THE USE OF RECYCLED ORGANIC WASTE AS A SOIL AMENDMENT FOR GROWING SHORT ROTATION COPPICE

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Abstract

This paper presents initial results of an investigation of the potential of using PAS 100 graded compost and Compost-Like Output (CLO) as a nutrient source for short rotation coppice energy crops. Initial analysis of the PAS 100 compost and CLO measured; electrical conductivity, pH, total nitrogen and total heavy metal content. Pot trials using both PAS 100 compost and CLO were then used to assess the growth rates of Willow (*Salix viminalis)* at application rates equivalent to 1500 and 3000 kg N/ ha mixed with an inert growing medium (perlite). A plant image analysis program was designed as a quick, simple and non-destructive plant growth estimation method to be compared to manual measurements.

Initial results showed higher total metal content in the CLO than PAS 100 compost, with both showing electrical conductivity levels of over 2.0 mS/cm. Excess soluble salts thought to be the cause of reduced initial growth of *Salix viminalis*. There are however indications of re-growth after leaching of the excess salts from the main body of compost.

Keywords

Recycled organic waste, PAS 100 compost, compost-like outputs, soil amendments, short rotation coppice.

Introduction

The European Landfill Directive (1999/31/EC) was introduced to reduce the dependence on landfills for the disposal of waste and to drive waste up the waste hierarchy by reducing, re-using and recycling materials. In particular as part of the Landfill Directive, strict limits have been introduced to control the amount of biodegradable municipal waste reaching landfills and by 2020 quantities of biodegradable municipal waste must be reduced to 35% of the levels reaching landfill in 1995 (Stretton-Maycock and Merrington, 2009).

The diversion of biodegradable waste from landfills results in the beneficial reduction in generation of methane from the decomposing organic material in anaerobic conditions. To enable this diversion local waste disposal authorities encourage source segregation of recyclable waste by households as well as biodegradable waste suitable for anaerobic digestion and energy production (CIWM, 2010; Environment Agency, 2010a). As an additional measure mixed Municipal Solid Waste (MSW) is sent to Mechanical Biological Treatment (MBT) plants to mechanically sort and segregate waste before biologically treating biodegradable material (Merrington *et al*. 2010).

The source and pre-treatment of waste streams determines the characteristics and future potential uses of the Recycled Organic Wastes (ROW). PAS 100 compost and Compost-Like Output (CLO) have received increased commercial interest as MBT by-products (WRAP, 2008; Stretton-Maycock and

Merrington, 2009). Compost created from source segregated organic waste streams can be commercially sold as PAS 100 compost under a British Standards certification scheme to demonstrate a minimum quality. In contrast, CLO is the biodegradable fraction from mixed MSW and has the potential to contain heavy metals, glass and plastics (Merrington *et al.* 2010); currently there is no standard specification for CLO so its characteristics can vary widely. CLO use is currently limited to a temporary landfill cover, or habitat restoration of landfill sites if it can be demonstrated that it brings ecological benefit to the restoration.

The uses of ROWs as soil amendments has two main benefits; 1) Use as a plant nutrient source, 2) as a soil conditioner to improve the soil structure (Britt *et al.* 2002). Source segregated ROWs which pass the PAS 100 Standard can be applied to land as an agricultural or horticultural nutrient source. The use of CLO however is restricted to brownfield sites only by England and Wales Environment Agency because of the potential heavy metal content from the MSW (Environment Agency, 2011). It has been suggested that CLO can be used on brownfield sites as a fertile soil amendment to aid the growth of short rotation coppice crops (Bardos *et al.* 2007; Chapman 2007).

Short rotation coppice has been identified as a suitable renewable biomass for use as a low carbon fuel to produce renewable heat and /or electricity. This is current of high relevance as the UK is committed to producing 20% of electricity from renewable fuel sources under the Climate Change Act 2008 (Environment Agency, 2010b). To be economically effective short rotation coppice crops require fast growing species to produce high yields every 2 to 4 years (Tubby and Armstrong, 2002).

The plantation of short rotation coppice crops on brownfield sites with ROW amendments to improve the growing medium and ensure sufficient nutrients are available for rapid growth has been identified as being potentially beneficial (Bardos *et al*. 2007). In particular ROWs are a significant source of nitrogen which is one of the most common limiting factors to the growth of plants (Madrid *et al*. 2007; Fircks *et al.* 2001). It should be noted that fertiliser application to agricultural land is restricted to 250 kg N/ ha due to the potential leaching risks associated with soluble nitrates and this restricts the usage of ROW on a site-by-site basis. Furthermore whilst ROW total nitrogen content typically ranges between 1.1% and 2.1% (Merrington *et al.* 2009ab) it is present mainly in organic forms which are less soluble because organic nitrogen must be mineralised by bacteria to become available to plants as nitrate or ammonium (Amlinger *et al*. 2003).

Currently the Environment Agency grant bespoke permits for the application of CLO to land for scientific trials (Environment Agency, 2011). In such cases the heavy metal, nitrogen and electrical conductivity content of the CLO is often the main limiting factor in restricting the use of CLO to brownfield sites because of evidence from previous studies that repeated CLO application to soil results in the build up of heavy metals in soil (Ayari *et al*. 2010; Madrid *et al.* 2007; Smith, 2009; Lee *et al*. 2004).

This paper presents an investigation into the potential use of two ROW products as nutrient sources for Willow (*Salix viminalis)* to be grown as energy crops in the UK. PAS 100 compost and CLO was analysed to compare the material characteristics. Pot trials are used to assess the ability for *S. viminalis* to be grown at the equivalent of 1500 and 3000 kg N/ ha of CLO and 3000 kg N/ ha of PAS 100 compost to control pots.

Methodology

ROW samples

PAS 100 compost was collected from a recycling centre in South Wales which is PAS 100 accredited by the Composting Association. The compost was derived from segregated food wastes which had been in-vessel composted for between 7 and 21 days before being further maturation for up to 10 weeks.

The CLO was sourced from a MBT in the south of England from a mixed MSW stream. The Biodegradable fraction of MSW is separated from the mixed waste and composted in bio-stabilisation halls for 6 weeks with repeated aeration and irrigation to maintain optimum composting conditions.

ROW sample preparation

Both compost materials were stored at <4°C in sealed containers before analysis and use in the growth trials. Each material was tested to determine the moisture content, electrical conductivity, pH, bulk density, total nitrogen and total metal content. The bulk density of ROW was determined using wet mass weight and volume. Approximately 500g of each material was weighed out in 250g batches, dried for 16 hours at 80°C and weighed again to calculate the moisture content. Electrical Conductivity (EC) and pH of each sample was tested by using 1:5 ratio of material to ionised water before using mettle Toledo Seven Multi (UK) testing probes, See BS EN 13038 and BS EN 13037 for testing methods respectively.

To determine the total nitrogen and total heavy metal content of ROW, 100g of dried sample was ground using a gyro crusher to grind and homogenise the sample material to a ,2mm fraction. Total nitrogen content was analysed using a total nitrogen analyser (Shimadzu, UK). The total heavy metal content used a full *aqua regia* digestion of the samples before ICP-OES (Perkin Elmer Optima 2100 DV, UK) analysis.

Pot Trials

S. viminalis cuttings approximately 150mm in length were planted in commercial compost for 4 weeks to allow roots and shoots to develop. For replanting with ROW, the root systems were washed to remove all compost soil. *S. viminalis* saplings root length, number of shoots, sapling length and weight were recorded.

S. viminalis was grown in CLO at concentrations equivalent to 1500 kg N/ ha and 3000 kg N/ ha with 3 replicates each, PAS 100 compost pots were grown at concentrations equivalent to 3000 kg N/ ha with 3 replicates each. For material input calculations average total nitrogen, bulk density and dry mass content were used for each material; the field mix depth was assumed as 150mm. Perlite was used as an additional inert growing medium mixed with the ROW. Control pots containing perlite only were watered weekly with 100ml of quarter strength Hoagland solution (Sigma Aldrich, UK) as a nutrient supply, and additional 100ml deionised water. ROW pots were watered weekly with 200ml of deionised water. Pot trials were grown under daylight spectrum fluorescent bulbs for 16:8 hours of light: dark, at temperatures ranging between 15-28°C on a diurnal temperature cycle, for 5 weeks.

The growth rates of *S. viminalis* were monitored weekly by manual height and leaf measurements, and observational notes. Weekly photographs were taken of each plant from 3 fixed points.

Plant analysis program

Matlab (Mathworks, UK) was used to create a plant analysis program using three photographs taken from fixed points at 0°, 45° and 90° on each pot. Plant height was calculated from a datum established at the top of the plant pot from a cropped image. Weekly photos of each pot were imported to Matlab and the final calculated data exported into Microsoft Excel.

Results

ROW characteristics

Initial ROW were analysed to compare the differences between source segregated (PAS 100) and mixed MSW stream (CLO) composts. Table 1 shows the initial characteristics of PAS 100 and CLO alongside the PAS 100 heavy metal compliance concentrations for BSi certification (BSi, 2011).

There is a notable difference in the results between PAS 100 compost and CLO. PAS 100 compost has a fairly alkaline pH compared to a neutral pH in the CLO. The EC of the CLO was over twice as much as the PAS 100 compost. The moisture content of the ROWs differed significantly, with the CLO having a moisture content of 10.94% compared to PAS 100 of 58.05%, as a result of different storage conditions. PAS 100 compost has a greater total carbon and nitrogen content than CLO, although they both have similar carbon: nitrogen ratios.

The heavy metal concentrations identified in the PAS 100 compost sample were all below the BSi compliance limits except zinc which was 464.73 mg/ kg^{-1} when the limit is 400 mg/ kg^{-1} limit. The concentrations of cadmium and chromium in CLO were below the PAS 100 certification limits, however the copper, lead, nickel and zinc all exceeded the limits. In particular the copper and zinc concentration in CLO were higher than the standard limits.

Table 1: BSi PAS 100 minimum quality limits, PAS 100 compost and CLO initial characteristics

Parameter	PAS 100 Limits	PAS 100	CLO
pH		9.29	7.37
Electrical Conductivity (mS/cm)		2.15	5.82
Moisture Content (%)		58.05	10.94
Total Carbon (%)		38.71	23.2
Total Nitrogen (%)		2.59	1.49
Carbon: Nitrogen Ratio*	20:1	14.95	15.57
Total Cadmium (mg/kg)	1.5	<1.0	<1.0
Total Chromium (mg/kg)	100	41.02	85.2
Total Copper (mg/kg)	200	133.00	419.05
Total Lead (mg/kg)	200	92.16	275.55
Total Nickel (mg/kg)	50	11.02	60.16
Total Zinc (mg/kg)	400	464.73	1667.83

**Recommended C: N of soil improvers (Edwards et al. 2011).*

Pot Trials

Within the first week of planting there were visible signs of distress shown by all trial pots. All *S. viminalis* shoots on specimens grown in CLO and PAS 100 compost were pale green with yellowing and wilting leaves. The lower leaves on the control plants had also turned yellow, however upper leaves remained green. In the third week there was evidence of new bud growth in both CLO pots 4 and 6 pots (1500kg N/ ha) and in one PAS 100 (PAS 2, 3000kg N/ ha) pot. The remaining PAS 100 and CLO specimens showed no evidence of new growth, with the remaining yellow and wilted leaves curling. In contrast, the cuttings in the control pots had green and healthy shoots with no visible signs of distress. Table 2 shows the results.

After 5 weeks of growth the CLO (CLO 4) specimen containing equivalent to 1500 kg N/ ha nitrogen loading showed evidence of new growth and at week 3 had developed small buds in place of the previously wilted stems. Specimen CLO 6 (1500 kg N/ ha) had no evidence of new growth. The PAS 100 specimen (PAS 2) which showed new growth at week 3 did not fully recovery and showed no evidence of new growth; although the replicate [PAS 100 (PAS 3]) specimen with 3000 kg N/ ha of nitrogen rate had two small buds growing below the pot level at week 5. There was no evidence of new growth on any of the remaining ROW pot. The control pots were healthy with dark green leaves.

Plant analysis program

Due to initial wilting and limited re-growth of the CLO and PAS 100 compost pots; there were negative height changes after 1 week with little change over the following weeks. Control pots showed good growth as shown in Table 2. The relationship between the manual height measurements and the image analysed heights using the Matlab program showed good correlation with a R^2 value of 0.9832.

Table 2: Manual height measurements, Observations and Plant image analysis height measurements for week 0, week 1, week 3 and week 5

	Week 0		**Week 1**			**Week 3**			**Week 5**		
Plant ID	Manual Height (mm)	Matlab Height (mm)	Manual Height (mm)	Matlab Height (mm)	Observations	Manual Height (mm)	Matab Height (mm)	Observations	Manual Height (mm)	Matlab Height (mm)	Observations
CLO 1	122	126	115	119	Yellow, wilted	99	97	Wilted, NNG	96	97	NNG
CLO 2	164	166	162	163	Yellow, wilted	146	148	Wilted, NNG	143	136	NNG
CLO 3	162	163	151	149	Yellow, wilted	129	135	Wilted, NNG	126	126	NNG
CLO 4	121	116	107	101	Yellow, wilted	98	97	Wilted, SNG	96	94	2 small shoots
CLO 5	114	114	130	124	Yellow, wilted	111	110	Wilted, NNG	99	95	NNG
CLO 6	146	149	132	137	Yellow, wilted	124	129	Wilted, SNG	118	116	NNG
PAS 1	203	191	187	196	Yellow, some wilting	185	178	Wilted, NNG	185	-	NNG
PAS 2	188	-	185	143	Yellow, some wilting	146	148	Wilted, SNG	123	120	NNG
PAS 3	166	156	159	163	Yellow, some wilting	126	120	Wilted, NNG	124	114	2 small shoots
Control 1	138	142	141	148	Lower leaves yellow, top leaves green	227	-	Healthy growth	318	307	Health growth
Control 2	182	-	164	172	Lower leaves yellow, top leaves green	152	158	Healthy growth	229	226	Healthy growth
Control 3	157	-	151	155	Lower leaves yellow, top leaves green	156	161	Healthy growth	230	-	Healthy growth

CLO 1 -3 Total N application equivalent to 3000 kg N/ ha, CLO 4- 6 Total N application equivalent to 1500kg N/ ha
NNG No New Growth evident, SNG some new growth evident, - Image could not be processed.

Discussion

ROW

The initial measured pH of PAS 100 compost and CLO are consistent with previous studies that have shown the pH of ROW to range between neutral and slightly alkaline (Cameron *et al*. 2009). The impact of pH variations can be significant with the application of ROW to soils having a potential liming effect by increasing pH and soil buffering capacity (Cameron *et al*. 2009). Also increasing the bulk pH and buffering capacity of soils reduces the solubility of heavy metals by forming stable metal-humic complexes (Smith, 2009).

The total carbon and nitrogen concentrations present in the CLO were 23.2 and 1.49 % respectively; these are consistent with values measured by Merrington *et al.* (2010). An indication of the maturity of ROW is the carbon: nitrogen ratio. High C: N ratios of >30:1 can cause the immobilisation of inorganic nitrogen. Microorganisms immobilise the available nitrogen in ROW to decompose the high concentrations of organic matter thus reducing the available nitrogen for plant uptake. Once the organic matter is decomposed, the organic nitrogen within the organic matter can be mineralized to inorganic available forms (ammonium and nitrate). Edwards *et al.* (2011) suggest the threshold above which immobilisation occurs is 20:1, the C: N of PAS 100 compost and CLO were 14.95 and 15.57 respectively suggesting suitable maturity.

The EC of both ROWs was high, in particularly the CLO being classed as 'slightly saline' (4.0-8.0 mS/cm) (Cameron *et al*. 2009). Excessive EC is known to restrict the yield of crops and even levels of 1.4mS/cm can affect root develop and plant growth (Cameron *et al*. 2009). The high concentration of soluble salts affect the osmotic pressure created by roots to uptake water causing plants to wilt and restricting growth rates (Duggan, 2005; Cameron *et al.* 2009). Brady and Weil (1996, Cited in Hargreaves *et al*. 2008) identified MSW compost EC to range between 3.69 to 7.49 mS/cm consistent with the CLO concentration (5.82 mS/cm). The EC for the PAS 100 compost was measured at 2.15 mS/cm, slightly above the recommended range for PAS 100 compost as a soil improver of 2.0 mS/cm (Edwards *et al*. 2011).

The PAS 100 compost contained low concentrations of heavy metals; all metal concentrations were below the PAS 100 limits except zinc. The concentration of zinc exceeded the upper concentration to be certified as PAS 100 and as such would not be suitable for application to agricultural land.

The CLO heavy metal concentrations were higher than PAS 100 for 4 out of the 6 heavy metals tested. Cadmium and Chromium were below the PAS 100 limits of 1.5 and 100 mg/ kg respectively. The concentration of zinc in the CLO was over four times the PAS 100 limit, and significantly higher than previously reported values from MSW stream composts. Cameron *et al*. (2009) reported values between 492 and 585 mg/ kg and Smith (2009) between 130 and 757mg/ kg from UK sites.

Copper concentrations in CLO were 419 mg/ kg, over twice the 200mg/ kg PAS 100 limit. This value is similar to the values reported by Cameron *et al.* (2009) ranging between 240 and 481 mg/ kg, whereas Smith (2009) reported slightly lower levels of 25 to 306 mg/ kg. The levels of lead (275.55 mg/ kg) detected were only slightly above the PAS 100 limit of 200 mg/ kg. This was much lower than lead concentrations identified by Cameron *et al.* (2009) ranging between 612 and 630 mg/ kg.

The literature suggests zinc and lead are the most abundant heavy metals associated with both segregated and mixed waste compost (Smith, 2009). The results of the PAS 100 compost and CLO are consistent with this statement for zinc, however excess levels of copper was identified within the CLO, with lower than average concentrations of lead. A possible cause of these variations is the result of waste stream variability between households, across regional waste collections and seasonal differences as suggested by Stretton-Maycock and Merrington (2009).

Pot Trials

Growth trials using *S. viminalis* showed significant wilting and yellowing of leaves in all ROW pots and slight wilting in control pots after one week. This was initially attributed to the stress of replanting and damage incurred to the roots while removing commercial compost. Control pots recovered with good healthy growth after 3 weeks; however the remaining ROW pots still exhibited phytotoxic effects suggesting other contributing factors were affecting the growth.

The wilting and necrosis of *S. viminalis* in ROW was attributed to the high EC and excess soluble salts; although high concentrations of specific metals such as zinc may also have had a phytotoxic effect. The new growth of 2 buds in 2 ROW pots suggest after repeated watering some of the excess salts may have been leached from the pots. Only one pot containing CLO at equivalent to 1500 kg N/ ha and one PAS 100 compost at equivalent to 3000 kg N/ ha showed new growth after initial wilting at week 5. Initial growth trials are inconclusive as recovery was not evident in any of the replicates or the remaining ROW containing CLO equivalent to 3000 kg N/ ha. Understanding the composition of the leachate produced from the ROW will identify excess concentrations of specific soluble ions. Previous studies have applied landfill leachate with an EC of 8.89 mS/ cm to willow saplings (Cureton *et al*. 1991, cited in Duggan, 2005), this exceeds the levels measured in the composts which ranged between 2.15 and 5.82 mS/ cm. Chlorosis or yellowing of leaves due to a lack of chlorophyll, necrosis and leaf desiccation were observed after leachate application (Cureton *et al*. 1991, cited in Duggan, 2005) similar to the phytotoxic effects observed in the *S. viminalis* grown in the PAS 100 and CLO composts.

Plant image analysis

The plant image analysis program showed good correlation (R^2= 0.9832) with the manual height measurements of the *S. viminalis*. There is limited previous work on height estimation for tree growth. Lindsey and Bassuk (1992) investigated the use of images to calculate the leaf area of an intact tree by Delta-T video image analysis. Photos of entire trees were taken against a contrasting background and processed to produce negative images for surface area analysis. Positive correlation of tree silhouette area and actual leaf area was shown for 3 different tree species ranging between 0.920 and 0.977 (Lindsey and Bassuk, 1992).

Further development of the Matlab program aims to calculate the tree mass volume and volume occupied by a plant (envelope volume). From the plant volume and the envelope volume a density factor can be calculated to estimate density of leaves which will vary between tree species in future testing.

Conclusions

This paper presented the initial results of ROW as a nutrient source for short rotation coppice crops. Initial analysis of the ROW materials identified differences in the pH, EC and total heavy metal content due to different sources of waste streams. The EC values from both materials showed excess soluble salts were present in both PAS 100 compost and CLO.

Growth trials of *S. viminalis* indicated significant phytotoxic effects from the excess soluble salts present in the ROW. This is supported by the recovery of only two plants after leaching of salts. The results are therefore currently inconclusive and further investigations into the composition of leachate from each material and the effect on plant growth are required.

The plant image analysis program showed good correlation with the manual height measurements. Further development of the program will estimate the plant volume, however new plant growth below pot levels or large leaves lower than the pot level may lead to under and over estimations. Further work will be required to ensure consistent volume results and testing with other tree species.

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