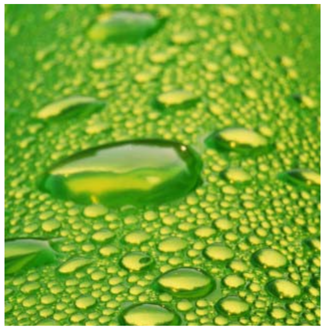


Recycling of wastewater and sludge in Salix plantations

Sustainable and profitable use
of waste resources and farmland in Europe
for production of biofuels

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The idea of growing willows (Salix spp.) for production of biofuels was introduced in Sweden already 25 years ago. Today, willows are commercially cultivated on a reasonable scale and the Swedish concept is now being introduced in other European countries.

Willows, as all green plants, require nutrients and water to grow. Various municipal waste products that are rich in nutrients and/or water, such as wastewater, sewage sludge, organic residuals, ashes and leachate from sanitary landfills, could partly or to a full extent replace the need of conventional fertilisation and enhance growth.

In this leaflet you will learn more about the Swedish concept of growing willows for energy purpose and the combined treatment and recovery of municipal wastewater or sludge in willow plantations.

Willow biomass plantations in Sweden

Since the oil crisis in the 1970's, willow has been tested as an energy crop in many European countries. Although growing willows is a rather new phenomenon in agriculture, the acreage in Sweden has increased rapidly and today, willow is grown on 15 000 hectares (~0,5% of the farmland). An extensive breeding programme towards frost and disease resistance and high biomass production has resulted in varieties with higher yield and less damages. The average annual production of wood chips from a well-established willow plantation is in the range of 8–12 tonnes of dry matter per hectare, which is equivalent to 3.5–5.5 tonnes of oil per hectare.

Commercial willow plantations in Sweden are established with stem cuttings planted with special machinery in a double-row pattern. The distance between the double-rows is 1.50 m with 0.75 m between the two rows within the double-row, allowing access of the various machines used. The number of cuttings is usually about 15 000 per hectare. Planting takes place in spring and after 3–4 years, in wintertime after defoliation, a first harvest is taken using certain harvesters.

Harvest every 2–5 years

A few types of harvesting machines, equipped with either circular or chain saws, have been developed. Direct harvesting and chipping and immediate transportation to the consumer is the method most widely used. This method also gives the lowest costs but requires possibilities to incinerate moist wood chips (about 50% dry matter content). Most large district heating plants currently in operation in Sweden are constructed to combust moist wood material.

Depending on the growth rate, a willow plantation is harvested every 2–5 years, and a plantation is assumed to produce well during a 25–30-year period when it becomes subject to replanting or breaking for possible change to other crops.

Recycling of wastewater and sludge in willow plantations

In Sweden the implementation of wastewater treatment started early and the most intensive period for construction was during the 1960s and the 1970s. Today, all the 8 million Swedes living in urban areas are connected to a sewage treatment plants with at least biological or chemical treatment. Biological/chemical wastewater treatment plants serve 80% of the population, and 40 % of the population is served by treatment plants with additional nitrogen treatment. The investment has led to a decrease in pollution load on receiving water so that the present load is similar to that at the beginning of the last century. Typical limit values according to authorised licenses expressed in mg per litre are for organic matter (BOD_7) 10–15, phosphorus (Total P) 0.2–0.5, and nitrogen (Total N) 10–20.

The treatment plants produce over 200 000 tonnes of sludge annually expressed as dry solids. Traditionally, sludge has been used as a fertiliser on farmland. However a never-ending debate is in progress whereby the risks of contaminating the soil are disputed. Even though Sweden does have very rigid standards, far beyond the corresponding EU directive, only a small percentage of the sludge is used in traditional agriculture today. However, sewage sludge is used to fertilize willow plantations, a procedure becoming gradually more popular than utilisation in the traditional agriculture. Today, almost 10% of the biosolids from the Swedish sewage treatment plants is utilised in commercial willow plantations.

The trends now are towards minimising the use of finite resources (chemicals, energy) in wastewater treatment by implementing new biological purification methods. The utilisation and treatment of municipal wastewater and sludge in willow plantations have been introduced on a commercial scale in Sweden. Several facilities with wastewater irrigation of willow plantations in sizes from 10 to 75 hectares have been established since 1997 with combined recycling and tertiary treatment of wastewater.

Kågeröd – pre-treated wastewater

Planting

Wastewater irrigation

Harvest

In Kågeröd, a town in the southernmost part of Sweden (municipality of Svalöv), pre-treated wastewater from a traditional treatment plant is used for irrigation of an adjacent 11-ha willow plantation. The plant serves about 1 500 people and also receives effluent from a milk powder industry. This industrial wastewater is treated separately to "domestic" quality before being co-treated with the municipal wastewater. The total BOD (biodegradable organic material) load amounts to approximately 5 000 person equivalents.

The main objectives are to exemplify the use of sustainable wastewater treatment technology where at the same time wastewater resources (water, nutrients, organic material) could be utilised.

The treatment plant consists of bar screens, an aerated sandtrap, a surface-aerated activated sludge unit, and a chemical post-precipitation step for phosphorus removal. Outflowing water from the activated sludge clarifier (before the chemical precipitation process) is used for irrigation. This secondary effluent is assessed having an appropriate quality partly due to the fact that a reduction of pathogens could be obtained in the biological step besides removal of solids in the sandtrap and the clarifier, reducing the risk of clogging of the irrigation equipment. Furthermore, the main part of the wastewater nutrients is still available in the wastewater after the biological treatment step.

In the license permit is regulated:

- Biologically treated wastewater is required as irrigation quality and the amount of water and nutrients applied must not exceed plant requirements
- Wastewater must be applied close to the soil surface for avoiding spreading of aerosols to the surroundings
- Hygienic aspects in terms of possible spreading of infectious diseases secondarily by animals to animal/man must be evaluated

The wastewater irrigation started in full-scale in 1997 according to the regulations above. During a 2-year period before the final permit was given, the hygienic aspects according to point 3 above were investigated at the site. The results in summary were that pathogens found in droppings or organs of animals living in or passing the irrigated plantation were those belonging to the natural pathogenic burden in the animals. Hence, the hygienic risks are low as long as normal operation procedures are maintained.

Average operational data during the last 7 years:

- Irrigation period: 10 May–20 October with conventional treatment during the rest of the year
- Wastewater application: 730–770 mm/y, 4–5 mm/d
- Nutrient application: N–P–K/72–10–85 kg/ha/y

Parameter	Discharge before 1997	Discharge after 1997	Improvement rate, %
Total N, mg/l	8.2	1.7	79
NH_4-N, mg/l	2.6	0.21	92
NO_3-N, mg/l	5.0	1.2	76
Total P, mg/l	0.053	0.047	11
BOD_7, mg/l	2.9	1.3	55

Treatment performance is continuously evaluated and comparisons of data concerning outlet qualities of treated wastewater to the receiving river before and after the irrigation season show clear improvements (see table). Hence, irrigation with biologically treated wastewater as an advanced treatment method results in lower pollution load on the river than conventional tertiary treatment.

Other advantages:

- Replaced manufactured fertilisers: N–P–K/800–110–400 kg/y
- Saved precipitation chemicals: 13 t AVR ($AlSO_4$)/y
- Decreased chemical sludge production
- Decreased electricity use:
  –Less stirring in the flocculation step
  –Less aeration and pumping of sludge
- Decreased fuel use:
  –Fewer transports of chemical and sludge
- Awareness of resource recovery (closed–loop–like system) among citizens

Enköping – decanted water from sludge centrifugation mixed with treated wastewater

In Enköping, central Sweden with 20 000 inhabitants, a 75-ha willow plantation is used to treat and utilize decanted water from dewatering of sewage sludge. This water contains approximately 25% of the nitrogen entering the wastewater treatment plant, but less than 1% of the water volume. Thus, by treating this water separately instead of pumping it back into the treatment plant the total nitrogen load is reduced by 25%.

The relatively limited water volume (20 000 m^3 per year containing some 15 000 kg N) enables storing in ponds during wintertime, which also is required to reduce the number of pathogens. During the period May-September the water is used for irrigation of the adjacent willow plantation by use of drip pipes laid in every double-row in order not to obstruct harvest. To boost growth and further improve the overall nitrogen treatment efficiency of the wastewater treatment plant, the system is designed so that conventionally treated wastewater is added through the irrigation system.

The irrigation load is approximately 300 mm per year resulting in a load of some 250 kg nitrogen and 7 kg phosphorus per hectare. Ongoing research has this far shown low nitrogen leaching losses, and thus, the system is apparently capable of transforming very large quantities of nitrogen.

Local district heating plant

The municipality covered all costs for the storing ponds, pumps, automatic filters, and irrigation pipes (which were lower than the estimated costs for improved conventional nitrogen treatment), whereas the farmer/landowner planted the willows and is responsible for maintenance of the irrigation pipes.

The produced biomass is used in the local district heating plant thereby contributing to the local supply of heat and electricity. The ash from the boiler is then recycled back to the willow plantation. Thus, the treatment system is an excellent example of how treatment and recycling of society's waste products can be combined with production of biofuels.

75-ha Salix plantations with ponds for storage of decanted sludge-water. Enköping, Sweden.

Dewatered and stabilised sludge

The Swedish quality requirements for sewage sludge recycling in agriculture are among the most restricted in the world. Nevertheless, most sludge in Sweden is formally accepted for agricultural use. The high quality has been reached due to an effective and persistent work with e.g. control of industrial wastewater connected to the sewerage and disconnection of polluted storm waters and landfill leachates.

Still, the demand for sewage sludge for use in conventional farming is very weak, while utilisation of sewage sludge in willow plantations has a considerably higher acceptance.

The main reasons why sludge is utilised in willow plantations are that:

- Willow is not included in the food production – willows are not eaten
- Existing routines and equipments for sludge management can be utilised – it is just another crop
- Sewage sludge replaces to large extents chemical fertilisers, especially phosphorus, and increases the soil content of organic material
- Nitrogen leaching from willows is negligible which gives a higher utilisation of the resource compared to traditional agricultural use of sludge

Potentials for Europe

Short-rotation energy forestry is about to achieve commercial status also in other countries in Europe. Willow plantations have been established, especially in Poland and UK with a total acreage of a few thousand hectares.

A development of Salix plantations on a wider scale may contribute to eliminate some of the problems within sectors that are of great political concern in Europe. Among these problems we can list:

The over-production of conventional crops in the agriculture. As much as 30 millions hectares of arable land within EU are regarded as non-profitable and subsidised to a large extent. It is urgent to find alternative crops for profitable use of the farming land.

The use of finite fossil energy sources instead of renewable alternatives. From year 1995 to year 2010, the bioenergy use within the EU was predicted to increase from 3.3 to 8.5% of the total energy consumption. The midterm review stated that the bioenergy percentage has in fact decreased to 3%.

The worrisome increase of greenhouse gas emissions. EU is committed to reduce the CO_2 emissions with 8% to 2008–2012 compared with the emissions year 1990. However, the trend is that emissions are increasing.

Protection of water quality. Several directives for the protection of water quality in the EU have been approved which will force the European agriculture to take measures e.g. against nitrate leaching and the use of herbicides and pesticides. The nitrate leaching from willow plantations is negligible, and the use of herbicides and pesticides is very low in willow plantations making the crop highly interesting in sensitive (water protection) areas.

The increasing unemployment in many rural areas. A wider development of willow plantations for bio-fuel production in Europe could help many sparsely populated areas to increase employment rates.

In this respect also the benefits of application of municipal waste products in willow plantations should be considered.

The potential that waste products also could be treated at reasonable costs might encourage the municipal sector as well as the energy and agricultural industry in Europe to participate in the further development of the concept, resulting in an enhanced production of environmentally friendly biofuels as a consequence.

Produced by Lindoff Communications, Lund, Sweden 2004. Printed by Grahns Tryckeri.

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