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Biomass, Remediation, re-Generation (BioReGen Life Project): Reusing brownfield sites for renewable energy crops

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ABSTRACT: Biomass fuel composition is compared to host soil contamination for energy crops grown on five contrasting sites in NE England. These include three contaminated brownfield sites and control sites in both urban and rural settings. Fuel quality is compared for willow (*Salix* spp.) short rotation coppice (SRC), miscanthus (*Miscanthus* spp.), reed canarygrass (*Phalaris arundinacea*) and switchgrass (*Panicum virgatum*). The information is used to assess the potential for long-term remediation of contaminated land during energy crop growth. Concentrations of Zn and Cd are consistently higher in SRC willow for a given site, whereas the grasses have higher ash contents, which are richer in SiO_2 but lower in K_2O. Initial actions of the full-scale demonstration plantings carried out under the Life III Environment Programme are described together with an analysis of the wider economic, environmental and social benefits of this sustainable type of reuse of derelict brownfield land and carbon neutral approach to remediation.

INTRODUCTION

In the UK the term "brownfield" refers to land that has been previously developed for any non-agricultural purpose (i.e. the opposite of "greenfield" land). Current estimates suggest that there are 63,500 ha of brownfield land in the UK, of which some 36,000 ha are currently vacant or derelict (National Land Use Database, 2006). This definition is independent of any potential or known contamination, environmental hazard or risk. Indeed some undeveloped greenfield sites may also be contaminated. In many areas of the UK, however, brownfield land left by the retraction of traditional heavy industries is indeed contaminated to the degree that it would require treatment prior to being suitable for use. Much of this land area is either too expensive to remediate or simply surplus to current requirements for any appropriate new industrial use. As a result derelict industrial sites are often cleared of above ground structures, secured and left to await future redevelopment.

The Tees Valley, NE England, contains one of the largest heavy industrial clusters in W Europe, including petrochemicals, iron and steel, bulk inorganic and specialty chemicals. Recent industrial history included extensive coal-based heavy industry, while mining, smelting and metallurgy of ferrous and non-ferrous metals has been carried out over two millennia. The result is a legacy of contaminated land amounting to an estimated 20,000 ha (2.3%) of NE England (Environment Agency, 2002). Due to decline and restructuring of remaining heavy industries there is also now 1155 ha (1.5%) of available derelict or vacant brownfield land in the Tees Valley alone.

Development of the 30 MWe Wilton 10 biomass power station by SembCorp Utilities has created a local market opportunity for energy crop production in Teesside. In 2003 a consortium led by CLEMANCE was formed to investigate the potential of reusing derelict industrial sites for energy crop production to supplement production from agricultural land.

The aim of the BioReGen Life project (www.bioregen.eu) is to demonstrate at full commercial scale on a variety of contaminated sites the feasibility of reusing brownfield land for biomass production (Lord et al. 2007). Five 1 ha demonstration sites were planted in April-May 2007 included a former shipyard site, a steel slag heap, coal and coke oven yard, a former sewage treatment works, and a landfill site. The purpose of this paper is to compare the results of soil contamination and fuel properties for energy crops grown at five earlier pilot scale field trials.

PILOT SCALE FIELD TRIALS

Field trials commenced in 2004 with the establishment of duplicate hand-planted plots of four candidate energy crop species on a former landfill site at Fyland's Bridge near to Bishop Auckland, County Durham (site (a) Table 1). Desk study of historical mapping and initial site investigation showed that this former glacial brick clay pit had been back-filled largely with domestic coal ash and incineration residues, resulting in potentially phytotoxic heavy metal contamination and levels of As and Pb of concern for redevelopment. Individual plots were planned to be 6.9 x 7.5 m, the area needed to accommodate 100 short-rotation coppice willow plants using conventional spacing and agricultural equipment. No amendment was used, although the plants were mulched with compost to aid weed suppression in August 2004. Lord et al. (2007) gives further details of planting methods, contamination assessment, bio-accessibility testing and energy crop survival rates for this site.

Hand planting was also employed at site (d) which was located within an eco-park, a visitor attraction specializing in educational facilities, which demonstrate sustainable living (www.naturesworld.org.uk/). The aim was to provide examples of energy crops in a publicly accessible location, coupled with a control site. The site is in an urban location a few km from the heavy industrial areas of Teesside, which

Table 1. Details of pilot scale sites

	Site (a)	Site (b)	Site (c)	Site (d)	Site (e)
	Clay pit and coal ash landfill	Oil foam land farm, near to Pb-Zn smelter	Agricultural (arable)	Agricultural, (formerly licensed wastes management site)	Shipyard, reclaimed estuary
Current land use	Derelict	Within industrial compound	Agricultural (biomass)	Ecopark (visitor attraction)	Derelict, partially cleared site
Site type	Brownfield	Brownfield	Rural control	Urban control	Brownfield
Planting date	April 2004	May 2004	May 2004	June 2004	(May) June 2005
Area, ha	0.04	0.4	4	0.01	(0.5 failed), 0.01
Coppice planting details	Hand-planted, 20 cm sticks	Mechanized step-planter, 20 cm sticks	Mechanized step-planter, 20 cm sticks	Hand-planted, 20 cm sticks	(Mechanized) hand-planted 2 m sticks with tree-guards
SRC age (growth), years	3 (2)	3 (2)	3 (2)	3 (2)	2 (2)
Grasses	MC, RC, SG	MC & RC (failed)	MC, RC	MC, RC	None – Future trials

Note: SRC = short rotation coppice, MC = miscanthus, RC = reed canarygrass, SG = switchgrass.

include an integrated steel works, coke works, power station and other potential sources of airborne heavy metal contamination. The site was originally part of a small horticultural farm and had also formerly included licensed waste management but no contamination was suspected. The site was pretreated with glyphosate but no fertilizer amendment was used. The plants were mulched in late summer with wood chip to aid weed suppression.

Conventional tractor-towed step-planters were used to plant SRC at three sites with varying success. Site (b) was part of an oil refinery complex within the Seal Sands petrochemicals complex. This industrial area is built within former salt marshes of the Tees Estuary on a raised platform typically composed of blast-furnace slag with some thin imported soils. The North Tees area includes the site of a former Zn and acid works that had associated widespread heavy metal soil contamination. The pilot site had previously been used for land-farming of dissolved-air flotation scum, a foam of crude oil, air and formation water generated by the initial treatment of crude oil. Land-farming, a type of bioremediation, involved regular ploughing of soil within shallow bunded depressions, onto which oil-water mixtures were occasional discharged or covered with imported soil. As a result the land was already in a cultivated state.

Site (c) was an agricultural site on heavy clay soil with no known contamination. The site is in a rural area but still only 2 km from heavy industrial facilities, including a chromium metallurgical plant. The main area of the 4 ha site was planted with a mixture of six clone varieties, including Scandinavian and UK examples. No amendments were made. Smaller single clone plots were also planted for direct comparison of performance. An area of miscanthus rhizomes were planted semi-mechanically by dropping into the slit made by a sub-soiler. Reed canarygrass and switchgrass were broadcast, although the latter failed to establish.

The following year site (e) was used for a broader trial of the technical and regulatory issues of establishing crops on non-agricultural land. The former shipyard had been cleared in preparation as an industrial estate. The soil was essentially made ground on former salt marshes, comprising coal ash, crushed brick, concrete and slag, mixed with clay. Site preparation included amendment at 250T/ha of composted source-segregated green waste prepared to BSI PAS100 (2005) standard. At the time this material was still treated as a "waste" by the UK Environment Agency until fully "recovered" by combination with the receiving soil, and was therefore subject to UK Wastes Management Licensing Regulation (1994). This amendment rate was the maximum annual application to land permitted under a Paragraph 7A Exemption for "Land Treatment for Agricultural Benefit or Ecological Improvement", a formal derogation under specific circumstances from the usual regulatory controls. It was only equivalent to adding a layer of compost < 5 cm thick across the site. During site preparation with a sub-soiler plough a variety of obstructions were encountered, including steel plate, wire rope, bricks, boulder-sized pieces of slag and concrete. SRC was step-planted but due to remaining ground obstructions and the stony made ground, poor penetration was achieved with cuttings left protruding from the soil. Due to difficulties of site preparation and the regulatory issues surrounding compost use, the planting was not completed until late May and was followed by a period of drought. As no perimeter rabbit fencing was erected, the substantial rabbit population in the surrounding site nibbled shoots and all willow cuttings later died.

To establish if soil composition and contamination had contributed to this failure limited replanting was carried out by hand using 2 m willow whips protected by spiral plastic tree-guards. They were planted by inserting into a 0.5 m hole created using a crowbar and then watered in thoroughly. These willows survived where tree guards remained intact. It is this growth which is used to compare fuel characteristic to the other sites.

SOIL CONTAMINATION

Surface soil samples were collected during walkover site survey, typically at depths of 10-20 cm. Pots of > 1kg were submitted to commercial laboratories (Seven Trent or NRM) for contaminant suite analysis (Table 2). Current UK soil guideline values are set as triggers to indicate levels of contamination requiring further investigation and site-specific assessment (DEFRA-EA, 2002). The values vary according to the sensitivity of the end-use, reflecting the pollution linkage from source, though pathways, to the receptors that it introduces. The sites can be ranked in order of the severity of contamination as follows: site e (shipyard) > site a (coal ash landfill) > site b (land farm) > site d (urban control) > site c (rural control). Sites a and e show average concentrations of As and Ni respectively that exceed the SGV for allotments or residential uses with plant uptake, and both have Cu and Zn levels exceeding the ICRCL (1987) thresholds for the onset of phytotoxic effects at low pH.

Table 2. Concentrations of potentially toxic elements in soils (ppm).

Site code	(a)	(b)	(c)	(d)	(e)	SGV[a]	ICRCL[b]
No. samples	8	3	2	2	6		
As	31	10	4.7	8.0	18	20	n/a
Cr	29	28	33	28	45	130	n/a
Cu	130	30	12	23	1153	n/a	130
Pb	271	73	37	60	425	450	n/a
Ni	51	21	21	22	161	50	70
Zn	365	168	68	111	541	n/a	300
Cd	0.86	0.34	0.17	0.28	0.62	1, 2, 8	n/a
Hg	0.42	2.49	0.06	0.15	0.48	8	n/a

[a]soil guideline values, [b]Inter-Departmental Committee on the Redevelopment of Contaminated Land

BIOMASS FUEL ANALYSIS

All crop samples were collected between mid February and late March 2007. Representative examples of willow SRC were cut using a pruning chain saw whereas the smaller areas of miscanthus and reed canarygrass were completely harvested by hand using gardening secateurs or edging shears. All material was hand supported during sampling and collected with extreme care, so as to avoid any additional soil contamination. The material was not washed, as the intention was to assess the contribution to the fuel composition that any adhering contaminated soil dust would have after conventional harvesting, together with any plant uptake. All samples, including the grasses, were processed on site using a petrol-driven garden chipper. After homogenization 25L sub-samples were sealed and dispatched to a specialist commercial laboratory (Knight Energy Services Ltd) for fuel and contaminant suite analysis (Table 3).

Contamination by potentially toxic elements is at sub-ppm levels for elements other than Zn and Cu. The Zn contents found in SRC willow are consistently higher than for other crops grown at the same site (Fig. 1). Cd concentrations are lower but are only detected in SRC. The highest recorded Cu concentration also occurs in SRC from the most Cu contaminated site.

Ash contents are higher for the grasses than for the SRC willow, particularly for reed canarygrass. The ash compositions are calculated as weight percent oxides for an ashed sample, so reflect the compositions of the ash component, rather than the actual concentration in the biomass. The relative proportions of alkali metals show consistent differences for each crop. The ash of willow SRC is richest in K_2O, in miscanthus this is accompanied by higher concentrations of SiO_2, whereas in reed canarygrass K_2O and Na_2O are lower but SiO_2 is higher still. The different elemental ratios indicate that this is not merely due to different degrees of soil adhesion related to the different physical properties of the plants. Levels of fluorine are uniformly low, whereas chlorine shows wider variation.

Table 3. Biomass fuel quality

Site	(a)	(a)	(a)	(b)	(c)	(c)	(c)	(d)	(d)	(d)	(e)
Crop	SRC	MC	RC	SRC	SRC	MC	RC	SRC	MC	RC	SRC
Contaminants (ppm)											
As	< 0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cr	0.18	0.4	0.47	0.41	0.97	1.3	0.28	< 0.1	< 0.1	0.34	0.57
Cu	5.2	2.3	5.8	6.2	3.9	2.1	2.5	3.3	0.86	3.2	35
Pb	<0.30	0.36	2.08	0.47	0.36	<0.30	<0.30	<0.30	<0.30	0.4	3.73
Ni	0.33	0.36	0.54	0.61	0.58	0.25	0.34	0.22	< 0.1	0.47	0.46
Zn	160	48	100	180	132	58	28	74	8.1	55	200
Cd	0.26	<0.05	<0.05	0.95	0.41	<0.05	<0.05	0.34	<0.05	<0.05	0.15
Hg	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Halogens											
Cl (%)	0.13	0.31	0.31	0.28	0.03	0.07	0.69	0.10	0.22	0.25	0.48
F (ppm)	220	210	230	220	220	210	220	220	230	220	220
Ash content											
(%)	1.5	4.0	6.7	1.8	1.8	4.1	5.6	2.0	2.6	6.7	2.3
Ash composition (weight % oxides)											
Na_2O	1.59	1.89	0.40	3.54	1.49	1.90	0.49	0.60	0.79	0.45	3.34
K_2O	18.75	10.33	2.44	18.27	21.25	6.46	4.15	17.96	10.71	3.38	18.68
SiO_2	2.19	68.42	83.36	3.74	1.72	73.69	82.99	4.42	77.24	84.01	5.77

Note: SRC = short rotation coppice, MC = miscanthus, RC = reed canarygrass, SG = switchgrass.

DISCUSSION

An excellent environmental case can be made for the activities and results that the full scale BioReGen project will demonstrate: Climate change is addressed both by providing carbon-neutral biomass and by diverting biodegradable material from landfill as compost and thereby reducing methane emissions. In situ remediation of organic contaminants is anticipated due to amendment and cultivation while sequestration and phytoremediation may have a long-term impact on available metal contamination. Not only are organic wastes diverted but this activity also eliminates the need for disposal of contaminated soils as hazardous wastes. Instead the land is reused for a purpose for which it is suitable and without displacement of land otherwise used for food production. This is a low energy passive treatment or management strategy for a contaminated brownfield site, without the energy intensive, resource utilization or waste generation that typifies many remediation methods. Wider environmental benefits include the improved aesthetic and amenity value, coupled with habitat creation and ecological value that exceed those of more intensive farming on agricultural land. In summary, the type of brownfield land use envisaged following application of the BioReGen Project results appears to meet the economic, environmental and social aspirations of sustainable development.

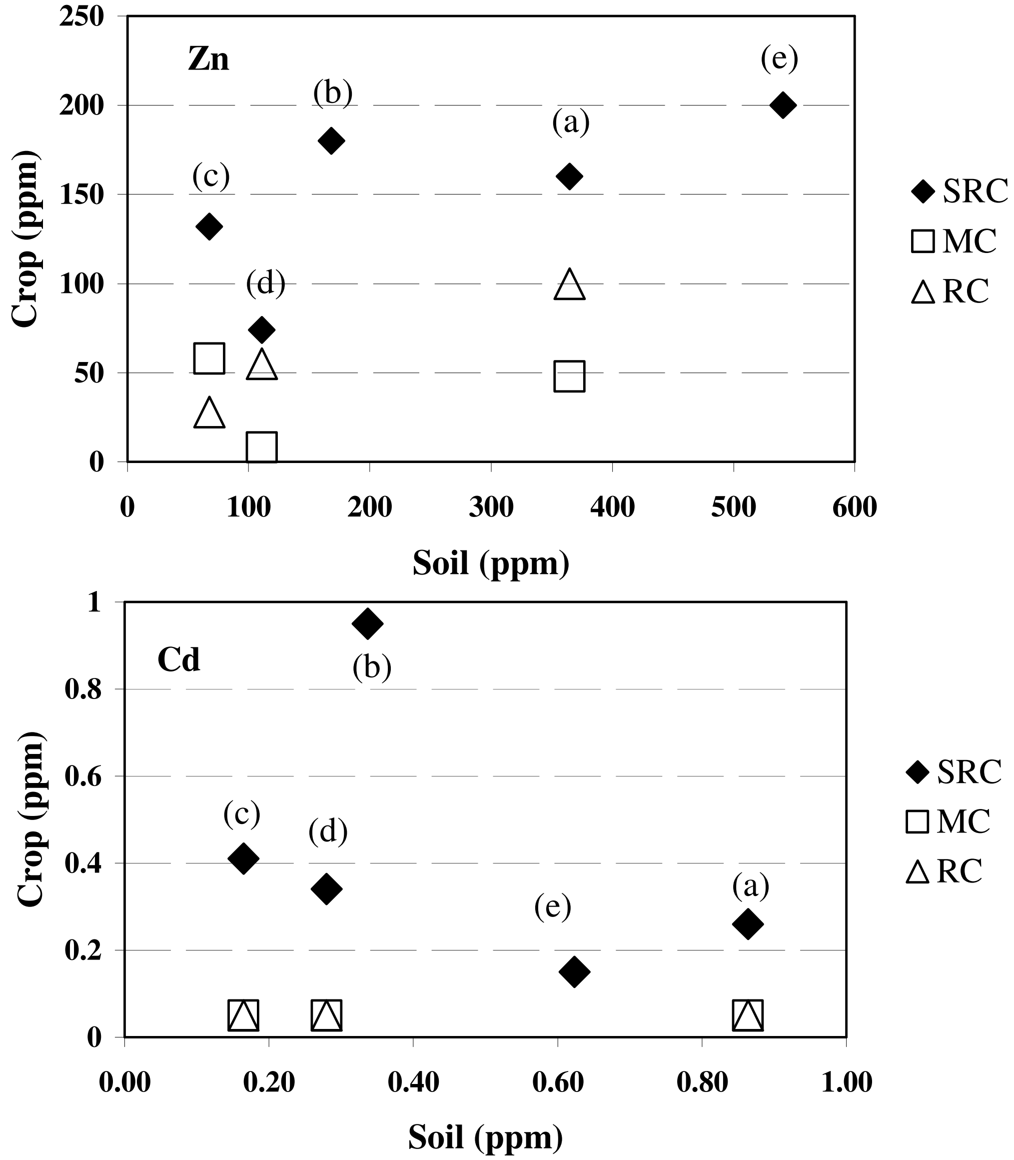

FIG. 1. Comparison of Zn and Cd contents of biomass types to average host soils at each energy crop site (a, b, c, d, e). Note: SRC = short rotation coppice, MC = miscanthus, RC = reed canarygrass.

Our pilot scale plantings have shown that a range of energy crops can be successfully established on potentially contaminated brownfield land. Uptake of available Zn and Cd by willow is reported in the literature (French et al. 2006), which is consistent with the higher contents of these metals reported here in SRC at each site. Assuming the metals are extracted from a 0.3 m soil profile, a conservative harvest of 10 oven-dry tonnes per hectare, biomass concentrations of 1 ppm Cd and 200 ppm Zn equate to annual removal of 2 ppb Cd and 40 ppb Zn from the average soil concentration. Critically, it is the most available (and hence most ecotoxic) fraction of the contaminant that is removed by phytoremediation (Lord et al. 2007). Higher metal uptake can be expected on more contaminated sites.

Conversely, planting other energy crop species will produce clean fuel while reusing a dirty site. Differences in ash contents and compositions between biomass types indicates that any undesirable characteristic of one fuel can be offset by blending with another to gain an intermediate composition between those given in Table 3.

In northern UK 1 ha of energy crop can produce fuel for 1-1.5 KWe of continuous generation. The scale of available derelict land would allow immediate widespread implementation without displacing food production. Furthermore, if this carbon-neutral renewable energy is used to reduce use of fossil fuels, the BioReGen approach to phytoremediation probably also has the smallest carbon footprint of any currently available remediation technique.

CONCLUSION

Field scale trials confirm the technical feasibility of reusing brownfield sites to grow energy crops. The higher relative Cd and Zn content of SRC biomass offers the prospect of additional long-term phytoremediation during biomass production. Future trials will demonstrate the commercial viability of these fuels.

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