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Composted Municipal Green Waste Enhances Tree Success in Opencast Coal Land Reclamation in Wales

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ABSTRACT: The United Kingdom has a problem in the disposal of municipal green waste (MGW). This is unsuitable for landfill, but when properly composted may be beneficial to tree growth. A formal controlled trial of the 11-year growth (height, diameter at breast height [DBH]) and survival of 3 tree species was evaluated on degraded former opencast coal land on the margins of UNESCO's Blaenavon Industrial Landscape World Heritage site in South East Wales. Forest reclamation is considered a viable cost-effective approach to reclamation but success may be compromised by infertile and seriously compacted substrates, the depleted bio-geoecological system, and a lack of funding. In this trial, trees were (or were not) supplied, on planting, with 0.75 kg per stem of composted MGW – here a mixture of 40% domestic food waste and 60% garden waste. Results show that the application of MGW made no significant difference to either tree height or DBH. Survival rates were highest for Common Alder (*Alnus glutinosa* (L.) Gaertn.) followed by Silver Birch (*Betula pendula*, Roth) and European Larch (*Larix decidua* Mill.). However, Silver Birch and Larch treated with MGW compost had significantly greater survival rates, whereas Alder had significantly lower survival rates, compared with trees planted without MGW treatment.

KEYWORDS: MGW compost, afforestation, alder, birch, larch, opencast coal land, Wales

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Introduction

The United Kingdom generates more than 14.4 million tons per year of municipal green waste (MGW), mainly from household sources.¹ Its disposal, especially in landfill sites, can be an environmental problem because of its capacity to generate CH₄.² However, once it has been composted, MGW may have beneficial uses in plant cultivation. Several studies describe the benefits to be derived using mixtures of composted food and garden waste as a growing medium or mulch, typically, in urban contexts.^{3–6} The MGW compost has also been deployed in land reclamation forestry, although its benefits for forestry are not fully explored and may depend on local soil properties.⁷ Nevertheless, in New South Wales, Australia, the application of MGW compost at 60 t ha⁻¹ to mine spoil covered with 100 mm of topsoil increased, significantly, forest canopy cover, tree density, and size. Furthermore, 2.5 years after application, soil loadings of total N, P, soluble K, Ca, and Mg – and less beneficially Cu and Zn – had increased significantly, whereas pH had decreased.⁸ In other types of UK 'brownfield' contaminated sites in the United Kingdom, the application of MGW compost was also found to improve tree growth significantly, at least in the context of a brief 19-month study.⁹ Of course, experience shows that short-term results can be deceptive.¹⁰ Hence, this research aims to explore the long-term results of using MGW in the forest reclamation of opencast coal lands in the United Kingdom. This approach provides 'green' or 'nature-based' solutions to 3 environmental

problems. These are the disposal of MGW and, through forestation, the rehabilitation of some poor-quality soils on former opencast coal lands and the improvement of environmental and visual qualities of a landscape devastated by centuries of mining and heavy industry.^{11,12} Of course, this aligns with UN Sustainable Development Goal (SDG) 15, which concerns the reversal of land degradation and sustainable use of terrestrial ecosystems, SDG 11, which concerns the sustainability of human settlements, as well as contributing to the carbon sequestration envisaged by SDG 13 'Climate Action' (see <https://sustainabledevelopment.un.org>).

In fact, the regeneration of lands affected by surface (opencast) coal mining is a problem for many post-industrial areas, and many find their economic regeneration constrained by poor environmental quality. In the Blaenavon area of northern Torfaen, South East Wales, industrial heritage has been turned into a positive attribute through its recognition as a UNESCO World Heritage Industrial Landscape area,^{13,14} and reclaimed lands are included among its key landscape features. Unfortunately, not all land reclamation treatments have been successful. Even within the UNESCO World Heritage area and its immediate environs, much of the land described in official records as 'reclaimed' is undergoing obvious degradation because of soil compaction, vegetation dieback, and erosion.¹¹

The problem is compounded because while official statistics have a category for 'reclaimed land', they do not recognise



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'failed reclaimed land'. Consequently, there is no official funding for remedial action, even inside the UNESCO World Heritage area. Hence, remediation work falls to piecemeal voluntary and community action.

The research described here, thus, contributes to a larger study that aims to empower those engaging in voluntary land reclamation interventions by determining reliable and inexpensive ways of restoring these now degraded, but formerly 'reclaimed', lands.¹¹ This contribution addresses the specific question: Does the addition of a small quantity (~0.75 kg per stem, ie, 7.5 t ha⁻¹) of inexpensive composted MGW (created from a 40:60 mixture of domestic food and garden waste) on planting contribute, significantly, to the long-term survival and growth of trees planted into the thin, infertile, and compacted soils of a former opencast coal mine?

Of course, the amount applied as a supplement during planting is quite small, so it is likely that the effects may also be small. Hence, this project's null hypothesis is that the application of a small amount of MGW on planting to trees grown on opencast coal spoils makes no significant difference to 11-year tree survival and/or growth.

Materials and Methods

Compost: MGW's source and properties

Between 70% and 40% of urban green waste is biodegradable material, primarily food and garden waste.¹⁵ Potentially, recycling such waste as compost is a beneficial and productive means of waste disposal. However, there are some potential hazards. For example, microbiological research in Northern Ireland has found that municipal composts from food waste contain a wide array of potentially harmful bacteria, notably *Clostridium perfringens*.¹⁶ Perhaps inevitably, the same food waste-derived MGW composts also showed high levels of microbial resistance to antibiotics, with the risk that this resistance could be transferred to new habitats.¹⁷

For such reasons, the sourcing and treatments used for preparing MGW compost are very important. Here, the compost used was sourced locally from CWM Environmental's Nantycaws Recycling Centre. This produces 'Merlin's Magic' brand compost¹⁸ under a Natural Resources Wales Permit (EPR/EP3698FL/V004)¹⁹ from a mixture of 40% domestic food waste and 60% domestic garden waste, which is blended and shredded for composting according to the European Union's ABPR (Animal Byproducts Regulations).²⁰

The decontamination process involves composting in an enclosed vessel where, under controlled oxygen and carbon dioxide levels, 250-ton batches are held for at least 48 hours at temperature >60°C to kill pathogens and weed seeds. The process then is repeated, in a second container, to ensure that all parts of the compost reach the required temperature. After this, the compost is 'matured' for ~6 weeks in wind row mounds 2 m high and aerated by weekly turning. Finally, the certified compost is bagged for retail.²¹

The quality and safety of the resulting compost have been checked by independent laboratory testing against the United Kingdom's PAS 100:2018 ('Publically Available Specification for Composted Materials') specification, a recognised standard for the safety of recycled organics.²² Table 1 includes both soil test data (Table 1, column 3) for the Varteg test plot used in this study (Test plot: MD07²³) and the results from the latest PAS 100:2018 certification test of the MGW used. This suggests that this compost is largely free of microbial and other biological contaminants.

Microbiological issues are not the only problems that may result from the application of MGW composts.¹⁵ The MGW may contain other contaminants including metals. Their addition to soils in post-industrial landscapes has the potential to shift already marginally contaminated lands above recognised thresholds of contamination.²⁴ For some years, the forestry reclamation of coal land with sewage sludge was high fashion; unfortunately, most such materials are loaded with metals, especially Cd and Zn, as well as other pollutants, sometimes to a greater degree than the coal mine spoils themselves.²⁵

Typically, MGW composts contain more metals than normal background concentrations, although, by themselves, most comply with the metal limits of the United Kingdom's PAS100 regulations and are below thresholds likely to affect human health in domestic garden contexts,^{26,27} as is the case for the compost used in the MD07 test plot. The problem is that this metal loading is an addition to pre-existing soil loadings. Fortunately, research on other Varteg test plots has shown that long-term forestation is an effective means of reducing the loadings of some heavy metal in these opencast coal mine substrates,²⁸ which means that the use of MGW is appropriate in the context of forestation.

The MGW also has its own capacity to bind metals and reduce their bioavailability, which is also beneficial to the remediation of contaminated soils.²⁷ However, by way of contradiction, MGW has also been proposed for use in the phytoextraction of metals, such as Hg, because it increases the formation of soluble organo-mineral complexes that are both soluble and bioavailable.^{29,30} So this issue remains unresolved.

Of course, the application of MGW to the soil should also provide benefits in the form of plant-available nutrients. In this case, this MGW compost should provide around 0.66 kg t⁻¹ of plant-available N plus 3.8 of P₂O₅, 8.0 of K₂O according to the WRAP Compost Quality Protocol³¹ (the compost used here is advertised as NPK 6:3:4), plus 3.4 of each of SO₃ and MgO, and this mix is recommended for land reclamation forestry in the United Kingdom.³²

Study area

The MGW forestation test site lies less than 100 m southwest of the southern margin of UNESCO's Blaenavon Industrial World Heritage area in South Wales, UK (51°44'45"N 03°04'39"W), on the southern edge of the former Mynydd Varteg Opencast

Table 1. Varteg (MD07) soil chemistry plus MGW data from the UK (PAS100:2018 Test) Certification for this MGW compost.^{19,22}

PARAMETER	UNIT	MD07 SOIL (PH 5.21-5.51)	MGW PAS 100 TEST RESULT	PAS 100 UPPER LIMIT	PASS OR FAIL	MAXIMUM METALS ALLOWABLE IN UK SOILS (EC DIRECTIVE 86/278/EEC FOR SOIL OF PH 5.5)	METHOD REFERENCE
<i>Escherichia coli</i>	CFU/g		<5	1000	Pass		BS ISO 16649-2
<i>Salmonella</i> spp.	Presence in a 25-g sample of MGW		Absent	Absent	Pass		BS EN ISO 6579, Schedule 2, Part II
As	mg kg ⁻¹	6.5-8.3				40.0	BS EN 13650
Cd	mg kg ⁻¹	<0.03	0.40	1.50	Pass	3.00	
Cr	mg kg ⁻¹	16.6-19.4	23.0	100.0	Pass	400	
Cu	mg kg ⁻¹	26.8-45.4	53.0	200.0	Pass	100	
Pb	mg kg ⁻¹	31.3-37.5	76.0	200.0	Pass	300	
Hg	mg kg ⁻¹	<2	<0.1	1.0	Pass	1	
Ni	mg kg ⁻¹	20.7-37.7	17.00	50.00	Pass	60	
Zn	mg kg ⁻¹	119-167	175	400	Pass	250-300	
CO ₂ (stability)	mg CO ₂ , g ⁻¹ OM/d ⁻¹		11.9	16.0	Pass		ORG0020
Weed plants	number/L		0.0	0.0	Pass		OFW004-006
Glass, metal, plastic, etc.	% of 'air-dry' sample >2 mm		0.05	0.25	Pass		AfOR MT PC&S: 05/12/2012
Plastic			0.00	0.12	Pass		
Sharps			0.00	R	R		
Stones in 'mulch'	% of 'air-dry' sample >4 mm		0.74	10.0	Pass		
Stones in other than 'mulch'			0.74	8.0	Pass		

Abbreviation: MGW, municipal green waste; PAS, Publicly Available Specification for Composted Materials; CFU, colony-forming unit.

coal mine (Figure 1). The Registered Landscapes of Outstanding Historic Interest in Wales, produced by the Countryside Council for Wales and International Council on Monuments and Sites, recognises this area (HLCA 019 Mynydd Varteg Opencast) as 'one of the best preserved, relict industrial landscapes in Wales. The whole area is covered by early, coal opencasts and it survives as probably the only sizeable, abandoned, multiple period, opencast mineral working in South Wales' (Torfaen County Borough, 2013, p. 183).¹⁴

The test plot is located on land that has become degraded since the (mainly unsuccessful) reclamation of a former opencast coal mine. In 1963, the Waun Hoscyn Extension (of the Mynydd Varteg Opencast) mine was closed, the void re-filled, and the waste reshaped and re-soiled (at least partially). Being assessed 'unsuitable for forestry', it was then reseeded as grassland.³³ The 30 m × 30 m 'MD07' test plot for this forest

planting is located on a terrace bench on the southern edge of this former opencast coal mine at about 384 m above mean sea level (Figure 2). The site has a monthly mean air temperature of between 2.5°C and 15°C.³³ Average rainfall (1971-2000) is 1543 mm per year at Cwmavon Reservoir, 800 m northeast on the Afon Lwyd Valley floor (51°45'26" N 03°3'35" W).³³ Evaporation is estimated as 472 mm per year on rough grazing land, whereas natural soils are at field capacity for 285 to 325 days per year.³⁴ They are, nevertheless, subject to severe summer soil water deficits, especially in the thin, excessively free-draining, soils of this former opencast land.

Before tree planting, the test site was a patchy grass land, rich in lichens and bryophytes. The grass sward was a close fit to National Vegetation Classification Category U4 (*Festuca ovina*, *Agrostis capillaris*, *Galium saxatile* grassland),³⁵ which is common on local semi-natural and disturbed industrial lands.

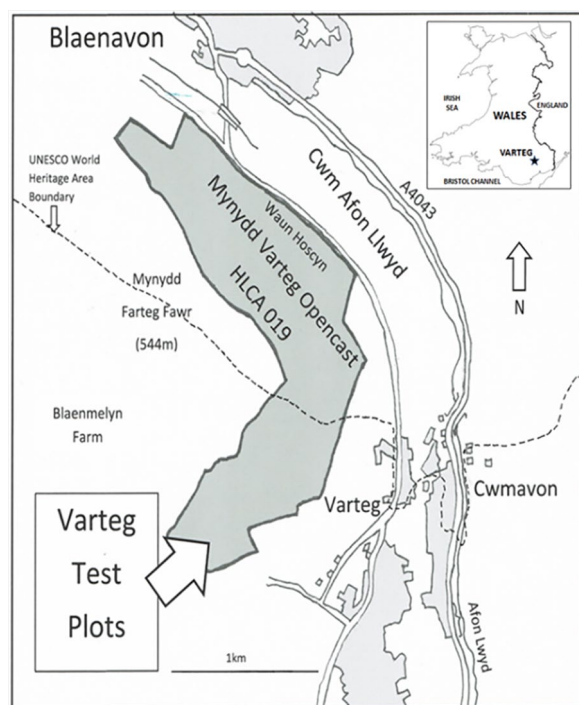


Figure 1. Location of Varteg test plots.

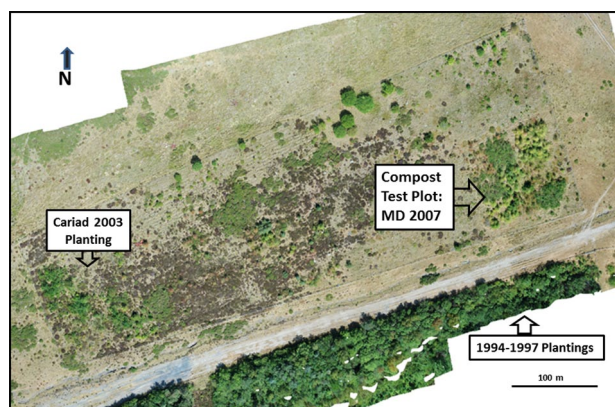


Figure 2. Location of MGW compost test plot, Varteg test plots: North Field (orthophotomosaic by Ben Sansom, 2018). MGW indicates municipal green waste.

Here, the major obstacles to tree growth in the soil are a lack of plant-available nutrients and rooting space. The grassed topsoil, a thin organic layer of around 5 cm, rests on a subsoil of weathered mine spoils, which has a clayey matrix with clasts of sandstone, coal shale, and some coals. Beneath an organically enriched layer, ~15 to 20 cm deep, is a dense, auto-compacted accumulation layer of weathered mine spoil, which is enriched with fine particles created by the accelerated breakdown of water-unstable shales and mudstones.³⁶ Soil bulk densities, recorded on this MD07 test plot ahead of planting, were high: 1.63 g cm^{-3} at 35 to 40 cm depth and 1.81 g cm^{-3} at 50 cm.²³ Consequently, these spoil layers have a low infiltration capacity, a low water-holding capacity, low soil organic content (0.32%–0.40%), and very low nutrient status.³⁷

However, the Varteg mine spoils are not, in general, acidic. Typically, soil pH ranges from 5.3 to 5.7 – on this test plot 5.2 to 5.5 – although there are occasional hot spots as low as pH 3.8.¹⁹ Chemical tests of surface waters found them to have pH 6.8 to 7.3 ($\text{EC } 237\text{--}277 \mu\text{S cm}^{-1}$), although spring water can be as low as pH 3.0.³⁸ Surface runoff may contain elevated levels of iron (ca. 0.2 mg L^{-1}), manganese ($0.015\text{--}0.064 \text{ mg L}^{-1}$), nickel ($<0.008 \text{ mg L}^{-1}$), and arsenic ($<0.008 \text{ mg L}^{-1}$).³⁹

Apart from the poor-quality substrate and summer water deficit, exposure to wind also challenges tree growth. This causes desiccation, stunting, and physical damage to leaves and shoots.^{40,41} By European standards, Wales has a severe wind climate, with the strongest winds affecting west-facing slopes, higher ground, and sites exposed to the sea, in this case the Bristol Channel to the south.⁴² Winter gales make conifers, especially, vulnerable to wind-throw, and the site is exposed to the main prevailing winds from the south and west.

Selection criteria for tree species

The MD07 test plot is located on the edge of a larger experimental field devoted to developing the 'Cradle for Nature' approach to land reclamation¹¹ (Figure 2). Since 1990, this has involved mixed plantings of native broad-leaved species, mainly Common Alder, Oak, and Scots Pine, with some Silver Birch, Rowan, and Goat Willow, using a variety of fertilisers, planting regimes, and subsequent records of tree growth.^{33,37}

The 2007 (MD07) planting differs from the earlier plantings on the Varteg site in using mono-specific blocks of trees, which reduces potential problems from allelopathy. It also introduces European Larch (*Larix decidua* Mill.) to the larger Varteg test site, which, although widely planted in Central Europe, is not native to the United Kingdom. However, in common with the earlier plantings, MD07 also includes Common Alder (*Alnus glutinosa* (L.) Gaertn.) and Silver Birch (*Betula pendula*, Roth).³³ All 3 tree species belong to genera that are recommended for use in land reclamation contexts by the United Kingdom's Forestry Commission.⁴³

Common (European or Black) Alder is a riparian species, typically found in wet and boggy sites, but it is also widely used in land reclamation on upland hillsides (Figure 3A). Alder also fixes nitrogen because it carries root nodules that support the nitrogen-fixing bacterium, *Frankia alni*. Hence, it performs well in nutrient-poor substrates. In the compacted mine spoils of the Varteg, rooting depths might be expected to be low but excavation finds alder roots extending downwards through cracks and fissures to depths greater than 1.5 m. This deeper rooting helps explain why alder proves relatively drought tolerant. The species is also wind tolerant and sometimes used in shelterbelts.

By contrast, Silver Birch, a common, shallow-rooted, native species is an important primary coloniser of drier lighter soils and also tolerates wind exposure (Figure 3B). It is a soil



Figure 3. MD07 test plot species: (A) Common Alder, (B) Silver Birch, and (C) European Larch (Photographs: Mansi Desai, 2011-2012).

improver linked to increased earthworm populations and supports several mycorrhizal (vesicular-arbuscular mycorrhiza [VAM]) associates that help it cope with nutrient-poor or acidic soils.³³ Silver Birch also tolerates acidity, and air and soil pollution.

European Larch is widely used in coal land reclamation, especially in its native Central Europe and in Appalachia, although Japanese Larch (*Larix kaempferi*) is more often used by commercial forestry and coal land reclamation in Wales. European Larch is not quite native to the United Kingdom; rather, it is listed among those species that did not manage to re-establish naturally after the Ice Age and was re-introduced in 1629.⁴⁴ However, it is a pioneer species, fast-growing, and often used to afforest disturbed land (Figure 3C). It is tolerant of stony thin soils, cold, and drought, but less so of N deficiency, and prefers well-drained soils.

Experimental design

The MD07 test plot was set out as a subdivided Latin Square (Figure 4). The Latin Square is a balanced 2-way experimental design consisting, here, of a 3×3 square where each row and each column is a permutation of the same distinct elements.⁴⁵ Here, the square systematically balances the distribution of tree species and then is further divided by splitting each cell into 2 parts, one treated on planting with 750 g per stem of the 40:60 mixture of composted municipal food and garden waste¹⁸ and the other not. This creates 2 further Latin Squares, one for each treatment, within the same test plot. The result is 18 subplots, 6 plots per tree species, each containing 50 trees. The trees were planted in 2007 (Figure 5) and their height (cm) and diameter

at breast height (DBH) (diameter at 1.3 m above the surface [mm]) were recorded in 2018.

The MD07 test plot was planted out at a high planting density of 10 000 stems per hectare²³ in an attempt to achieve early canopy closure and in anticipation of slow growth in the poor and compacted soils.³³ The trees were notch-planted, as in normal forestry practice, as 2-year whips in root trainer plugs.³⁷ During planting out, half of the trees were treated with a supplement of ~750 g of MGW compost, which was used to back-fill the planting-notch void ahead of soil closure. Half the trees were given no supplement.²³ Records of tree growth were collected in the 11th year after the planting of the MD07 test plot to determine whether the compost supplement had benefitted tree survival and tree growth, using the standard measures of height (cm) and DBH (diameter at a height of 1.3 m).

Statistical testing used the Fisher exact test for nominal data such as 'survival' because of its greater accuracy than alternatives such as χ^2 . The independent sample t test, which is commonly used for hypothesis testing, was used to explore the impacts of initial treatment with 750 g per stem of the MGW on tree height and DBH across the 3 different species. The formal null hypothesis applied was that the addition of composted MGW on planting made no significant difference to tree survival or growth.

Results

Survival rates with and without MGW

Survival rates varied both by species and by treatment (Figure 5; Table 2). In general, and for Silver Birch and European larch, survival was significantly greater ($P < .001$) for trees

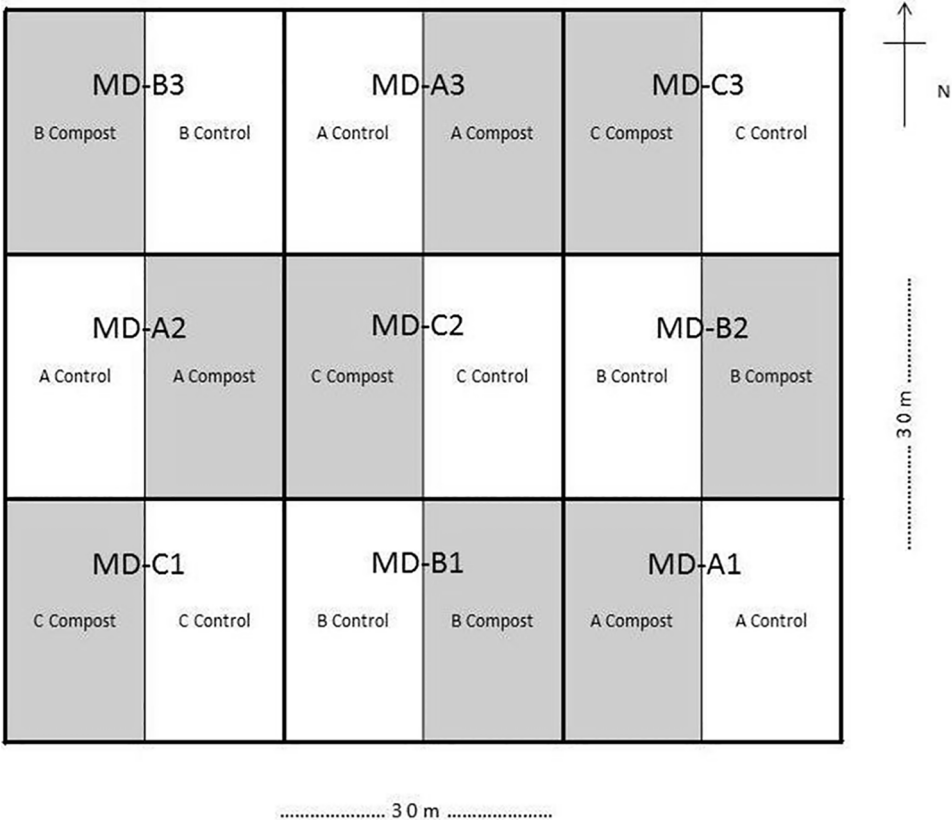


Figure 4. Experimental design – layout of test plots. (A) *Alnus glutinosa*, (B) *Betula pendula*, and (C) *Larix europaea* (Plan by Mansi Desai, 2014).



Figure 5. Planting out MD07, November 25, 2007 (Photograph: Mike Cullis, 2007).

treated with MGW compost on planting compared with those not treated with MGW compost. However, in the case of Alder, a nitrogen fixer, significantly more trees not treated with compost survived ($P = .04$). Nevertheless, whether treated with MGW compost or not, survival rates were best for Alder, better for Silver Birch, and least for Larch (Figure 6; Table 2, columns 1-2).

Table 3 and Figure 5 show that the survival rates for MGW compost-treated Larch were significantly smaller than Alder and Silver Birch – but there was no significant difference between these 2 species. The survival rates for untreated Alder were significantly greater than for Silver Birch and Larch – but

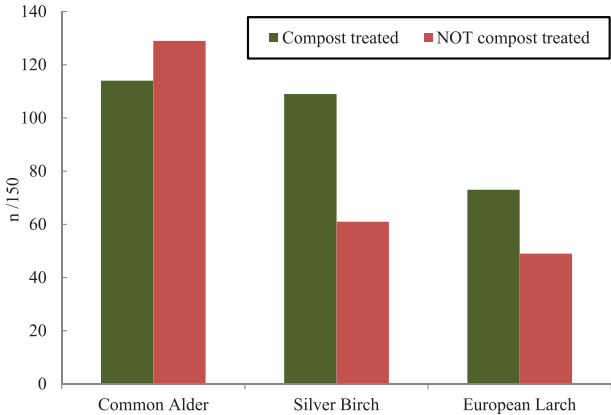


Figure 6. Year 11 survival rates (n/150) of tree species planted with and without MGW. MGW indicates municipal green waste.

there was no significant difference between these 2 species. The species that responded best to the MGW compost was Silver Birch.

Growth with and without MGW

Eleven years after planting, there were no remotely significant differences in tree height or diameter (DBH) between the MGW compost and untreated populations of survivors for any species, although it is worth noting that in every case (except Alder's DBH), compost-treated trees are slightly smaller on average than the trees that received no compost (Table 4; Figure 7 and 8).

Table 2. Positive impact of MGW compost on 11-year tree survival (Fisher exact test).

TREE SPECIES	OVERALL SURVIVAL (N=300)	COMPOST-TREATED SURVIVAL (N=150)	NOT COMPOST-TREATED SURVIVAL (N=150)	SIGNIFICANCE OF DIFFERENCE (P=)
Common Alder	243	114	129	.0387
Silver Birch	170	109	61	<.0001
European Larch	122	73	49	.0068
All species (n=900)	535 (59%)	296 (66% of 450)	239 (53% of 450)	<.0001

Abbreviation: MGW, municipal green waste.
The better scores are emboldened.

Table 3. Significant differences in compost vs no compost survival by tree species (cf. Figure 6).

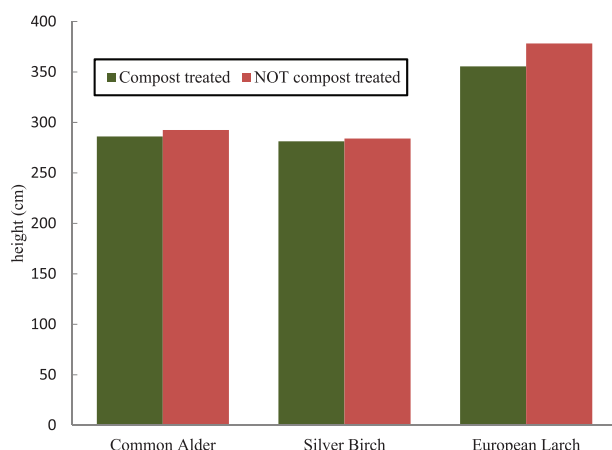
MGW COMPOST	NO MGW	NO MGW	NO MGW	MGW COMPOST	MGW COMPOST	MGW COMPOST
	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH
Common Alder		<.0001	<.0001		ns	<.0001
Silver Birch	<.0001		ns	ns		<.0001
European Larch	<.0001	ns		<.0001	<.0001	

Abbreviation: MGW, municipal green waste.

Table 4. MGW compost treatment makes no significant difference to tree height or DBH of trees surviving after 11 years (independent sample *t* tests).

TREE SPECIES	HEIGHT (CM) WITH MGW COMPOST (SD)	HEIGHT (CM) WITH NO COMPOST (SD)	SIGNIFICANCE OF DIFFERENCE (P=)	DBH (MM) WITH MGW COMPOST (SD)	DBH (MM) WITH NO COMPOST (SD)	SIGNIFICANCE OF DIFFERENCE (P=)
Common Alder	286.14 (62.19)	292.54 (61.49)	.42 (ns)	22.08 (9.58)	21.76 (9.12)	.79 (ns)
Silver Birch	281.32 (86.57)	284.07 (82.26)	.85 (ns)	21.07 (12.81)	22.10 (14.26)	.65 (ns)
European Larch	355.57 (113.52)	378.28 (121.88)	.31 (ns)	43.26 (24.71)	47.41 (26.00)	.39 (ns)

Abbreviation: MGW, municipal green waste; DBH, diameter at breast height.

**Figure 7.** Height (cm) of MGW compost-treated and untreated trees. MGW indicates municipal green waste.**Figure 8.** Growth of MD07 test plot, July 2017 (Photograph: M. D'Aucourt, 2017).

Tables 4 and 5 explore the significance of the differences in relative growth between species for compost-treated and

untreated trees, which is useful information for those selecting species for coal land reclamation. These results confirm that the smaller number of surviving Larch trees were, in all cases, significantly ($P < .0001$) greater in height and DBH than either Alder or Silver Birch. Silver Birch, however, was significantly smaller than both, including Alder (height: $P = .011$; DBH $P = 0.020$). For trees that were not treated with compost, Larch was still significantly larger than Alder and Birch in

Table 5. Significant differences ($P=$) in 11-year relative growth by tree species for MGW compost-treated and untreated trees.

MGW COMPOST	NO COMPOST			MGW COMPOST		
HEIGHT	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH
Common Alder		ns	.003		.011	<.0001
Silver Birch	ns		.001	.011		<.0001
European Larch	.003	.001		<.0001	<.0001	
DBH	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH	COMMON ALDER	SILVER BIRCH	EUROPEAN LARCH
Common Alder		ns	<.0001		.020	<.0001
Silver Birch	ns		<.0001	.020		<.0001
European Larch	<.0001	<.0001		<.0001	<.0001	

Abbreviation: MGW: municipal green waste.

DBH ($P < .0001$), but the significance levels for differences in height were less emphatic (Alder: $P = .003$; Silver Birch: $P = .001$, respectively). There were no significant differences in either the 11-year height or DBH of Silver Birch and Alder.

Discussion

Compared with similar plantings on the same site, the growth of trees on test plot MD07 was relatively good. For example, after 11 years, the mean height and DBH of untreated Alders on MD07 were 292.5 cm and 21.8 mm compared with the 98.1 cm and 7.6 mm after 10 years for the untreated, notch-planted, Alders on the more wind-exposed test plot Cariad03³⁷ (Figure 2). Survival rates were also higher (86% vs just 39%) on Cariad03 test plot. These differences may be related to climatic factors, especially the availability of soil moisture, because Cariad03's other Alders, both those planted in water-holding soil pits and 0.5 m \times 0.5 m planting trenches, fared much better.³⁷

The question addressed here is whether or not the addition of a small amount (0.75 kg per stem, ie, 0.75 kg m⁻²), of MGW (domestic food and garden waste) compost on planting has a measurable impact on the long-term growth and survival of 3 tree species: Common Alder, Silver Birch, and European Larch. Elsewhere, greenhouse studies suggest that adding even very small organic supplements on planting can produce positive outcomes for plant growth.⁴⁶ For example, in China, just 15% of organic compost proved ideal for the nursery cultivation of a *Larix* sp.⁴⁷ In Wales, the application of similar compost at a similar 'low rate' (0.66 kg m⁻², 36.6 kg N ha⁻¹) in reclamation trials at the Ffos-y-fran opencast coal land reclamation, near Merthyr Tydfil, found that it encouraged a better establishment of grass and herbs over untreated plots.⁴⁸ However, here, the addition of MGW produced no significant differences in tree height or DBH for any of the 3 trees species, although in 5 of 6 records, trees given no MGW had slightly larger

dimensions (Table 4). From a practical point of view, it is useful to know that, after 11 years, European Larch produced the largest trees.

In general, survival rates were greatest for Alder, less for Silver Birch, and least for Larch. However, significantly more of the Silver Birch and Larch survived among trees treated with MGW than those that were not, with the survival benefit more marked for Silver Birch. However, significantly fewer Common Alder survived. Alder is a nitrogen fixer and, hence, both less likely to benefit from additional N and, possibly, more likely to suffer in a higher N initial environment. So this finding suggests that it was the additional N provided by the MGW that aided the survival of Silver Birch and European Larch.

Another series of test plots at the same location evaluated the benefits of a single initial application of 2-year slow-release fertiliser (SRF) in a planting medium (<1.0 kg) of spent mushroom compost through a 10-year controlled study of a mixed planting of Common Alder and Silver Birch with Oak (*Quercus petraea* (Matt.) Liebl., *Quercus robur* L., and hybrids), Scots Pine (*Pinus sylvestris*, L.), Goat Willow (*Salix caprea*, L.), and Rowan (*Sorbus aucuparia*, L.).³³ This produced very different results. After 10 years, SRF-treated trees had a survival rate that was slightly, albeit marginally significantly, smaller (85% vs 83%) across all species, except Oak. However, SRF-treated trees were significantly larger than those given no-SRF at planting (421 cm vs 368 cm).³³ This was not the case with trees that were given higher doses of SRF, which had lower rates of growth and survival.³³ The results from MD07, especially the response of Alder, suggest that the nutrients provided by the MGW compost may have negative impacts on the tree's rhizosphere's microbial and fungal associates (VAM), not least of Alder. However, this remains to be proven.

Something the present study, which is based on a single data collection 11 years after planting, cannot address is whether these results would be similar were the measurements taken

earlier or later.¹⁰ However, data recorded in the fifth year after planting on these neighbouring test plots found that SRF-treated Alders (alone) were (very marginally) significantly larger than those untreated. By contrast, after the first to third year, across all 6 species tested, significantly more records showed greater mean growth in trees given no-SRF than in those given SRF on planting. Again, the authors speculate that this delayed response to SRF treatment could result from the slower development of the larger soil ecosystem.³³ The question remains open concerning what the present study would have reported had it been undertaken 1, 3, or 5 years (eg, Figure 5) after planting as, indeed, for the character of the results that will be reported when 20-year data, already collected from neighbouring test sites, are reported.

While there are many clear environmental benefits in using MGW as compost in forestry rather than sending it to landfill, there are also potential problems. Here, there is no evidence for the microbiological issues described in Northern Ireland by Furukawa et al.^{16,17} The number of *Escherichia coli* discovered in the MGW compost used is very small, which is positive, but there are no data on pathogens such as *Clostridium perfringens* or on bacteria with anti-microbial resistance. No doubt, this topic also merits further investigation.

As for metal contamination, previously, Desai et al²⁸ discovered no significant differences between the levels of Cd, Cu, Mn, Pb, and Zn in the soils and leaves of treated and untreated trees on this MD07 test plot. At the Ffos-y-fran opencast reclamation site, researchers also discovered no changes in metals consequential upon the addition of their PAS100 biofertiliser.⁴⁸ However, others^{24,27} caution about the metals that can be mobilised by dissolved organic carbons from composted green waste, including both those listed above and As, which tends to be common in coal mining spoils, if not at this site (Table 1).

Here, it is argued that the application rate of 0.75 kg per stem was low. However, in the high-density, 1 stem per square metre plantings required by this land reclamation context, this sums to a substantial 7.5 t ha⁻¹, which would add 1.75 kg ha⁻¹ of Zn, 0.73 kg ha⁻¹ of Pb, and so on into post-industrial land that is already borderline contaminated. Even so, the amount of metals added is small compared with ambient local soil loadings.²⁸ In sum, on present evidence, there seem to be good positive reasons for, and no demonstrated negatives against, using this type of MGW in forestry contexts.

Conclusions

In 2017, the United Kingdom was still sending 7.4 million tons of biodegradable municipal waste to landfill, where anaerobic decomposition generates CH₄, a highly flammable and potent greenhouse gas. Clearly, it is desirable to find a better use for this MGW and this article explores the possibilities of using it to positive effect in coal land reclamation forestry. In May 2019, the UK power grid achieved its first week without coal-fired power generation, a milestone in the retreat from fossil

fuels.⁴¹ However, for many generations to come, communities will be faced with remedying the collateral damage caused by coaling. The use of MGW composts in coal land reclamation forestry contexts may not be entirely unproblematic because of possible microbiological, metal, and other contaminants (Table 1). However, the use of low doses (0.75 kg per stem) of the (PAS100-certified) MGW compost used in this study was significantly beneficial to the 11-year tree survival rates of 2 of the 3 tree species planted here: European Larch (*L. decidua* Mill.) and Silver Birch (*B. pendula*, Roth), although the reverse was true for Common Alder (*A. glutinosa* (L.) Gaertn.) (Table 2; Figure 5). Nevertheless, overall survival rates were highest for Alder followed by Silver Birch and Larch. The MGW compost application made no significant difference to either tree height or DBH (Tables 4 and 5). Collectively, the findings suggest that the additional N from the MGW compost provides benefits to species that, unlike Alder, do not fix N themselves.

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Author Contributions

MH conducted the data collection and analysis, wrote the manuscript, and helped with project management. M Desai helped with the experimental design, soil testing, and planting out. MC helped with planting out, compost sourcing, editorial, data collection, and photography. M D'Aucourt helped with planting out, data collection, editorial, and photography. BS helped with drone photography and data collection. EA, LH, and MK conducted the data collection. SG conducted the soil testing. RJ supervised the research team. WP helped with data collection and community relations. GW helped with data collection, editorial, and cartography.

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