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Willows for the treatment of municipal wastewater: Performance under different irrigation rates

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ABSTRACT

Willow cropping is increasingly spreading worldwide for various purposes including vegetation filter. Willow plantations are highly nutrient-demanding and site fertilization may be required to maintain soil fertility and nutrient balance. In this context, municipal wastewater could be a valuable source of nutrients (especially N and P) and water for plant growth. The aim of this study was to assess the performance of willows to recycle municipal wastewater supplied at different rates. In particular, we sought to evaluate the quality of groundwater water collected under willow and assess the effect of wastewater supply on willow growth. Irrigation with wastewater had a positive effect on willow growth and biomass yield. It was also estimated that willows were able to remove nearly 90% of the N and 85% of the P found in the wastewater. This study shows that a willow vegetation filter is very efficient at removing nutrients found in wastewater.

1. Introduction

Willow cropping is increasingly spreading worldwide for various purposes including bioenergy (Volk et al., 2006), phytoremediation (Wieshammer et al., 2007), erosion control (Wilkinson, 1999), rehabilitation of degraded soils (Vandenhove et al., 2001), streambank restoration (Schaff et al., 2003), and other mitigation purposes (Kuzovkina and Quigley, 2005). The use of willow for recovery/recycling of nutrients from waste is another option that has been shown to be very attractive for it may enhance the biomass yield while reducing environment pollution risks (Börjesson and Berndes, 2006).

Willow plantations are highly nutrient-demanding and in some cases to respond well to fertile sites (Mitchell et al., 1999). Thus, fertilization is very important to compensate the removal of the stem biomass at harvest and thereby maintain soil fertility and nutrient balance (Adegbidi et al., 2001). Municipal wastewater, even when pre-treated, is a valuable source of nutrients (mainly nitrogen and phosphorous) and water for plants (Perttu, 1999) and does not pose much sanitary risk especially when used on non-food, non-fodder crops (Hasselgren, 1998). Thus, when using pre-treated municipal wastewater on willows, the biomass yield of the stand, and thereby the economic value of the harvestable biomass, normally increase due to extra nutrient and water supply to plants (Rosenqvist et al., 1997; Dimitriou and Rosenqvist, 2011). Moreover, willow stands may significantly reduce the nitrogen and phosphorous concentrations in the wastewater either by direct root uptake or by other mechanisms (e.g., denitrification) (Aronsson and Perttu, 2001). For instance, it has been shown that the root systems of mature willow stands can take up 75–95% of the nitrogen and phosphorus in the wastewater (Börjesson, 1999). Therefore, irrigating willows with municipal wastewater can provide substantial yield increases without considerably increasing the risk of groundwater pollution and eutrophication of water bodies.

Despite a relatively large body of information concerning the use of willows as vegetation filter technology it mostly originates from few northern European countries (chiefly Sweden, Estonia and Denmark) and information is scarce from other temperate regions where willow is successfully grown. In general, the performance of a vegetation filter system depends on several properties of the crop (e.g., water demands and evapotranspiration rates, nutrient-use efficiency) that vary broadly among different species and within the same species among location. Eastern Canada is one of the regions in the world where willow crop shows very high levels of biomass yields both in the short- (Labrecque and Teodorescu, 2005; Volk et al., 2011) and the long-term periods (Guidi Nissim et al., 2013). Since evapotranspiration and nutrient

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uptake are linked to a great extent to biomass yield, is likely that eastern Canada willow crops would show very high performance as vegetation filters. The aim of the current study was to assess the performance of willows to recycle municipal wastewater supplied at different rates on a highly-productive site and in particular (i) to evaluate the quality of groundwater collected under willow stands and how it compares to legal limit values; (ii) to assess the impact of wastewater supply on willow aboveground biomass yield.

2. Materials and methods

2.1. Study site

The trial was carried out on a site in Saint-Roch-de-l'Achigan (45°50′ 50″N – 73° 38′27′W), 55 km northeast of Montreal (Quebec), Canada. The region has a humid continental climate characterized by wide seasonal temperature variations, warm, humid summers and cold winters. According to the nearest weather station (Mascouche, Quebec; 45°45′N; 73°36′W; ~11 km), the average annual temperature for the 1981–2010 period was 6.4 °C, and average annual precipitation was 998 mm, with 40% falling during the growing season (Environment Canada 2014). The average number of degree-days (>5 °C) is 2100, and the growing season lasts approximately 180 days. The experimental field was formerly used for conventional agricultural crop (maize). At the beginning of the trial, soil texture was characterized at two depths and determined to be sandy loam in the top layer (0–20 cm) and loamy sand in the lower layer (20–40 cm) (Table 1). Both organic matter content and nutrient concentrations (including N, P, K, Ca and Mg) were higher in the top soil layer, whereas pH was slightly lower in the top layer than in the 20–40 cm layer.

2.2. Site preparation, irrigation system setup and willow planting

In spring 2008, prior to planting the site was mowed and the ground ploughed with a rotary tiller to a depth of 0.15 m. The experimental site was then planted at density of about 16,000 plants per hectare with the willow cultivar *Salix miyabeana* SX67. In order to prevent weed development, a pre-emergence residual herbicide mix (2.30 kg ha^{-1} Devrinol and 0.37 kg ha^{-1} Simazine) was applied. During the first growing season (2008), the field was weeded between willow rows with a vibra-shank cultivator. In autumn 2008, all willows were cut back to allow the development of a denser stand canopy.

In spring 2009, a 0.72 ha area was delineated and laid out for the trial in a strip-plot design. A sub-irrigation system was installed between willow rows at a depth of 0.30 m. Wastewater was supplied through a 1.5 km long hose linking the Saint-Roch-de-l'Achigan's effluent treatment facility to the willow plantation. A filtration system was installed at the pump outlet to remove coarse particles. Flowmeters, power-supplied by an electronic solar energy panel, were installed and programmed to deliver the scheduled volume of wastewater for each treatment, and to control irrigation levels throughout the growing season. The main chemical and physical characteristics of the irrigation wastewater are shown in Table 2.

2.3. Irrigation and fertilization treatments

The strip-block experimental setup comprised 4 blocks within which 2 factors were randomized: irrigation (main plot factor; 4 levels, D0, D1, D2, D3) and fertilization (sub-plot factor; 2 levels, fertilized/unfertilized), to constitute 32 plots. Each plot had a surface of 225 m^2 and contained 10 rows with approximately 35 plants per row.

Four treatments corresponding to four wastewater doses, D1, D2 and D3, as well as D0 (the latter with no irrigation, i.e., control), were scheduled, and each treatment was applied along ten willow rows (Table 3). During the first 2-years rotation (2009–2010), we supplied four wastewater irrigation doses as follows: 0 mm (D0), 300 mm (D1), 393 mm (D2), 584 mm (D3) in 2009 (128 days of irrigation) and 0 mm (D0), 414 mm (D1), 487 mm (D2), 794 mm (D3) in 2010 (150 days of irrigation) which corresponded in both years to an increase of wastewater supply of about 33% between treatments. During the second 2-year rotation (2011–2012) the irrigation rates were: 0 mm (D0), 185 mm (D1), 386 mm (D2), 634 mm (D3) in 2011 (134 days of irrigation) and 0 mm (D0), 302 mm (D1), 601 mm (D2), 926 mm (D3) in 2012 (135 days of irrigation) which corresponded to an increase of wastewater supply between treatments of about 33% in the first year and 50% in the second year.

In addition to the wastewater treatment, a fertilization treatment (fertilized or not) was also applied (i.e., 100 kg ha^{-1} of N and 60 kg ha^{-1} of P), as illustrated in Table 3. Fertilization was performed after each harvest (i.e., 2009 and 2011), in two steps, i.e., 30% of the total amount of nitrogen was applied at the end of May and the remaining 70% at the end of June.

2.4. Monitoring equipment setup

During the late spring of 2009, one groundwater sampler (Model 1900 Soil moisture Equipment Corp.) was set out in the center of each plot (on the 5th row) according to the manufacturer's specifications. Boreholes were drilled using a manual auger, and soil water samplers were inserted into the ground to an

Table 1
Soil physico-chemical properties of the study site.

Parameters	Units	Soil depth (cm)	
		0–20	20–40
Sand	wt%	76	79
Silt	wt%	15	13
Clay	wt%	9	8
Texture		Sandy loam	Loamy sand
Organic matter	wt%	2.57	1.99
Total N	wt%	0.12	0.09
pH		6.69	6.74
Available P	mg kg^{-1}	87.5	72
Exchangeable K	mg kg^{-1}	58.7	46.4
Exchangeable Ca	mg kg^{-1}	1189	962
Exchangeable Mg	mg kg^{-1}	70.3	56
Exchangeable Na	mg kg^{-1}	5.2	4.2

Table 2
Physico-chemical properties of wastewater used for irrigation from 2009 to 2012.

Parameters	Units	2009–2010	2011–2012
pH	–	8.04	8.11
Conductivity	uS cm^{-1}	1269	977
Total N	mg L^{-1}	29.7	20.2
NH_4–N	mg L^{-1}	20.8	13.9
NO_3–N	mg L^{-1}	0.2	0.02
Organic N	mg L^{-1}	8.7	6.3
Total reactive P	mg L^{-1}	1.17	0.11
Soluble reactive P[1]	mg L^{-1}	1.08	0.1
Available K	mg L^{-1}	11.4	10.6
Available Ca	mg L^{-1}	38.4	24.5
Available Mg	mg L^{-1}	22.1	9.7

Mainly PO_4–P (Jones and Reynolds, 2006).