

Wastewater phytoremediation treatment systems in Sweden using short rotation willow coppice

Ioannis Dimitriou and Pär Aronsson

Swedish University of Agricultural Sciences, Department of Short Rotation Forestry,
PO Box 7016, SE-750 07 Uppsala, Sweden

1. BACKGROUND

Short rotation willow coppice (SRWC) has been grown in Sweden for bioenergy purposes already from the 1970's [1]. Soon SRWC was also used as a natural-like system for treatment of municipal wastewater, landfill leachate (water coming from percolation of landfills), industrial wastewaters and municipal sludge [2], [3]. The basic idea behind the treatment of different wastes on SRWC is to reduce the content of pollutants and/or nutrients in waters and soils by plant uptake and/or facilitate microbial transformation. Willow as a crop for phytoremediation of different wastes offers advantages as high biomass yields, high evapotranspiration rate, good coppice ability and reported ability to take up substantial amounts of heavy metals [4]. Furthermore, by further using willow as fuel, CO₂ emissions are reduced and so are greenhouse gases. In this paper, an overview and examples of the use of SRWC in natural-like phytoremediation systems for treating different wastes in Sweden are described.

2. MUNICIPAL WASTEWATER TREATMENT

Municipal wastewater is in most cases a well-balanced nutrient solution that can be used for fertilisation of most plants, though for sanitary reasons, non-food non-fodder crops like willow are preferable [5]. In that case, wastewater is regarded more like a resource rather than a problem. Application of wastewater as a fertiliser on green plants is widely performed worldwide.

In Sweden, the need to improve the nitrogen treatment efficiency of wastewater treatment plants (WWTP) during the 1990's has led to the establishment of large willow plantations equipped with drip or sprinkler irrigation systems. Assuming a biomass production of 10 tons per hectare (dry matter) and that the N-concentration in the willow shoots is 0.5%, then 50 kg N ha⁻¹ yr⁻¹ is being removed from the field at harvest. Research however has shown that the N retention in SRWC can be up to 200 kg N ha⁻¹ yr⁻¹, due to denitrification and long term binding of N into the soil. Furthermore, nitrogen leaching losses, which are of great environmental concern, are negligible after the first year of establishment [6]. An example of a system for treating municipal wastewater in a willow plantation in a cold-temperate climate as Sweden's and some special features is described below.

In Enköping, a town with around 20000 inhabitants in central Sweden, a novel system has been constructed. There, the very N-rich wastewater coming from dewatering of sludge, which until previously was re-treated in the plant, is now distributed to a neighbouring 76-ha willow plantation during the summer period. This water contains around 800 mg N l⁻¹ and

corresponds to 25% of the total N treated in the wastewater treatment plant. Today this water is pumped into lined storage ponds during wintertime and used for irrigation of willows during summer. The system was designed so as conventionally treated wastewater can be added in order to promote plant growth. Irrigation is conducted for around 120 days per year and the total amounts of N and P that is treated by the system is 30 t N and 1 t P per year, with irrigation of 200,000 m³ wastewater, 30,000 m³ of which is water coming from dewatering of sludge after sedimentation and centrifuge.

3. LANDFILL LEACHATE

Conventional treatment of landfill leachate generally involves co-treatment with municipal wastewater in WWTP. In Sweden, sewage sludge from WWTP, which also receive landfill leachate, has been banned in agriculture since 1994. Therefore, landfill operators in Sweden are increasingly interested in nature-like treatment systems, which include aeration followed by irrigation of energy crops (mainly SRWC) on either restored parts of the landfills or on adjacent arable fields. A willow plantation, if established on a restored cap of the landfill, decreases the leachate formation due to high evapotranspiration [7]. In fact, by recycling this water into a willow plantation, a close to zero net discharge of landfill leachate can be achieved, even in the climate of northern Europe. Simultaneously, hazardous compounds in the leachate (i.e., ammonium and a range of persistent and potentially toxic organic substances) are taken up by the willows or retained in the soil-plant system [8]. Willow also tolerates low oxygen levels in the root zone enabling high irrigation rates, which is in great favour of the landfill operator [9]. In most cases 3-4 mm per day leachate is applied to the plantation when Cl concentrations do not exceed 1200 mg/l leachate. The usually high ionic strength of landfill leachate, which is due to high concentration of sodium chloride (NaCl), constitute a special problem, since NaCl is neither transformed or retained in the soil, nor taken up by common plants to any significant extent. For Swedish conditions though, due to the dilution with rainwater, saline problems seem to be of minimal importance.

There are currently around 30 systems in Sweden treating landfill leachate by irrigation of SRWC. The fields are equipped with sprinkler or drip irrigation systems and the irrigation is conducted during the vegetation period. The main advantage is the low establishment costs compared with conventional engineered systems. The differences in leachate composition from various landfills, in soil and climatic conditions as well as in willow clone material that is used is only some of the parameters that affect system's performance. The result in some cases is fields with bad growth with different reasons as source in each case. To reduce these risks, more knowledge is needed both in terms of the salt and ammonium tolerance of different willow varieties, and in terms of management practice to compensate for site- and climate specific conditions.

4. INDUSTRIAL WASTEWATER

Large quantities of wastewater are produced in Sweden after wet storage (sprinkling) of wood in sawmills and pulp mills. The sprinkling of timber and pulpwood with tap water during summer offers protection from damage by insects and fungi and from cracks due to drying out of the wood. Even if there is no sprinkling, wastewater is still produced in large quantities after rainfall or snow melting, resulting in pollution to neighbouring water basins or groundwater if the water is not collected and treated in ponds. Until now, in most cases this

Short Rotation Crops for Bioenergy: New Zealand, 2003

water has been disposed to rivers or lakes. The content of this wastewater varies and is dependent on the wood material stored and the log-yard storage conditions [10]. The main environmental problems are caused by phenolic acids, TOC (total organic carbon), heavy metal concentrations in the water, increased P concentrations and the large water volumes themselves: a middle-sized sawmill consumes 100,000 m³ water annually for watering the stored wood, resulting in large water amounts that need to be treated.

In Heby sawmill, central Sweden, around 60,000 m³ per year of log yard run-off are recycled to a 1-ha SRWC field and an approximately 0.5-ha field with grass naturally grown. That corresponds to an irrigation rate to SRWC of about 4,000-4,500 mm per year (33-38 mm per day for 120 irrigation days), a very high irrigation rate comparing with the respective amounts for municipal wastewater and landfill leachate. This is due to the relatively low hazards posed by the water quality, since log yard run-off is a type of water containing large amounts of organic compounds but not excess concentrations of hazardous components that can be harmful to the plants. Experiments so far have shown that after application of this water to willows grown on lysimeters, the result is a decrease of the TOC and of phenolic compounds (though phenolic compounds do not seem to be a potential problem due to low initial concentrations) in the groundwater. Furthermore, the growth of SRWC in field does not seem to be negatively affected.

5. SUMMARY

A comparison of the wastewaters treated after application on SRWC is given below adjusted to the willow need for macro-nutrients. The actual concentrations of the macronutrients are also given.

Table. Comparison of the relative concentrations of the three macronutrients nitrogen (N), phosphorus (P) and potassium (K) in the different wastewaters in relation to N = 100 and actual concentrations in mg l⁻¹. The data for the concentrations in the wastewaters are from different locations in Sweden and are average values

Element	Optimum composition for SRWC	Wastewater from dewatering of sludge		Landfill leachate		Log yard run-off	
		%	Conc. (mg l ⁻¹)	%	Conc. (mg l ⁻¹)	%	Conc. (mg l ⁻¹)
N	100	100	680	100	80	100	1
P	14	1.5	11	1.5	1	125	1.2
K	72	7	48	110	88	500	5

From the table it is clear that the compositions of the different wastewaters highly differ and that none of the wastewaters are ideal for willow according to the optimum composition. Furthermore, the variations in the concentrations of different, e.g., landfill leachates are also high and vary substantially due to landfill age, geographic area etc. Therefore, applying a certain wastewater to SRWC is site and case specific and an integrated approach taking into account the effects on soil, plants and the atmosphere (and their interactions) can be the only solution to avoid environmental hazards.

6. REFERENCES

- [1] Sirén, G.; Sennerby-Forsse, L.; Ledin, S. 1987. Energy Plantations - Short Rotation Forestry in Sweden. In: *Biomass*, eds. D.O. Hall & R.P. Overend, John Wiley and Sons Ltd.: England. Pp. 119-143.
- [2] Perttu, K.L. 1993. Biomass production and nutrient removal from municipal wastes using willow vegetation filters. *Journal of Sustainable Forestry* 1(3): 57-70.
- [3] Aronsson, P.; Perttu, K. (eds.), 1994. Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Dept. of Ecology and Environmental Research, *Swed. Univ. Agric. Sci.*: Uppsala, Sweden. Report 50, 230 pp.
- [4] Perttu, K.L.; Kowalik, P.J. 1997. Salix vegetation filters for purification of waters and soils. *Biomass and Bioenergy*, 12(2): 9-19.
- [5] Ericsson, T. 1981. Growth and nutrition of three Salix clones in low conductivity solution. *Physiologia Plantarum*, 52: 239-244.
- [6] Aronsson, P. 2000. Nitrogen Retention in Vegetation Filters of Short-Rotation Willow Coppice. Doctoral thesis. *Silvestria 161*. Swed. Univ. Agric. Sci., Uppsala, Sweden.
- [7] Ettala, M.O. 1988. Short rotation tree plantations at sanitary landfills. *Waste Management and Research*, 6(3): 291-302.
- [8] Aronsson, P.; Perttu, K. 2001. Willow Vegetation Filters for Wastewater Treatment and Soil Remediation Combined with Biomass Production. *The Forestry Chronicle*, 77(2): 293-299.
- [9] Jackson, M.B.; Attwood, P.A. 1996. Roots of willow (*Salix viminalis* L.) show marked tolerance to oxygen shortage in flooded soils and in solution culture. *Plant and Soil* 187 (1): 37-45.
- [10] Borgå P. 1994. Chemical and microbial interactions in environmental degradation processes, Implications on water storage of timber and decomposition of peat. Doctoral thesis. *Swed. Univ. Agric. Sci.*, Uppsala, Sweden.