The net energy balance of wastewater irrigation of salix

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The energy balance of bioenergy systems has been analyzed extensively. Besides clarifying whether specific bioenergy systems are sinks or sources of energy, assessments of energy use in biomass production and processing are employed in order to evaluate the overall environmental performance of bioenergy systems. Willow plantations are being tested in large-scale trials in Sweden as vegetation filters for municipal wastewater. Willow plantations can also be used for the treatment of drainage water, landfill leachate and sewage sludge. The interest in vegetation filters, as a complement to conventional treatment methods, is due to the high purification efficiency and low costs. In this paper we estimate the net energy results of employing municipal wastewater and drainage water irrigation of willow plantations. The aim is to establish whether bioenergy systems based on willow would gain or lose in net energy terms when the willow plantation is used as a vegetation filter. This paper is based on a more extensive paper discussing the implications of irrigation and water management for the net energy performance of bioenergy systems [1].

The primary energy input associated with irrigation system establishment is estimated based on a 40-year irrigation system life, with specific energy inputs for products[1] manufacture and excavation (see [1] for details). The primary energy input for irrigation water lifting and pressurization (TDH[2]) is estimated assuming an average efficiency of pumps and power source at 20 percent. The irrigation water application depth and TDH are specified based on Swedish experience of willow vegetation filters [1]. Energy savings from reduced fertilizer requirements and from substitution of conventional N and P removal with the willow vegetation filter are calculated based on Swedish experience [1]. Willow plantations irrigated with wastewater and drainage water are estimated to have yields around 50 percent higher than those obtained under conventional cultivation [2]. Assuming an average yield of 10 Mg DM ha^{-1} yr^{-1} under conventional cultivation, willow irrigation with municipal wastewater or drainage water results in a gross yield increase of around 100 GJ ha^{-1} yr^{-1} (the higher heating value of willow is about 19.5 GJ per Mg DM [3]).

The energy input for establishment of a furrow system for distribution of drainage water from about 700 ha of intensively cultivated land on a 3 ha willow filter system is estimated to be 360 MJ ha^{-1} yr^{-1}, with 70 percent of this being excavation work. The energy input for the establishment of a 10-50 ha controlled-flooding willow filter system suitable for treatment of municipal wastewater from municipalities with around 50,000 inhabitants is estimated to be 500 MJ ha^{-1} yr^{-1}. The pumping energy input for the municipal wastewater treatment system is estimated at 12 GJ ha^{-1} yr^{-1}, given 600 mm application depth and 40 m TDH (50 kPa end-use pressure plus distribution losses [4, 5]). For the drainage water treatment system, the pumping energy input is estimated at 2.3 GJ ha^{-1} yr^{-1}, given 900 mm application depth and 5 m TDH (pressurization and losses).

The energy input for N removal in a conventional treatment plant varies, for example with N concentrations and the C/N ratio. On the average 6 MJ is required to remove one kg N, corresponding to 25 percent of total net energy inputs at the plant. Additional indirect energy inputs for N removal (pumps, pipes and concrete) are estimated to be 0.5 MJ per kg N. Direct and indirect energy inputs for chemical P precipitation correspond to around 5 percent of total energy inputs at the plant. The replacement of P precipitation leads to lowered production of sewage sludge, and consequently to

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1 pipes, pumping unit, and other equipment.

2 The pressure required to overcome friction in water distribution lines and to operate field distribution systems is converted to meters (pressure in kPa is multiplied by 0.10) and added to required meters of lift to obtain the total dynamic head (TDH).

reduced handling and transportation requirements. This indirect energy saving is not included in the net energy analysis employed here. The energy input for N-fertilizer production is taken to be equivalent to 45 MJ per kg N, referring to the performance of modern fertilizer plants [3]. Energy inputs in older plants can be significantly higher, while the theoretical minimum energy input is around 25 percent lower. The energy inputs for production of commercial P- and K-fertilizers are taken to be 7.9 and 4.8 MJ kg^{-1}, respectively [3].

The energy input for willow filter system establishment and pumping is estimated to be higher than the combined energy savings gained from reduced fertilizer requirements and substitution of N and P removal in conventional wastewater treatment plants. Willow filter cleaning of drainage water from intensively cultivated cropland requires less establishment and pumping energy than the energy gained from reduced N-fertilizer requirements. The major reason is lower TDH due to assumed location of the drainage water storage pond and willow plantation at the same site. Both vegetation filter systems have a positive net energy gain thanks to the expected yield increase. Note that the energy balance in Table 1 is limited to the vegetation filter function of the willow plantations. Willow production requires additional inputs, such as motor fuels for harvesting and other operations. The overall net energy yield in conventional willow production in Sweden is around 170 GJ ha^{-1} yr^{-1} [3]. The overall net energy yield of willow vegetation filter cultivation will be substantially higher –provided the suggested yield increases are realized.

Table 1. The energy balance of using willow filter systems for treatment of municipal wastewater and drainage water from intensively cultivated croplands[a].

	Energy input (-) / saving (+) (GJ ha^{-1} yr^{-1})	Yield increase[b] (GJ ha^{-1} yr^{-1})	Net energy balance (GJ ha^{-1} yr^{-1})
<u>Municipal wastewater treatment</u>			
Irrigation[c]	-12.5		
Substitution of conventional treatment[d]	+0.8		
Reduced N fertilizer requirements	+4.5		
Reduced P & K fertilizer requirements	+0.5		
Sum	**-6.7**	**100**	**+93**
<u>Drainage water treatment</u>			
Irrigation[c]	-2.7		
Reduced N fertilizer requirements	+4.5		
Sum	**+1.8**	**100**	**+102**

[a] The energy balance is estimated based on a reference case where willow is cultivated without irrigation using commercial fertilizers. Conventional methods for treatment of municipal wastewater. No treatment of drainage water.
[b] 5 Mg dm ha^{-1} yr^{-1}, 20 GJ Mg^{-1} dm
[c] Including direct energy use for pumping and indirect energy input for irrigation system establishment.
[d] Energy savings (direct and indirect) from replacement of conventional N and P removal in wastewater treatment plants.

References

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