival rates, soil analyses, diary notes, pictures and the calculation of costs. Two test sites were selected to this study: one is in organic farming and the other one in conven-tional farming. The costs analyzes include land rental and preparation, plant material, planting and maintenance.

The results reveal that willow clones established well, reaching survival rates from 95 to 100 %. *Miscanthus* clones reached survival rates only from 12 to 69 % and the survival was dependent on the quality of rhizomes. However, the establishment of willows was more expensive, $6332 in conventional farming and $6572 in organic farming. For *Mis-canthus* costs were $3000 in conventional farming and $4140 in organic farming. Costs in organic farming were higher because more time was consumed for maintenance and weeding.

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Establishment of Short Rotation Woody Crop Trials in Atlantic Canada

Toimeksiantaja
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Tiivistelmä

Tämän opinnäytetyön tarkoituksena oli selvittää lyhytkiertoviljelmien perustamisen onnistumista ja kustannuksia New Brunswickin provinssissa, Kanadan itärannikolla. Tutkimuksessa tarkastellaan kahta energiakasvilajia: pajua ja elefanttiheinää. Molemmista lajeista tutkittiin kolmen kloonin (*Salix Viminalis*, *Salix Eriocephala*, *Salix Miyabeana*, *Miscanthus* M114, M115 ja M116) selviytymistä.

Menetelmänä työssä on kesällä 2011 toteutettu kenttäkoe. Aineistona ovat selviytymis-prosentit, maanäytteet, muistiinpanot, kuvat ja laskelmat. Opinnäytetyöhön tarkastel-tavaksi valittiin kaksi 1 hehtaarin koealaa, joista toinen on luomuviljelyssä ja toinen tavanomaisessa viljelyssä. Syksyllä 2011 määritettiin selviytymisprosentit ensimmäisen kasvukauden jälkeen. Perustamisen kustannukset, mukaan lukien pellon vuokra ja valmistelu, kasvimateriaalit, istutus ja rikkaruohontorjunta laskettiin kesän jälkeen.

Tutkimus osoitti, että pajukloonien perustaminen onnistuu hyvin, mutta oli käytetyillä menetelmillä melko kallista. Pajukloonien selviytymisprosentti vaihteli 95–100 %:n ja kustannukset tavanomaisessa viljelyssä 4850 € ja luomuviljelyssä 5040 €. Elefanttiheinän selviytymisprosentti oli selvästi heikompi, vaihdellen 12–69% välillä ja riippuvainen istutettujen juurakoiden tuoreudesta. Elefanttiheinän perustamis-kustannukset tavanomaisessa viljelyssä olivat 2300 € ja luomuviljelyssä 3170 €. Luomuviljelyn kustannukset olivat suuremmat, sillä rikkakasvien torjuntaan käytettiin enemmän aikaa ja työvoimaa.

Kieli
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Asiasanat
bioenergia, paju, perustaminen, kustannukset

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Abbreviations

AFC	Atlantic Forestry Centre, Canadian Forest Service
CANBIO	Canadian Bioenergy Association
CBEC	Canadian BioEnergy Centre
CO_2	carbon dioxide
DMT	dry metric tonne, ie. biomass yields
GDD	growing degree day
GJ	gigajoule
ha	hectare, 100 acres
kWh	kilowatt hour, equal to 1000 watt hours or 3.6 megajoules
MJ	megajoule
MW	megawatt
NCV	net calorific value (kWh/kg)
NO_x	nitrogen oxide
odt	oven dry tonne, mass of dry matter ie. biomass yields
SO_2	sulful dioxide
SRC	short rotation crops
SRWC	short rotation woody crops
tDM	tonnes dry matter, ie. biomass yields
toe	tonnes of oil equivalent

Table 1. Conversions of different energy units

Unit	**toe**	**MWh**	**GJ**
toe	1	11,63	40,868
MWh	0,0886	1	3,6
GJ	0,02388	0,2778	1

1 Introduction

In the first chapter, the context of this study is presented, including a short summary of bioenergy use in Canada. Also the background and the main objectives of this thesis are written down.

1.1 Interest in Bioenergy

The field production of biomass for use as a large-scale energy source has become a current topic due to the rising costs of energy and concerns about global warming (Dickmann 2006; Smith et al 2000). The Kyoto protocol and other global agreements encourage increasing the use of renewable energy sources instead of fossil fuels. (IEA Bioenergy 2002.) In Canada there is beginning to be more interests to its biological potentials in the field of bioenergy; there are studies and tests for new varieties and also commercial scale plantings (Bradley 2010). Similarly, the public is becoming increasingly interested and aware of issues related to bioenergy. In November 2002, the Canadian Biomass Energy Association (CANBIO) was established to promote the use of biomass for energy in Canada. CANBIO launched a program called Go Pellets to improve markets for Canadian pellets and promote domestic use. (Bradley 2010; Hall 2002.)

Biomass production on a field enhances sustainability and increases the security of energy supply. Solid biofuels can be chipped and burned as they are or they can be processed into pellets or briquettes to bring more value. Pelletizing is a way to increase bulk density and lower transport costs and it is an option when fuels are being sold further away or exported. Pelletizing also increases the energy value and makes the fuel more homogenous in composition. (Pastre 2002.)

Taking agricultural land out of conventional crop production can be justified if the land is marginal, or if it cannot be used to produce food. Production of biomass and decentralized energy production will boost the economies in rural areas, bring extra income to farmers and create new jobs. Switching from oil and coal to local energy sources such as short rotation woody crops or perennial grasses will bring the money to the community. The use of agricultural land as a means of producing renewable fuels allows not relying only on wood and agricultural residues. (Pastre 2002.)

1.1.1 Bioenergy Use in Canada and in the Maritime Provinces

Canada is a nation rich in fossil fuel resources. In 2008 total primary energy supplies were divided between oil 35.8%, gas 28.6%, hydro 12.2%, coal and peat 9.7%, nuclear 9.1%, combined renewable and waste 4.5% and geothermal/solar/wind 0.1% (OECD/IEA 2010). Since 2006 the government has started to combat against climate change in different ways; investing in renewable energy, distributing incentives to develop green technologies, and developing regulations to reduce emissions. (Bradley 2010.)

Biomass plantings for testing and operational scales have been done in various places in Canada. In Quebec, a study of poplars on disused farmland and with fertilization by solid waste has been carried out. In Ontario, a study was testing growth and development of many varieties of poplar, willow and alder under various planting and fertilization methods. In western Canada on the Prairies, evaluation is underway of poplars planted more than 30 years ago. (Hall 2002.)

Many provinces in Atlantic Canada have their own programs and goals for increasing renewable energy use. In New Brunswick, where there are good resources of bioenergy, now 23% of energy comes from renewable energy sources, mostly hydro and wood. The government would like to increase renewable power by 10% by 2016. For Nova Scotia the situation is different, because the province has a long history of using imported coal. There the

Renewable Energy Standards came into effect in 2007 and the aim is to produce 18.5% of the provinces electricity from renewable sources by 2013. (Bradley 2010.)

1.2 The Present Study

This thesis is a part of larger study that started in the summer 2011 in Eastern Canada in the Maritimes Provinces. The study in total includes seven research fields which of two has been selected to be examined in this thesis. Field trials are collaboration between the University of New Brunswick, Canadian BioEnergy Center (CBEC) and Natural Resources Canada, Canadian Forest Service – Atlantic Forestry Centre (AFC).

This is one of the first short rotation crop trials in Maritimes provinces and it will give valuable information about the possibilities and challenges of biomass production in this area. Atlantic Forestry Centre (AFC) is working together with the private landholders for the plot establishment, maintenance, and in the future biomass quantity and growth measurements. In summer 2011 the sites were established and in future years studies will continue and biomass harvesting and measurements will be conducted.

Two of the test fields have been selected for closer analysis to this study to examine the establishment period. Sites are located in eastern coast of Canada in the province of New Brunswick. These two sites were selected as case studies due to their differences, which makes the comparison interesting. The other site is in conventional farming and the other one is organic. The sites differ also in soil conditions and in climatic conditions.

1.2.1 The Main Objectives of This Study

The purpose of this study is to compare the survival and costs of the establishment of three shrub willow (*Salix*) species and three *Miscanthus* cultivars in two different sites, conventional farming site and organic site. Firstly, the survival rates of different cultivars will be analyzed. Secondly, the costs of establishment are calculated and compared between the sites. Also, some initial estimates and comparisons of growth after first growing season are made.

1.2.2 Willow and *Miscanthus* as Bioenergy Crops

Willow (*Salix*) and *Miscanthus* are both well-known bioenergy crops that produce high amounts of biomass (Styles et al 2008). The *Salix* clones included in these trials have been successfully cultivated in Northern climates (Labreque & Teodorescue 2005; Larsson & Lindegaard 2003). Less information is available on *Miscanthus* cultivation in the Maritimes provinces. However if successfully cultivated, *Miscanthus* has the potential to produce high amounts of biomass and it can provide regular income to the farmer because it can be harvested annually (Jones & Walsh 2001). This study here is one of the first experiments in the Maritimes Canada.

The use of *Miscanthus* in Canada has been promoted by New Energy Farms, which is a company based in Ontario and has been developing technologies and producing *Miscanthus* clones in Canada, the US and Europe. One of the major implements to cropping *Miscanthus* in Northern regions is a lack of winter hardiness. In order to try to solve this problem, New Energy Farms has been conducting research and developing new crosses with improved winter hardiness. (New Energy Farms 2011.)

1.2.3 Organic Farming

The principles of organic farming are to reduce the use of fossil fuels and forbid the use of synthetic biocides and synthetic mineral fertilizers. For short rotation crop production the use of synthetic mineral fertilizers is not a necessity, in fact the utilization of wastewater or sewage sludge is well suitable. Wastewaters serve for irrigation and nutrient supply. Short rotation plantations may also be used for the protection and cleansing of ground water in intensively farmed areas. (Jörgensen et al 2005.)

2 Literature View

This chapter presents short-rotation crops, first in general and then in detail the requirements to establish willow and *Miscanthus* plantations.

2.1 Short-Rotation Woody Crops

Short-rotation woody crops (SRWC) are a group of fast growing and high yielding species that can be cultivated on many different kinds of soils. The different SRWC species include poplars, willows, *Miscanthus*, cottonwood, sycamore, sweetgum, *Robinia*, *Eucalyptus*, reed canary grass and switch grass (Shepard 2003; Short Rotation Crops 2011). SRWC are capable of producing biomass between 8 and 20 oven dry tonnes per hectare annually. The frequency of harvest varies from 3 to 15 years depending on the species. Short-rotation woody crops use both agriculture and forestry technologies. Commercial harvesting machinery is already available. (Shepard 2003.)

The interest using short-rotation woody crops began in the 1960s and 1970s, when first concerns of wood availability arose and the oil crisis occurred. (Shepard 2003). Since then the use of SRWC has increased and spread to all over the world. At the moment coppiced wood species such as willow and poplar are most popular ones. Testing and development to use other species is going on, and one of the promising species is *Miscanthus* for both its high productivity and good combustion qualities. (Pastre 2002.)

Short rotation woody crops are an environmentally acceptable and economically efficient alternative for producing renewable energy. SRWC plantations bring possibilities to improve local rural economic development, ensure future wood supplies and reduce demands on natural forests. The environmental benefits of woody crops in the world scale are important: they can reduce the rate of atmospheric CO_2 buildup by sequestering carbon and by reducing the use of fossil fuels. Also the combustion of woody crops can reduce SO_2 and NO_x emissions compared to fossil fuels. (Shepard 2006.)

At the local environmental level woody crops have many advantages. They can reduce soil erosion, filter soil leachates from water and increase different wildlife habitats and biodiversity: they can be used in stream protection, remediation of contaminated sites or effluent filtration. SRWC reduce chemical application on agricultural lands compared with annual row-crop agriculture. (Shepard 2006; Shepard 2003.)

There is a lot of potential and possibilities to use SRWC in Canada. The amount of potential land suitable for short-rotation woody crops under moderate cost scenarios range from 8-16 million hectares on presently non-forest lands primarily in the Prairies, Ontario, and Quebec. At the moment approximately 2500 hectares SRWC plantations are being established annually. (Bradley 2010.)

2.2 Willow

The cultivation and characteristics of willow biomass; including the history of growing biomass, crop requirements, growth and productivity, establishment, weed control, fertilization, harvesting, quality of biomass and environmental impacts are presented in the following.

2.2.1 General Background on Willow

Willows have been cultivated for basketry and furniture for hundreds of years in Europe and North America. 1970s in Europe and 1980s in North America began the interests for willow biomass. Willow grows throughout the northern hemisphere, mainly in cold and wet areas and they are among the fastest growing woody species in northern climates. (Boyd et al 2000.)

The willows used in energy forestry are shrub willows and belong to the *Salix* family. They are generally bushy and tend to grow 5 to 7 meters in height and have numerous shoots. (Larsson & Lindegaard, 2003.) Willows have a number of production advantages: plants can be produced from unrooted cuttings directly in the field; they coppice easily; they can be grown with low inputs of agro-chemicals and harvesting can be done every 2 to 4 years (Boyd et al 2000).

2.2.2 History of Growing Willow in Canada and Northern Europe

The production of willow biomass started in Europe, especially in Sweden, in the 1970s. Similarly, first willow productions in North America were in mid 1980s in New York. (Keoleian & Volk, 2005.) Between 1998 and 2000 over 500 acres of willow biomass crops were established in western and central New York (Abrahamson et al. 2002). In the province of Quebec in Canada there have been more than 10 years of studies in short-rotation willows (Labrecque and Teodorescu 2005).

Sweden is the pioneer country of growing willow biomass in boreal climate. In 2003 there were 16 000 hectares of willow plantations providing wood fuel for district heating plants. In the mid-1990s there was a boom in planting willows due to the new energy policy that made biofuels the most competitive fuel in the production of district heat. (Larsson & Lindegaard 2003; Ericsson & Nilsson 2003.)

2.2.3 Crop Requirements

Willow is not a demanding species in terms of its site requirements. It thrives on a range of soil types. Suitable pH range for willow should be from 5.5 to 7. (Defra 2004.) Like other crops, productivity of willow will vary with fertility, temperature and the availability of water and light. A good water supply appears to be particularly crucial. Best sites to produce willow biomass should have a minimum annual rainfall of 600 mm and up to 1,100 mm. Willow can grow on land that is too wet for other crops, but areas should always be planned so that mechanical harvesting can be carried out without site accessibility limiting harvest procedures. (Caslin et al 2010; Boyd et al 2000.)

2.2.4 Growth and Productivity

Commercial willow plantations produce high amounts of biomass with good energy ratio (Aylott et al 2008). The growing results vary between different climate and soil conditions, but the average yields are between 10-15 dry tonnes per hectare per year. In Scandinavian countries and northern Europe, where plantations are usually grown for 4-5 years before first harvest, yields vary from less than 10 dry tonnes per hectare up to nearly 20 tonnes per hectare on best sites and best cultivars. Yields over 20 dry tonnes per hectare can be achieved in temperate regions with 3 years harvest cycle. (Larsson & Lindegaard 2003; Caslin et al 2010; Mola-Yudego 2010; Stolarski et al 2011).

2.2.5 Establishment

Willow is one of the easiest trees to propagate. The easiest and cheapest way to establish a willow plantation is to use dormant unrooted cuttings (Figure 1). Cuttings need to be taken from one year old shoots. Before planting they should be stored in a cooler to prevent premature budding or drying out. Cuttings are around 200 mm long and at least 8 mm in diameter and they are planted into the soil to 90% of its length. Cut-and-plant machines are most used ones at the moment and it is an efficient way of planting commercial willow fields. Before planting, large stones have to be removed, because they lead to problems during planting, and can cause damage to harvesters. Before planting the land should be cultivated deep enough (200-250 mm) to ensure the success of machine planting. (Boyd et al 2000.)

Figure 1. Willow cuttings (photo: Satu Malinen)

According to previous studies research made in Finland (Heikkinen 2009 and Tahvanainen 1997), the establishment costs of willow plantation into agricultural land are between $2000 and $4500 (1500-3500€[1]) per hectare. The costs for establishment include field preparation, plant material, planting and weed control. (Heikkinen 2009, Tahvanainen 1997.) In Sweden costs have been approximately the same, $1300 (1000€) for site preparation and planting (Heikkinen 2009).

Usually willows are planted at a density of approximately 15 000 cuttings per hectare. Row width can vary but it must be compatible with the harvesting system. Generally at least two rows are planted side by side. A spacing of 0.75 meters between rows and 1.5 meters alternately between pairs of rows suits most of the currently available machines. (Boyd et al 2000.) The willow crop has an expected life-span of 20 years and it will re-grow from the coppiced stumps after every harvest (Caslin et al 2010). Sometimes it is recommended to cut back willows at the end of the first year, to encourage growth of multiple shoots (Boyd et al 2000).

[1] exhange rate 1 EUR = CAD 1.2986 (07.05.2012)

2.2.6 Weed Control

Weed control is extremely important for willow, because new shoots cannot compete strongly against most weeds. Most plantation failures are due to poor weeding. Weed control for willow site should start the previous fall by ploughing and removing all the previous perennial weeds. Herbicide, such as glyphosate, should be applied before ploughing in the spring. Applying a pre-emergent herbicide prevents or reduces weed seed from germinating in the spring of the second year. Mechanical weed control using inter-row cultivators is a good option used in combination with the chemical weed control. (Caslin et al 2010; Boyd et al 2000.)

2.2.7 Fertilization

On rich sites, fertilization may not be necessary. If site preparation is not thorough, fertilization in the planting year is not recommended because weed competition may increase (Caslin et al 2010). Fertilizer amendments are usually only applied following a biomass harvest. When fertilization is needed, nutrition additions are modest, only 100 kg N per hectare every three years. (Keoleian & Volk 2005.) Sewage sludge or residual ash from burning can be used as a fertilizer. Depending on the soil type, nutrient application should not exceed the equivalent of 120-150kg nitrogen, 15kg-40kg phosphorus and 40kg potassium per hectare per year. (Caslin et al 2010.)

2.2.8 Harvesting

Willow is typically harvested in a three year cycle. In northern climates harvesting occurs during the winter months (November - March), as the level of snow permits. Harvesting methods include three different options: 1) direct chipping, 2) whole stem harvesting and 3) billeting. (Caslin et al 2010; Boyd et al 2000.)

1) *Direct chipping* is the most commonly used method as it is the simplest one: the crop is cut and chipped in a single pass. It is efficient and does not require advanced technology. The problem in this method is that at harvest time the biomass is still high in moisture content, and must be dried to prevent deterioration. (Caslin et al 2010.)

2) In *whole stem harvesting* the crop is harvested as entire stems, which allows the stems to be dried out in a simple storage just as they are with natural ventilation. Chips produced from this dried material will have a wider range of particle size than that produced from the direct chip harvesting method. There is also a higher power requirement for the chipping operation. (Caslin et al 2010.)

3) *Billeting* is an intermediate of the first two methods. The billet harvester produces stems 5-10cm in length, which are blown into trailers for removal. In this method the piece size is larger providing improved air circulation, so the chips can be air dried similarly to the whole rod system. Prior combustion, the billets can be chipped to maximize the burning efficiency. (Caslin et al 2010.)

In Sweden, the most commonly used harvesting machines are modified maize harvesters with headers adjusted specifically for use with willow (Larsson & Lindegaard 2003). To prevent harvesting losses it is better to chip the biomass while harvesting rather that bailing it first and chipping later. The harvest losses when using direct chip method are approximately 0.9t/hectare. (Finnan et al 2011)

2.2.9 Quality of Biomass

Overall, whole stem willow chips have lower elemental and ash concentrations than some other biomass fuels such as switchgrass. Willow biomass can be considered to be nearly comparable to clean wood fuels such as sawdust (Tharakan et al 2003). Table 2 presents extensive information about chemical composition of short rotation willow and other wood fuels. It shows that nitrogen (N) content – which is responsible for NO_x formation – in willow is approximately same as other wood fuels. NO_x emissions belong to the main environmental impact factors of solid biofuel combustion. Another important figure is ash content (which in willow is higher than in other wood fuels) and the different ash forming elements (Al, Ca, Fe, K, Mg, Na, P, Si, Ti) that defines the ash melting behavior, deposit formation and corrosion. For corrosion chlorine (Cl) and sulfur (S) are important factors. What comes to these values, willow concentrations are higher than what other wood fuels. (Obernberger 2006.)

Table 2. Typical mean values for the chemical composition of wood fuels including SRCW (Obernberger 2006).[2]

Parameter Unit		Wood without bark		Bark		Logging residues		Short rotation coppice Willow
		Coniferous wood	Deciduous wood	Coniferous wood	Deciduous wood	Coniferous wood	Deciduous wood	
Ash	wt%	0.3	0.3	4.0	5.0	2.0	1.5	2.0
N	wt% daf	0.1	0.1	0.5	0.3	0.5	0.5	0.5
S	wt% daf	0.02	0.02	0.1	0.1	0.04	0.04	0.05
Cl	wt% daf	0.01	0.01	0.02	0.02	0.01	0.01	0.03
Ca	mg/kg	900	1200	5000	15,000	5000	4000	5000
Fe	mg/kg	25	25	500	100	-	-	100
K	mg/kg	400	800	2000	2000	2000	1500	3000
Mg	mg/kg	150	200	1000	500	800	250	500
Mn	mg/kg	147	83	500	190	251	120	97
Na	mg/kg	20	50	300	100	200	100	-
P	mg/kg	60	100	400	400	500	300	800
Si	mg/kg	150	150	2000	10.000	3000	150	-

In bark the chemical concentrations are higher than in the stem. With different clones of willow, the bark percentage ranges from 3.6% to 8.1%. The use of clones with a higher bark percentage in combustion can result in a marginal lowering of energy output and increase the potential for fouling and corrosion. Thus it is desirable to select clones with lower bark percentage. (Tharakan et al 2003.)

Willow biomass has energy content of approximately 19MJ per kg or 45% of the energy in an equivalent volume of light fuel oil (Caslin et al 2010). As a rough guide, 1 kg of willow will yield about 1 kWh of electrical output (Boyd et al 2000). The net caloric value (NCV) of short rotation woody crops is approximately 2.1 kWh/kg with moisture content of 50% and it is comparable to other wood biomass after harvesting as shown in Table 3. For instance recently harvested wood has an energy value of 2.2 kWh/kg, green wood 1.6; peat 2.8 and pellets 4.7. (Aebiom 2011).

[2] wt% = weight percent, daf = dry basis, ash free; ash content measured at 550 °C

Table 3. Typical moisture content of biomass fuels and corresponding calorific values as received (Aebiom 2011).[3]

	Moisture content (%)	kWh/kg (NCV)	GJ/t	toe/t
Green wood direct from the forest, freshly harvested	60 %	1.6	5.76	0.14
Recently harvested wood	50 %	2.2	7.92	0.19
Saw mill residues, chips etc	40 %	2.9	10.44	0.25
Pellets	8-9 %	4.7	16.92	0.4
Wood, dry matter	0 %	5.2	18.72	0.45
Chips from short rotation coppices after harvest	50-55%	2.1	7.56	0.18
Rape seed	9 %	7.1	25.6	0.61
Hard coal		8.06	29	0.69
Brown coal		4.17	15	0.36
Peat		2.8	10	0.24

2.2.10 Environmental Impacts

Biomass is often cited as carbon neutral energy source because the carbon emissions are considered as part of a natural cycle, where growing plants would

[3] Net Calorific Value (NCV)

The net calorific value is the amount of heat released by a unit quantity of fuel, when it is burned completely with oxygen, and when the water contained in the fuel is transformed to vapor and not condensed to water again. This quantity therefore does not include the heat of condensation of any water vapor. The net calorific value of a given biomass depends on the content of dry matter (excluding minerals) and moisture. The higher the moisture content and minerals content (giving ashes) the lower the net calorific value. (Aebiom 2011.)

over time re-capture the carbon emitted by wood-burning energy production plant. Yet in recent years researchers have begun to study the whole carbon cycle of biomass production on combustion. In fact in some cases – like in traditional wood harvest from natural forests – one biomass unit of useable energy can release more CO2 than natural gas, oil or coal. However, biomass from plantations grown explicitly to fuel bioenergy facilities, energy generation can be carbon neutral or close to it if the biomass plantation represents stored carbon that would not have been there absent the biomass plantation. (Manomet 2010.) This would be the case in growing short rotation woody crops like willow and *Miscanthus*; anyhow before estimating the carbon neutrality every step of the production chain should be evaluated.

Willows have other significant environmental advantages that make the crop versatile and useful in many kinds of aspects. As the plants are not grown for food, they can be irrigated with contaminated water, or fertilized with sewage sludge. Willows are used in cleaning waste water and leachate from landfill sites, and for bio-remediation of contaminated land. Willow plantations can increase biodiversity by providing an attractive habitat for a wide range of plants, animals, insects and birds. They also provide excellent game cover and when the harvest is done in winter time, birds nesting won't be harassed by the machinery. (Boyd et al 2000.) As a downside willows can have remarkable effects on countryside landscape because the plants will reach height of 8 meters and differ quite a lot from traditional arable crops. For preventing the disadvantages willow biomass fields should be well planned and managed. (Caslin et al 2010.)

2.3 *Miscanthus*

The cultivation and characteristics of *Miscanthus* biomass; including the history of growing *Miscanthus* biomass, crop requirements, growth and productivity, establishment, weed control, fertilization, harvesting, quality of biomass and environmental impacts are presented in the following.

2.3.1 General Background on *Miscanthus*

Miscanthus, sometimes called Elephant Grass, is a genus of perennial grasses growing 3 to 4 meters high. *Miscanthus* is a C4 photosynthesis species that adapts well to temperate and cold climates, although its origins are in the tropical and subtropical parts of Southeastern Asia. (Christian & Haase 2001.) *Miscanthus* can be used to produce heat and electricity, liquid fuel, industrial materials and agricultural products. It can also be processed into a range of fuel formats such as pellets or briquettes. The end product is a dry biomass similar in appearance to bamboo canes, and it can be harvested and processed using existing farm machinery. (Jones & Walsh 2001.)

Miscanthus combines several properties that make it a promising crop for biomass production. It has a high yield potential to produce quality lignocellulosic material for both energy and fibre and it can be grown with very low pesticide and fertilizer inputs. When harvested in spring time, its moisture content is low. Also, *Miscanthus* is not very susceptible to pests and diseases. (Jones & Walsh 2001; Lewandowski et al 2000.)

2.3.2 History of Cultivating *Miscanthus*

Miscanthus has been grown in many parts of Europe and the US, first used as ornamental plant and then as a energy crop. In Europe it has been cultivated commercially since 1983 whereas in North America the first large scale trials began in 2004 (Heaton et al 2010). Most biomass trials have used a sterile clone *Miscanthus* x giganteus. (Lewandowski et al. 2000).

Test sites in Europe have been both successful and also revealing some of the weaknesses of the crop. A 3-year study of 15 *Miscanthus* genotypes was performed at five different countries in Europe: Sweden, Germany, Denmark, England and Portugal. The study showed that only one of these 15 genotypes survived in the northern sites (Sweden and Denmark). The study showed strong genotype x environmental interactions, with respect to yields: the highest yielding genotypes in Sweden and Denmark were among the poorest performing genotypes in Portugal and Germany. (Clifton-Brown et al. 2001.)

Winter survival of *Miscanthus* has been one of the concerns of many studies, but the problem can be solved by using the right clones to each climate (Clifton-Brown and Lewandowski 2000; Heaton et al 2008). In Canada research trials in British Columbia and Alberta suggest the three clones chosen to this present study are rather high yielding and that they survive over the Canadian winter (Hoelk 2006 unpublished).

2.3.3 Crop Requirements

Key factors for successful yield are sunshine, adequate temperature and water availability. *Miscanthus* can produce high yields on a range of soils, from sands to high organic matter. It is also tolerant of a wide range of pH, but the optimum is between pH 5.5 and 7.5. Annual amounts of rainfall will strongly influence *Miscanthus*; limited soil water availability during the growing season will prevent the crop from reaching full potential yield. (Defra 2007.)

2.3.4 Growth and Productivity

Miscanthus is a high yielding crop. Yields of up to 25 dry matter tons per hectare have been obtained in the spring harvest in Central Europe, between the latitudes 37º N (Southern Italy) and 50ºN (central Germany) (Lewandowski et al 2000). Another research included 15 sites from Ireland and the UK to central Europe and all the way to Sicilia and Portugal. In these sites the yields ranged between 7 and 26 dry matter tons per hectare after the third growing season. The highest yields were obtained with irrigation, without it the yields were maximum 15-19 DMT per hectare. In Germany the mean yields have been between 18-20 DMT per hectare. (Clifton-Brown et al 2001b.)

In Canada, one of the few test studies made with *Miscanthus* was done in British Columbia with good yield results. Trial plots with 6 different *Miscanthus* clones were harvested in 2006 and the yields were between 20-36 DMT per hectare. The harvest was made 3 years after establishment. (Hoelk 2006 unpublished.)

2.3.5 Establishment

Miscanthus can be propagated using rhizomes or sometimes micro-propagation (Figure 2). Rhizome division is favored because it is less expensive and generally produces more vigorous plants. It is highly important that the planting material is fresh, vigorous and good quality. Rhizomes must have several buds and they must be kept moist and cool before out-planting. (Defra 2007.) Ideally rhizomes should be put in cold storage (3-5°C) within 4 hours after harvesting and planted within 4 hours of removal from storage (ADAS 2006).

Figure 2. *Miscanthus* rhizomes and micro-propagated *Miscanthus* (Defra 2007).

Most of the costs of *Miscanthus* plantation come from the establishment period and the purchase costs of rhizomes. The costs of establishment in production scale are $4000 (3100 €[4]) per hectare, from which half is the cost of rhizomes. (Caslin et al 2010b.) It takes two to five years for a *Miscanthus* plantation to fully establish. Some biomass harvesting may be done before maximum yields are reached. The time required to reach maximum production will vary with soil characteristics, climate, and general growing conditions. (Hopwood 2010; Anderson et al 2010.) Planting densities in commercial scale are approximately 15,000 plants/ha (Hopwood 2010). To plant, it is possible to use conventional farming machinery such as potato planters. (Defra 2007.)

2.3.6 Weed Control

In the year of planting *Miscanthus* competes poorly with weeds, so weed control either mechanical or chemical is needed (Lewandowski et al 2000). In the previous autumn and prior to planting applying broad-spectrum herbicide is recommended to remove perennial weeds, followed by a further application the first spring if necessary (Hopwood 2010). The problem in North America is that no herbicides are currently labeled for use in *Miscanthus* grown for biomass. Most likely herbicides used in corn are suitable to *Miscanthus*, but still the registration process needs to be done before starting to use chemicals in production scale. (Anderson et al 2010.)

2.3.7 Fertilization

The nutrient demand of *Miscanthus* is high but it can be replaced with good harvesting procedures (Styles et al 2008). Large amounts of nutrients are returned to the site with leaf drop and only a small amount is remained in the harvested biomass. Small amounts of phosphorus and potassium and in some cases nitrogen might be needed to ensure the maximum yield. Instead of chemical fertilizers, it is possible to use farm-yard manure, sewage sludge or other organic manure with low available nitrogen content. (Defra 2007.)

[4] 1 CAD = 0.78 EUR (16.5.2012)

2.3.8 Harvesting

After establishment crop is harvested annually for at least 10 years and possibly up to 20 years. Annual harvesting of the crop is a low cost cutting and baling operation. (Jones & Walsh 2001.) It is recommended to harvest during spring time, since then the moisture and mineral content will be lower and combustion qualities better than in the fall or winter. Also during winter most of the leaves and the non-woody tops fall off leaving the nutrients in the field. Due to the woody stem of the plant, it will stay upright despite snow and enables harvesting practices. (Lewandowski et al 2000.) In a study in Ireland (Finnan et al 2011) it has been shown that for minimizing harvesting losses it is better to harvest mid-April than early May. Still the harvesting losses are significant: direct losses are 10% with a yield of 10 t dry matter per hectare.

2.3.9 Quality of Biomass

Good biomass combustion quality depends on minimizing moisture, ash, concentrations of kalium (K), chloride (Cl), nitrogen (N) and phosphorous (S). The quality of *Miscanthus* biomass for combustion is in some respect comparable to woody biomass. Moisture content will be lower in spring than in fall harvested biomass. (Lewandowski et al 2000.) Overall compared to other solid biomass fuels, combustion and energy values for *Miscanthus* are good as can be discovered from table 4. Usually the moisture content is low (8-20 %) due to the spring/winter harvest. The bulk density for *Miscanthus* is low, but the net caloric value is high because of the low moisture content, approximately 4 kWh/kg or 18.4 MJ/kg[5], as it is only around 2 kWh/kg for wood chips (45-55% moisture) and 4.6-4.9 kWh/kg for wood pellets. (Aebiom 2011.)

[5] 1kWh/kg = 1 MWh/ton = 3.6 GJ/ton

Table 4. Net calorific value, moisture content and energy density for some biomass fuels (Aebiom 2011).[6]

Fuel	Net calorific value, dry content kWh/kg (moisture content 0%) (qp,net,d)	Moisture content w-% (Mar)	Net calorific value, as received =actual value kWh/kg (qp,net,ar)	Bulk density kg/loose m3	Energy density (MWh/loose m3)	Ash content, dry, %
Sawdust	5.28-5.33	45-60	0.6-2.77	250-350	0.45-0.70	0.4-0.5
Wood pellets	5.26-5.42	7-8	4.60-4.90	550-650	2.6-3.3	0.2-0.5
Logging residue chips	5.14-5.56	50-60	1.67-2.50	250-400	0.7-0.9	1.0-3.0
Whole tree chips	5.14-5.56	45-55	1.94-2.78	250-350	0.7-0.9	1.0-2.0
Reed canary grass, (spring harvested)	4.78-5.17	8-20	3.70-4.70	70	0.3-0.4	1.0-10.0
Grain	4.8	11	4.30	600	2,6	2
Straw, chopped	4.83	12-20	3.80-4.20	80	0,3-0,4	5
***Miscanthus*, chopped**	5.0	8-20	3.86-4.06	110-140	1.72-2.19	2.0-3.5
Straw pellets	4.83	8-10	4.30-4.40	550-650	2.4-2.8	5

The mineral content of *Miscanthus* is low compared with wheat straw, but higher than for willow or poplar coppice. Mineral concentrations are reported to be low

[6] Net Calorific Value (NCV) is calculated according to equation:

$$q_{p,net,ar}=q_{p,net,d} \times [(100 - M_{ar})/100] - 0.02443 \times M_{ar}$$ **where**

$q_{p,net,ar}$ is the net calorific value (at constant pressure) as received [MJ/kg]

$q_{p,net,d}$ is the ner calorific value (at constant pressure) in dry matter [MJ/kg] (net calorific value of dry fuel)

M_{ar} is the moisture content as received [w-%, wet basis]

0.02443 is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25°C [MJ/kg per 1 w-% of moisture) when harvesting spring time. (Lewandowski et al 2000.) In Table 5 there are elemental analysis of *Miscanthus*, average wood and wheat straw (McKendry 2002). In some cases, the soil type can have significance for the ash and mineral contents of the crop, which will be lowest for *Miscanthus* grown on coarse sandy soils (Kristensen 2003).

Table 5. Elemental analyses of *Miscanthus*, average wood and wheat straw (wt%) (McKendry 2002).

Material	**C**	**H**	**O**	**N**	**S**	**Ash**
Wood (average)	51.6	6.3	41.5	0	0.1	1
Miscanthus	48.1	5.4	42.2	0.5	<0.1	2.8
Wheat straw	48.5	5.5	3.9	0.3	0.1	4

One of the main issues of combustion of *Miscanthus* biomass is the low ash melting point. It can cause sintering of ash and agglomeration. *Miscanthus* ash can show sintering tendencies at temperatures as low as 600 C, which is very low comparing to other biomass crops. (Lewandowski et al 2000.) For bioenergy use in large scale it is not a problem when co-firing. *Miscanthus* has been successfully burned on a commercial scale in Denmark in a 78MW circulating fluidized-bed combustor (50% co-firing with coal) and a 160MW powdered fuel combustor (20% co-firing). (Lewandowski et al 2000.)

2.3.10 Environmental Impacts

The use of *Miscanthus* for energy conserves the primary energy sources such as oil and coal and thus can reduce the greenhouse gas emissions. The amount of avoided greenhouse gas emissions depends on the methods used to biomass production and the type of fossil fuel which was substituted. (Oliveira 2001.)

Miscanthus has some positive effects on soil, water and ecosystems compared to other arable crops. As a perennial crop, *Miscanthus* protects against soil erosion and can enrich the soil with organic matter. (Shepard 2003.) The risks for soil and groundwater contamination on *Miscanthus* sites are low because its low pesticide and fertilization requirements. *Miscanthus* fields also have a positive impact on biodiversity and wildlife on arable lands by bringing a different kind of environment that resembles forest edge. Deer, partridges, quails and hares have been reported to adapt well in *Miscanthus* fields in Europe. Plantations create a high number of ecological niches where a stable species ratio can develop. (Oliveira 2001.)

3 Methods and Materials

The methods and materials chapter includes the presentation of research method, the plant material and case studies and the procedures of establishment period.

3.1 Research Method

In this study, the practical data was collected from field tests and theory from literature. Field data was collected during the summer of 2011 by the workers included in the project. Field notes include work diary notes and photos taken in different stages of establishment. Diary notes were converted into Microsoft Word file in the autumn of 2011. Data for the cost was gathered during establishment period from different sources including land owners, AFC and UNB researchers and project workers. The costs were then assembled for both sites and calculated using Microsoft Excel. The costs have been verified and approved by project leaders. The prices of materials and cost of human labour includes taxes.

3.2 Plant Material

Plant material includes the three willow clones and three *Miscanthus* cultivars.

3.2.1 The Willow Clones: *Salix Viminalis, Salix Miyabeana* and *Salix Eriocephala*

The three willow clones that were selected to this research are *Salix Viminalis, Salix Miyabeana* and *Salix Eriocephala*. *Salix Viminalis* is a European clone introduced to Canada from Sweden. It has a long history of use as a basket willow and in energy production in Europe and chosen for this study because it is well-known and highly productive. In southern Quebec, *Salix Viminalis* has been successfully cultivated since the 1990's. The climatic conditions seem to be suitable for this clone and the yields have been high. However, it has shown some sensitivity to insect attack. (Labreque & Teodorescu 2005.)

The two other clones, *Salix Miyabeana* (SX67) and *Salix Eriocephala,* were chosen because they are domestic species from Canada. *Salix Miyabeana* (SX67) and *Salix Eriocephala* have been studied in southern Quebec and compared to many other willow clones and they were among the best performing ones producing the tallest and thickest stems (Labreque & Teodorescu 2005). *Salix Eriocephala* has been proven to produce good quality biomass in North America since the 1980s. (Mosseler et al 1988.).

3.2.2 The *Miscanthus* Clones: M114, M115, M116

In this study, *Miscanthus Giganteus* clones coded M114, M115 and M116 were used. Most European trials have involved clones of this sterile clone *Miscanthus x Giganteus,* which is a hybrid of *Miscanthus sinensis* and *Miscanthus sacchariflorus*. The plants that are used in this particular research are originally from Tinplant from Germany, Tinplant is the main breeder of *Miscanthus* in Europe and it has over 900 genotypes of different *Miscanthus* species and varieties. (Hoelk 2006 unpublished.)

Research trials in British Columbia and Alberta suggest the three clones chosen for this study are high yielding, the yields that were achieved for each clone were: M114 23,07 DMT/ha, M115 20,13 DMT/ha and M116 36,43 DMT/ha. (Hoelk 2006 unpublished.) Most importantly, the clones survived over the Canadian winter. Overwintering is one of the most crucial issues when growing *Miscanthus* in northern climates.

Before planting the rhizomes were kept in cooler covered in soil. Clones were divided into bunches (Figure 3) and gathered in to groups of 200 rhizomes per clone to facilitate planting procedures.

Figure 3. Dividing *Miscanthus* rhizomes (photo: Satu Malinen)

3.3 Case studies: Organic and Conventional

The geographical locations, climatic conditions and the soil qualities of the two sites are presented in the following chapters.

3.3.1 Geographical Locations

The case studies are situated in different parts of New Brunswick, the conventional farming site in Grand Falls in the north of province and the organic site in Thulium Farm in the west near Atlantic coast. The two sites differ quite a lot what comes to the climatic conditions and the soils. The locations of sites are shown in the Figure 4.

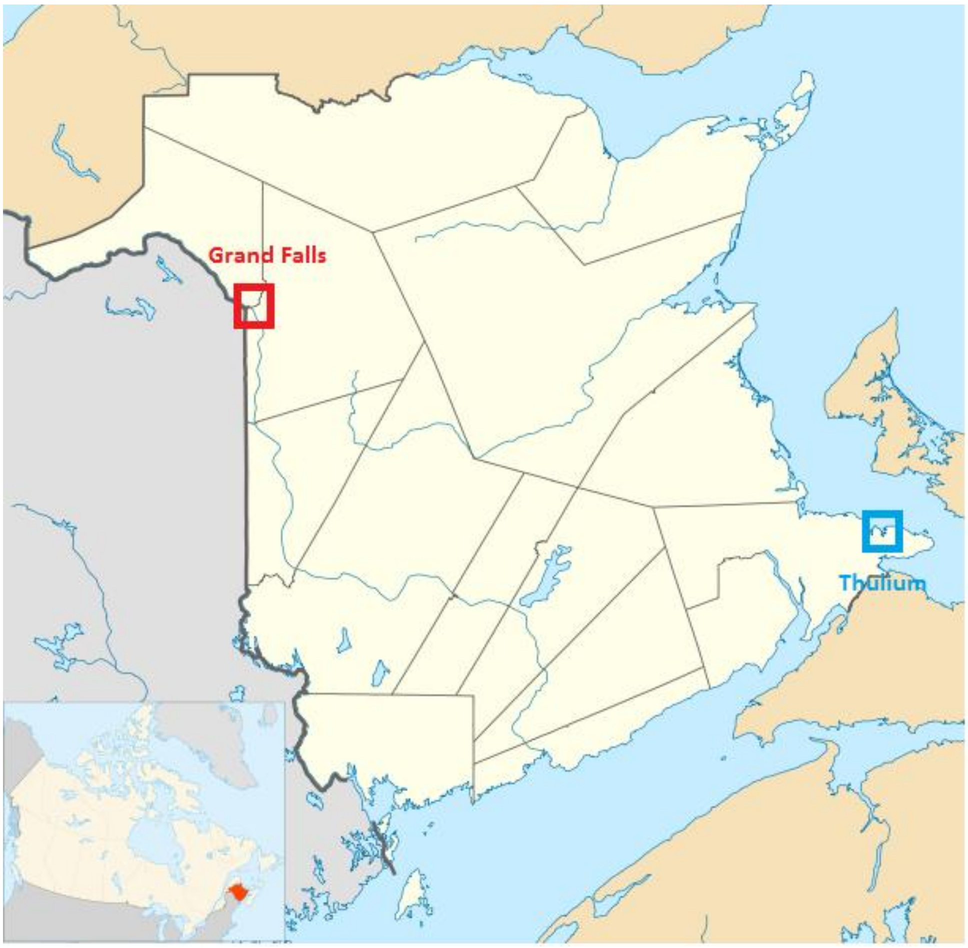

Figure 4. Geographical locations of the case studies (Wikipedia 2012.)

Grand Falls is situated in northwest New Brunswick just few kilometers north from the village of Grand Falls and the US border. The site had been prepared in the fall of 2010, but heavy precipitation, including hail, resulted in considerable soil compaction during the months of spring and early summer. The clayey soil was disked prior to planting (Figure 5). The site here has been used as a farmland for decades the previous year it has been on clover and before that on potatoes. Because of the intensive use of this field, the weeds were not a problem. The field was not very productive and the farmer was interested in finding some alternative use to this field.

Figure 5. Grand Falls site before and after tilling (photos: Satu Malinen)

The Thulium Farm site is organic field and situated in southeastern New Brunswick, just few kilometers from the sea and about 70 kilometers east from the city of Moncton. The site is sunny and lush as can be seen in Figure 6.

Figure 6. Thulium Farm before planting (photo: Satu Malinen)

3.3.2 Growing Degree Days and Precipitation

The two sites vary climatically what comes to the growing degree days and precipitation. Growing degree-days (GDD) are a measure of heat accumulation used to predict plant and pest development. GDD are usually calculated above base temperature 5°C. In the Maritime Provinces growing degree days vary from 1100 to 1800. (Gordon & Bootsma 1993.)

The climatic data is collected during 1971-2000 and the figures are averages from that period of time. Data is presented in Table 6. The growing degree days range from 1577.2 in Grand Falls (conventional farming) to 1615.8 in Thulium (organic). Precipitation varies from 1163.9 mm in Thulium to 1134.4 mm in Grand Falls. (National Climate Data and Information Archive 2011.)

Table 6. Growing degree days and precipitation on sites

Growing degree days and precipitation	**GDD**	**Rainfall (mm)**	**Snow (cm)**	**Total precipitation (mm)**
Thulium Farm (organic)	1615.8	934.1	229.9	1163.9
Grand Falls (conventional)	1577.2	834.3	300.1	1134.4

3.3.3 Soil Analysis

Soil samples include both physical (soil texture) and chemical soil analyses from both test fields. A composite sample comprised of ten, 2 cm cores was obtained for each plot. Soil cores were taken to an approximate depth of 10 to 15 cm. Analyses were done on each of the 24 samples per site.

Table 7 presents the results of chemical soil analysis. The analysed values include organic matter (OM %), total nitrogen (N total %), carbon/nitrogen proportion (C/N), pH, available amount of phosporus (P) mg/kg and the amount of sulfur (S) and carbon (C). Analysis shows that both sites are rather acid, pH is between 5.3 and 5.6. Values are rather similar for both sites except the available phosporous, of which in Grand Falls is 21 mg/kg and in the organic Thulium Farm 8 mg/kg.

Table 7. Soils data

	O.M. %	**Tot.N %**	**C/N**	**pH**	**Avail. P mg/kg**	**S %**	**C %**
Grand Falls (conventional)	2.4	0.190	7.32	5.6	21	0.0110	1.40
Thulium (organic)	2.6	0.145	10.56	5.3	8	0.0110	1.51

Results of soil texture analysis are presented in Table 8. Both sites fall into silt loam texture classes based on the USDA soil texture triangle classification system (Figure 7) (NRCS 2012).

Table 8. Soil types

Site	Sand %	Silt %	Clay %
Grand Falls (conventional)	16.6	61.7	21.7
Thulium (organic)	30.9	54.5	14.6

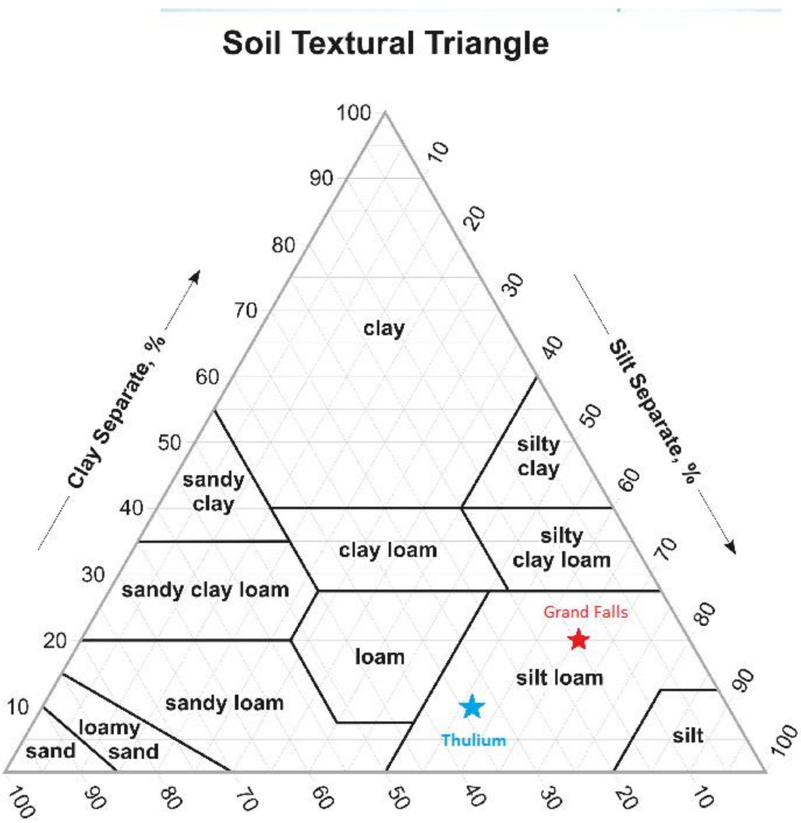

Figure 7. Soil textural triangle (NRCS 2012)

3.4 Planting

In the following chapters, the planting methods are presented. Experimental layouts including plot randomizing are introduced. Also site preparation and the stages of planting are described.

3.4.1 Experimental Layout

Sites consist of an area of approximately one hectare. The general field design was four blocks with six plots in each, total of 24 plots per site (Figure 8). The dimension of each plot is 4 x 50m with two meters between plots and a two meter road between the blocks.

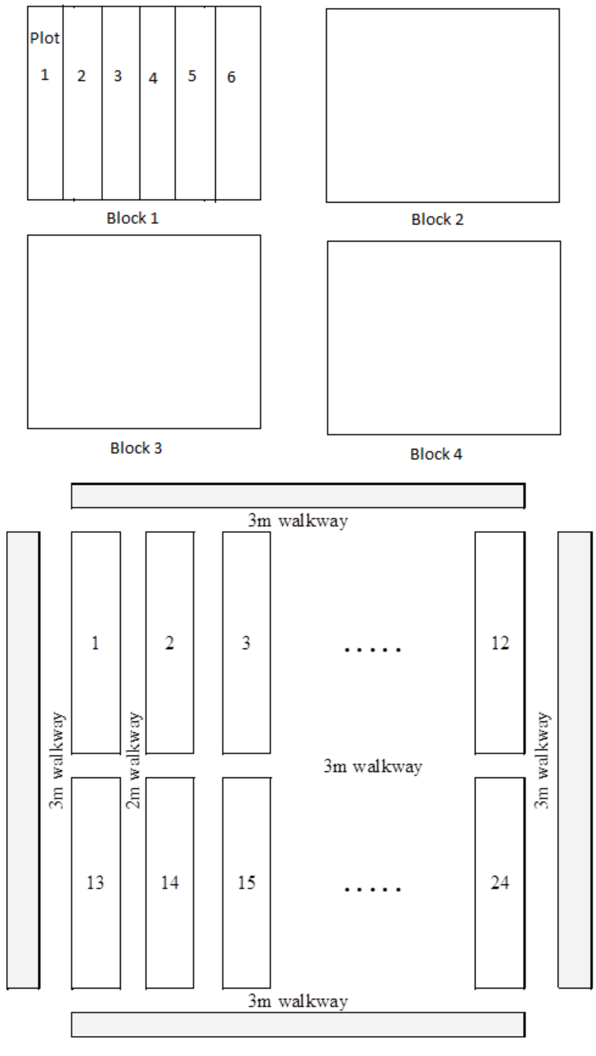

Figure 8. Illustration of the general block and plot layout

Per plot there are 200 seedlings planted at a within and between spacing of 1 x 1m. Each plot is planted with a single species, and the six clones are randomized in four replicates on the site. Eventually, there are total of 800 plants of each clone per site. Before planting in each site the plots have been randomized so that growing conditions are equal to each species and each clone. In Figure 9 is an example of randomized site plots. Each plot from 1 to 24 has been numbered and the planted clones are marked. Plot 1 is planted with *Salix Miyabeana*, plot 2 with *Miscanthus* M116, plot 3 with *Salix Viminalis*, plot 4 with *Miscanthus* M114 etc, so willow and *Miscanthus* clones alternates.

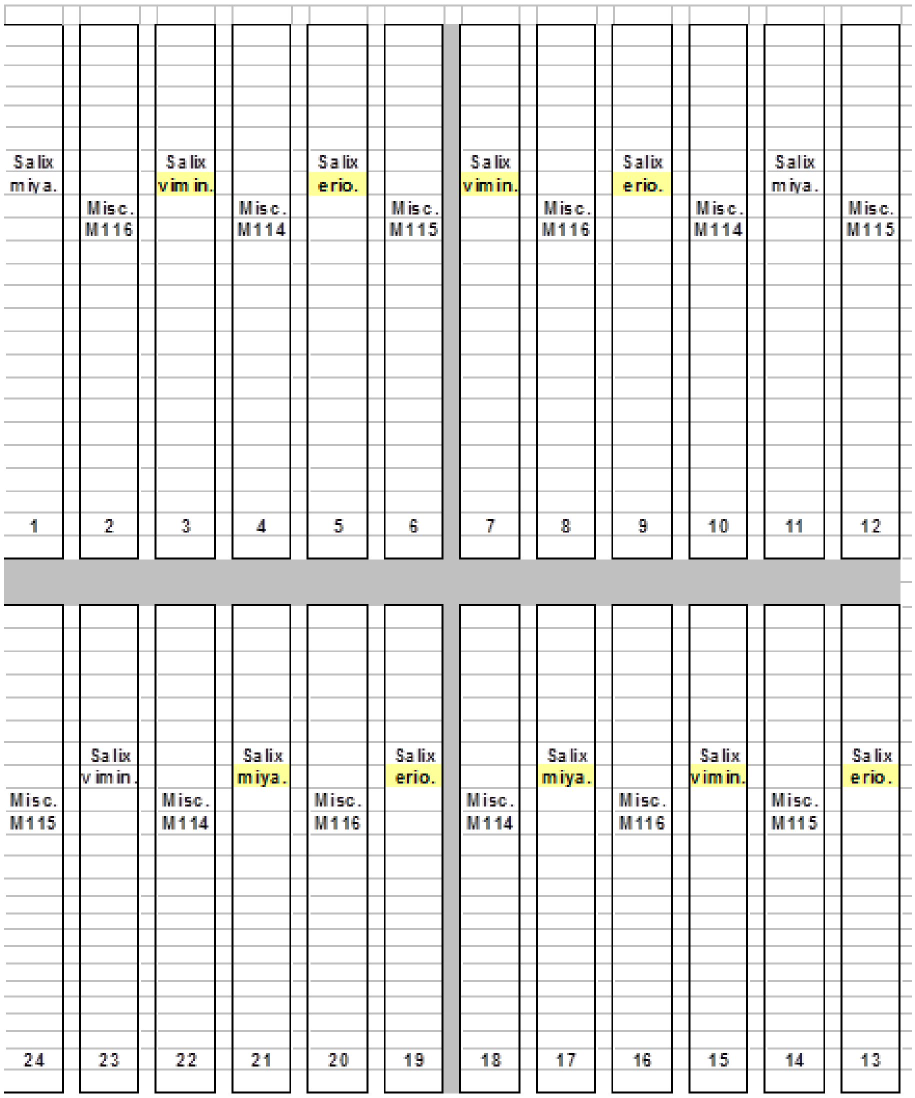

Figure 9. Randomized plots

3.4.2 Site Preparation

Site preparation for sites was done in the fall of 2010 and the spring of 2011. Preparation work includes plowing, tilling and the possible use of herbicides. Land use history differs among the sites. Site preparation is presented in the

Table 9. Grand Falls site was plowed in fall 2010, sprayed with Round up in spring 2011 and then 2 weeks later tilled. Thulium site was tilled in the autumn of 2010 and in the spring 2011. No herbicides were applied, since the farm is organic. Grand Falls site was in active agricultural cultivation before SRC plantations, therefore the weeds were in good control. Thulium farm site had been out of cultivation more than 5 years, no herbicides were added and thus the weeds were a major challenge.

Table 9. Site preparation

Site	**Herbicide**		**Preparation**	
	Fall 2010	**Spring 2011**	**Fall 2010**	**Spring 2011**
Grand Falls (conventional)	no	yes	plowing	tilling
Thulium (organic)	no	no	tilling + plowing	tilling + plowing

3.4.3 Planting Methods

Each test site was planted with 4800 plants, 2400 each of Salix and *Miscanthus*. Planting was carried out by hand by a group of workers in pairs. To make the planting easier and more accurate, we used planting frames and planting ropes. The planting frames were sized to fit the 4 meters wide plot and hold the planting ropes in their place in one meter distance of each other. The 4 planting ropes each 50 meters long had a mark every meter to show the place where to plant. Corner stakes were positioned at the corners of the blocks using a transit and tape to show which species is in the block.

3.4.4 Planting Dates

The planting of the study trials started on June 28th at Thulium Farm. On that day only *Miscanthus* clones were planted because the willow clones had not arrived yet. The willow was planted here on 8th of July. The site of Grand Falls was planted on 14th July for everything except the *Miscanthus* clone M116, because the clone was in poor condition and there was new replacements coming in soon. Grand Falls M116 was replanted on 20th July and Thulium 22nd July (Table 10).

Table 10. Planting dates

	Willow	**Miscanthus**
Thulium Farm (organic)	8th July	28th June
		22nd July (M116)
Grand Falls (conventional	14th July	14th July
		20th July (M116)

3.5 Maintenance

Maintenance includes weed control and survival counts for willows and *Miscanthus*.

3.5.1 Willow Weed Control

Weed control for willow in the first few years is essential. For controlling weed competition in these trials, we used BioDisk coconut mats. The mats are placed around the saplings and stapled with metal staked as shown in Figure 10. The mats are 100 % natural coconut fibers and they should last for three years until they biodegrade. Mats are sized 27 or 29 cm diameter. The reason for two sizes was that there was not a sufficient quantity of any one size available and the two cm difference in disc diameter was not assessed to make any significant variation to the trials.

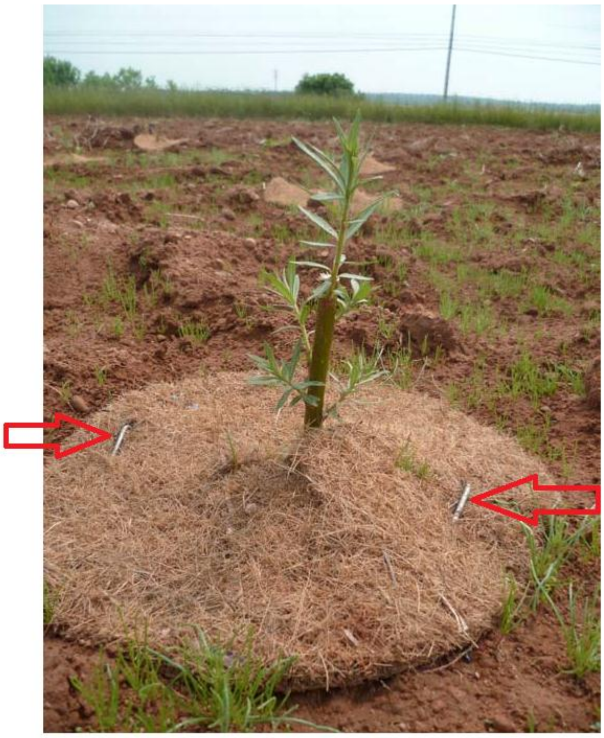

Figure 10. BioDisc with the staples. (photo: Satu Malinen)

Site maintenance included weed control for both *Miscanthus* and willow. We used mowers, weed whackers and some hand weeding. For willow weeding was easier and faster, because we were able to mow in the middle of the rows. Biodisks were covering the land around the cutting and preventing weeds growing just next to plant. Willow rows were clearly visible and mowing between the rows did not hurt the plants. For *Miscanthus* weeding was more complicated, because plants were not clearly visible and they were easily mixed up with other plants and weeds.

3.5.2 *Miscanthus* Weed Control

Miscanthus weed control was more complicated than for willow. The main issue is that unlike willow, which is remarkably easy to distinguish from other plants, *Miscanthus* in its early growth resembles greatly just any other ordinary weed. After it reaches height of more than 30 cm, it can be tell apart. In Thulium (organic farm) the weeds were flourishing and probably limiting the favourable growing conditions, but weeding was not an option because the plants were not recognizable. After *Miscanthus* grew over the weeds and was recognizable for sure, weeding between the rows with lawnmoers and weed whackers was carried out.

3.5.3 Survival

Survival counting was carried out in the fall of 2011. The method was simply to investigate how many plants were alive after the first summer. For willow the method is simple, as it is very clearly visible if there is any sprouting in the cuttings. Willow cuttings are easy to find and observe in the field, as they were planted in rows. Plant was calculated as dead, if there was no green sprouts in the cutting.

For *Miscanthus* the method was more complicated and time consuming, since Micanthus is a herbaceous species and resembles many weeds in its early stages of growth. We developed criteria to identify *Miscanthus* from other plants, ie. the colour and the shape of the young plant. Usually *Miscanthus* diverges into two thin and long stalks, which are green and a bit purple in the middle.

4 Results

Results of the establishment period include the survival rates, initial growth assessments and the calculations of establishment costs.

4.1. Survival Rates

Survival rates were counted in September 2011. Overall, the willow clones established remarkably well. As presented in tables 11, 12 and 13, the survival for all three willow species was close to 100% at both locations. Salix Eriocephala was the only clone that did not establish 100%, nevertheless reaching 95 to 97 % survival.

Table 11. Salix Eriocephala survival (%) for test sites. Values represent total survival by clone.

Site	Salix Eriocephala
Thulium Farm (organic)	97,5
Grand Falls (conventional)	95,9

Table 12. Salix Viminalis survival (%) for test sites. Values represent total survival by clone.

Site	Salix Viminalis
Thulium Farm (organic)	100
Grand Falls (conventional)	99,9

Table 13. Salix Miyabeana survival (%) for test sites. Values represent total survival by clone.

Site	Salix Miyabeana
Thulium Farm (organic)	99,1
Grand Falls (conventional)	99,1

For *Miscanthus*, survival rates were significantly lower, varying between 69% and 12 % (tables 13, 14 and 15). Survival for M116, the clone that was replanted, survival was the best of all three clones varying between 62.8 to 69.3%, approximately double comparing to the other two clones. The survival for M114 and M115 was low, for M114 only 12 % and M115 24.12 in Grand Falls. Altogether the *Miscanthus* survivals were better in the organic Thulium Farm than in Grand Falls.

Table 14. *Miscanthus* M114 survival (%) for test sites. Values represent total survival by clone.

Site	**Miscanthus M114**
Thulium Farm (organic)	39,3
Grand Falls (conventional)	24,12

Table 15. *Miscanthus* M115 survival (%) for test sites. Values represent total survival by clone.

Site	**Miscanthus M115**
Thulium Farm (organic)	45,3
Grand Falls (conventional)	12

Table 16. *Miscanthus* M116 survival (%) for test sites. Values represent total survival by clone.

Site	**Miscanthus M116**
Thulium Farm (organic)	69,3
Grand Falls (conventional)	62,8

4.2 Growth

To reveal the growth of saplings in the end of the first growing season pictures were taken in both sites in August 2011. In the conventional farm pictures were taken 9^{th} of August and in the organic farm 25^{th} of August. Out of each clone one picture is chosen to represent the average growth of the clone in both sites. To demonstrate the size of saplings, a 30 cm long metal staple is placed next to the plants.

4.2.1 Willow Growth in Organic Farm

In the organic farm, willow clones *Salix Miyabeana* and *Salix Viminalis* reached height of over one meter towards the end of the summer (Figures 11 and 13). *Viminalis* (Figure 13) had multiple, long and strong shoots and was the highest of the three willow clones. *Salix Eriocephala* (Figure 12) reached the height of only 30 – 50 cm, though having multiple shoots. *Miyabeana* (Figure 11) tended to grow straight upwards and have only one stem.

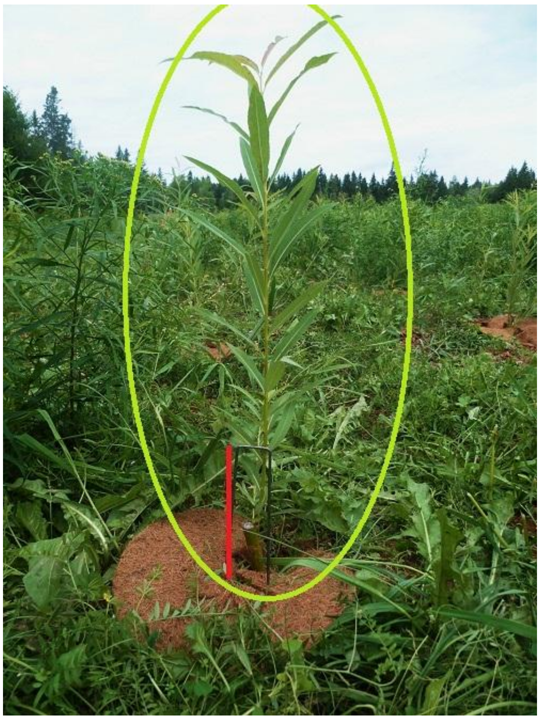

Figure 11. *Salix Miyabeana* 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

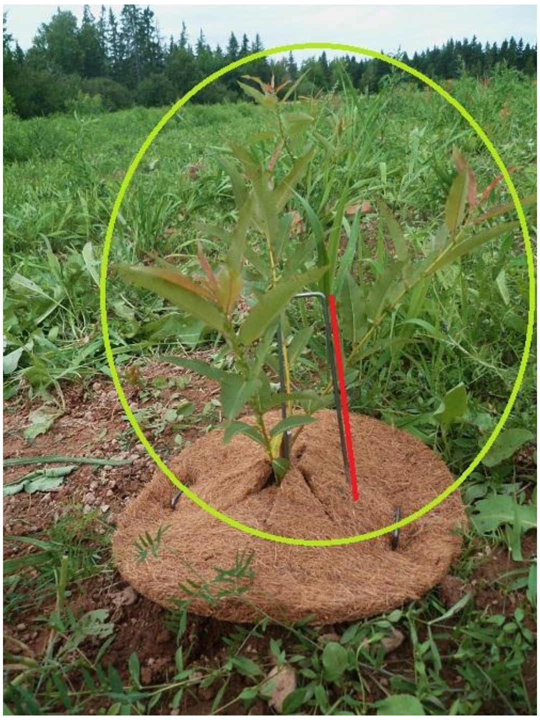

Figure 12. *Salix Eriocephala* 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

Figure 13. *Salix Viminalis* 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

4.2.2 *Miscanthus* Growth in Organic Farm

The *Miscanthus* clones grew to similar height (approximately to one meter) in the end of summer, and the shapes of clones resembled each other (Figures 14, 15 and 16). M116 did not reach as high as the other two clones (Figure 16).

Figure 14. M114 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

Figure 15. M115 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

Figure 16. M116 25.8.2011 Thulium Organic Farm (Photo: Satu Malinen)

4.2.3 Willow Growth in Conventional Farm

Willow clones reached the height of approximately 30 to 60 cm in the conventional farm. *Salix Miyabeana* (Figure 17) had multiple, vigorous shoots. *Salix Eriocephala* (Figure 18) was the smallest and weakest clone. *Salix Viminalis* (Figure 18) again was the tallest of the willow clones.

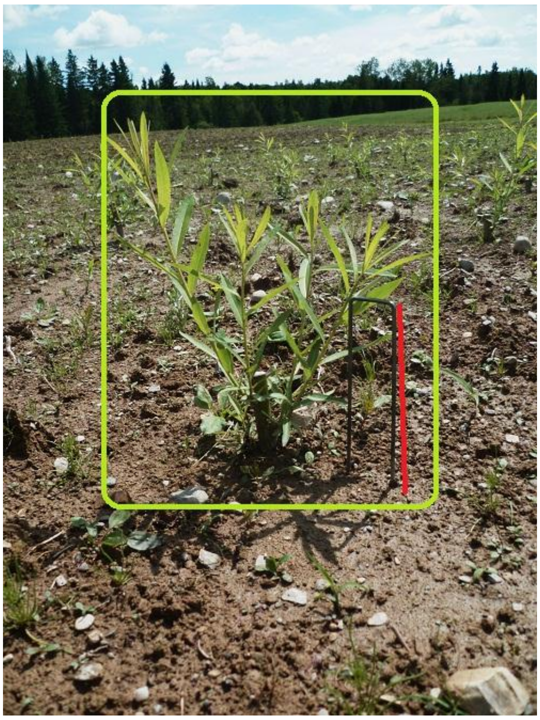

Figure 17. *Salix Miyabeana* 9.8.2011 Grand Falls (Photo: Satu Malinen)

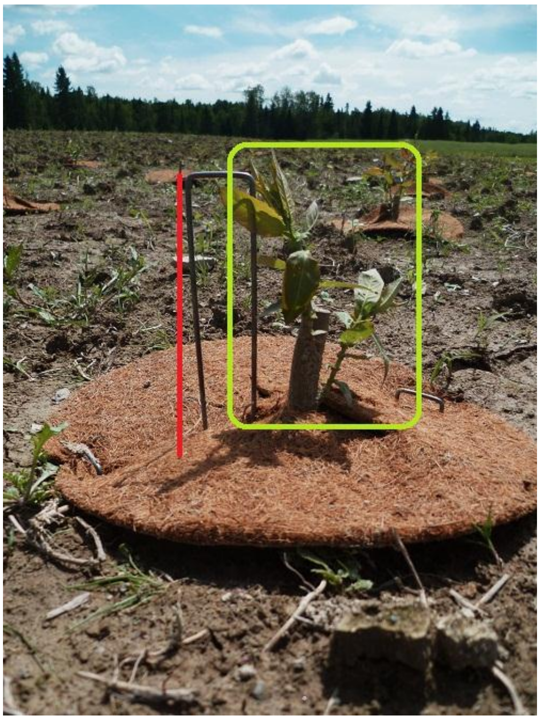

Figure 18. *Salix Eriocephala* 9.8.2011 Grand Falls (Photo: Satu Malinen)

Figure 19. *Salix Viminalis* 9.8.2011 Grand Falls (Photo: Satu Malinen)

4.2.4 *Miscanthus* Growth in Conventional Farm

In the beginning of August, *Miscanthus* clones in the conventional farm were only approximately 30 cm high. Clones had no significant differences in their growth as can be seen from Figures 20, 21 and 22.

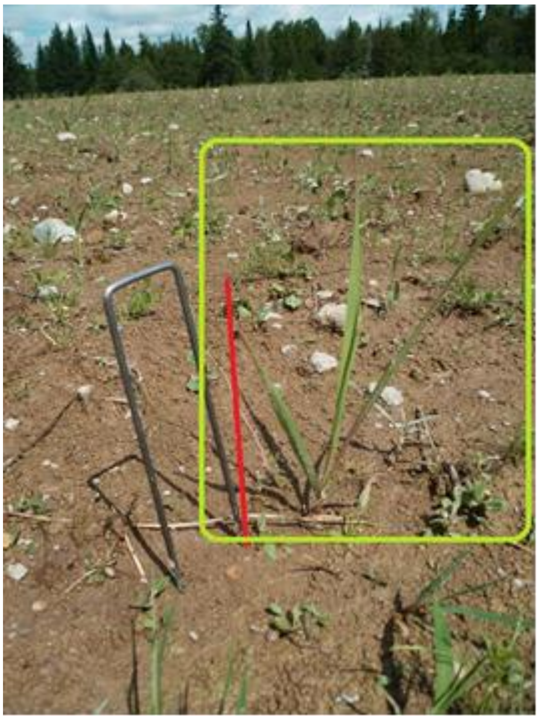

Figure 20. M114 9.8.2011 Grand Falls (Photo: Satu Malinen)

Figure 21. M115 9.8.2011 Grand Falls (Photo: Satu Malinen)

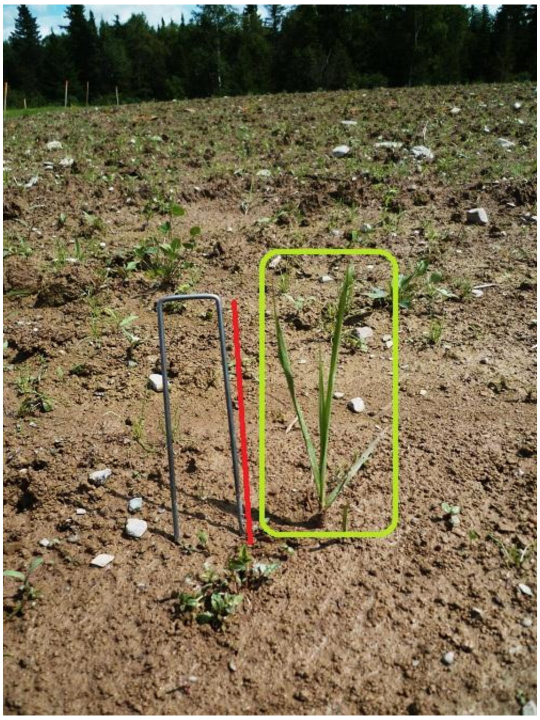

Figure 22. M116 9.8.2011 Grand Falls (Photo: Satu Malinen)

4.3 Costs

Costs of establishment include the costs of site preparation, material costs, planting, laying mats and weed control.

4.3.1 Site Preparation

For each landowner, the project paid $1000 for the site preparation and land rental for the whole period of the test, which is ought to be at least 10 years, preferably 15 year to achieve reliable results when harvesting biomass. The cost was same nevertheless the operations were different between sites. In other words, this cost is not comparable to the amount of work done in the field, whether or not the field was sprayed, the cost is same.

4.3.2 Material Costs

Materials for these trials include willow and *Miscanthus* plant material and the BioDisks coconut mats for willow. The cost for willow cuttings is $0.50 apiece with shipping ($0.48 without shipping) and for *Miscanthus* rhizomes $0.4 apiece with shipping ($0.35 without shipping), total $1200 per site for willow cuttings and $690 per site for *Miscanthus* rhizomes. The BioDisks costs $0.28 apiece, including the cost of two staples per disk, adding the total cost of willow materials to $1872. The total cost of materials per site was $2832. In table 17 is a summary of material costs.

Table 17. Material costs

Material Costs	**Willow**	**Miscanthus**	**Per site**
Plant material	1200	960	
BioDisks	672	0	
Total $	1872	960	**2832**

4.3.3 Planting Costs

Planting took different amount of time for both sites because of the different personnel used. Also planting time varies between species – willow cuttings are faster to plant than Miscanhuts rhizomes. Table 18 presents the costs of planting for both sites and for both species. Willow planting with 8 persons working took 3 hours (24 person working hours in total), *Miscanthus* planting with 8 persons working took 4 to 6 hours (34 - 48 person working hours in total). Cost for worker is $20 per hour. The work cost for planting is between $1160 and $1440.

Table 18. Planting Costs

Planting Costs	**Willow**	**Miscanthus**	**Total Cost $**
Thulium	480	960	**1440**
Grand Falls	480	680	**1160**

4.3.4 Laying Mats

Table 19 presents the costs for laying BioDisk weed mats for willow. At the organic Thulium Farm some of the mats were laid down simultaneously when planting, which reduces the time used for laying the mats. Laying mats took approximately 20 person working days (150 hours) per site. In the test sites approximately 8 persons were working for 2 to 3 days laying down mats. Cost for worker is again $20 per hour and the total cost varies between $2880 and $3060.

Table 19. Costs of laying down BioDisks

Laying Mats	**Cost $**
Thulium (organic)	2880
Grand Falls (conventional)	3060

4.3.5 Weeding

Weeding was carried out twice for both sites during the growing season. Table 20 presents the cost of weeding, which is double more in the organic Thulium than in Grand Falls. Also weeding *Miscanthus* is slower than willow: for willows lawnmowers were used and for *Miscanthus* weed whackers. In the organic farm 8 persons were weeding for 2 days, in the conventional farming field 8 persons were working for one day only. The cost for worker is $20 per hour and the total cost varies between $1280 and $2560.

Table 20. Cost of weeding

Weeding	**Willow**	**Miscanthus**	**Total Cost $**
Thulium (organic)	840	1720	**2560**
Grand Falls (conventional)	420	860	**1280**

4.3.6 Total Costs per Site

Tables 21 and 22 present the total cost for the establishment for both sites, including site preparation, plant material, and the costs of planting, laying down mats and weeding. The total costs are $10 712 for Thulium Farm (organic) and $9332 for Grand Falls (conventional). Site preparation and material costs were the same in both sites, for the planting and maintenance costs sites differ: planting and weeding was more expensive in organic Thulium farm, laying mats was more expensive in Grand Falls. Although weeding is more time consuming for *Miscanthus*, the total costs for willow are higher due to the higher costs of plant material and the extra cost of Biodisks.

Table 21. Total costs for organic farm

Costs	Miscanthus	Willow	Thulium total
Site Preparation	500	500	1000
Plant materials	960	1872	2832
Planting Costs	960	480	1440
Laying Mats	0	2880	2880
Weeding	1720	840	2560
Total $	**4140**	**6572**	**10712**

Table 22. Total costs for the conventional farm

Costs	Miscanthus	Willow	Grand Falls total
Site Preparation	500	500	1000
Plant materials	960	1872	2832
Planting Costs	680	480	1160
Laying Mats	0	3060	3060
Weeding	860	420	1280
Total $	**3000**	**6332**	**9332**

The costs are not comparable to commercial scale prices per hectare, although the test sites consisted of area of one hectare, the planting density was only 4800 plants per hectare, while it is 15 000 plants per hectare in commercial scale. Naturally the costs are higher in research trials than in commercial scale plantation – nevertheless they give an idea of the proportion of different procedures involved in establishment of short rotation plantation.

5 Discussion

In the following chapters the results of the establishment period; including survival, growth and cost, are being discussed.

5.1 Survival and Growth

Factors that effected on the survival and growth were poor plant material and the soils and precipitation. Unfortunately no definite conclusions cannot be made from many of the factors which may have effected to the survival and growth of the establishment period, because the statistical data was insufficient. The pictures presented in Chapter 4.2 indicate that both species succeeded better in Thulium Farm. This may be due to many things, which of one is the planting date. In Thulium Farm the willows were planted one week earlier and *Miscanthus* two weeks earlier than in Grand Falls. However, M116 was planted at the same time at both sites and still the growth in Thulium farm was greater than in Grand Falls. The photos were taken earlier (9th of August) in Grand Falls than in Thulium farm (25th of August) and also because of that they highlight the difference between sites. However, the photos tell the general situation, which was that growth was visibly better in Thulium farm than in Grand Falls.

5.1.1 Poor Plant Material

The survival of willow clones was nearly 100 percent for both test sites, i.e. there is only a little or no difference in the quality of plant material. *Miscanthus* survival was unsatisfactory, being as low as 12 % for one clone in Grand Falls. *Miscanthus* survival for all three clones was significantly poorer in Grand Falls than in organic Thulium Farm.

According to previous studies, *Miscanthus* survival is highly dependent on the quality of rhizomes, which need to be fresh and kept in cold storage. More than 6 weeks cold storage reduces the survival to 70-80 % and if kept in ambient temperature, the survival rates may collapse near to 10-20% (ADAS 2006). The plant material used in the case studies had been placed in cold storage for approximately 6 to 8 weeks prior to planting. During this period considerable deterioration occurred amongst the rhizomes. Reduced survival was likely due to the long storage time prior to planting. Despite plants having been sorted and graded and poor material discarded, the clone M116 in the original shipment had deteriorated such that a request for replacement rhizomes was submitted. The new materials that were received were lifted and shipped within a week. These were of better health, and the fall 2011 survival counts reflect this.

The replanting of the M116 was done approximately three weeks after the first planting. As can be seen in Table 16, the survival counts were better for M116. According to discussion with the supplier New Energy farms, the 60% +/- survival appears to be closer to what might have been expected but still low (Smith 2012 unpublished). As a result of generally poor survival, New Energy Farms will provide replacement *Miscanthus* rhizomes in 2012.

5.1.2 Soils and Precipitation

No statistical method was used in this thesis to reveal the correlation between the survival and the soils and precipitation. This is due to the poor collection method of survival data, which was done by total survival of the species for each site. However, the soils data was collected from each individual plot, total 24 samples from both sites. Thus, only presumptions can be made what comes to the relation between survivals and soils and precipitation.

In summer 2011 there was excessive rainfall, especially in the north of province where Grand Falls site is situated. During May, the total precipitation in New Brunswick weather stations was in many cases 150 % to even 200 % from normal. (Environment Canada 2011.) According to previous studies (Caslin et al 2010), the best sites to produce willow biomass should have a minimum annual rainfall of 600 mm and up to 1,100 mm. Both of the test sites average annual rainfall is more than 1,100 mm. During the summer poor drainage was noticed in many plots of Grand Falls site. Standing water may have drowned some of the plants and created anaerobic conditions. In the organic Thulium Farm the field was in good condition through summer and there were no drainage problems.

As can be seen in pictures presented in Chapter 4.2, both species flourished in the organic site, and the growth in the conventional site was poor. There may be several reasons to that – which may include soils, precipitation and the planting dates. None of these can be proven to be true, because no statistical method was used.

5.1.3 Weed Control and Organic Farming

Weed control was known to be extremely important for the establishment of willow. It is difficult to establish a willow plantation without the use of herbicides. Many previous plantation failures were due to poor weeding (Boyd et al 2000). In the organic Thulium farm, where weeds took over the field, weeding was slow and labor intensive, but the weeds did not have negative impact on the survival, considering that the survivals in Thulium Farm were nearly 100% for willow and between 40-70% for *Miscanthus*. On the contrary, in Grand Falls the *Miscanthus* survival varied between 12 and 62 %.

The use of BioDisks together with chemical weed control worked well. The mats covered land around cuttings and prevented weeds taking space and light. Also later during the summer the mats allowed mechanical weeding more securely, not having the risk of damaging the sapling. Disadvantages for the weed mats are high costs and short lifespan. Laying down mats is labor intensive and slow and the benefit lasts only one summer. It was noticeable towards the end of the summer that a lot of the mats had decomposed and would not be of any use during following summer. Decomposing might have increased in consequence of the extremely rainy summer, and perhaps in dryer conditions the mats would withstand longer, as the manufacturer estimates – two or three years.

Weeds were known to be a problem for *Miscanthus* too. Especially in the year of planting *Miscanthus* competes poorly with weeds (Lewandowski et al 2000). Chemical weed control is highly reasonable and with the aid of that mechanical weeding would be easier. In Thulium Farm, where no herbicides were added, it was extremely difficult to distinguish crops from weeds as can be seen from pictures presented in the Chapter 4.2. Nevertheless the plants there established better than in Grand Falls. It seems that SRWC plantations may succeed on organic land, though weeding needs to be carried out more often and it is more labor intensive.

5.2 Costs of Establishment

In the following the costs in organic field and conventional fields are being discussed and compared to production scale. Note that the costs in this study are not cost per hectare, as they are in commercial studies.

5.2.1 Organic vs. Conventional

Total establishment costs per site was $ 10 712 for organic field and $ 9332 for conventional field. All costs except laying down mats were more expensive in organic site. Factors that influenced to the cost were the consumed time during each phase: planting, laying down mats and weeding. The time varies because different personnel were used for each work phase, and the workers experiences were different. The organic site was planted first and thus took longer than the conventional one, where planting was carried out with routine. Planting willow cuttings is generally faster than planting *Miscanthus* rhizomes. At the organic site some of the mats were laid down simultaneously when planting, which reduces the time used for laying the mats. Weeding was twice more time consuming in organic site than in conventional due to the lack of chemical weed control.

5.2.2 Costs Compared to Production Scale

The establishment costs in this project were high comparing to studies carried out in similar climates and with similar outputs. Research made by Canadian Forest Services (Sidders & Clinch 2009) concluded the following costs for willow plantations: site preparation $600/ha, planting $470/ha, vegetation management $700/ha and plantation maintenance $400/ha, total cost $3450 – $3930 per hectare. In Sweden and Finland the costs of establishment in agricultural land varies between $2000-4500 (1500-3500€) per hectare. (Heikkinen 2009; Tahvanainen 1997). In the case studies the cost of only willow cuttings was $0.5 apiece, which would make a total cost of $7500 when planting 15 000 cuttings per hectare. It is notable that in this study the test sites consists of area approximately 1 hectare but the planting density was only 4800 plants/hectare, while in commercial production scale plantations are normally planted with 15 000 plants per hectare.

For *Miscanthus* the establishment costs in production scale are around $4000 of which half is the cost of rhizomes and $700 for planting (Caslin et al 2010b). In this study, the cost of rhizomes was $0.4 apiece, which would make $6000 cost assuming planting density of 15 000 rhizomes/hectare. New Brunswick test site cost were $10712 – 9332 per hectare. The main reasons for high costs are the methods used – the great amount of human labor and the lack of machine work.

5.3 Conclusions

This study revealed some of the characteristics involved in short rotation crop cultivation in arable land. The case studies represent examples of organic and conventional farm land. The poor data collection and the lack of valid statistical data led to the situation, where the correlations between test results remained unclear. Hopefully in future years more attention will be paid to the data collection and then more diverse results will be revealed.

The costs of establishment are an example of research field trials and are not comparable to production scale. The survival rates, however relate to production scale and the poor survival of *Miscanthus* acts as a risk for commercial plantations. The main barriers to increase energy crop production in Maritimes Canada are market uncertainty combined with the high establishment costs. Farmers may be reluctant to invest into long-term financial commitments for short rotation willow and *Miscanthus*, although subsidies for establishment and production are available.

Benefits for *Miscanthus* are higher yields, higher potential profits, shorter harvest period, similarity with existing cropping practices and the existing farm machinery. Disadvantages are high establishment cost and plant materials and the risk of poor survival and winter hardiness. However, willows may perhaps be grown on less agriculturally productive (less profitable) soils. Willow wood chips are also more suitable for small-scale heating boilers than *Miscanthus*, which would need to be pelleted. (Styles et al 2008.) Small scale use for *Miscanthus* may be a problem also because of the low ash melting point. However co-firing with other renewables or fossil fuels is preferable solution for *Miscanthus*. (Lewandowski et al 2000.)

Further research and development is needed to find the most suitable clones for *Miscanthus*. The good quality of plant material seems to be essential for the success of establishment. Willow short rotation biomass production has longer history and it has been proven to be profitable in Europe, in Maritimes Canada obstacles for the increasing use has more to do with the lack of wood chip markets and the insufficient knowledge of farmers and policymakers. In the future SRWC may well be grown as feedstock for second-generation liquid biofuels (Houghton 2006).

This study is part of research which includes seven field trials in Maritimes Canada and will continue for several years. In summer 2012 there will be evaluations of first winter survival and from that on also the amount and quality of biomass will be examined and biomass harvests will start on the 3rd year. The research will hopefully increase the use of biomass as an energy source and at least it will bring more information on SRWC in Atlantic Canada to researchers, farmers and politicians.

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