

# Biomass Production in Energy Forests

## Short Rotation Plantations

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### Energy Forest – Short Rotation Plantations

Energy forest is a forest grown and used for biomass production, that is, for energy purposes. Energy forest, properly called short rotation plantation (SRP), is fairly new, developed since the 1970s (Venturi et al., 1999). It includes the production of rapidly growing species of trees; the most popular are willow *Salix* and poplar *Populus*. Short rotation plantation can grow in a wide variety of climate and soil conditions. While poplars are commonly cultivated in drier areas, willows have been found to be the most suitable crop for regions characterized by a short period of vegetative growth and a higher level of precipitation. To obtain a good result the soil has to be of good quality and prepared carefully, weeds have to be removed and the plantation fertilized as with other crops.

SRPs usually have a rotation cycle ranging from 3 to 6 years, in some cases even 1-2 years. They involve fast growing tree species planted at very high density with up to 10,000 trees per hectare (Calfapietra et al., 2010). The annual yield of biomass produced could then be as high as 20 tonnes (Mg) of dry matter per ha per year, if the soil and moisture conditions are optimal, and appropriate fertilisers are used. In average it is possible to harvest from 15 Mg dry matter (d.m.) per year of the rotation cycle to 20 Mg d.m. of biomass from a 3 years plantation of willow.

The harvest of the plantation is done during winter when the ground is hard enough to allow the very heavy harvesting machines. The fields are then clear-cut. The harvesting machines cut the wood into wood chips directly. The chips are then dried before being used as a fuel.

Energetic value of dried biomass can be as high as 274 GJ per ha for one year plantation to 1,262 GJ per ha for a 3 years rotation cycle. It gives an energetic efficiency (measured as relation of energy value of biomass and energy input to plantation) from 22,5 to 42,0 for one and three years plantations respectively. To compare, energetic efficiency of rape amounts only 3,53 (Czart, 2005). The 5-7 cm stubs shoot new plants and after another 3-5 years it is possible to harvest again. After 20-30 years the field needs re-plantation.

### Industrial and Economic Aspects

With a good organization, SRPs are economically a good choice. The concentration of willow plantations to a relatively small area will scale up the operations enough to allow the farmers to establish an industrial infrastructure for processing willow biomass and distribute the produced wood chips in the most cost-effective way.

Energy forests give a renewable solid fuel. They contribute to local independence from external fossil fuels,



Figure 17.1. Willow plant plantation near the combined heating power station in Enköping, Sweden. The plantation is fertilized with effluents from the nearby waste water treatment plant and produces 10% of the input of biomass to the power station. Photo: Lars Rydén.

and reduce emissions of green house gases and climate change. They also reduce air pollution from burning of coal, oil and gas. Around 1-2 ha of SRP can cover energetic needs of a single household, but to be profitable at least 50 ha of SRP is needed. A very important factor for a cost effective business is to assure that there is a local biomass market.

Reliance on locally produced biomass is an advantageous economic solution for energy supply. Compared to being dependent on imported fossil fuels, it increases energy safety, and in most cases also reduce costs, however, depending on the prices which fluctuate with markets. Local production obviously also provides local work opportunities. If wastewater is used for fertilisation (see below) it also provides a low cost method to take care of nutrients in the wastewater before it is released to the water recipient.

Energy forest production should be seen in the perspective of the increasing need for producing renewable energy, to reach the 20% goal of total production to 2020 according to the European Union Agreement. The present level of renewables is for the 27 EU member states 18,3% (2012) although this figures varies considerably in the different member states.

### Use of Energy Forest Biomass

Biomass cultivated in order to generate energy can be used in a wide variety conversion products and processes. These fall into three major categories:

- direct combustion,
- gasification,
- hydrolysis and fermentation.

These produce electricity, heat, combined heat and power (CHP), and ethanol, respectively. As an example we may take Enköping municipality in Sweden (Börjesson and Berndes, 2006) where the power plant use a mixture of wood chips from energy forest and wood waste from the forest industry in a combined heat and power generation. The plant provides close to 50% of all electricity consumed in the town (about 40,000 inhabitants) and all heating needed through district heating.

The production of bioethanol from woodchips requires hydrolysis (so called second generation bio fuels) which consumes quite much of the energy and thus has a smaller yield. Bio ethanol may be used as a car fuel, but it is more often produced from other crops.

### Metal Adsorption and Soil Decontamination

Before certifying an area for energy plantation and sludge fertilization, it is necessary to determine the condition of the soil. Areas where the limits of the concentration of hazardous metals in the soil are exceeded could be used for energy plantations, but without sludge fertilization. In such cases nutrients should be provided by irrigation only.

Salix has an excellent capacity to take up metals from the soil. This may be used for environmental protection.

Salix equally offers a good possibility to absorb cadmium from contaminated arable land and caesium from the soil. Since caesium (Cs-137) is the main radioactive element after a nuclear fallout or contamination, including the Chernobyl fall out, energy forest has a role in the decontamination of such soils. Caesium and potassium competes in the metabolism of the plant and thus if uptake of caesium is intended one needs to reduce potassium fertilization. Strontium (Sr-90) is also one of the elements in the radioactive fallout, although after some time it is present in much smaller amounts; it is absorbed by Salix in the same way as caesium. These operations are

less efficient than with cadmium since Cs accumulates preferably in the roots and Sr in the leaves.

### Energy Forest in the European Union

Energy forest is not a main alternative for biomass production in EU. Only few countries have a sizeable stand of SRPs. In some European countries the areas of SRP range between some thousands and tens of thousands of hectares. Swedish plantations seem to be the largest, although it only amounts to about 14,000 ha which translates to about 0.5% of the total arable land in the country and currently contributes about 1% of Sweden's wood fuel requirements (González-García et al., 2012).

In Poland in 2005, the area of willow plantations for energy totalled 6 000 ha (Stolarski et al., 2008) and in 2009 it was 8 700 ha. The interest was preliminary highest for willow, which is a natural component of Polish vegetation, but also non-tree species *Virginia mallow* and *Miscanthus* has been used.

The potential for energy forests is however much larger. As an example Poland, with a vegetation period from 210 days (Gdańsk) to 215 days (Kraków) and annual precipitation of 500-700 mm, has favourable conditions for producing willow biomass. From 1.5 to 2.1 million ha of agricultural land in Poland could be used for SRP. Likewise the potential for energy forest plantations in the Baltic countries, is large. The land suitability for willow, poplar and *Miscanthus* cultivation has been estimated to be 353,000 ha in Estonia, 481,000 in Latvia and 1,332,000 ha in Lithuania, or 19%, 7.5% and 20.6% of the available agricultural land, respectively (Fischer et al. 2005). So far there are only small scale plantations in most EU countries (eg. Vande Walle et al., 2007).

## Wastewater and SRPs

### Wastewater for Irrigation and Fertilisation of SRPs

Effluents from wastewater treatment plants (WWTPs) can be effectively used for irrigation of energy forest plantations. By avoiding a direct discharge of the wastewater to the recipient and rather channel it to an energy forest plantation an additional treatment step in which nutrients are removed is achieved. Sludge, as a residue from waste-



Figure 17.2. Poplar (*Populus*) plantation irrigated with wastewater within VVACOSYS 6 FP UE project. Photo from the first year of experiment. On the left site – reference part irrigated only with water. Photo: [www.vvacosys.info](http://www.vvacosys.info)

water treatment, could also be used to fertilize SRPs. In areas with limited access to modern treatment facilities, such as sparsely populated rural regions, SRPs may be a low-cost alternative to the construction of cost-intensive, high standard treatment of wastewater.

The use of SRP to take care of wastes, such as wastewater or sewage sludge, from the society has been identified as one of the most attractive methods for achieving environmental and energy goals, while simultaneously increasing farmers' income (Dimitriou and Rosenqvist, 2011). It has been estimated that from 7 to 20 Euro could be saved per kilo of nitrogen by using natural instead of mineral fertilizers (Rosenqvist et al., 1997).

To get 20 Mg of dry willow biomass per hectare, about 150 kg of nitrogen, 18 kg of phosphates and 60 kg of potassium are needed (Pertu, 1993). Therefore, the content of available nutrients in the soil, sludge and irrigation water should be determined.

Currently, willows in particular seem to meet the requirements for efficient treatment / utilization of wastewater by irrigation because of their fast growth, level of water and nutrient uptake rates and coppicing ability. On the assumption that 15 m<sup>2</sup> of SRP are required for wastewater treatment from 1 person with a daily discharge of 100 liters, 10 ha of SRPs would suffice to treat wastewater from 6,500 people during the vegetation period.

### The Role of SRPs in Development of Wastewater Treatment in the EU

The application of wastewater on SRPs has enormous potential in regions where treatment is currently ineffective or unavailable, as in sparsely populated rural areas. From 49 to 93% of the population in the Baltic states is connected to advanced wastewater treatment systems (tertiary treatment). For those which are not decentralized wastewater treatment systems are important. SRPs could then be an alternative to other biofilters (e.g. constructed wetlands), because they combine treatment and production.

Based on a Northern Ireland case study Rosenqvist and Dawson (2005) concluded that the most important economic factor, when considering wastewater irrigation of SRP, is the possibility of reducing cost of conventional wastewater treatment (£5,83-£14,8 per kg N compared to reduced cost for the farmer which was only £0,66 per kg N). Thus wastewater treatment can be the main driving force for introducing SRP in a region.

The amount of sludge produced in wastewater treatment plants is continually increasing as the number of people connected to wastewater treatment plants increases. Sewage sludge from urban wastewater treatment plants generated in the Baltic Sea region countries in 2009 exceeded 3,000 thousand tonnes. From the beginning of 2005, sewage sludge disposal in landfill sites has been banned in the EU. One potential solution for the growing volume of sludge produced could be the use of sludge for increasing wood biomass to generate energy.

SRPs thus offer double advantages. Firstly SRPs represent an economic solution enabling highly efficient biomass production and low-cost wastewater and sludge treatment. Secondly they could contribute to local independence from external fossil fuels and fluctuations in their prices, to reduced environmental pollution and increasing local employment. The main advantages of wastewater/sludge use on SRPs are:

- effective wastewater treatment (high nutrient uptake and high transpiration rate),
- increase in the rate of biomass production without the use of mineral fertilizers,
- reuse of nutrients by introducing 'waste' into the biological cycle,
- decrease in the volume of waste,
- protection of surface waters.



Figure 17.3. Treatment of municipal wastewater treatment plant effluent in soil-willow system experiment. Results show high removal of phosphorus and medium removal of nitrogen from wastewater (see above). Photo: Agnieszka Karczmarczyk

All in all, the potential of SRPs arises from biomass production and wastewater/sludge treatment. This makes the approach a very interesting opportunity for farmers and will further contribute to sustainable rural development.

### Environmental Functions of SRPs

The role of closing the nutrient cycle in the environment as a way of making the environment sustainable is being described in the literature more and more often (Boyden and Rababah, 1995; Karczmarczyk and Mosiej, 2007). Many scientists point out the advantages of using wastewaters rich in nutrients for irrigation (Mant et al., 2003; Labrecque and Teodorescu, 2001). A possible risk is that the wastewater may contain other pollutants (e.g. heavy metals), which then may accumulate in the environment. Thus it is recommended to use nutrient rich effluents from wastewater treatment plants for irrigation (Mosiej and Karczmarczyk 2006).

In years 2004-2006 at Warsaw University of Life Sciences SGGW (within the SPB program connected with WACOSYS 6FP project) have run an experiment with irrigation of willow with wastewater treatment plant effluent. The WWTP was overloaded that time, and average total phosphorus and total nitrogen concentrations were 9,66 mg/l and 41,5 mg/l respectively. Pots with willow were irrigated with the different loads of wastewater 1; 3

and 5 mm per day. As the result of irrigation, decreasing of nutrients concentration in wastewater were observed (total phosphorus concentration varied from 0,7 mg/l to 2,2 mg/l; total nitrogen from 16,8 mg/l to 28,1 mg/l). In general reduction of total phosphorus was high (84%) and reduction for total nitrogen medium (47%). The highest removal of nutrients were obtained using low irrigation rate (1mm). The results showed that using wastewater for irrigation of SRP's can be a promising way for the protection of wastewater recipients.

The willow (*Salix viminalis*) is one of several plants used for energy plantations and wastewater treatment. It has several advantages. The plant's demand for water is high, so it could be cultivated on irrigated fields (Pulford and Watson, 2003). It grows well, even if soil is polluted with heavy metals. As a non-food crop, it could also be fertilized with sludge. It can improve surface water quality by treating WWTP effluents. It is also identified as the most energy efficient carbon conversion technology to reduce greenhouse emissions (Styles and Jones, 2007). Fast growing tree species irrigated with wastewater contributes to meeting EU targets for increasing amount of renewable energy and improving surface water quality.

### Fast-growing Willow in Belarus

#### The Potential for SRPs in Belarus

The Republic of Belarus does not have an adequate potential for domestic fossil fuel. Presently about 5% of Belarus' demand for energy is met by local renewable resources. A National State Program was approved to increase this input to 25% by 2012. The largest resources of renewable energy in Belarus are biomass, wind- and hydropower. Belarus has about 9.5 million hectares of forests, 5.7 million hectares of arable land, and 3 million hectares of pastures. Part of these areas may be used for biomass production by cultivation of fast-growing crops such as willow. The yield of willow biomass crops can reach 10-15 tonnes of dried wood or 5-6 toe (tonnes of oil equivalents) per hectare. The potential area for willow biomass production in Belarus is estimated at 0.5 millions hectare, which means that the annual energy potential of willow biomass systems in Belarus is 2.5-3 millions toe.

Willow biomass cropping systems simultaneously produce not only energy and economic value, but also environmental and social benefits. These include reduced SO<sub>x</sub> and NO<sub>x</sub> emissions, no emissions of additional CO<sub>2</sub> to the atmosphere, reduced soil erosion and pollution from non-point source of agricultural lands, and enhanced agricultural landscape diversity. Willow plants may be successfully grown on different types of lands and also have potential in reclamation of degraded and polluted soils.

Nowadays we see several experimental plots of willow plantation in different regions of Belarus. The adaptive technology of willow production have been developed and approved by Belarusian producers. There is no big industrial plantation of SRPs yet, even if there is some progress in this direction.

A special paragraph concerning SRPs production was included in the Belarusian national Programme for developing local and renewable energy sources during 2011-2015. In accordance with this Programme a harvester for SRPs has been transferred to the country. From 2012 we plan to test clones of willow and poplar and include them into the National State List of Belarus if the result are good.

#### Willow Plantations on Peatland

Another environmental benefit of willow plants is reclamation of cut-over peat. The area of such lands in Belarus is 20-30 thousand hectares. The problem is the absence of adequate technology for willow production on cut-over peat, which is very heterogeneous, poorly drained, low density and nutrient-poor.

A field study conducted at Lida region, in western Belarus, willow clones (*Salix viminalis*) was planted on peaty soils in a cut-over peat landscape. The soils in experimental plots were characterised as heterogeneous and available water capacity was moderate to high. The aim of the experiment was to study the scope for willow in unfavourable soil conditions.

Degraded peat soil conditions are not favourable for successful plant cultivation. As a result, once peat harvesting has ceased it is impossible to grow any cultural plants for some years, with the most critical period being the time after planting. We expected the same problems to be typical for willow and therefore examined willow survival and rates of willow growth during the first couple of months post-planting. Weed control is crucial in



Figure 17.4. Willow plants on site (2), with a low degree of peat decomposition and peat depth > 50 cm. Four months after willow plantation". August 2010



Figure 17.5. Willow plants on site (1), with a high degree of peat decomposition and peat depth > 50 cm. Four months after willow plantation". August 2010

this period because of competition between weeds and young willow plants.

Adequate rates of survival and growth of willow require fertiliser treatment, as cut-over peat soils have a low content of N, K, P and microelements. Our studies showed that fertilisation increased willow plant height by 20-50% depending on cultivar. The most positive effect was observed on the peat soil with the highest content of nutrients.

Cut-over peat soils are very heterogeneous, with widely varying nutrient content and different degrees of peat decomposition, so the cultural practices most suitable for a particular type of peat soil must be specified. To establish the best conditions we investigated the scope for willow cultivation on soils distinguished by different depth of peat layer and degree of peat decomposition.

The field experiment included 4 different soils: Peat layer depth larger than 50 cm and (1) high degree and (2) low degree of peat decomposition; (3) Peat layer depth larger than 30 cm and high degree of peat decomposition; (4) Sandy-peaty soil with peat layer depth larger than 30 cm and with sandy insertion. The crucial factor for willow plant development proved to be not only the nutrient content of the soil, but the level of peat composition. The contents of P and K were higher in soils with low peat decomposition, but the plant was growing better in soils with higher degree of peat decomposition.

#### **Willow Plantation on Radioactively Polluted Areas**

One of the key environmental problems in Belarus is the effective use of agricultural lands contaminated by radio nuclides, mainly Cs137, from the Chernobyl disaster and by heavy metals from traffic and industrial activities. After the Chernobyl disaster the area of radioactively contaminated agricultural soils in Belarus is about 1.3 million ha, including 0.8 million ha of arable lands. The optimal system of cultivation of this type of soils is a serious problem, since traditional crops such as grass and cereals accumulates radionuclides.

An alternative to traditional agricultural crops is fast growing willow, which can be used for renewable energy. In a series of field studies during 2007-2011 we studied the environmental aspects of willow production in polluted areas. The field experiments were conducted at Krichev district in Mogilev region in eastern Belarus, close to the Russian border. This region has a high level of Cs-137 contamination as well as much pollution of heavy metals (Rodzkin et al. 2010).

The concentration of cesium-137 in different parts of willow biomass was measured and transfer factors calculated for leaves, roots and wood. The results varied dependent on the levels of nitrogen, phosphorus and potassium fertilization. Potassium levels turned out to be a key factor for Cs-137 accumulation, which is expected since cesium is known to compete with potassium in the

metabolism. The optimal dose of potassium was found to be 90 kg/ha.

We calculated that the concentration of cesium-137 in the wood after a 21 year period, normal time for re-plantation, will not be higher than permitted levels even with cesium 137 levels in the soil of 1480 kBq/m<sup>2</sup> (maximum 140 kBq/m<sup>2</sup> ; allowed levels for firewood is 740 Bq/kg). The concentration of cesium-137 in the roots increased gradually to 3,000 kBq/m<sup>2</sup> after 21 years.

A future problem may be the utilization of more polluted roots. There are two alternatives. The first is to re-

cultivate the plantation already after 12-15 year, not after 21. Then parts of roots can be used as firewood. An alternative is to leave the roots in the soil, then plough the plot and plant new trees.

The yield of willow wood on the experimental plots was about 11-12 tonnes of dry biomass per hectare annually. We concluded that about 0.8 million hectares of radioactively polluted arable land in Belarus, today partly excluded from agriculture could be used for willow biomass production (Rodzkin et al. 2010).

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