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Treatment and utilization of pulp industry residues using Short Rotation Forestry

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To my dear friend Emma Mattila

ما درس سحر در ره میخانه نهادیم
محصول دعا در ره جانانه نهادیم

Abstract

Pulp and paper industry produce large amounts of waste annually. Pulp mill effluents are highly polluting and a subject of great environmental concern (Chaudhari et al., 2010). Due to the large volumes of waste generated, the high moisture content of the waste and the changing waste composition as a result of process conditions, sludge recovery methods are usually expensive and their environmental impact is still uncertain (Monte et al., 2008). All these, bring the great importance to find a new method to handle sludge. This experiment suggests an alternative method for treating sludge from pulp and paper industry. This experiment was conducted to investigate the tolerance of the plants when grown in such substrates, to determine any differences in growth performance when different substrates and clones were used, and to evaluate the fate of chemical compounds in the different substrates. Experiment implement in two parts. The first part of this study was a pot trial in greenhouse which was practiced as a pre-study to evaluate initially effects of sludge on plant growth. The second part was consisted of a field experiment carried out in the Iggesund pulp and paper mill, where the performance of willow plants with two different plant densities grown on two different substrates were examined. Plants did survive and established in the sludge in both parts. This successful survival indicates the possibility of application of this method.

Introduction

Pulp industry residues

Sludge is the semi-solid material left after industrial processes of the consequent treatments they have been conducted. Different types of sludge are produced in modern-day industry; among others, sludge from pulp and paper, mining and metal processing, food processing industry and communal sewage plants. Paper industry produces large amounts of sludge from a range of industrial processes using water created when pulp and paper is produced, and the further treatment and disposal of this sludge is a costly process since any environmental impact must be avoided.

Pulp and paper effluent is highly polluting and is a subject of great environmental concern (Chaudhari et al., 2010). Pulp mill effluents contain chemical compounds such as sulphates (SO_4), sodium (Na), chloride (Cl) and different heavy metals or of nutrients such as nitrogen (N), phosphorus (P), potassium (K) that can pose environmental problems when they are disposed of in adjacent fields. Such problems include increases of soil pH and of sodium absorption ratio (Patterson et al, 2008). Additionally, the used water from a pulp mill contains lignin and other organic compounds from the trees, which can result in high biological demand (BOD) and dissolved organic carbon (DOC) if disposed of in water bodies. As a result, living organisms in the water bodies are threatened due to lack of oxygen. Disposal of residues with relative high content of N and P can cause eutrophication in rivers and lakes. Pulp mill wastewater may also contain organochlorine compounds (such as chlorinated dioxins which are recognized as a persistent environmental pollutant) from chlorine bleaching of the pulp, which are toxic and have effects on human’s immune and hormonal system (WHO, 2011)

Different methods are being applied to manage residues from the paper industry. The most common disposal method is landfilling (Mahmood and Elliot, 2006). Shortage of space for landfills, public opposition to opening new landfill sites and increasingly stringent environmental regulations are some of the limitations with this method. With few exceptions, landfilling is taxed, according to EU directive. Landfilling of organic material is very restricted or forbidden. In some cases, opposition from the public due to odour problems has been also occurred. Incineration or combustion, which is second after landfilling in popularity, suffers from its own drawbacks. Rising supplemental fuel costs, high capital costs and air pollution concerns have historically limited the use of this method (Mahmood and Elliot, 2006). Other options such as pyrolysis, gasification, land spreading, composting and reuse as building material are being used, although research is still needed for optimization of the processes. Due to the large volumes of waste generated, the high moisture content of the waste and the changing waste composition as a result of process conditions, recovery methods are usually expensive and their environmental impact is still uncertain (Monte et al., 2008). Sludge management costs 60%of the total wastewater treatment plant operation costs (Mahmood and Elliot, 2006).

European paper industry generates about 11 million tonnes of waste annually (Monte et al, 2009). In the process of making paper different types of sludge are produced in a mill. Indicatively., at Iggesund pull mill, which is a commission company of the Holmen Group and Europe's third largest manufacturer of high quality virgin fiber paperboard and the place where the field trial of this thesis has been running, ”lime mud” is one type of sludge from the remainders of resting of the lime which is dewatered and mixed with bark and peat. Approximately 200-250 t/yr of “lime mud” is produced in Iggesund. “Green liquor” sludge is another type that comes from chemical recycling process and produced in large volumes (ca. 7500 t/yr are produced at Iggesund pulp mill; Personal communication). “Dredge sludge” which is a product of the coating process and around 8000 t/yr of this sludge is produced at Iggesund. Finally, “chemical sludge” is the type of sludge produced in high amounts at Iggesund pulp mill (ca. 18500 t/yr) and it is a product of the biological cleaning of the wastewater after treatment with $Al_2(SO_4)_3$. Chemical sludge is the sludge that was used in the experiments described in this thesis. The above indicate that the content of the produced sludge that needs to be treated is very diverse and an easy and cheap solution difficult to find. From the brief description above, the necessarily of finding a new method to handle high amount of produced sludge becomes more visible.

Short Rotation Forestry for energy and as a treatment system for residues

Short Rotation Forestry (SRF) is a broad term describing forest systems for biomass production (for energy purposes but also for others) using fast-growing tree species grown at denser spacing and elevated maintenance than in traditional forestry, typically harvested after 2 to 25 years depending on the desired end-product (Dimitriou et al., 2009). Species used for this purpose include plants of ash, alder, birch, eucalyptus, poplar and willow (Biomass Eenergy Center, 2011; Perttu, 1998; Walle et al., 2007).

Cultivation of willow short rotation coppice (SRC) was introduced in Sweden after the oil crisis in the 1970s, with the intention of replacing fossil fuels by new energy sources. Extensive research to identify fast-growing species that could be grown intensively for use in energy production suggested that willows grown in coppice systems were more suitable than other fast-growing species tested (Sirén et al., 1987). Nutrient utilization and stand management were seen to be more cost efficient for willow than for other woody species, and willow SRC proved to be a sustainable way of producing carbon dioxide-neutral fuels, since the released CO_2 in the atmosphere after burning of wood fuel had been once taken up by the plants from the air. In this thesis, I consider that SRC is a more specialized and intense practice of SRF dedicated mainly for energy purposes, whereas SRF is a more general term.

SRC is fully mechanized from planting to harvesting. Conventional fertilizer is applied every year except the year after planting. Willows are harvested every 3-4 years in winter time when the soil is frozen. The above ground biomass is chipped on site with special harvesters for SRC and then sent to be burned in power plants. The economic life span of SRC is about 25 years which means that SRC is harvested around 6-7 times. About 12 500 hectares of willow SRC are grown in Sweden in 2010 (Jordbruksverket, 2011). In these commercial plantations, the biomass production is approximately 6 to 10 t DM/ha yr. In total willow contributes about 1 % of Sweden's wood fuel requirements. Several incentives boosted the development of SRF in Sweden between the years 1991 to 1996: (1) The introduction in 1991 of a new agricultural policy in Sweden which, through deregulation, created lower grain prices and simultaneously introduced compensation for set-aside land as well as subsidies for willow plantations; (2) higher taxes on fossil fuels; and (3) the existence of a biofuel market in Sweden based on forest fuels. (Rosenqvist et al., 2000). However, since then the area cultivated with SRC has remained stable and SRC has not fulfilled the expectations of decision makers for rapid increases of SRC area (Jordbruksverket, 2006).

In recent years, nutrient-rich waste products – mainly urban wastewater, landfill leachate, industrial wastewaters (e.g. log-yard runoff), sewage sludge and wood-ash – have been successfully applied to willow SRC (Dimitriou and Aronsson, 2005). This practice has both environmental and economical benefits. Pollutants are removed from soil and water through plant uptake and plants act as a vegetation filter, and simultaneously biomass for energy is produced. This method of treating waste products is more cost effective than conventional treatments, and the nutrients contained in the waste products serve as low-cost fertilizers to increase biomass production (Dimitriou et al., 2009), but to be successful minimal environmental hazards and high biomass production need to be achieved.

General purpose, description and objectives of this thesis

This thesis investigates the use of SRC in treating sludge from paper industry. SRC plantations require large amounts of water and sludge needs to be dried to reduce its volume; therefore, if SRC plants are growing in this sludge, it might offer an alternative method to reduce the sludge volume. In recent years, nutrient-rich waste products – mainly urban wastewater, landfill leachate, industrial wastewaters (e.g. log-yard runoff), sewage sludge and wood-ash – have been successfully applied to the willow (Dimitriou and Aronsson, 2005). Furthermore, willow clones having a high ability to accumulate heavy metals without suffering any growth constraints are in the focus of research interests (Zacchini et al., 2009). Therefore, it would be interesting to investigate the tolerance and growth performance of the plants when grown or cultivated in pulp industry sludge, which contains a range of harmful contaminants.

The first part of this study was a pot trial in greenhouse which was practiced as a pre-study to evaluate initially effects of sludge on plant growth. Plants of three willow clones, birch and alder were planted in three different substrates (pure sludge, sludge/sawdust mixture and fertile plant soil as control), and different comparisons between clone/substrates to evaluate differences in growth patterns were made. The second part was consisted of a field experiment carried out in the Iggesund pulp and paper mill, where the performance of willow plants with two different plant densities grown on two different substrates were examined. The objectives of these experiments were to test the tolerance of the plants when grown in such substrates, to determine any differences in growth performance when different substrates and clones were used, and to evaluate the fate of chemical compounds in the different substrates.

Material and Methods

Laboratory experiment (pot trial)

Establishment

A greenhouse pot trial was carried out in Uppsala, Ultuna (59 °3 ' N, 17 °4 ' E). The trial started on March 11 2010 as a pre-study to test if a sludge application will negatively affect plant vitality and growth of three willow clones, birch and alder. Each plant of the willow clones and the species was planted in three different substrates: pure sludge, sludge/sawdust mixture and fertile plant soil as control. Five replicates for each treatment were planted.

75 different pots were washed with tap water and afterwards set with a thin layer of geo textile fabric at the bottom of each, in order to avoid soil losses. Pots had a volume of 5 liters with six holes at the bottom and geo textile was cut in a way to cover the entire bottom of the pots. In

order to have similar conditions for the experiment, equal-sized plants were chosen for planting. The cuttings were divided into three groups based on their diameter and 15 of each species/clones of middle diameter were chosen to be planted in the pots.

The average wet weight and length of each species/clones was measured (Table 1).

Table 1: The average wet weight and length of cuttings/seedlings of each species/clones (n=15)

Species/clones	Average wet weight (gr)	Average length (cm)
Alder (*Alnus glutinosa*)	31.5	69.1 (without roots)
Birch (*Betula pubescens*)	31.0	97.9 (without roots)
Salix (Karin)	16.0	20.8
Salix (Gudrun)	15.8	20.8
Salix (Klara)	19.6	20.9

The sludge/sawdust mixture substrate was made after mixing equal volumes of sludge and sawdust (every time one bucket of each) in a mixer machine and blend for 30 minutes.

Figure 1: Pots preparation in the greenhouse. Photo: Pär Aronsson

The plants were placed randomly in the greenhouse to avoid systematic mistakes due to placement of the pots (Table 2).

Table 2: Experimental design of the pot trial, where for "plant", 1, 2, 3, 4, 5 is plants of Gudrun, Karin, Klara, alder and birch, respectively, and for "Substrate" 1, 2, 3 is sludge, sludge mixed with sawdust and control, respectively

	block 1		**block 2**		**block 3**		**block 4**		**block 5**	
Position	***Plant***	***Substrate***	***Plant***	***Substrate***	***Plant***	***Substrate***	***Plant***	***Substrate***	***Plant***	***Substrate***
1	4	1	3	2	5	2	1	1	5	3
2	5	2	5	1	2	2	2	1	1	1
3	3	3	1	2	2	1	3	2	3	1
4	1	2	1	1	1	2	3	3	4	3
5	5	1	2	2	1	1	1	3	4	2
6	2	3	4	1	4	1	3	1	3	3
7	4	2	4	2	3	3	5	1	5	1
8	5	3	2	1	3	2	4	1	4	1
9	1	1	2	3	5	3	2	2	3	2
10	1	3	5	3	4	3	1	2	1	2
11	2	1	4	3	3	1	4	3	2	1
12	3	2	1	3	4	2	5	2	2	2
13	4	3	3	1	5	1	5	3	1	3
14	2	2	5	2	1	3	2	3	5	2
15	3	1	3	3	2	3	4	2	2	3

Figure 2: Pots location in the green house. Photo: Fargam Neinavaie

Three big pots were filled with every substrate and 10 plants of each species/clones were planted and kept as a back-up. The back-up pots received the same treatment during the experiment.

To estimate the dry matter of each substance, the content of one pot of each substrate was weighted and put in the oven at 70 °C. Dry weight was measured after one week. The percentage of dry matter of each substrate is presented in Table 3.

Table 3: Dry matter percentage of each substrate used in the pot trial

Substrate	Wet weight (g)	Dry weight (g)	Dry matter (%)
Sludge	5447.0	1123.2	20.6
Mixture: sludge and saw dust	5377.7	1390.2	25.8
Control	2857.9	1463.9	51.2

Treatments

Humidity in the greenhouse was adjusted by a fogger to avoid dry conditions. Pots received 18 hours of light with the help of lamps automatically set to provide with light for this duration. Pots received different water amounts during the greenhouse experiment. During the first month of the experiment pots were weighed every day to determine if water was needed. Pots with weight less than 3.5 kg were irrigated. Except for the two first watering occasions when plants were irrigated with tap water, irrigation was conducted using water which contained 50 mg N/l. Pots containing sludge, mixed substrate and control soil received 89.3, 109 and 137.3 ml water in each irrigation time respectively. Pots were not weighed during the second month of the experiment but were checked daily to prevent water deficiency: 376, 383.7 and 444.7 ml were the average amounts of water in each irrigation occasion for pots containing sludge, mixed substrate and control, respectively.

Figure 3: Daily check of plants to prevent water deficiency. Photo: Pär Aronsson

One of the plants from the Klara clone which was planted in the normal plant soil died in the beginning of the second month of the experiment and was replaced by a back-up plant. At the end of April some flies were seen on the leaves of plants mostly Alder and Birch which were removed by hand.

Measurements

The height of each plant was measured each week during the two months of the experiment except for the first two weeks, due to slow initial growth. Length of the plants of Alder and Birch was measured from the lowest part of the stem (soil surface) to the end of the leader. In the cases when the leader of the plant was dead, length of the longest shoot of the plant from the soil surface was measured while keeping the meter all the way along the stem. (Fig. 4)

Shoot length of Alder and Birch plants and the longest shoot and leaf length of willow plants were measured every week. In the case of having equivalent shoots of similar height in one plant, all the leaves from both shoots were measured and the average was taken. From each shoot the two longest leaves were measured and the average was taken.

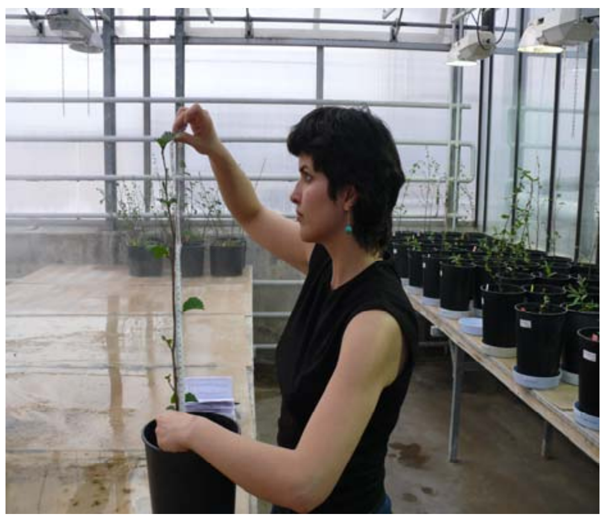

Figure 4: Plant measurement. Photo: Fargam Neinavaie

The experiment was finished in May 7 2010 and the plants were harvested. Each plant was separated into leaves, shoots and stem. For the plants of the clone Klara, roots were separated as well. Fresh weight of each plant parts were weighted separately. Plant parts were put in paper bags and placed in the oven in 70℃ for three weeks. The dry weights of the shoots, stem, newly branches, leaf and roots were measured after drying.

Root separation of Klara plants was done in the way that, all pots were put in tap water in order to be separated easier from the soil. Roots were separated after cuttings were sieved and washed with water. Fresh and dry weights of the roots were measured.

Field trial

Establishment

In an adjacent to Iggesund pulp mill area (61° 38' N., 17° 4' E.), a sludge bed was established in the beginning of June 2010. The sludge bed was 1 meter deep. The field was located closed to a forest area, but the location of the sludge bed was arranged at a distance from the forest to avoid shadowing. The field size was approximately 900 m^2 enabling a design according to:

Sludge Clone: Gudrun density (pl/m2): 5	Sludge Tora 5 *	Sludge Gudrun 10
Sludge Tora 10	Sludge Klara 5 *	Sludge Klara 10
Sludge/sawdust Klara 5	Sludge/sawdust Tora 5 *	Sludge/sawdust Gudrun 5
Sludge/sawdust Tora 10	Sludge/sawdust Gudrun 10	Sludge/sawdust Klara 10

Corridor 3 m wide

Figure 5: Experimental design of the field experiment. Each plot was 6×8 m^2, stars indicate the plots which TDR-system and where suction cups were placed

Two planting densities and two different substrates were tested, i.e. pure sludge and a sludge/saw dust mixture. The mixture was consisting of two volumes of sawdust and one volume of sludge.

Figure 6: The field experiment during planting with the different substrates at Iggesund. Photo: Fargam Neinavaie

The day before planting, four holes in different parts of the field were dug in order to establish a TDR-system and suction cups (SK20). The place of holes is marked in Figure 1. In the Tora part with the density of 5 pl/m^2, one hole was dug (hole number one and four) and in the division of Klara with the density of 5 pl/m^2, two holes were made (holes number two and three). Holes were dug manually and were place towards the center and away from the borders of every division. TDR probes were put in the depth of 15, 45 and 75 cm of the surface in holes number one, two and four. Hole number three was used for calibration. Two TDR probes were put in 15 cm depth and one in the depth of 45 cm in hole number three. Suction cups were put in the depths of 15, 45 and 75 cm in the holes one, two and four (Fig. 7).

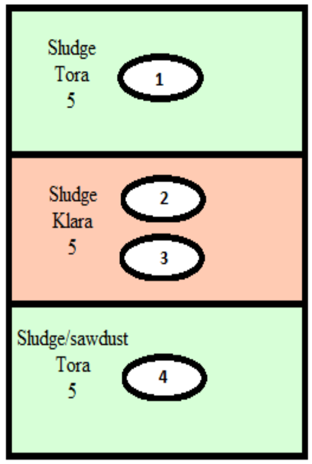

Figure 7: Location of the holes in the different parts of the field.

SK20 is a simple ceramic cup with removable shaft. It is able to extract continuously and discontinuously and is suitable for determination of nitrate and common organic and inorganic substances. Nine ceramic cups were established in the field. Each of them was backed with a glass bottle with a plastic head. Bottle pressure was adjusted on 500 mbar with the help of a mechanical pump and kept with the help from two clips. Samples were taken every two weeks and the liquid was kept in the fridge to send to the laboratory afterwards. TDR-System enabled to study how the soil bed drying up. Data from the TDR-system were collected weekly.

Plants arrived on June 7, were soaked in the water for 24 hours and were planted on June 8 and 9. The corridors of the sludge bed were also planted with cuttings of clone Tora that arrived on 14 June and soaked for 24 hours in the water, and were planted the day after. Cuttings were 1 m long and were planted manually by pushing them all the way down; about 30 cm of each cutting was left out of the soil surface. Due to the high number of delivered cuttings, corridors in the end became much broader than 3 meter in each side.

Figure 8: Willow cuttings soaked in water before planting. Photo: Fargam Neinavaie

Treatments

Plants were fertilized with 300 kg N/ha immediately after planting. Fertilizer was poured around the stems, in order to have proper access to plants. The sludge/sawdust mixture part received irrigation with tap water the first day after planting. Plants were checked every day to estimate if they had vigorous growth. In the first two months after planting, the field was manually irrigated once per week. From the beginning of August, irrigation was stopped and plants were receiving water only from precipitation.

Figure 9: Fertilizer around the stems. Photo: Fargam Neinavaie

In mid August, some larvae were seen on the leaves of the plants in the sludge/sawdust mixture substrate, and were manually removed.

Measurements

The length of the longest shoots of each cutting in a net plot 4m×4m in the center of each plot was measured at the end of September to estimate above-ground biomass. The number of all plants and living plants in each net plot and also the number of living shoots on each plant in the net plot were also counted.

For each treatment, 20 shoots representing all ranges of lengths were cut and weighed in middle November. The dry weights of all shoots were determined after weighing them one week after being in the oven in 70°C.

Results

Pot trial

Growth patterns of plants were differed between substrates. Shoot length of Birch plants in control and sludge was similar and it was bigger than shoot length of birch plants in sludge/sawdust substrate (Fig. 10). Alder plants had similar shoot length in all substrates. Shoot length in willow plants in sludge was significantly less than shoot length of willow plants in control. The average shoot length of the plants in the sludge/sawdust was in between that of the other two substrates. A sharp increase in shoot length of all the plants in the beginning of April was observed. This sharp increase was less evident in plants in sludge/sawdust mixture and sludge respectively. Clone differences in shoot length were not evident in sludge. Klara grew better in control and Karin had lower shoot length in the sludge/sawdust mixture.

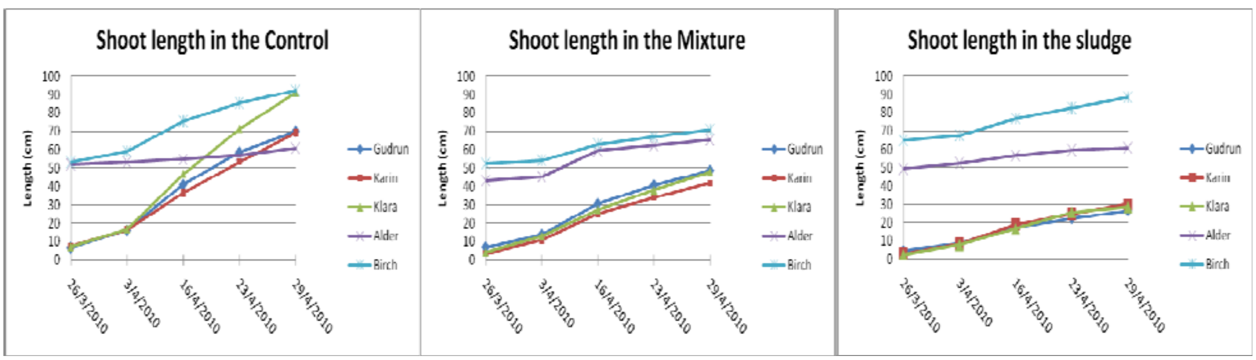

Figure 10: Averages of shoot length in the different substrates (n= 5).

Leaf weights of the willow plants in control were approximately five times higher than in sludge and approximately 2.5 times than sludge/sawdust mixture (Fig. 11). For Klara, differences between the leaf weights in the different treatments were the lowest compare to other clones.

Leaf weights of alder plants in the sludge/sawdust mixture were higher than in sludge and control (Fig. 11). Fore birch, leaf weights were similar in sludge/sawdust mixture and sludge but lower than control.

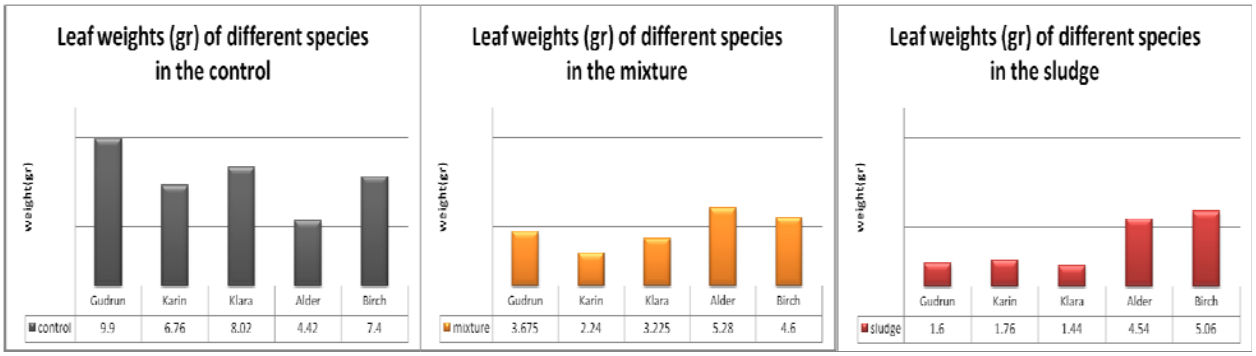

Figure 11: Averages of leaf weights of the plants in the different substrates (n=5)

Leaf lengths of willow plants in control were higher than those in other substrates during the running time of experiment, and there were slightly higher in the sludge/sawdust mixture than sludge.

Gudrun plants had longest leaves in the first 20 days of experiment in all the substrates (Fig. 12). In control and sludge/sawdust mixture it continued in the same manner but in sludge substrate a significant decrease was evident after April 16, and Gudrun leaves become the shortest in comparison with the other willow plants in sludge. In all substrates, Karin and Klara plants had similar leaf length sizes during the experiment.

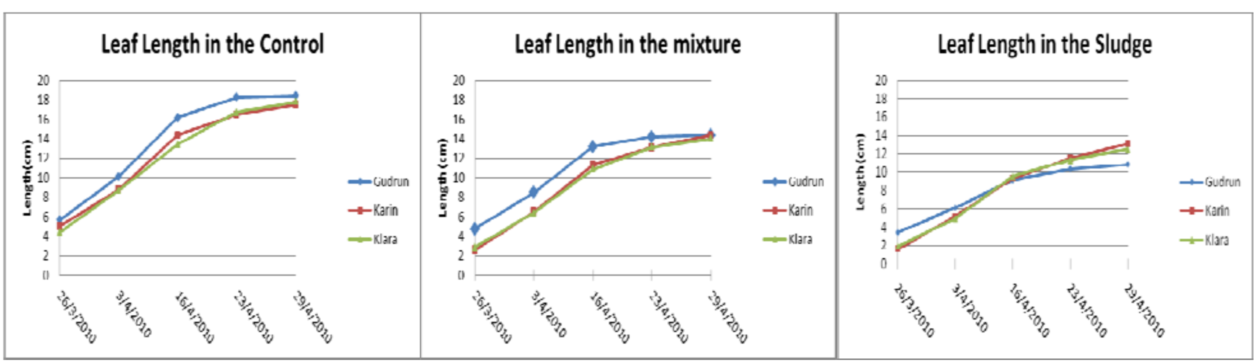

Figure 12: Averages of leaf length in the different substrates (n=2)

For willow clones significant differences between control and sludge/sawdust mixture substrates were observed concerning the shoot dry weight (Fig. 13). For instance, shoot dry of Gudrun plants weights were 3.8 times higher in control than in sludge/sawdust mixture. This number was

16 times higher than the respective for plants in sludge. Shoot dry weights for Klara plants shoot dry weights were 5.2 times higher in control than sludge/sawdust mixture and 25 times for those in sludge.

For alder, no differences for different substrates were observed.

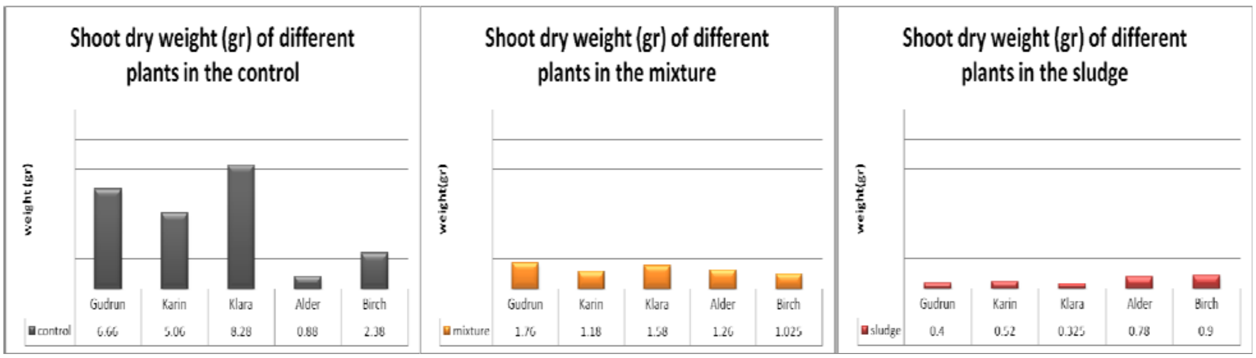

Figure 13: Averages of shoot dry weight in different substrates (n= 5)

Klara plants had higher cuttings and root weight average in control compared to sludge/sawdust mixture and sludge respectively (Fig. 14).

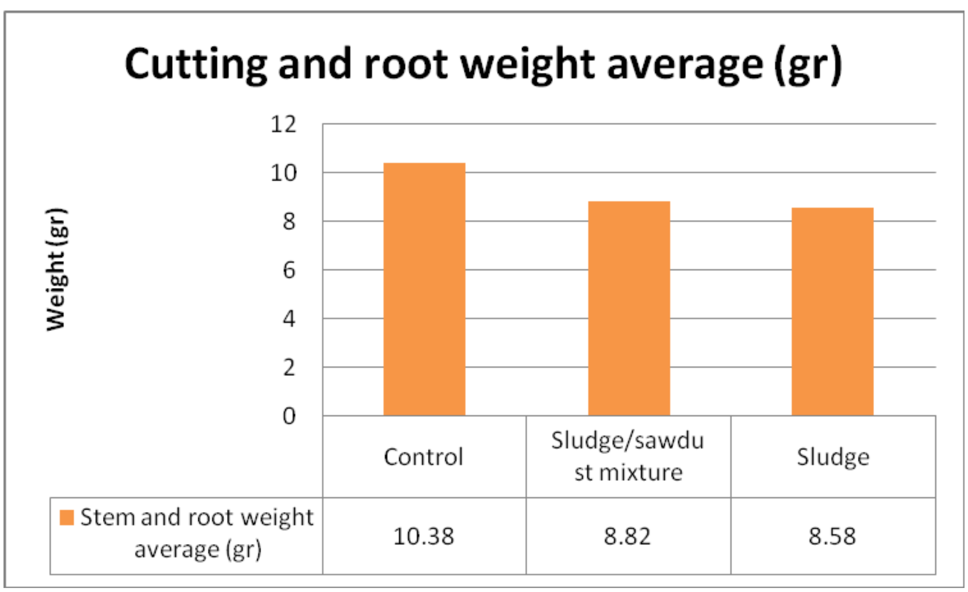

Figure 14: Cutting and root weight average of Klara plants in different substrates (g)

Field experiment

80% of plants in the sludge and 100% of plants in the sludge/sawdust mixture survived after the end of the experiment (Fig. 15). Growth was much higher in the sludge/sawdust mixture compared with plants grown in pure sludge (approximate ratio1:2, Fig. 7).

Klara plants had the highest above-ground biomass in the sludge/sawdust mixture by the three willow clones (followed closely by Gudrun). Gudrun had the lowest in the sludge substrate (Tora and Klara almost equally high).

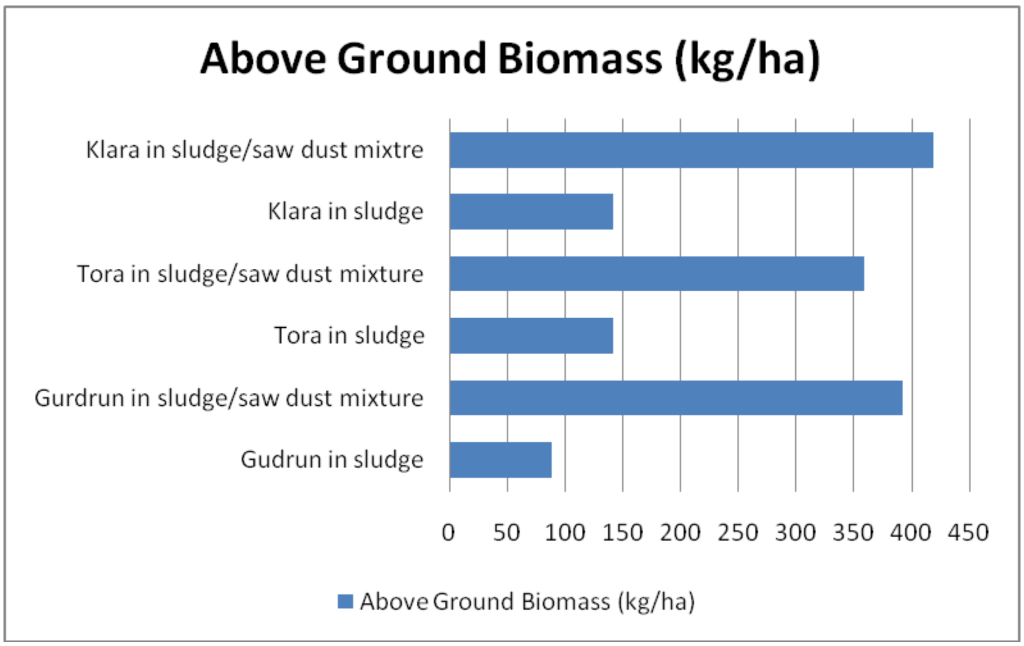

Figure 15: Above ground biomass of different clone of willow plants in different substrates (kg DW/ha)

Water content in sludge had similar pattern with absolute highest values in top soil in both clones (Fig. 16). The result from TDR-System was unexpected and very difficult to interpret. Data obtained from TDR-System were not used in the further analysis.

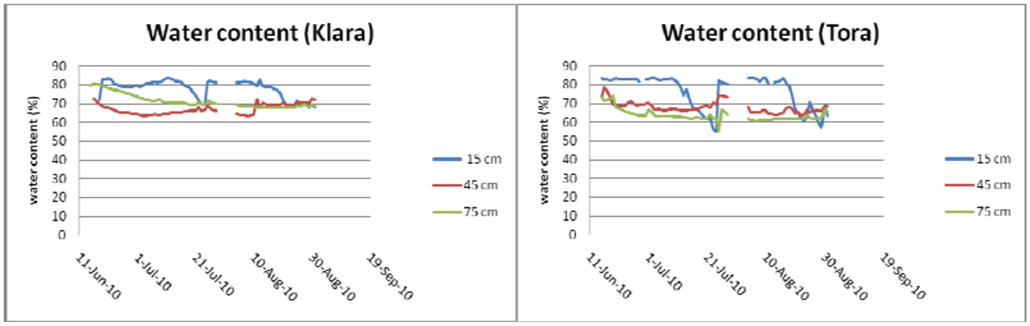

Figure 16 (The left graph): Water content (%) in sludge for Klara and Tora plants in different soil depths.

Measurements of dry matter of the sludge in Klara were taken at 2 occasions (June 15 and July 9) in 15 cm depth to estimate water losses. The respective values of sludge dry matter were 51.8% ± 0.12% in June 15 (n=3) and 53.3% ± 0.45% (n=4) in July 9. Therefore a slight reduction in the water in the sludge was observed during this period.

Concentrations of NH_4-N, Cl, Na and Fe in the water from the suction cups placed in the sludge substrate were higher than the respective in sludge/sawdust mixture substrate. Concentrations of Mg and Ca in the water from the suction cups placed in the sludge/sawdust mixture were higher than the respective in the sludge (Fig. 17). Concentration of NO_3-N in both substrates was zero throughout the experimental period.

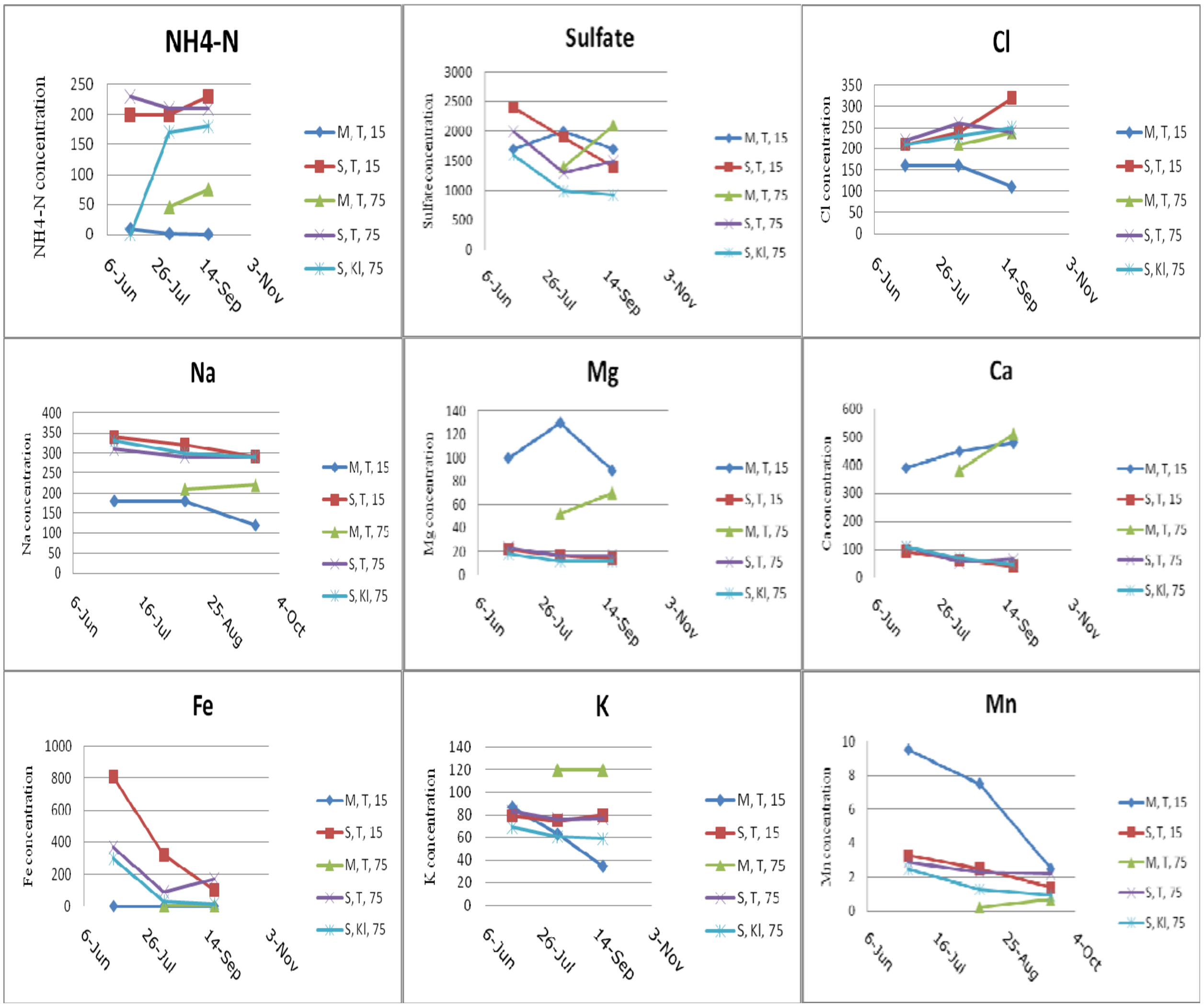

Figure 17: Concentrations of different chemicals in the water from suction cups for the different substrates (M=sludge/sawdust mixture, S=Sludge), and clones (T=Tora, Kl=Klara), at different depths (15, 75 cm).

Discussion

This thesis suggests an alternative method for treating sludge from pulp and paper industry. As it is evident in the experiments, plants did survive and established in the sludge (both in pot trial and field trials). This successful survival indicates the possibility of application of this method. Although there were differences in growth performance of the plants in different substrates used in the experiment, in the sense that plants performed weaker and had lower biomass production in sludge and sludge/sawdust mixture than in control, the survival of plants was high and growth was satisfactory especially in the sludge/sawdust mixture. Sludge is not the ideal environment for tree plants to grow, but can be a potential substrate to establish SRC especially if mixtures with other substrates will be considered.

Birch and alder plants in the pot trial were slightly affected when grown in sludge. This might be explained by the fact that they were planted as seedlings with already established roots. Species that establish fast and successful in this difficult environment with an anaerobic conditions and rich in pollutants need to be selected. Willows have been reported to be tolerant to anoxic conditions (Jackson and Attwood, 1996) and to difficult environment with high amounts of hazardous compounds (Dimitriou and Arronson, 2005), and therefore might be suitable to be used in such systems. The possibilities of willow plants to survive the second season when their roots are established seem to be higher, as it was the case for birch and alder, and thus the success more even more likely.

At the end of the experiments (pot trial and field trial), shrinkage (reduction in the volume) in the sludge and sludge/sawdust mixture was observed with the depth of the soil reduced almost to a half. This observation indicates that SRF can help drying and reducing the volume of sludge. Different processes may have caused that shrinkage in sludge and sludge/sawdust substrate, such as dewatering of sludge and decomposing of the sawdust. However, due to the limited period of the experiment the most dominating process was probably due to dewatering of sludge, and the plants grown in both substrates have a direct impact on those processes. Maximum dewatering is directly connected to maximum evapotranspiration of plants, which is achieved if the plants are not stressed and produce high biomass. Therefore to identify plant stress in an early stage is important. In the pot trial experiment, all the willow plants in sludge and sludge/sawdust mixture had shorter leaf length than willow plants in control. It will make sense if we consider that leaf length is an indicator for stress in willow plants (Dimitriou et al, 2006).

Obvious clone differences in growth in the field were not observed (Gudrun grew better than Tora and Klara) and Tora seemed to grow less than Klara in the sludge/sawdust). There might be clones to better tolerate these substrates. More long-term experiments are needed to evaluate this.

In certain cases, other factors might affect growth, since particularly Gudrun plants were grazed by wild animals. If such systems are to be established in areas where game is present, then fencing to avoid plant losses is recommended.

The chemical analyses of the water collected in suction cups show differences between the different substrates which can partly explain the differences in growth: NH_4-N was higher in the water from sludge which is probably due to the lack of oxygen which does not allowing nitrification to occur. This can cause problems both for N uptake of the plants and increased NH_4-N leaching to the groundwater which can be harmful. In the sludge/sawdust mixture, NH_4-N is lower than its amounts in sludge substrate. It is probably due to better aeration and higher immobilisation (more carbon due to sawdust), which is a sign that mixture in this case is better from the contamination of groundwater point of view. Differences in Mg and Ca in water in the suction cups from the different substrates were observed. These results are difficult to interpret on how they can affect plant growth or contamination to groundwater since both elements are not harmful to plants or water.

The treatment system of pulp industry sludge described in this thesis is a new idea and to my knowledge has not tested before; therefore any comparisons and definite conclusions are difficult to make. More research should be done in order to receive a broader view on the process and the hazards involved. It would be interesting for instance to test other substrates than sludge/sawdust mixture substrates, i.e. sludge/peat or sludge/compost mixture. Also, different percentage of sludge applied in the mixture could be tested i.e. 25% or 75%, to find optimal mixture percentages for the different substrates.

Survival of the plants over the winter remains to be evaluated. Temperature in the sludge/sawdust mixtures are higher than in common soil during winter, due to decomposition of organic matter, and as a result plants might start grow earlier than expected causing high mortality due to frost damages in spring. Testing clones with different growth patterns might be a solution to solve this potential problem.

More studies should be done to evaluate the further use of the dried sludge produced by this method. Sludge can be pumped every year in the field and its volume reduces and dries up by the help of willow plants. It needs to be investigated if the cumulative sludge can be burnt with willow plants after harvest time in a sustainable and safe way. It was also observed that the sludge used in the experiment did not reabsorb water once lost after drying. Therefore, it may be possible to be used for construction purposes.

The presented method is comparatively very cheap and economically profitable compared to the current methods used for treating this type of sludge. Huge amounts of money are spent annually on drying of the sludge. The examined system is designed for willow plants will do the same thing with minimal costs (establishment and management of the willow field), and also producing a product (biomass and dried sludge) that could be potentially used as a fuel product.

Figure 10: Willow plants in the sludge/sawdust mixture at the end of experiment. Photo: Jörg Brucher

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References

Chaudhari, P., Majumdar, B., Choudhary, R.; Yadav, D.; Chand, S., 2010. Treatment of paper and pulp mill effluent by coagulation. Environmental Technology, 31(4): 357 – 363.

Dimitriou, I., Aronsson, P., 2005. Willow for energy and phytoremediantion in Sweden. International journal of forestry and forest industries 56: 47-50.

Dimitriou, I., Aronsson, P., Martin, W., 2006. Stress tolerance of five willow clones after irrigation with different amounts of landfill leachate. Bioresource Technology 97: 150-157.

Dimitriou, I., Baum, C., Baum, S., Busch, G., Schulz, U., Köhn, J., Lamersdorf, N., Leinweber, P., Aronsson, P., Weih, P., Berndes, G., Bolte, A., 2009. The impact of Short Rotation Coppice (SRC) cultivation on the environment. Agriculture and Forestry Research 3 (59): 159-162.

Jackson MB, Attwood PA., 1996. Roots of willow (Salix viminalis L) show marked tolerance to oxygen shortage in flooded soils and in solution culture. Plant and Soil 1996; 187: 37-45.

Jordbruksverket. 2006. Bioenergi – ny energi för jordbruket (In Swedish). Rapport 2006:1.

Mahmood, T., Elliot, A., 2006. A review of secondary sludge reduction technologies for the pulp and paper industry. Water Research 40: 2093-2112.

Monte, M.C., Fuente, E., Blanco, A., Negro, C., 2008. Waste management from pulp and paper production in the European Union. Waste Management 29: 293-308.

Patterson, S.J., Chanasylk, D.S., Naeth, M.A., Mapfumo, E., 2008. Effeluent on the nutrient concentrations and growth of reed canarygrass (Phalaris arundinacea L.) and hybrid poplar (Populus deltoids P. petrowskyana L.). Canadian Journal of Soil Science 89(2): 223-234 .

Perttu, L.K.,1998. Environmental justification for short-rotation forestry in Sweden. Biomass and Bioenergy15: 1-6

Rosenqvist, H.; Roos, A.; Ling, E.; Hektor, B., 2000. Biomass and Bioenergy 18: 137-145.

Sirén, G., Sennerby-Forsse, L., Ledin, S., 1987. Energy plantations – short-rotation forestry in Sweden. Regenerable Energy: 119–143.

Walle, I.V., Camp, N.V., Casteele, L.V.d., Verheyen, K., Lemeur, R., 2007. Short-rotation forestry of birch, maple, poplar and willow in Flanders (Belgium) I—Biomass production after 4 years of tree growth. Biomass and Bioenergy 31: 267-275

Zacchini, M., Pietrini, F., Scarascia Mugnozza, G., Iori, V., Pietrosanti, L., Massacci, A., 2009. Metal Tolerance, Accumulation and Translocation in Poplar and Willow Clones Treated with Cadmium in Hydroponics. Water, Air and Soil Pollution 197 (1-4): 23-34.

http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,18093&_dad=portal&_schema=PORTAL. Accessed on 26/1/2011

http://statistik.sjv.se/Database/Jordbruksverket/Markanvandning/Markanvandning.asp. Accessed on 3/2/2011

http://www.rfu.org/cacw/pollutionSludge2.htm. Accessed on 26/1/2011

http://www.who.int/mediacentre/factsheets/fs225/en/. Accessed on 26/1/2011