Green waste for greening brownfields: Using compost to establish energy crops on previously developed land.

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1. INTRODUCTION

Re-using brownfield sites for energy crops offers a unique opportunity to produce carbon-neutral biomass fuels without impacting on food production. The peri-urban context of many previously developed sites means that the synergistic re-use of organic wastes is economically viable, providing nutrients and adding value to the economic returns of biomass fuels. This industrial symbiosis diverts waste from landfill and methanogenesis, further reducing greenhouse gases and creates a sustainable alternative to redevelopment that is immune to recession and decoupled from economic growth. The capital cost of using productive agricultural land for biomass production is avoided. Instead, degraded land is improved with ecological improvement and biodiversity. Wider environmental and social benefits can accrue to post-industrial areas from such aesthetic improvement, with the potential for locally sourced biomass contributing to community or economic redevelopment of deprived areas.

For contaminated land, the potential synergy between organic waste recycling and biomass production extends to long-term risk management (Paulson et al, 2003). Cultivation and use of composted wastes as soil amendment is likely to promote *in situ* bioremediation of organic contaminants, stabilize and reduce the mobility of inorganic contaminants. Long-term growth and harvesting of willow is known to have the potential to reduce the concentration of certain mobile phyto-toxic contaminants (e.g. Zn, Cd, B) via phyto-extraction (Dickinson et al, 2009). Consequently, the resulting biomass fuel crop might be contaminated from such plant uptake or by contaminated soil adhesion, necessitating additional testing and adequate air pollution control measures to be used following combustion. However, if derelict industrial sites are suitable for use in their current condition for energy cropping this avoids the need for energy-intensive processed-based remediation, or excavation and removal, a solution which simply relocates and contains pollution as a challenge for future generations. Indeed, many "hard core" contaminated sites have negative asset values reflecting the costs of future remediation, or on-going maintenance costs, which might be partly offset if adequate biomass growth can be successfully established. Such wider economic, environmental and social benefits support this type of re-use as a sustainable option for derelict brownfield land and an example of a "green" approach to remediation.

2. METHODOLOGY

Following promising results at smaller scale trials on brownfield sites between 2004 and 2006 (Lord et al, 2007; 2008a; 2008b) short-rotation coppice (SRC) willow (*Salix* spp.), miscanthus (*Miscanthus* spp), reed canarygrass (*Phalaris arundinacea*) and switchgrass (*Panicum virgatum*) were planted at five 1 ha demonstration sites in 2007. The EU Life III Environment Programme Project ENV/UK/00128 "**Bio**mass, **Re**mediation, re-**Gen**eration (**BioReGen**): Re-using brownfield sites for renewable energy crops" (www.bioregen.eu) was a partnership between Teesside University, C.J. Day Associates, the New and Renewable Energy Centre, and, initially, North East Community Forests. It also provided the framework for two Waste & Resources Action Programme (WRAP) "Trailblazer" projects (OBF001-012 and OBF010-005) to examine the feasibility of using BSI PAS-100 (2005) compost to establish SRC and other energy crops on brownfield land and then to monitor the longer-term benefits of compost use in brownfield soils.

2.1 *Site characterisation*

For each demonstration site the previous development history and nature of any potentially contaminative previous industrial uses were first confirmed by desk study. The 1 ha sites included a former shipyard (site 1, Haverton Hill), a former iron and steel works and tip alongside railway land (site 2, Tees Barrage) on Teesside, a former colliery and coking site (site 3 Binchester) near Bishop Auckland, a former sewage treatment works (site 4, Rainton Bridge)in Sunderland, and a restored former landfill (site 5, Warden Law) in Sunderland. The current status and ground conditions varied from cleared sites with made ground, to semi- or fully-restored clay, subsoil or topsoil capped grassed open space. Representative surface soil samples (0-0.1 m depth) were collected and analysed for suites of determinants including inorganic and speciated organic contaminants, total and available nutrients, organic matter, soil constituents and physio-chemical parameters. The results indicated generally low levels of contaminants but poor nutrient status and limited organic matter content.

2.2 *Site preparation*

The five 1 ha demonstration sites were prepared for planting in March-May 2007, which typically involved the following general sequence of activities. Firstly, all sites with long grass were topped, then sprayed with glyphosate (generic Round-up) to remove weeds. Secondly, for derelict sites, any ground obstacles and boulders were first removed with a JCB digger. The soil was then broken with a three-prong ripper, prior to removal of any further unearthed obstacles with the JCB. A stone-rake was used to collect larger stones, which were then removed with the JCB. Capped sites were typically either ripped or ploughed prior to disking, or just heavy-disked repeatedly. For one site (Binchester) where an engineering operation was planned to replace soil from an on-site mound, boulders, bricks and other physical obstructions were first removed from the soil source (*ex-situ*) using a power-screen and back-actor. Thirdly, once the soil was ripped or ploughed, all sites were sprayed with chlorpyrifos (Dursban) to eliminate leather jackets (crane fly larvae), followed by erection of rabbit fencing. Typically this involved wooden posts inserted at 2m intervals using a post-driver, or excavated post-holes where necessary, with 1.2 m high wire mesh, keyed into a trench at the base.

2.3 *Compost application*

It was planned to amend all sites with composted source-segregated green waste prepared to PAS 100 standard (BSI PAS100: 2005) at a range of rates. This would determine the appropriate compost application prior to planting to ensure optimum establishment and productive growth of SRC and other energy crops on non-agricultural land. As the trials pre-dated the introduction of the protocol for re-use of quality compost (WRAP, 2007), a formal notification of an exempt activity from Waste Management Licensing Regulations 1994 (as amended) for "reclamation, restoration or improvement of land" (Paragraph 9A) was required. Compost was applied by surface spreading at rates of 250t.ha^{-1}, 500t.ha^{-1} and 750t.ha^{-1} and incorporated by disking in separate plots for each site for the SRC planting area and for all species areas at one entire site (Rainton Bridge). At the other four sites the rate for grass species was typically 500t.ha^{-1}. Unfortunately, no true control area (i.e. planted without compost application) was possible. However, the areas of each site with an application rate of 250t.ha^{-1} provided a common reference point from which to assess the benefits of the higher application rates possible under the Paragraph 9A exemption compared to the annual limit set by a Paragraph 7 A exemption on agricultural land.

2.4 *Planting*

SRC willow (Tora or Torhild varieties from Coppice Resources Ltd) was planted with a conventional step-planter, using 20 cm cuttings at a planting rate of 15,000ha^{-1}. Miscanthus rhizomes (*Miscanthus x giganteus* from Bical Ltd) were planted using a modified potato-planter at c.20,000 per hectare; Reed canarygrass was sown from seed (uncertified seed supplied by Advanta) at 20kg.ha^{-1}, whereas switchgrass (Ernst Seeds, variety Shawnee) was sown at 10kg.ha^{-1} following rate recommendations of Lewandowski et al. (2003). Both seeded grasses were broadcast sown.

Finally, all seeded and planted areas were rolled with a Cambridge roller. Further details of the trial establishment are given in Lord et al, (2008b).

3. RESULTS

3.1. *Compost composition*

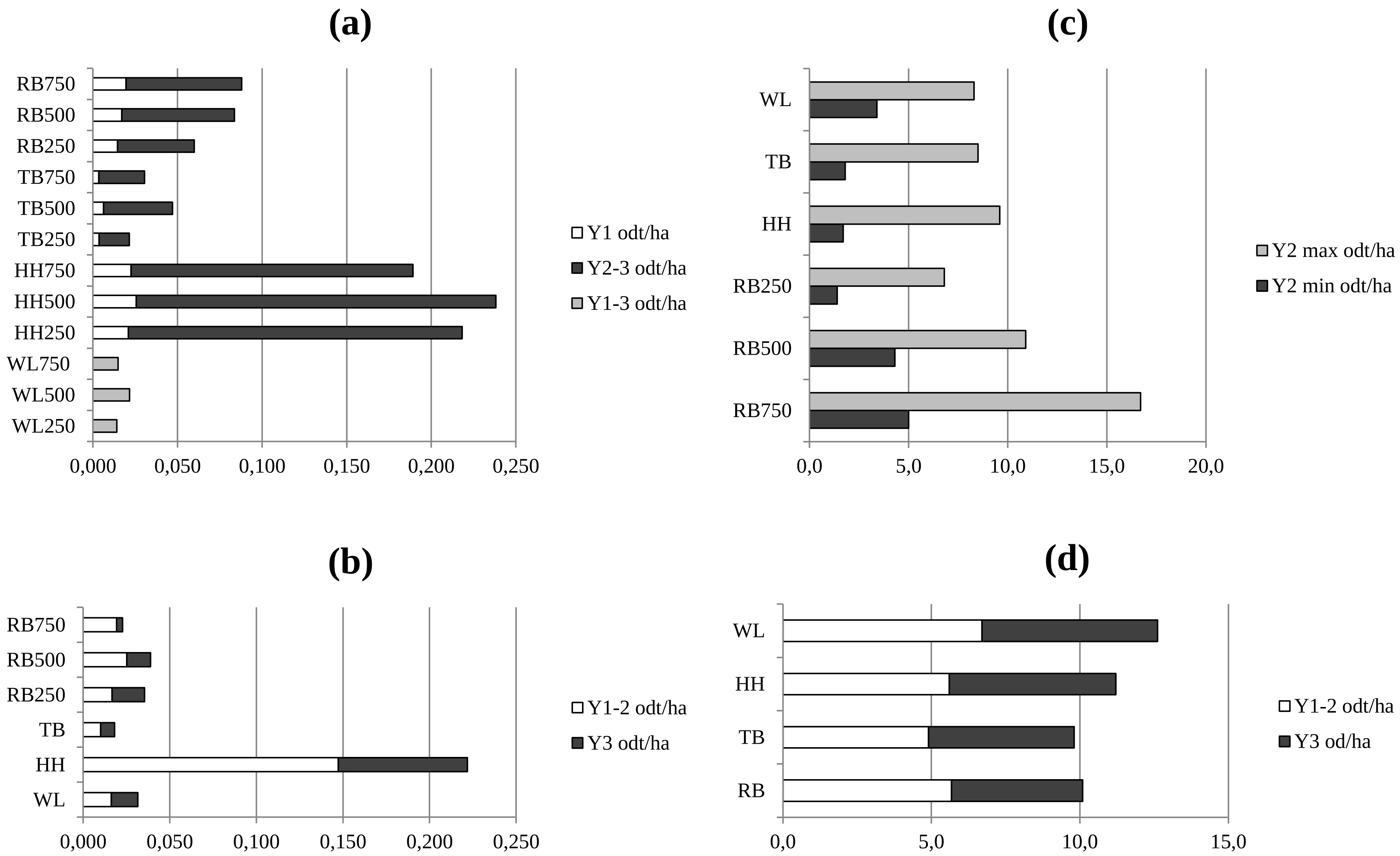
The compost was stockpiled after delivery to site allowing analysis for the same suite of inorganic and speciated organic contaminants, total and available nutrients, organic matter, soil constituents and physio-chemical parameters used for the receiving soils. The concentration ranges (in $mg.kg^{-1}$) for Cd (0.41-0.45), total Cr (18-42), Cu (42-59), Pb (88-106), Hg (0.22-0.37), Ni (15-32) and Zn (137-159) were acceptable for the six samples compared to limits for potential toxic elements set for PAS100 compost, and below the original Soil Guideline Values (DEFRA-Environment Agency 2002) then available for other elements such as As (7.9-10.3) or Se (0.43-0.54) or the current replacements (Environment Agency 2009). However, the concentrations of water-soluble B (8.4-12.4) were consistently above the limit set previously by ICRCL 59/83 (1987) for the potential onset of phyto-toxicity ($3mg.kg^{-1}$). Although this document is withdrawn from use, this particular threshold value is consistent with phyto-toxicity effects reported in the literature, including those specifically for leachable boron in municipal compost (Purves & Mackenzie, 1974). The worst case analysis and maximum application rate in our study corresponds to a B addition exceeding 9 $kg.ha^{-1}$, so initially phyto-toxic concentrations (i.e. above 3 mg/kg) might be expected to occur before leaching if compost was combined in soil profiles less than 0.3 m thick, which was the case in all of our trial areas.

Total nutrient concentrations (as % dry weight) of N (0.72-1.15), P (0.15-0.20) and K (0.53-0.82) were present in the compost as delivered with a moisture content of 30-39 % and organic matter content (by loss on ignition) of 27-37 %. Variable but limited available N was present (37-593 $mg.kg^{-1}$). For the average compost application rate of $500t.ha^{-1}$ this corresponds to an initial available N application of $11\text{-}180kg.ha^{-1}$. Compost is a slow-release source of N for which a first-year availability of 6% can be assumed from bio-degradation in healthy agricultural soils, corresponding to $132\text{-}215kg.ha^{-1}$ for our compost if applied at $500t.ha^{-1}$. This loading is then comparable with the current farm and field Nitrates Directive (1991) limits of $170kg.ha^{-1}$ and $250kg.ha^{-1}$ respectively in Nitrate Vulnerable Zones.

3.2 *Soil nutrients*

Representative samples of the amended soils were collected from each site starting in late summer 2007 shortly after compost application and annually thereafter for two further years. The immediate effects of PAS100 compost application were to correct the original soil deficiencies in available P or perhaps K, while increasing soil organic matter content, in turn providing a potential slow-release nitrogen source. However, compost addition had little impact initially on the original deficiencies in available N. It was anticipated that monitoring in subsequent growth seasons should show further effects of compost degradation on total N, P or K. Year-on-year comparisons were obscured by sampling issues, due to the limited depth of incorporation at many sites, creating a bipartite soil with an amended upper horizon (typical 0.10-0.15 m) overlying a compacted clay substrate. However, it was clear that compost addition has a long-term effect on nutrient status and provides only a very slow release nitrogen source with very limited available or leachable N. Thus, the annual availability of the total nitrogen by compost breakdown rate in agricultural land (5-10%) may be unrealistic for brownfield soil conditions with limited previous aeration or microbial activity.

Fig 1.
Yields of (a) SRC willow, (b) miscanthus, (c) reed canarygrass (as range determined by quadrat sampling), (d) reed canarygrass (as mown and baled), all expressed as oven dried tonnes per hectare (odt/ha) for years 1 to 3 of trial (2007-9).



3.3 *Growth monitoring and establishment*

Growth at all sites was monitored after planting for three growth seasons (2007 to 2009). For the two sites without rabbit fencing (Binchester and Warden Law) the willow failed to establish in year 1. At the three remaining fenced field sites the maximum shoot height was measured for each plant and an estimation of the establishment rate made in comparison to the rate at which cuttings were planted. Establishment rates ranged from 15-57 % for different combinations of site and application rate. The willows were then pruned by hand in January 2008 to mimic the maiden cut of conventional agricultural establishment and oven-dried biomass yields determined for each site and compost application rate. Field measurements were repeated in years 2 and 3, culminating in a final hand harvesting to determine yields (Figure 1a). Significant losses were recorded after the initial pruning, resulting in net establishment rate ranges for years 2 and 3 of 5-27 % and 5-39 % respectively, the latter reflecting a slight recovery by re-growth at all sites.

Both grasses were harvested at the end of year 2 and again in year 3. For miscanthus (Fig. 1 b) the individual stems were cut by hand. Establishment rates could not be determined due to the growth of multiple shoots from each rhizome and subsequent natural "tillering" or spreading. For reed canarygrass 0.5 m x 0.5 m quadrats were initially used to cut growth in year 2 above 0.1 m in 10 typical and 10 optimum growth areas selected at each site, from which minimum and maximum growth rates have been extracted (Fig. 1 c). As prolific growth of reed canarygrass was observed in all cases, four sites were mechanically harvested in May and again in October 2009, which corresponds to the cumulative growth during the first two establishment years and third year annual growth respectively (Fig. 1d).

Switchgrass failed to establish at any site, although scattered individual specimens were observed at Tees Barrage and Rainton Bridge.

3.4 *Effects of compost application rate on yield*

A combination of first-year establishment rate, plant height measurements and first-year oven-dried biomass after pruning were used to assess the optimum first-year compost application rates to establish SRC willow on brownfield sites. Although site specific variations due to soil type, nutrient availability and site ground conditions were evident, as a rule of thumb $500 t.ha^{-1}$ appeared to provide the best compromise between establishment and growth. The effect of compost on establishment was ambivalent, sometimes negative. This may have reflected desiccation of cuttings by the application of dry compost in late Spring immediately prior to planting. In contrast, the overall biomass yield was related more directly to the height of plants, rather than the establishment rate, and was thus dependent on nutrient levels and compost application rate. The longer-term benefits of the differing compost application rates selected can be deduced from the successive biomass yields (Fig 1 a). The highest yields for each site were achieved after applications of either 500 or $750 t.ha^{-1}$.

At Rainton Bridge the quadrat survey revealed a clear response to compost addition for reed canarygrass that was observable in the field as a combination of density and height. This is reflected in the proportionate increase in both minimum and maximum yield local yields with increasing compost rate. The response for miscanthus is ambiguous, which has struggled to establish at this site.

This result has clear implications for the type of compost used and regulatory permit required. Standard Rules Environmental Permits SR2010No4 and SR2010No5 have recently replaced Paragraph 7 or 9 exemptions respectively within the Environmental Permitting Regime (Statutory Instruments 2007 and 2010). The higher rates (i.e. $> 250 t.ha^{-1}$) possible from the choice of a Paragraph 9A notification are restricted to Standard rules SR2010No5 "Mobile plant for the reclamation, restoration or improvement of land" and to brownfield land for source-segregated green waste compost. Alternatively, the Quality Protocol approach can be used instead for application of quality compost (a recovered product) purchased from a fully Quality Protocol certified PAS100 compost supplier.

3.5 *Site conditions and species performance*

For both willow and miscanthus a significantly higher yield was obtained at one site, Haverton Hill, a former shipyard area of made ground which includes granular contaminated coal ash and slag dominated soils. Perhaps significantly, this is the only trial site that had not been capped, providing hydraulic continuity between soil and shallow groundwater.

Reed canarygrass has shown excellent establishment and yield at all sites (Fig 1d), including those which were either, elevated and free-draining, clay capped, compacted, waterlogged in winter or desiccated in summer – all common features of many brownfield sites. Reed canarygrass is a marginal wetland native species so would appear to be naturally suited to non-agricultural soils. It was observed to out-compete weeds and tolerate rabbit grazing, which distinguishes it from SRC and negates the need for expensive rabbit-fencing. Consistent dry yields ≥ 5 odt/ha in the second and third seasons after planting, coupled with simple and economical establishment distinguishes it as the best candidate species for rapid temporary deployment on derelict under-utilised or neglected land or brownfield sites awaiting redevelopment.

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