The impact of harvest interval on SRC willow plantations and phytoextraction of metals from biosolids

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Melbourne Water

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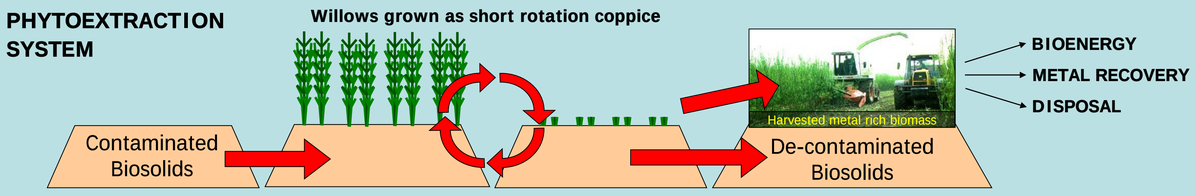
BACKGROUND

The Western Treatment Plant (WTP) uses activated sludge & lagoons to treat sewage from the city of Melbourne, AUSTRALIA. Sludge from treatment lagoons is air dried in bunded pans to produce biosolids. The majority of the older biosolids exceed the EPA Victoria threshold for un-restricted re-use, with respect to the metals and metalloids As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn.

AIM

The aim of this trial was to determine the most efficient harvest interval to maximise biomass production in a short rotation coppice willow plantation grown for phytoextraction of heavy metals.

A study was initiated in 2003 to investigate the potential of plants to remediate the contaminated biosolids. The overall aim is to develop a sustainable and cost efficient phytoremediation system. Willows (*Salix*) have a rapid growth rate and can be grown as a short rotation coppice crop (SRC). Willows also tolerate, take up and accumulate some metals. In initial trials (2005-2008) willow species were grown directly in biosolids and irrigated with potable water. Contaminant extraction rates (g ha^{-1} yr^{-1}) from biosolids using potable water were As 350, Cd 667, Co 162, Cr 1040, Cu 776, Hg -, Ni 3280, Pb -, Se -, Zn 57400.



METHODS & RESULTS 1

Small (n=16) high density (40K stems ha^{-1}) blocks of willows were planted in biosolids and harvested annually for two years. All blocks were irrigated with potable water by drip irrigation. In the third season the blocks were harvested up to 3 times within the growing season, 1) early summer, 2) late summer and 3) mid autumn. Group A blocks were harvested 3 times, group B twice and group C once at the end of the growing season. Biomass was divided into leaves and stems, weighed as dry matter and sub-samples were analysed for metal content.

Willows before harvest in November 2008.

Group A blocks after first harvest in early summer (Dec. 2008).

Groups A and B blocks after second harvest in mid summer (Feb. 2009).

Groups A, B and C prior to third harvest in autumn (April 2009).

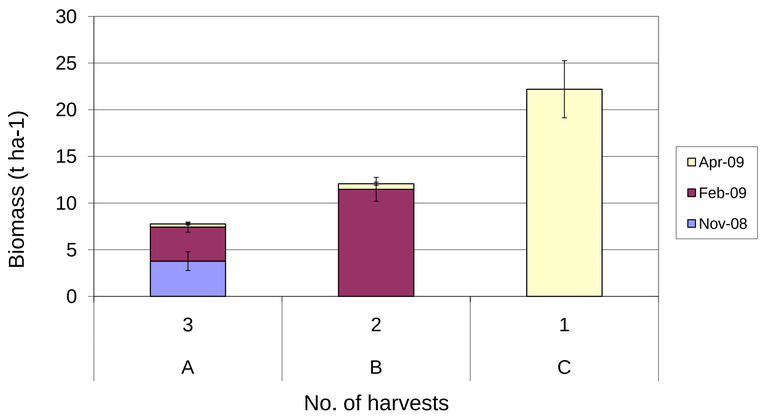


Figure 1. Total biomass harvested from blocks harvest once, twice and three times within a single growing season.

Table 1. Metal concentrations (mg kg^{-1} d.w.) in stem and leaf samples collected at each harvest.

		Cd	Co	Cr	Cu	Ni	Zn
Nov A	Leaf	13	0.5	0.6	8	27	878
	Stem	8	-	0.4	7	8	216
Feb A	Leaf	11	1.3	1.0	7	33	771
	Stem	9	0.3	0.5	6	9	230
Feb B	Leaf	21	1.4	1.0	6	33	1267
	Stem	8	0.3	0.6	5	6	215
Apr A	Leaf	16	1.8	0.9	5	38	1145
	Stem	15	0.2	0.5	5	14	457
Apr B	Leaf	23	1.8	4.1	7	38	1511
	Stem	19	0.3	0.4	6	12	592
Apr C	Leaf	17	1.9	1.0	6	42	1641
	Stem	9	-	0.5	5	8	293

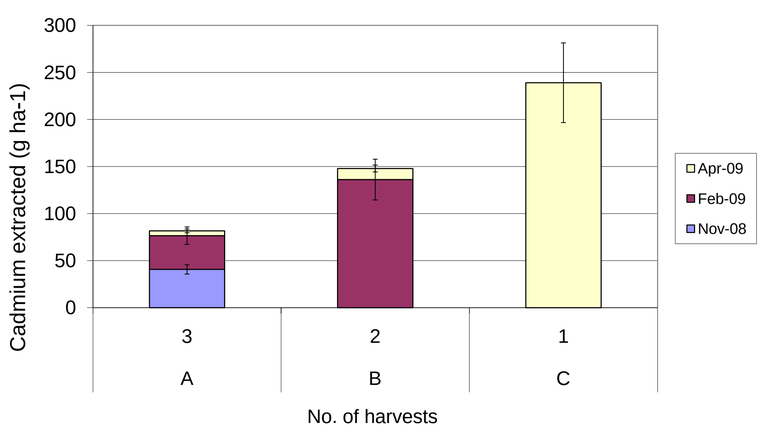


Figure 2. Total cadmium extracted in the harvested biomass from blocks harvest once, twice and three times within the growing season.

A single harvest (22 t ha^{-1}) produced a greater biomass than the cumulative mass removed from two and three intra-seasonal harvests (12 and 8 t ha^{-1} respectively)(Fig 1). In addition, multiple harvests did not increase the cumulative leaf harvest significantly and hence had little impact on overall contaminant metal removal from the biosolids (Fig. 2).

METHODS & RESULTS 2

Two models of a phytoextraction system incorporating a combined leaf and stem harvest in autumn were developed. Biomass production and metal concentration data from previous trials (Laidlaw *et al.* 2008) were incorporated into the models to compare the impact of 1-year and 2-year harvest rotations on cumulative metal extraction over a 7 year period. Models assumed biomass production was constant after year 3 and plant tissue metal concentration (uptake) was constant. One third of annual leaf production was removed at each harvest event with the remainder falling as litter.

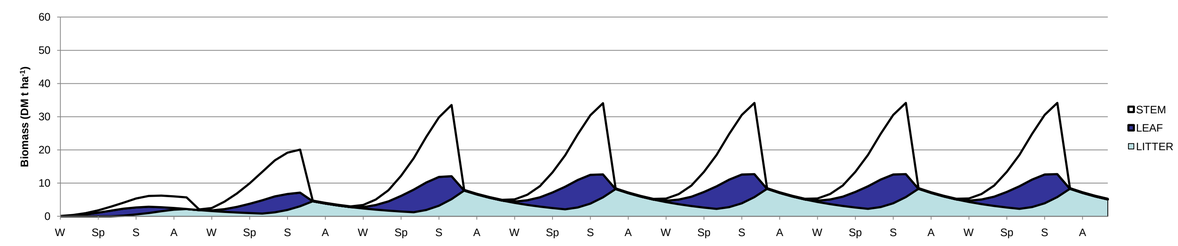


Figure 3. A model of willow biomass production with annual harvests in a src plantation. Biomass production is assumed to remain constant from the third growing season onwards. One third of the annual leaf production is removed along with the stems at harvest in autumn each year.

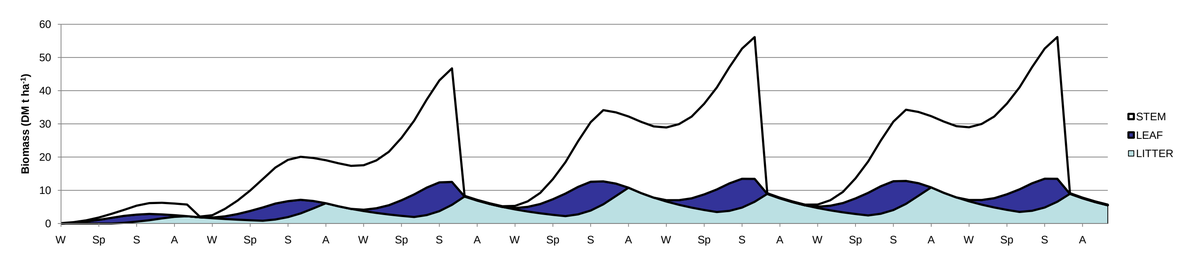


Figure 4. A model of willow biomass production with biennial harvests in a src plantation. Biomass production is assumed to remain constant from the third growing season onwards. One third of the annual leaf production is removed along with the stems at harvest in autumn each year.

Table 2. A model of cadmium extraction over seven years of consecutive willow harvests

year	Harvested leaf biomass t ha^{-1}	Harvested stem biomass t ha^{-1}	Leaf tissue Cd conc. g t^{-1}	Stem tissue Cd conc. g t^{-1}	Cd extracted in leaves g ha^{-1}	Cd extracted in stems g ha^{-1}	Total Cd extracted g ha^{-1}
1	0	3.3	16	9	0	30	30
2	2.3	12.8	16	7	36	89	125
3	3.8	21.3	13	7	49	149	198
4	3.8	21.3	13	7	49	149	198
5	3.8	21.3	13	7	49	149	198
6	3.8	21.3	13	7	49	149	198
7	3.8	21.3	13	7	49	149	198
Total	21.0	122.3			280	863	1142

Table 3. A model of cadmium extraction over seven years of biennial willow harvests

year	Harvested leaf biomass t ha^{-1}	Harvested stem biomass t ha^{-1}	Leaf tissue Cd conc. g t^{-1}	Stem tissue Cd conc. g t^{-1}	Cd extracted in leaves g ha^{-1}	Cd extracted in stems g ha^{-1}	Total Cd extracted g ha^{-1}
1	0	3.3	16	9	0	30	30
2	0	0	16	7	0	0	0
3	3.75	34	13	7	49	238	287
4	0	0	13	7	0	0	0
5	3.75	42.5	13	7	49	298	346
6	0	0	13	7	0	0	0
7	3.75	42.5	13	7	49	298	346
Total	11.25	122.3			146	863	1009

The models show that annual harvests would remove 13% more cadmium than a system based on biennial harvests. A stem and leaf harvest removes 17% more cadmium than a stem only harvest in a biennial system and 32% more in an annual system. The harvesting of leaf biomass contributes significantly to metal removal by a willow based phytoextraction system.

CONCLUSIONS

The results of this field trial and modelling indicate that a single annual harvest of stem and leaf combined in early autumn produced the most efficient removal of contaminant metals from biosolids. This conclusion however needs to be validated with longer term data from field trials subject to 1 year rotations for a period greater than three years.