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Creating new quarry landscapes using quality compost and biofertiliser

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Front cover photography Test area within Fron Haul Quarry

Executive summary

Introduction

As a general rule quarry operators are required to restore and landscape sites after mineral extraction works have been completed or during the operational lifetime of the quarry. Often there is little or no topsoil available which can be used in the creation of new landscapes. A 'Best Practice' approach to restoration will involve the utilisation of *in- situ* soil forming mineral materials blended with imported quality compost or biofertiliser, combining both environmental and cost-minimisation aspects.

A project funded by WRAP Wales was designed to investigate the use of Quality Compost and biofertiliser, blended with raw quarry waste, in order to create manufactured topsoil suitable as a growing medium for effective landscape restoration. The restored landscape will create a wildlife corridor consisting of wildflower meadow and woodland using native, Welsh provenance tree species.

Design of trial and setting up

A field trial designed to test various options for manufactured topsoil was set up at a sand and gravel quarry (Fron Haul Quarry) managed by Marshalls and located at Nannerch, North Wales. The project site comprised a level area of silty clay quarry waste approximately 1440 m^2 in area. The aim of the field trial was to promote appropriate vegetation establishment and growth and thus generally enhance the habitat of the former quarry, based on an effective growing medium that could hugely reduce the dependence on topsoil for future quarry restoration works. The field trial was designed to evaluate three types of organic material (BSI PAS 100 green waste compost, BSI PAS 100 foodwaste-derived compost and biofertiliser) as the basis for the creation of healthy functioning soils.

The experimental design of the trial involved three replicates of each blend of quarry waste and organic materials at high and low application rates. In addition to an untreated control comprising silty clay, there were six soil blend treatments that encompassed two rates of incorporation of BSI PAS 100 green waste derived quality compost, two rates of incorporation of BSI PAS 100 foodwaste derived quality compost and a single application rate of biofertiliser, combined with two application rates of BSI PAS 100 green waste quality compost.
The trial plot area was prepared by placing and levelling the quarry silt/clay material across the area. The PAS 100 compost materials were mixed with quarry waste in stages in order to ensure thorough mixing of the components and biofertiliser. Biofertiliser was mixed into the relative treatments as a final component as it is was in liquid form. Mixing was undertaken using a 360° excavator and bucket based on the relative volume of the components of each mix. The trial plots were constructed using a 15 tonne excavator which loose tipped the mixes to a depth of 0.35m always working away from constructed trial plots.

Four species of trees were planted as cell-grown nursery stock in early June 2010 together with a seed mix of 18 wild flowers forb species and six grass species. The seed species mixture (British native origin) was selected with the intention of creating a wildflower meadow community similar to unimproved grassland that occurs in the vicinity of Fron Haul Quarry.

Monitoring methods

The early establishment of meadow flora was measured in late July 2010 and the later establishment of wildflower meadow grassland, as recognisable plant communities, were assessed on 23rd September 2010. The percentage survival of each tree species in each experimental treatment was measured on two occasions; first on 13th August 2010 and again on 4th October 2010. The August count provided an assessment of the effect of a prolonged period without rainfall that commenced three days after planting, whilst the count in October provided a measure of tree performance over the first growing season. Growth of trees was also measured on 4th October 2010.

Results-soils

The chemical analysis of the raw quarry waste demonstrated that it was extremely nutrient deficient containing very low concentrations of available nitrogen, phosphorus or potassium; too low to support the growth of trees or even most meadow grassland plants. There were very low concentrations of all metals measured and also TPH and PAH's (EPA 16) were at very low concentrations in the raw waste. Also the quarry waste was physically unsuitable for final site restoration. The material contained a relatively high content of clay and silt and if compacted would impede drainage and impede infiltration of rainfall when dry. Blending compost and biofertiliser had a dramatic impact on soil fertility. Total soil nitrogen was increased twofold in the biofertiliser treatments and four times in the high food and green compost treatments, in comparison with the control. This was correlated with proportional increases in percentage soil organic matter. However during mid-summer the highest concentration of available nitrate nitrogen occurred in the biofertiliser treatments. In comparison with the quarry waste control treatment, the total soil concentration of both phosphorus and potassium were enhanced in all the compost and biofertiliser treatments. The biofertilser and compost treatment effects on soil fertility carried through to autumn 2011.

Results-meadow grassland

The number of sown meadow wildflowers per plot was higher in the green compost (low and high) and food-included compost (high and low) mixes with quarry waste, than in the biofertiliser treatments or the control. This suggested that the physical properties of the compost blend with quarry waste created a more favourable medium for the establishment of meadow wildflowers. All treatments supported substantially greater vegetation height (and therefore biomass) than the unamended quarry waste control. Growth in the high biofertiliser soil mix, high food-included compost and high green compost treatments were comparable. There was enhanced establishment and growth of many wildflower species in the biofertiliser and compost blends. Overall the inclusion of biofertiliser, PAS 100 green compost and PAS 100 food-included compost were either favourable or neutral in provision of a growing medium for wildflowers, when blended with quarry waste.

Results-survival and growth of trees

The average survival of oak and rowan was well above normal for woodland planting on brownfield land although grey willow suffered just over 50% mortality. Statistical analysis of tree height for each species and pooled over all species showed that there was no significant difference between the compost:quarry waste soil blend treatments. In the first growing season there was an inadequate time span for the growth of trees to respond to the different soil treatments. The trees were planted in early summer and experienced a period of drought lasting more than two weeks and thus suffered an early check to growth.

Conclusions

The first year of the trial located at Fron Haul Quarry has demonstrated that satisfactory establishment of three species of trees (except grey willow) and good establishment of meadow grassland was achieved on the majority of the blends of quality composts and biofertiliser. The full benefit of manufacturing soil *in-situ* using blends of quarry waste and PAS 100 green compost, PAS 100 food-included compost and biofertiliser, will not be revealed until tree growth and meadow vegetation development have progressed through the 2011 growing season when the biodiversity and nature conservation role of the restored trial area will start to become apparent. The wider setting will develop into a valuable grassland and woodland landscape in the medium to long-term and will provide the basis of a valuable informal recreation area with access to nature, following eventual closure of the quarry.

Contents

1.0 Introduction

1.1 Background of the Project

Many quarry operators face a common problem, as part of the planning application and permission process, due to the requirement to restore and landscape sites after mineral extraction works have been completed; there is often insufficient suitable topsoil available to do the job properly. As a result of the lack of suitable material, quarry operators frequently have to import costly topsoil from external sources, this in turn can place pressures on a finite resource that only regenerates over long periods of time. This scenario also has a high environmental impact caused by the large scale vehicle movements that are involved in the transportation of materials pertinent to the restoration works. There also exists a risk in non-native or invasive species such as knotweed, Himalayan balsam and giant hogweed (all of which are highly invasive species and are notoriously difficult to control) being transmitted to the site and disrupting the indigenous species composition.

To avoid the problems described above, and to minimise the costs of restoration, operators can try to make use of the native material on the site. This solution rarely proves suitable due to the lack of appropriate soil structure or nutrients to be an appropriate growing medium. The results from this course of action are therefore frequently unsatisfactory, with plants failing to grow properly and ultimately, the restoration programme proving unsuccessful.

This investigation for the use of Quality Composts derived from both kitchen and green waste and biofertiliser within the landscape and regeneration sectors in Wales, is intended as a "demonstrator" project. This investigation will involve the engineering and ecological design to create a naturalistic landscape with enhanced biodiversity within a working quarry.

1.2 Site Description and Setting

The chosen project site is located at the Lloyds Quarries, Fron Haul Sand and Gravel Quarry near Nannerch in North Wales and the site is currently managed by Marshalls. The project site comprises an area of approximately 1440m^2 and the material present at the quarry is predominantly light brown silty clay.

The site is bounded to the:

- North by an elevated slope and then a road, beyond which are green fields;
- East by Fron Haul Quarry and associated workings;
- South by a Protected Woodland; and
- West by grassed slopes and woodland.

1.3 Commission

Wardell Armstrong LLP (in conjunction with specialist ecological consultants, Ecological Restoration Consultants (ERC)) was commissioned by WRAP Cymru to undertake the management of the experimental restoration project at Fron Haul Quarry in North Wales.

1.4 Purpose of the Report

The aim of this report is to provide detailed information on the materials and methodology of the project and the relative level of success achieved with regard to plant health.

Conclusions are drawn regarding the relative success of each blend of growing medium. Potential restraints and recommendations for future projects of a similar nature are also provided.

2.0 Aims and Objectives

2.1 Specific aims

The primary aim of habitat restoration will be to promote appropriate vegetation establishment and growth to generally enhance the habitat of the former quarry.

By blending green and food-included Quality Compost and Biofertiliser with quarry waste, the projects main aim is to produce an effective restoration and growing medium that could hugely reduce the dependence on topsoil for future quarry restoration works.

The second aim is to create a wildlife corridor consisting of naturalistic grassland, wildflower meadow and woodland landscape via a planting scheme of twenty four native Welsh species including a variety of species such as cowslip, ox-eye daisy and wild carrot, yarrow and bird's-foot trefoil.

3.0 Methodology

3.1 Field Trial Design and Herbaceous Plant/Tree Selection

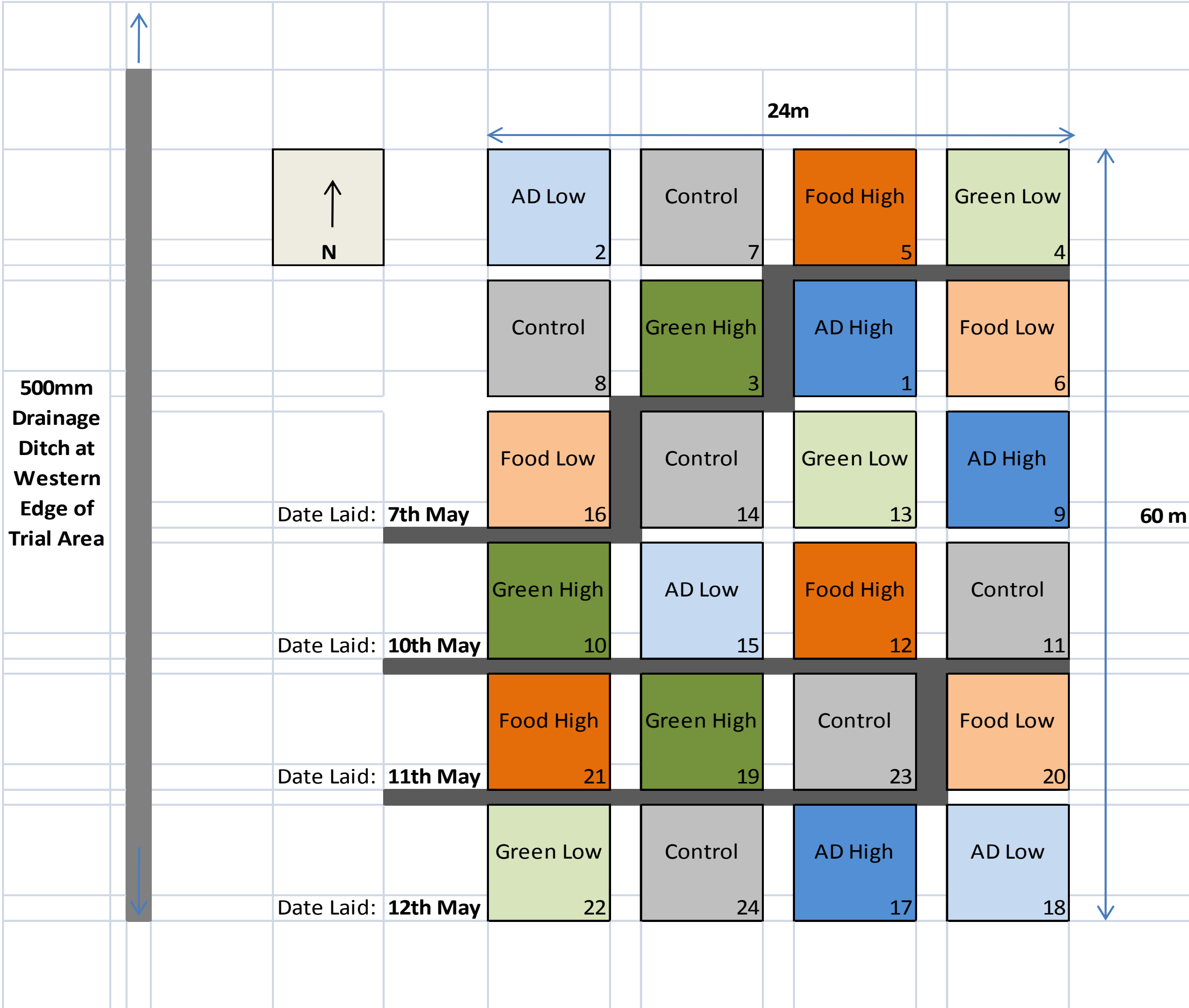
3.1.1 Field Trial Design

The field trial was designed to evaluate three types of organic material (BSI PAS 100 green waste compost, BSI PAS 100 foodwaste-derived compost and biofertiliser) as the basis for the creation of healthy functioning soils for supporting the growth and development of woodland and species-rich meadow grassland, which are naturalistic targets.

In order to create suitable soils, a mineral soil-forming material in plentiful supply at the quarry was blended with organic materials. The mineral soil-forming material was light brown silty clay which was excavated from a settlement lagoon used to collect unwanted minerals derived from washing sand and gravel aggregates produced by Fron Haul Sand and Gravel Quarry.

The experimental design of the trial involved three replicates of each blend of quarry waste plus organic materials at high and low application rates, which were laid out as three block
(one replicate per block). This encompassed seven treatments per block and therefore an additional dummy control treatment was included in each block in order to balance the plot layout with eight plots per block. The experimental design and plot layout is shown in Figure 1.

Figure 1. Design of field trial showing plot layout, date when mixes were laid down and key to treatments.



7 Treatments randomly allocated

Control (untreated silty clay)

biofertiliser high- 2.2% biofertiliser & 10% Green Compost

biofertiliser low - 2.2% biofertiliser & 5% Green Compost

Food high - 17% Food Compost

Food low - 12% Food Compost

Green high - 20% Green Compost

Green low - 12% Green Compost

In addition to an untreated control comprising silty clay, there were six soil blend treatments that encompassed two rates of incorporation of BSI PAS 100 green waste derived quality compost, two rates of incorporation of BSI PAS 100 foodwaste derived quality compost and a single application rate of biofertiliser, combined with two application rates of BSI PAS 100 green waste quality compost. The suppliers of compost and biofertiliser are given in Appendix Table 1.

The green and food derived quality composts were sourced within Wales and as they were created under a Quality Protocol they did not require an EA exemption under the Environmental Permitting Regulations 2007

Schedule 3, paragraph 9 (which was the regulatory regime in force at the time – January 2010). The biofertiliser was sourced from the nearest anaerobic digestion plant in Shropshire and required an EA exemption for it to be transported to site and mixed with quarry waste.

3.1.2 Herbaceous Plant and Tree Selection

Each plot was sown over the whole plot area on 2nd June 2010 with a mix of 18 wild flower forb species and six grass species. The species mixture was selected with the intention of creating a neutral soil plant community similar to National Vegetation Classification (NVC) MG5 (Rodwell, 1998). This designation is a meadow plant community similar to unimproved grassland that occurs in the vicinity of Fron Haul Quarry. The wildflower species and grasses were all of British native origin (supplied by Emorsgate Seeds Ltd). The list of species comprising the seed mixture and the relative proportion of each species in the mixture is given in Appendix Table 2 . It was not possible to obtain an appropriate species mix of specifically Welsh origin seeds. However the species were selected on the basis that they occur in local grassland and many are present within the quarry site boundary.

Four species of trees (all Welsh provenance) were planted as cell-grown nursery stock in spring 2010. The planted species were *Quercus rubur* (English Oak), *Betula pubescens* (Hairy Birch), *Salix cinerea* (Grey Willow) and *Sorbus aucuparia* (Rowan). These four species were selected because they are common within the vicinity of Fron Haul Quarry and also occur within the quarry site boundary. The suppliers of the nursery stock (and provenance if known) are listed in Appendix Table 3.

The planting design for the trees involved a row of six trees of each species per trial plot. The position of each species row was independently randomised as shown in Figure 2. Within each plot the position of each planted tree was in a herringbone pattern with a spacing of 1.5m between the rows in an east-west direction and 1.7m between trees in a north-south direction (Figure 3).

Figure 2. Design of the planting scheme for the tree species in randomised rows.

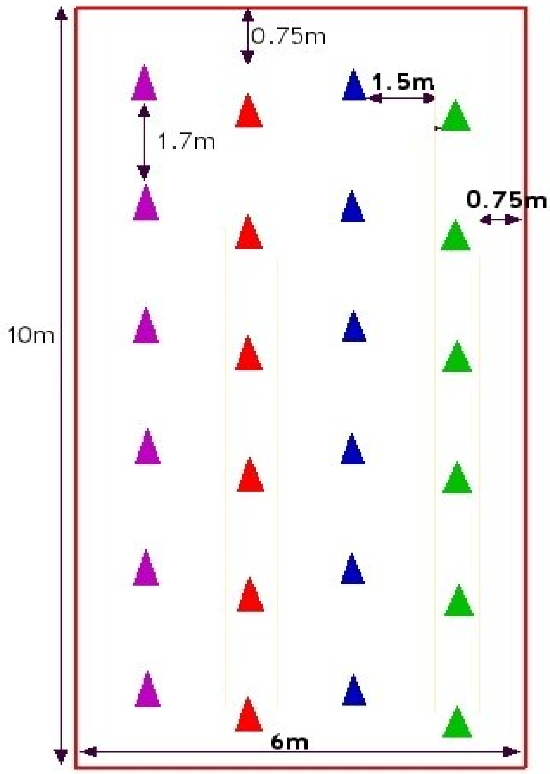


Figure 3. Planting pattern of individual trees within each trial plot

3.1.3 Sampling of composts and biofertiliser for plant nutrients, metals, metalloids and organic contaminants

Three samples of biofertiliser were collected from the IBC container which had been filled at the anaerobic digestion plant operated by Biogen-Greenfinch, Ludlow, Shropshire and delivered to Fron Haul quarry. The date of sampling was 7th April 2010. The samples were analysed by Scientific Analysis Laboratories Ltd., a UKAS accredited laboratory.

Samples of the Quality Composts were taken after these materials were delivered to the trial site at Fron Haul quarry. In each case a single composite sample was collected from each compost type. The composite sample was Quality Compost from four individual samples collected from different points in the heap of delivered material, not at the surface but at least 300mm below. The separate samples were bulked and thoroughly mixed. The date of sample collection was 7th April 2010. The samples were analysed by Scientific Analysis Laboratories Ltd.

3.2 Preparation and Engineering of Trial Plots

3.2.1 Sampling materials

Three samples of raw quarry waste, derived from washing sand and gravel aggregates, were collected on 20th January 2010 in order to determine basic chemical properties of the material. This provided the basis for calculating the quantities of BSI PAS 100 green compost, food-included compost and biofertiliser that would be incorporated in the soil blends. Each sample was a composite which comprised four individual samples bulked together and thoroughly mixed. The samples were taken from the top 120mm of the soil profile using a trowel. The samples were analysed by Scientific Analysis Laboratories Ltd.

3.2.2 The mixes of quarry waste, quality composts and biofertiliser sampled during summer and autumn 2010.

The manufactured soils within each experimental treatment were sampled on two occasions during summer and autumn 2010. The original intention had been to sample soils in late spring and again during late summer but the weather delayed setting up of the trial and caused the first episode of soil monitoring to be undertaken in mid-summer (23/07/10) and the second set of samples was obtained on 04/10/10. On each occasion the method of soil sample collection involved collection of three soil cores to a depth of 120mm from pseudo-random locations within each trial plot, which were then bulked together and mixed to create a composite sample. Samples were taken from two replicates of each experimental treatment.

3.2.3 Herbaceous Plant and Tree Selection

The trial plot area was prepared by placing and levelling the quarry silt/clay material across the test area and plots were measured out to be 6m x 10m each (adjusted from the initial 6m x 12m due to size restraints in terms of access to plots and available space for mixing) and clearly coloured pegs were placed at the edges of each plot to mark each corner. The material present at the base of each of the plots was observed to be silty sandy clay, with occasional fine to coarse gravel and cobbles. Anomalous materials were removed prior to any mixing of the material both by hand and where necessary due to size and weight of the anomaly, by excavator bucket. Areas around the trial plot area were cleared to allow space for the mixing and storage of the treatment stockpiles, plus sufficient room for the excavator to operate effectively.

3.2.4 Mixing of the Materials and Laying of the Trial Plots

Three separate stockpiles of the materials to be used in the restoration trial were deposited near to the trial plot area; these materials were then retrieved by excavator bucket and mixed using the same bucket, with care taken not to track over any of the materials to be mixed to avoid both compaction and contamination. The excavator was a 15 tonne machine with full 360° articulation.

Each of the selected materials was mixed together on a plinth of the quarry silt/clay material used in the soil manufacture which was formed by the excavator and then compacted to a level standing. This prevented any material or seed contamination from other soil sources in the vicinity, entering the mixes.

The materials were mixed in stages in order to ensure thorough mixing of the component soils and biofertiliser material. The biofertiliser was mixed into the relative treatments as a final component as it is was (and is usually) in liquid form. The treatments already containing the quarry clay and appropriate composts were worked by excavator into a depression, capable of holding the biofertiliser liquid to be mixed into the treatment. The depression was then worked and backfilled from the outside-in using the excavator bucket, ensuring that none of the liquid fraction was lost from the mixes.

Table 1 provides details of the number of bucket volumes added to each mix at each stage. The different treatments were mixed one at a time and once homogeneity was achieved (ascertained by visual assessment) they were then stockpiled separately to one another close to the trial area ready for construction of each of the trial plots. The materials were deposited by the use of a 22 tonne wheeled loading shovel and then the 15 tonne excavator was used to grade the treatments to the correct depth in the plots.

3.2.5 Additional or Adjustments to Works

Additional mixes were required upon deposition of the stockpiled material into the trial plots, as it became apparent that there was insufficient material present in the initial mixes to cover 3 trial plots (per mix) to the required depth of between 0.35 and 0.30m. These Additional mixes are described in the right hand column of Table 1 and were worked and mixed in the same manner as the rest of the materials on site.

Upon laying out the trial plots some complication was experienced due to the load bearing capacity of the quarry floor in the trial plot area. The area had formerly been waterlogged marsh which had undergone drainage and backfilling using additional quarried clay from Fron Haul. The excavator was required to deposit and compact additional quantities of clay to make good furrows created by the 22 tonne wheeled loading shovel as it tracked back and forth to deposit the materials for the trial plot areas.

Plate 1 – Placed Material in Trial Pits

Table 1.														
Treatment		**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Stage 6**	**Stage 7**	**Stage 8**	**Stage 9**	**Stage 10**	**Stage 11**	**Stage 12**	**Biofertiliser Additional Mix**
2	10% Green Compost and 2.2% biofertiliser	1:6	1:6	0.5: 5.5	1:6	1:6	0.5: 5.5	1:6	1:6	0.5: 5.5	230 litres in 2 x 115 litre buckets (mixing occurs between each addition)			Final mix of 4 x 1:9 with a further 345 litres of biofertiliser mixed in
3	5% Green Compost and 2.2% biofertiliser	9 (clay)	1: 10	9 (clay)	1: 10	9 (clay)	1: 10	230 litres in 2 x 115 litre buckets						Final mix of 2 x 1:19 with a further 345 litres of biofertiliser mixed in
4	17% Food Compost	1:4	1:4	1:4	0.5: 4	1:4	1:4	1:4	0.5:4	1:4	1:4	1:4	0.5:4	Final mix of 4 x 1.5:8 added
5	12% Food Compost	1:7	1:7	1:7	1:7	1:7	1:7	1:7	1:7	1:7				Final mix of 4.5: 31.5 added
6	20% Green Compost	4:16	1:3	4:16	1:3	4:16	1:3							Final mix of 4 x 2:8 added
7	12% Green Compost	1:7	1:7	1:7	1:7	1:7	1:7							Final mix of 4.5: 31.5 added

N.B. The ratio is in order of name of material in the 'treatment' column, therefore in treatment 3 a ratio of 1:3 would mean 1 bucket volume of Green Compost mixed in with 3 buckets of the native quarry clay.

3.3 Sowing Meadow Grassland Seed and Tree Planting Method

3.3.1 Sowing Meadow Grassland Seed

Seed was prepared for sowing by weighing two lots of seed for each half-plot ($30m^2$) to aid accuracy and evenness of sowing. The seed mix was that described under 3.1.6 was sown at a rate of 4.5g m^2. Prior to weighing seed lots, the bag of seed was mixed by hand and agitated vigorously, to ensure that the seed mixture was as homogeneous as possible.

Meadow grassland seed was sown in one day on 2nd June 2010 using hand broadcasting of seed followed by careful hand raking of the substrate surface, designed to disperse seed and cover the majority in a thin (c. 2-3mm) layer of substrate material.

3.3.2 Herbaceous Plant and Tree Selection

Trees were planted on 8th-9th June 2010 according to the design described under 3.1.8. The planting date was later than anticipated due to delay in constructing the trial plots and delay by the landscape contractor in undertaking planting at the agreed time. The position of each tree was measured and marked in relation to the species row and order in the row and was marked with a wooden stake protruding c. 750cm above ground level.

Trees were planted into pits (diameter 50mm; depth 120mm) using a custom steel planting device driven into the ground to create the hole. Each cell-grown tree was firmed in place using a boot. A circular mesh tree guard was attached to each stake to provide protection to planted trees. Two days after planting trees the entire trial area was fenced with stock-proof and rabbit-proof fencing.

3.4 Ecological Monitoring and Management

3.4.1 Germination and Early Establishment of Meadow Flora

Germination of meadow wildflowers and grasses was assessed on 24th June 2010, three weeks after sowing seed. From 9th June onwards there was no rainfall so germination was retarded and patchily distributed within plots. The number of wildflower species that could be identified with confidence was recorded but grasses were too small to identify with confidence.

The early establishment of meadow flora was measured over two days, 20th and 23rd July 2010. In each trial plot two randomly (unpremeditated) located sample points were examined using a 0.5m x 0.5m quadrat subdivided into 25 squares, each 100mm x 100mm in area. The presence in each small square was recorded for each species that was identified with certainty. At this stage, grasses were mainly too small and insufficiently developed for positive identification. The total number of 'presences' of each species in the small squares was multiplied by 25 to give a percentage frequency in the whole sample. This provides a quantitative objective measure of early establishment of both sown meadow plants and unsown weedy colonising species that may have blown on to the trial area or have been present in the silty clay quarry waste compost blends when they were placed on site. The total number of unsown ruderal weed species was counted in each trial plot (6m x 10m).

3.4.2 Growth and Development of Meadow Plant Communities

The later establishment of wildflower meadow grassland and the assembly of species in recognisable plant communities were assessed on 23rd September 2010. The assessment involved collection of data from two randomly (unpremeditated) placed sampling quadrats (1.0m x1.0m) in each trial plot. The relative abundance of each species present in the sample area was assessed using the Domin Scale (Appendix Table 4). This scale ranks species abundance in a series of percentage foliage cover bands with upper and lower limit values. The mean height of vegetation was also assessed on 23rd September 2010. The method involved four random sample throws of a card disc (20cm diameter) in each plot. The height from the centre of the disc was measured for each throw and a mean value was obtained for each treatment plot.

3.4.3 Survival, Growth and Health of Tree Species

The percentage survival of each tree species in each experimental treatment was measured on two occasions; first on 13th August 2010 and again on 4th October 2010. The August count provided an assessment of the effect of a prolonged period without rainfall that commenced three days after planting was completed whilst the count in October provided a measure of tree performance over the first growing season. All trees in the trial were counted.

The general visual health of each tree was also assessed on the same dates that the counts were made. Parameters included in the assessment were leaf colour (yellow chlorotic colour was a sign of stress), premature leaf fall, marginal death of leaf lamina and loss of turgor. These various symptoms were recorded on a simple scale of 1, 2, 3 where 3 was healthy and 1 where one or more symptoms were present on 20% or more of the foliage.

Growth of trees was measured on 4th October 2010. This was assessed as height from ground surface to the terminal bud on the leading shoot. However, the leading shoot on a number of trees had died and one or more new shoots had emerged, usually from near the base of the tree. In this case the height of the longest shoot was measured and noted as 'regrowth'. In the case of Oak and Rowan it was also possible to measure new leading shoot extension growth over the growing period of 4 months but with Birch it was not possible to clearly distinguish shoot extension growth.

4.0 Results

4.1 Chemical analysis of composts and biofertiliser

The chemical analysis of the three organic amendments, biofertiliser, PAS 100 food-included compost and PAS 100 green compost, are shown in Table 2. Biofertiliser demonstrated a very high concentration of phosphorus (P) (1.0 – 1.1%) in comparison with food-included compost (0.11%) and green compost (0.14%). The potassium (K) concentration of biofertiliser was also extremely high, in the range 4.0% - 7.0%. In contrast, the potassium concentration of the food-included (0.28%) and green compost (0.38%) were within the normal range of values for these materials (unpublished data, Association for Organic Recycling).

There was no total nitrogen analysis available for biofertiliser used in the trial but the values for food-included (0.26%) and green compost (0.25%) were both low in comparison with the majority of composts which fall within the range 0.75% - 1.25%. There was also a considerable difference between biofertiliser and the two composts with respect to Nitrate NO_3-N and Ammoniacal Nitrogen NH_4-N. Biofertiliser as expected contained a high concentration of ammonia-N whilst the two composts contained high concentrations of nitrate-N. This suggests that the composts were relatively mature.

The sulphate content of all three materials was low. In all cases the concentration of analysed metals (Cu, Zn, Pb, Cd, Hg, Ni and Cr) was low, well below the upper limits for PAS 100 compost and generally lower than the mean and median values for a sample of 285 PAS 100 composts (unpublished data, Afor). The only relatively high metal concentration was Zn in the three samples of Biofertiliser. However these zinc concentrations (180-190 mg/kg) were no more than the mean value in 285 samples of PAS 100 composts. The metalloids, arsenic and boron exhibited low concentrations of these elements in Biofertiliser and both types of compost.

The concentration of total petroleum hydrocarbons (TPH, C10-C40) was extremely low in biofertiliser and relatively low in the two types of compost. However, the compost values may not be entirely due to TPH contamination because in the absence of special analytical methods, TPH can be over-estimated due to release of plant based hydrocarbons which enhance measured values. Total PAH (EPA 16) concentrations were very low in both types of compost and relatively low in biofertiliser. There was absolutely no contamination risk caused by using the composts and biofertiliser as organic constituents of manufactured soils.

Table 2. Analysis of Biofertiliser, BSI PAS 100 food-included compost and BSI PAS 100 green compost for major nutrients, metals, metalloids, total TPH and total PAH (EPA 16).

ND = no data

		Biofertiliser			Food-included compost	Green compost
Chemical determinands	unit	Sample			Sample	Sample
		1	2	3	1	1
P	mg/l	11,000	10,000	11,000	1100	1400
K	mg/l	40,000	67,000	70,000	2800	3800
Total N (Kjeldahl)	mg/kg	ND	ND	ND	2600	2500
NO3-N	mg/kg	0.55	0.60	0.07	390	300
NH4-N	mg/kg	410	430	420	11	<5
SO_4	mg/l	16	20	29	0.23	0.31
Total Cu	mg/kg	53	46	48	18	38
Total Zn	mg/kg	190	180	180	75	150
Total Pb	mg/kg	26	16	17	31	74
Total Cd	mg/kg	<1	<1	<1	<1	<1
Total Hg	mg/kg	<1	<1	<1	<1	<1
Total Ni	mg/kg	10	12	12	6	9
Total Cr	mg/kg	17	13	13	8	10
Total As	mg/kg	<2.0	<2.0	2.3	5	4
Boron (hot water extr.)	mg/kg	<1	<1	<1	<1	<1
TPH (C10-C40)	mg/kg	<1	<1	<1	130	100
PAH (total) EPA 16	mg/kg	6.0	6.2	5.6	<0.1	2.0

4.2 Chemical analysis of quarry waste and manufactured soil blends of quarry waste with BSI PAS 100 composts and Biofertiliser

The chemical analysis of raw quarry waste is shown in Table 3. The main properties of the silty clay quarry waste are as follows. The concentration of the major mineral nutrients P and K was very low, too low to support adequate growth of plants, even when part of a meadow grassland semi-natural species assemblage. Nutrient content was also too low to support adequate growth of most tree species. The concentration of available NO_3-N and NH_4-N were also very low.

Table 3. Analysis of untreated silty-clay waste for major nutrients, metals, metalloids, total TPH and total PAH (EPA 16) sampled on 20th January 2010.

Chemical determinands	unit	Sample		
		1	2	3
Available P	mg/l	<10	<10	<10
Available K	mg/l	60	77	57
NO3-N	mg/kg	5	<4	<4
NH4-N	mg/kg	6	6	<5
SO_4	mg/l	23	27	20
Total Cu	mg/kg	23	24	21
Total Zn	mg/kg	56	58	52
Total Pb	mg/kg	30	30	27
Total Cd	mg/kg	<1	<1	<1
Total Hg	mg/kg	<1	<1	<1
Total Ni	mg/kg	37	38	34
Total Se	mg/kg	<3	<3	<3
Total Cr	mg/kg	28	28	25
Total As	mg/kg	10	10	9
Boron (hot water extr.)	mg/kg	<1	<1	<1
TPH (C10-C40)	mg/kg	<1	<1	<1
PAH (total) EPA 16	mg/kg	<0.1	<0.1	<0.1

The total concentrations of all metals in the quarry waste was very low and in the case of some elements (Zn, Cu) even lower than the equivalent concentration in biofertiliser or the two types of compost. The concentration of arsenic was low and boron was very low. Concentration values for TPH (C10-C40) and total PAH (EPA 16) were also extremely low. Thus there were absolutely no contamination issues, either with the raw quarry waste or the organic materials being mixed with it to create new soil blends. These data reinforce the general principle and practical experiences that quality compost and biofertiliser contain low concentrations of metals and harmful organic compounds and therefore are ideal materials for blending with uncontaminated quarry wastes.

The analysis of soil samples taken from each replicate plot for all compost/biofertiliser/quarry waste mixes is given in Table 4 (23/07/10) and Table 5 (04/10/10). The effect on soil properties caused by addition of compost or biofertiliser is described in the following paragraphs.

Soil pH was relatively high (in the range 7.8 – 8.2) in July and September on all treatments although the biofertiliser high and biofertiliser low treatments had a slightly lower pH on both occasions. Percentage soil organic matter content was raised significantly in all compost and biofertiliser treatments in July and September and with the exception of food-included compost in September 2010, the high rate of compost or biofertiliser correlated with higher soil organic matter content. The absolute amount of soil organic matter was relatively low in comparison with the semi-natural (or agricultural) grassland on loam soil.

As would be expected, the total nitrogen content of the soil was considerably enhanced in all compost and biofertiliser treatments in comparison with raw quarry waste. The highest percentage total nitrogen was in the high rates of food-included and green compost in both July and September. There were no major changes in percentage soil nitrogen between the two sampling dates although the values for both biofertiliser high and biofertiliser low were somewhat greater in September than in the previous July. High concentrations of nitrate-N were also recorded in the treatments containing biofertiliser. It was possible that a combination of biofertiliser and green compost (the biofertiliser low and high treatments) interacted to generate enhanced mineral nitrogen release. The concentration of ammonium-N was very low in all experimental treatments in both July and September 2010. When originally blended with raw quarry waste in March 2010, biofertiliser contained a substantial concentration of ammonium-N (in the range 410-430mg/kg). This must have volatilised or been converted to mineral nitrate-N in the four month period from late March to July 2010. The food-included and green composts contained very little ammonium-N when delivered and although further degradation of organic matter contained in the composts would have generated ammonium-N, this would have been rapidly lost to the atmosphere or converted to mineral nitrate-N.

In comparison with the quarry waste control treatment, the total soil concentration of both phosphorus and potassium were enhanced in all the compost and biofertiliser treatments.

Table 4. Analysis of untreated silty-clay quarry waste and manufactured soil blends for major nutrients, metals, metalloids, total TPH and total PAH (EPA 16) sampled on 23rd July 2010.

Determinands	unit	Soil blend treatments						
		biofertiliser high	biofertiliser low	Food high	Food low	Green high	Green low	Control
pH		7.9	8.1	7.8	8.0	8.2	8.1	8.2
Soil organic matter	%	0.95	0.9	1.4	1.35	1.5	1.2	0.4
Total N (Kjeldahl)	mg/kg	600	750	1200	750	1200	900	300
NH4-N	mg/kg	<5	<5	<5	<5	<5	<5	<5
NO3-N	mg/kg	42.5	119	43.5	48.5	47	42	21
P (total)	mg/kg	350	345	425	400	425	385	280
K (total)	mg/kg	1550	1550	1600	1700	1850	1650	1300
Total As	mg/kg	7	6.5	7	7.5	7.5	7.5	6.5
Total Cd	mg/kg	<1	<1	<1	<1	<1	<1	<1
Total Cr	mg/kg	17.5	18	17.5	17.5	18.5	18	17
Total Cu	mg/kg	17.5	18	19	18	21.5	19.5	17
Total Pb	mg/kg	24.5	24	25.5	24.5	28.5	27	23
Total Hg	mg/kg	<1	<1	<1	<1	<1	<1	<1
Total Ni	mg/kg	25.5	27	26	25.5	27	26.5	25.5
Total Se	mg/kg	<3	<3	<3	<3	<3	<3	<3
Total Zn	mg/kg	49.5	50	51	51	57.5	53	44
TPH (C10-C40)	mg/kg	2.5	6.5	12.5	6.5	12	17	2.5
PAH (total) EPA 16	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 5. Analysis of untreated silty-clay quarry waste and manufactured soil blends for major nutrients, metals, metalloids, total TPH and total PAH (EPA 16) sampled on 4th October 2010.

Determinands	unit	Soil blend treatments						
		biofertiliser high	biofertiliser low	Food high	Food low	Green high	Green low	Control
pH		7.9	7.9	8.3	8.0	7.8	8.0	8.0
Soil organic matter	%	0.75	0.5	1.25	1.65	2.0	1.25	0.2
Total N (Kjeldahl)	mg/kg	750	850	1100	950	1050	950	400
NH4-N	mg/kg	<5	<5	<5	<5	<5	<5	<5
NO3-N	mg/kg	6.5	11	<5	<4	<4	<5	<4
P (total)	mg/kg	259	250	320	360	385	305	190
K (total)	mg/kg	965	1055	1095	1200	1350	1150	780
SO_4	%	0.035	0.035	0.035	0.055	0.055	0.04	0.025
Total As	mg/kg	5.5	5	5.5	6	5.5	5.5	4
Total Cd	mg/kg	<1	<1	<1	<1	<1	<1	<1
Total Cr	mg/kg	13.5	14	13.5	14	14.5	14	11.5
Total Cu	mg/kg	14	13	14	15	19	14.5	11
Total Pb	mg/kg	19	17.5	19.5	21.5	23.5	20.5	15
Total Hg	mg/kg	<1	<1	<1	<1	<1	<1	<1
Total Ni	mg/kg	17.5	20.5	19	21	21	19.5	17.5
Total Se	mg/kg	<3	<3	<3	<3	<3	<3	<3
Total Zn	mg/kg	31.5	35.5	37.5	42	47	39	31.5
TPH (C10-C40)	mg/kg	<1	11	<1	<1	<1	<1	<1
PAH (total) EPA 16	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

4.3 Development of Meadow Vegetation

4.3.1 Germination of Meadow Flora

Following sowing on 2nd June 2010, there were 2/3 wet days but then from June 9th there was no rain for a period of over 2 weeks. This climatic experience will have delayed germination in comparison with a more varied distribution of rainfall. Nevertheless there was satisfactory initial germination on all trial plots except the control plots. However, germinated seedlings were distributed patchily and there was considerable variability so that it was not possible to distinguish clear differences in germination between the various compost and biofertiliser treatments.

Nine (50%) of the wildflower species had germinated out of 18 sown species but seed of some species may have been dormant when sown and not germinated rapidly. Grasses had germinated but individual species were generally too small to identify with confidence. A substantial number of different ruderal weed species (up to 15 different species per plot) had germinated in all compost and biofertiliser treatment plots although the control plots contained substantially fewer weeds (3-9 species). Some of the weed species (eg. Common Orache, Fat Hen, Common Chickweed and Knotweed) had grown to a height of 100-200mm, growing at a much faster rate than the sown species. At this stage of germination and early establishment, foliage cover was much too small to measure quantitatively.

4.3.2 Early establishment of meadow flora

Early establishment of meadow flora was measured as percentage ground cover by foliage and consequently the remaining bare ground and also by the percentage frequency and number of individual species of meadow wildflowers and ruderal colonising plants. Mean percentage bare ground in each of the experimental treatment mixes is shown in Figure 4 for the assessment made on 20th July 2010 (Figure 4 also includes data obtained on 23rd September 2010). The most rapid germination and early establishment occurred on the blends containing green compost (both high and low proportion in the mixes). Foliage cover was just over 70% for the high treatment of green compost. In the case of blends containing food-included compost, germination and establishment was slower but bare ground was around 50% or less for the low rate. Percentage bare ground was 85% in the biofertiliser blend with a low rate of green compost only slightly less than 90% bare ground which was present in the untreated controls. The substantially faster early establishment in the green compost blends may be a result of the soil physical structure which had a surface less prone to micro-erosion and with a greater number of sheltered micro-sites producing higher humidity values close to the surface and thus promoting faster germination and seedling root growth.

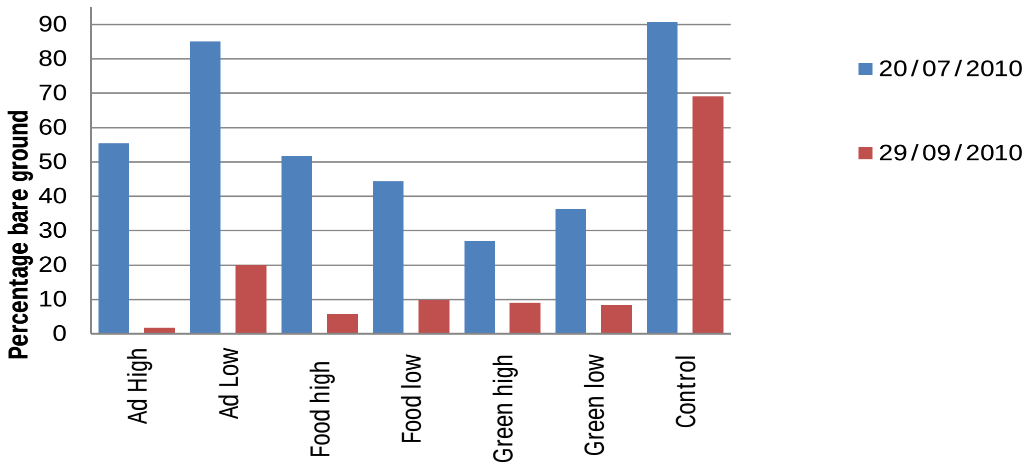


Figure 4. The mean percentage bare ground (n=6) recorded on 20th July 2010 in the differing blends of compost and quarry waste.

The mean number of wildflower species per sample (0.5m x 0.5m) in each individual plot in the various treatments, on 20th July 2010, is shown in Table 6. This gave a measure of species establishment by mid-summer. There was relatively little variation in mean species number between treatments with a range from 7.7 in the blend with a higher proportion of food-included compost in the mix, to 9.3 in the low rate green compost treatment. There were no obvious trends in the data or association of a treatment with higher or lower species number. In total, 18 wildflower meadow species were sown and approximately 45% -50% of these had established on 20th July 2010.

The total number of ruderal weed species that occurred in each individual trial plot (6m x 10m) is shown in Table 6. It is clear that the green compost blends supported the largest number of unsown colonising plant species which is probably caused by a favourable micro-topography for germination and establishment (the compost should have been weed-free). The control treatment plots contained the lowest number of colonising ruderals and the blends encompassing biofertiliser with green compost also supported lower numbers of ruderal species. These plots and the controls provided a less favourable surface micro-topography for germination and seedling establishment because the surfaces were flat, smooth and lacking micro-heterogeneity in contours leaving less suitable micro-sites for germination.

Table 6. The mean total number of sown meadow wildflower species counted per sample (0.5m x0.5m)(n=3) and the mean total number of unsown ruderal colonising species counted per trial plot (6m x 10m) on 20th July 2010 (n=3).

Experimental treatment	Plot number	Number of meadow wildflower species	Mean	Number of ruderal colonising species	Mean
biofertiliser high	1	10	9.0	8	12.7
	9	8		16	
	17	9		14	
biofertiliser low	2	10	8.7	12	13.3
	15	8		10	
	18	8		18	
Food high	5	8	7.7	11	14.0
	12	6		16	

	21	9		15	
Food low	6	8	8.3	13	12.7
	16	8		12	
	20	9		13	
Green high	3	8	8.7	11	15.3
	10	9		15	
	19	9		20	
Green low	4	10	9.3	16	18.3
	13	7		16	
	22	11		23	
Control	7	7	8.7	8	9.7
	14	10		10	
	23	9		11	

4.3.3 Species presence in September 2010

The number of plant species present in each treatment plot (6m x 10m), assessed on 23rd September 2010, is shown in Figures 5, 6, 7 and 8. The plant species were split into different life form groups showing sown meadow wildflowers (Figure 5), perennial and biennials (Figure 6), unsown annuals (Figure 7) and sown and unsown grasses (Figure 8).

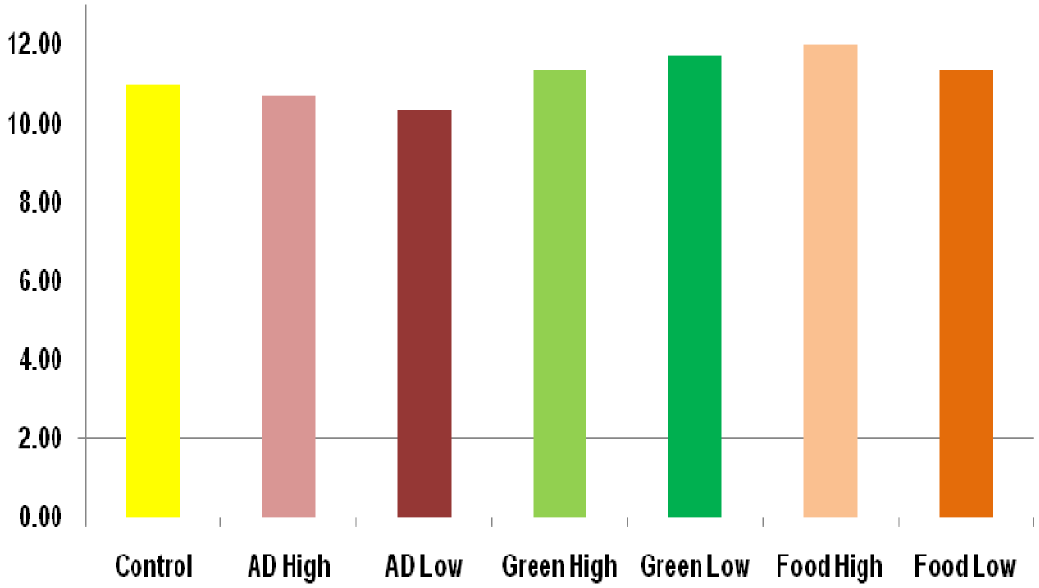


Figure 5. The mean total number of sown meadow wildflower species per plot (6m x 10m) assessed on 23rd September 2010 (n = 3).

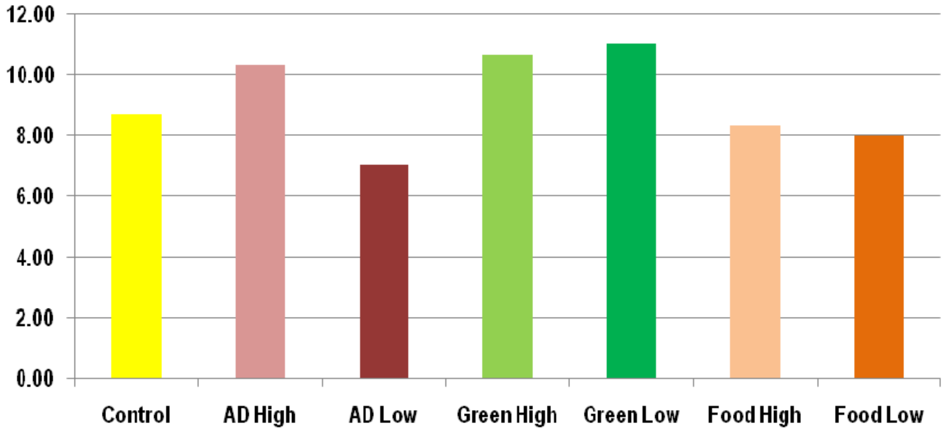


Figure 6. The mean total number of unsown perennial and biennial species per plot (6m x 10m) assessed on 23rd September 2010 (n = 3).

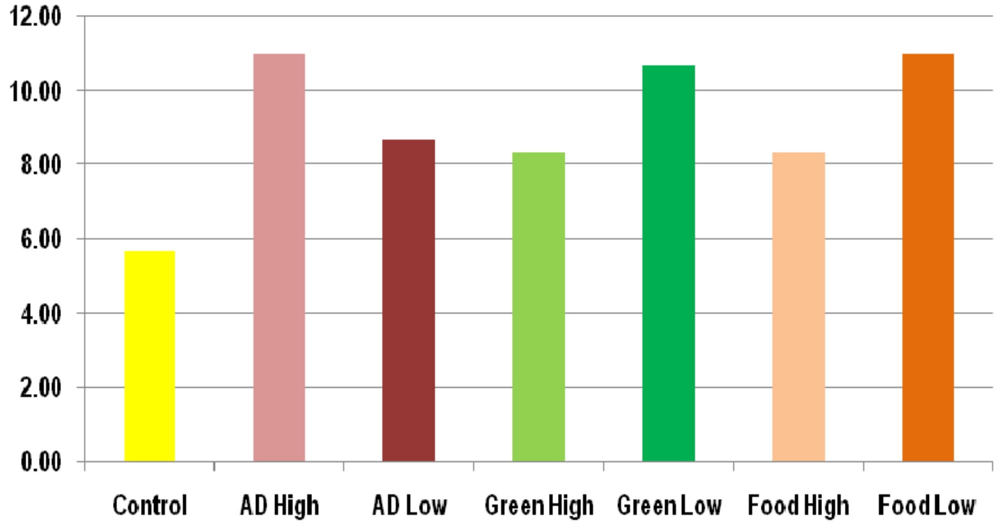


Figure 7. The mean total number of unsown annual species per plot (6m x 10m) assessed on 23rd September 2010 (n = 3).

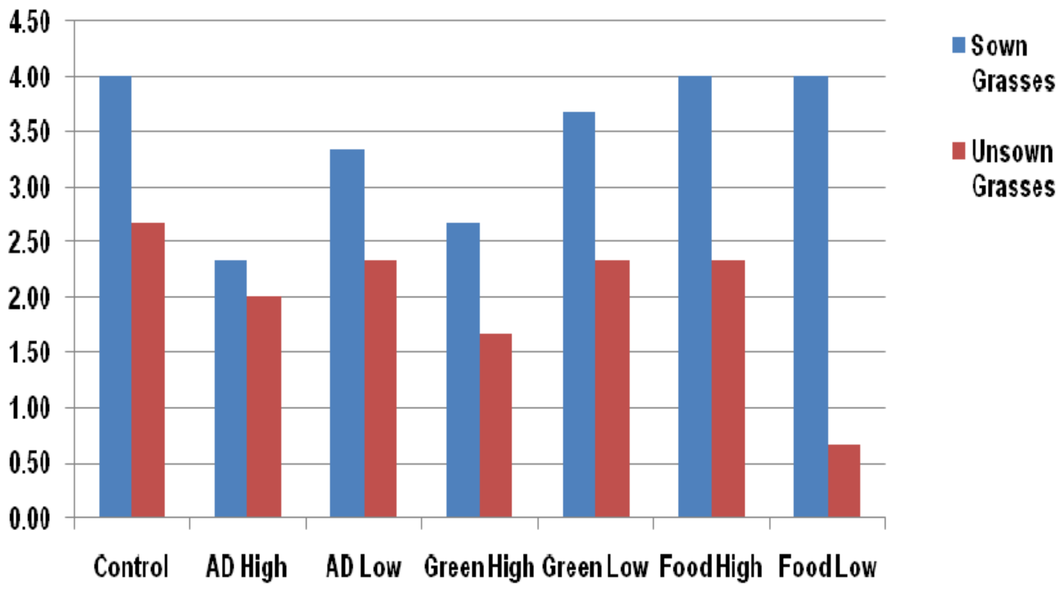


Figure 8. The mean total number of sown grass species per plot (6m x 10m) assessed on 23rd September 2010 (n = 3).

The number of sown meadow wildflowers per plot was higher in the green compost (low and high) and food-included compost (high and low) mixes with quarry waste, than in the biofertiliser treatments or the control. This suggested that the physical properties of the compost blend with quarry waste created a more favourable medium for the establishment of meadow wildflowers. However, this pattern was not repeated in the case of unsown perennial or biennial plants which established best in the green high and green low treatments but not in mixes containing food-included compost. The perennial and biennial plants were unwanted 'weed' species and therefore mixes containing food-included compost provided a more favourable outcome (i.e. fewer perennial weeds and more meadow wildflower species).

Unsown annual 'weeds'' established in greater numbers on all the compost and biofertiliser blends with quarry waste, in comparison with the control. The greater fertility in all of the compost and biofertiliser treatments may have caused the improved establishment of annual 'weeds'. The number of annual species per plot did not correlate with particular treatments in a predictable way. Thus the treatments with the higher number of unsown annual species were biofertiliser high, green low and food low. In the long-term unsown annuals are unimportant because they will disappear from grassland managed by cutting once or twice a year.

It is not possible to provide a rational interpretation of the data for the number of sown and unsown grass species in the different experimental treatments. Treatments containing compost and/or biofertiliser generally supported fewer grass species than the control except in the case of sown grasses in the high and low food-included compost:quarry waste mixes. The food low treatment contained the least number of unsown grass species per plot and all compost and/or biofertiliser treatments supported less unsown grass species than the control. Usually more fertile soils containing PAS 100 compost or biofertiliser support higher grass species numbers in addition to greater biomass of grass.

4.3.4 The impact of compost and biofertiliser mixes with quarry waste on the relative abundance of selected meadow wildflowers

The relative abundance of the five most common sown meadow wildflower species in the different experimental treatments is shown in Figures 9 and 10. The three species illustrated in Figure 9; Yarrow, Wild Carrot and Common Sorrel were all more abundant (in terms of Domin Score which measures percentage foliage cover) in the mixes of biofertiliser, food-included compost and green compost with quarry waste than in the untreated quarry waste control. The combination of biofertiliser, green compost and quarry waste was favourable for all three meadow wildflower species and mixes with food-included compost and quarry waste favoured Yarrow and Common Sorrel in particular. In contrast the abundance of Ox-eye Daisy and Bird's-foot Trefoil were relatively unaffected by the compost and/or biofertiliser treatments in comparison with the control. Overall the inclusion of biofertiliser, PAS 100 green compost and PAS 100 food-included compost were either favourable or neutral in provision of a growing medium for wildflowers, when blended with quarry waste.

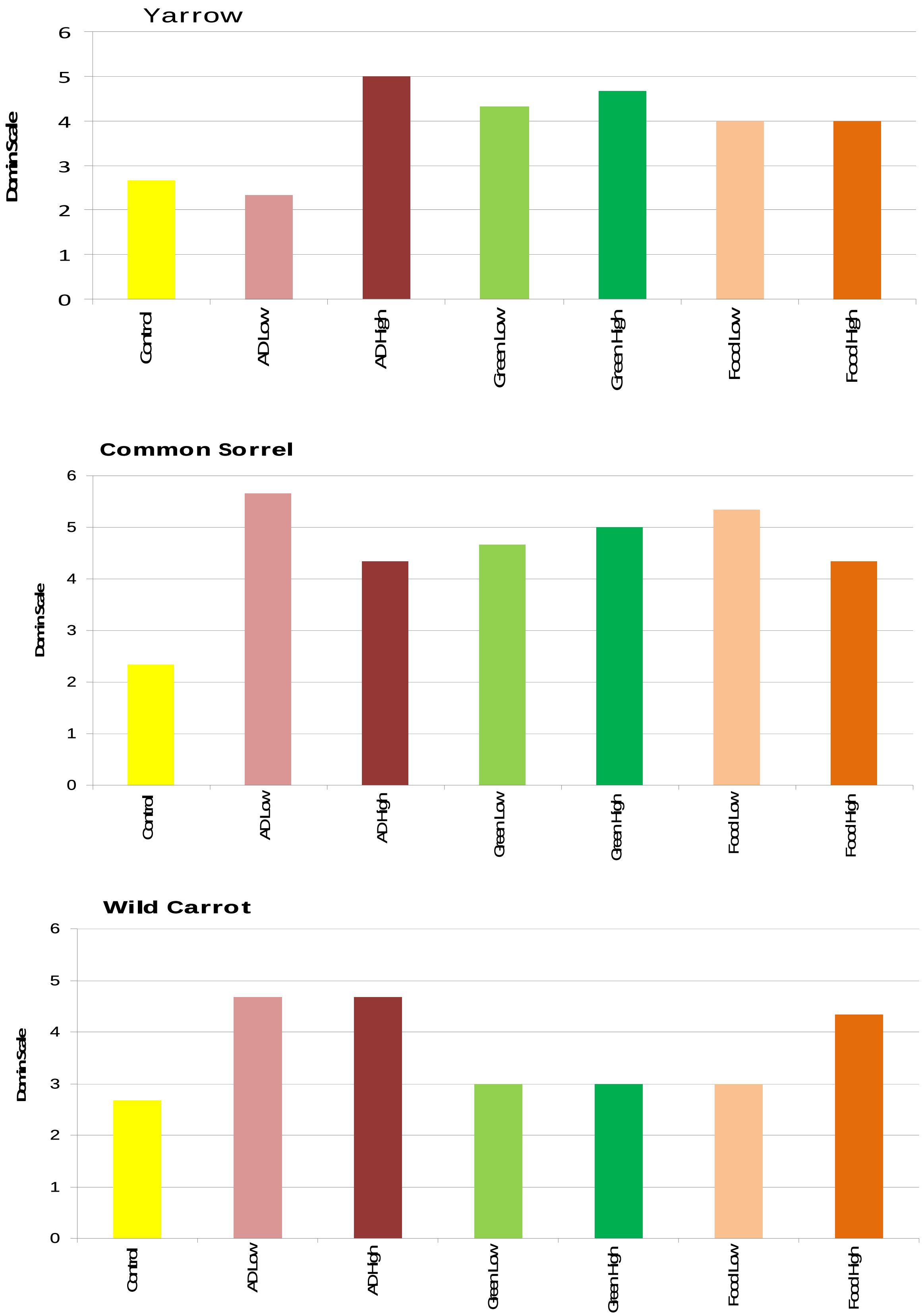
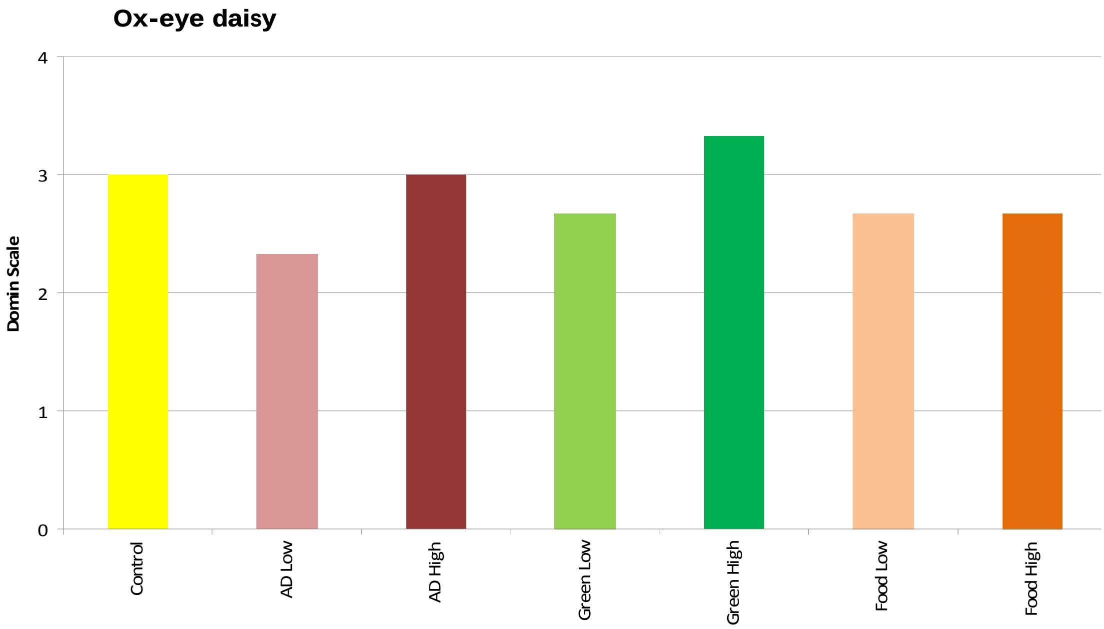


Figure 9. The mean relative abundance (measured on the Domin Scale) of three species of meadow wildflower; Yarrow, Wild Carrot and Common Sorrel, assessed on 23rd September 2010, in each experimental treatment.



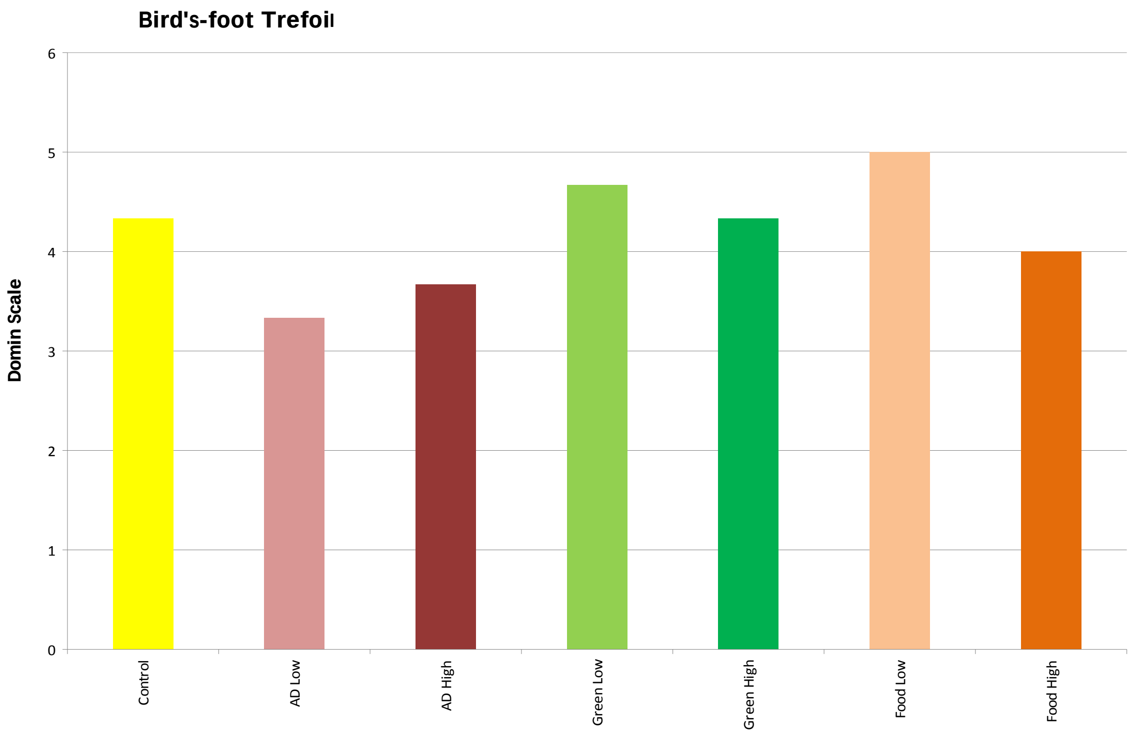


Figure 10. The mean relative abundance (measured on the Domin Scale) of two species of meadow wildflower; Ox-eye Daisy and Bird's-foot Trefoil, assessed on 23rd September 2010, in each experimental treatment.

4.3.5 Vegetation height

The mean height of meadow grassland vegetation measured on 23rd September 2010 is shown in Figure 11. This provided an indirect measure of fresh vegetation biomass in each plot and provides an insight into the soil fertility associated with each experimental treatment. All treatments supported substantially greater vegetation height (and therefore biomass) than the unamended quarry waste control. Growth in the high biofertiliser soil mix, high food-included compost and high green compost treatments were comparable and not associated with the greatest overall biomass.

4.3.6 Species richness and vegetation diversity

Three measures of species richness/vegetation diversity were calculated using the species abundance data. These were Simpson's Index and Shannon-Wiener Index which both measure species richness (diversity) in vegetation and Smith and Wilson's Index of evenness which measures the extent to which plant species are equally abundant. The calculated data are shown in Table 7.

The Shannon-Wiener Index was more useful than Simpson's for depicting species richness. The two most species rich treatments were the soil blends containing low input of food-included compost or low input of green compost. The diversity in these treatments was greater than the control. The only treatment that suppressed species richness below the value for the untreated quarry waste control was the green high treatment. Thus at the end of the first growing season five out of six compost or biofertiliser treatments were favourable to meadow flora. However, the Smith and Wilson evenness measure did show that all compost/biofertiliser treatments produced a lower value than the control. The interpretation is that some plant species were relatively more dominant in the compost/biofertiliser treatments.

Table 7. Measure of species richness (diversity) of wildflower meadow grassland in the various compost/biofertiliser/quarry wastes mixes/

Treatment	Simpsons Index	Shannon-wiener Index	Smith and Wilson Evenness
biofertiliser High	0.95	4.33	0.79
biofertiliser Low	0.94	4.33	0.77
Food High	0.94	4.31	0.77
Food Low	0.95	4.45	0.75
Green High	0.93	4.03	0.75
Green Low	0.95	4.50	0.77
Control	0.94	4.31	0.83

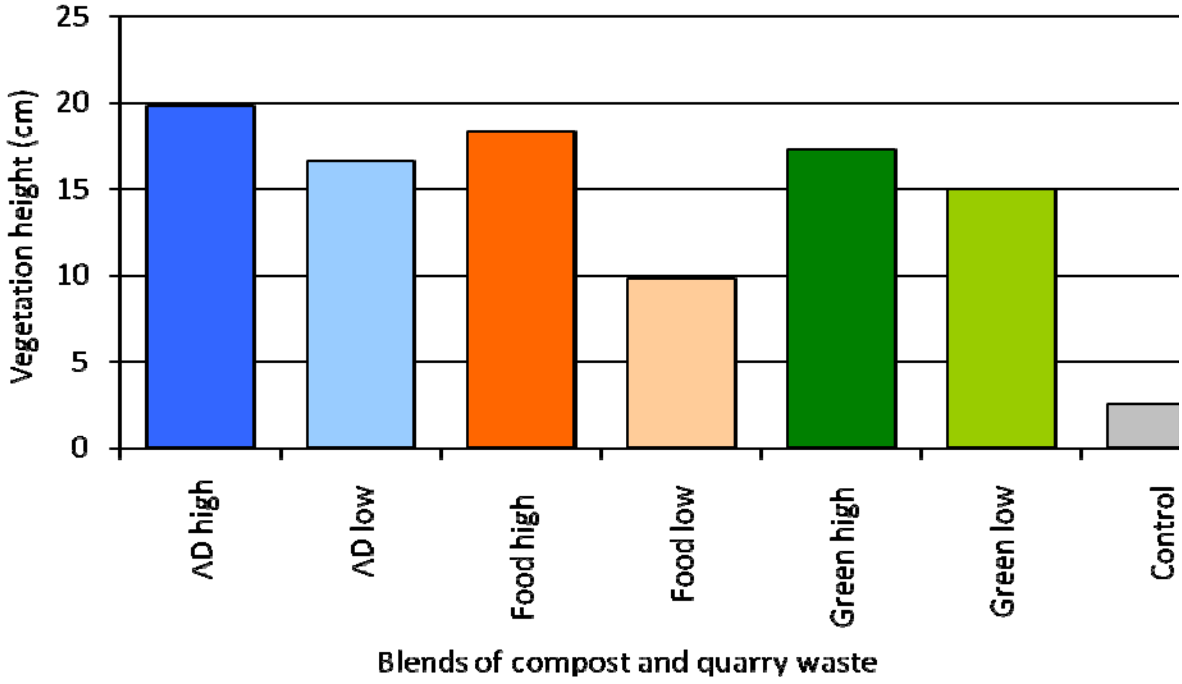


Figure 11. The mean height of vegetation in each experimental treatment, assessed on 23rd September 2010 (n=12).

4.4 Growth and survival of tree species

4.4.1 Survival of trees

The census of tree numbers made on 4th October 2010 gave an evaluation of tree performance over the period of growth since planting on 8/9th June 2010. Table 8 shows the number of dead trees of each species in each experimental treatment, plus the percentage mortality per species and per soil blend treatment.

Table 8. The total number of dead trees in each compost or biofertiliser soil blends treatment recorded on 23rd September 2010, plus the mean percentage mortality per species and per treatment.

Soil blend treatment	Hairy birch	Rowan	English oak	Grey willow	Mean % mortality in each treatment
biofertiliser high	0	0	1	11	16.7
biofertiliser low	5	0	0	9	19.4
Food high	1	0	0	6	9.7
Food low	2	0	1	7	13.9
Green high	6	3	0	16	34.7
Green low	4	3	0	7	19.4
Control	2	0	0	9	15.2
% species mortality in trial	15.9	4.8	1.6	51.6	18.5

Overall percentage mortality in the trial was relatively high (18.5%) although two species mainly contributed to this high value. These were grey willow (51.6%) and hairy birch (15.9%) whereas there was very low mortality of oak (1.6%) and low mortality of rowan (4.5%). The period of negligible rainfall experienced just after the trees were planted had a very adverse effect on the grey willow which either died or die back to the base and when rainfall was adequate a new shoot would develop from a basal bud. There was also die back of the leading shoot of some birch. In contrast, English oak was drought tolerant and all but two individuals survived.

There was significant variation in mean percentage survival between the soil blend treatments: Mortality was greater in the treatment soil blends containing biofertiliser than in the control and also both the green high and green low compost: quarry waste blends supported a high percentage mortality compared to the control treatment. In contrast, tree mortality in the treatments containing food-included compost was relatively low in comparison with all other soil blend treatments.

4.4.2 The growth of trees

The mean height of trees growing in each of the blends of compost or biofertiliser and quarry waste are shown for each tree species separately in Figure 12 (hairy birch), Figure 13 (rowan), Figure 14 (English oak) and Figure 15 (grey willow). The tree height data were normally distributed (Kolmogorov-Smirnov test) and therefore an Analysis of Variance was valid statistically.

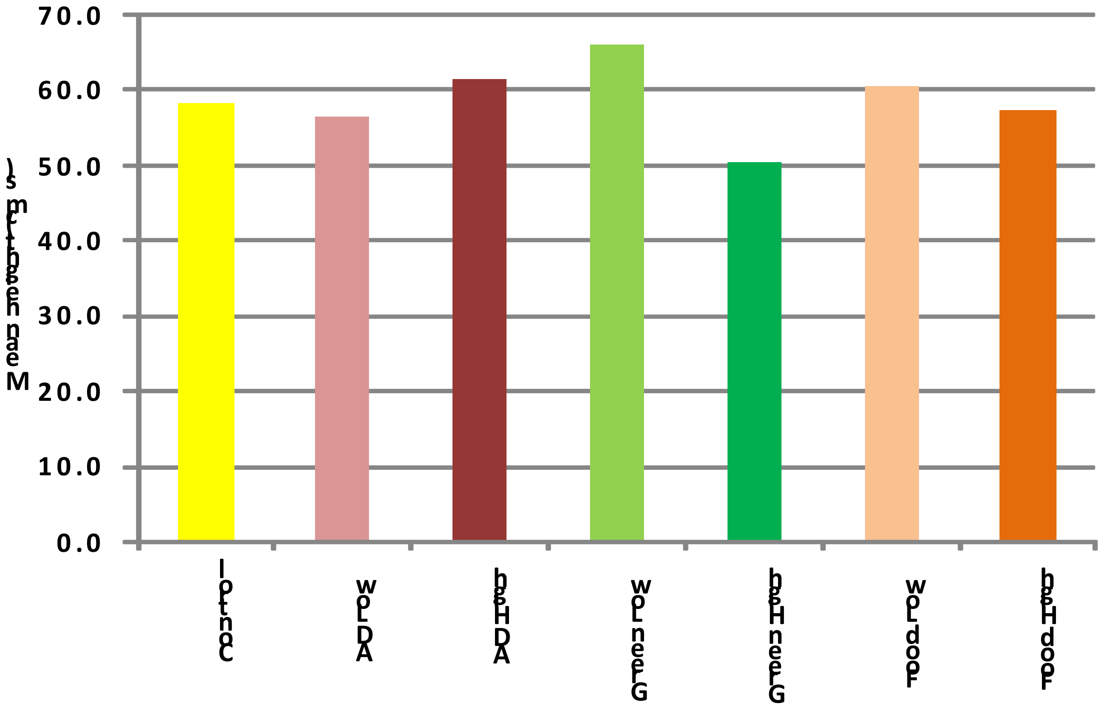


Figure 12. The mean height of hairy birch growing in each of the blends of compost or biofertiliser and quarry waste.

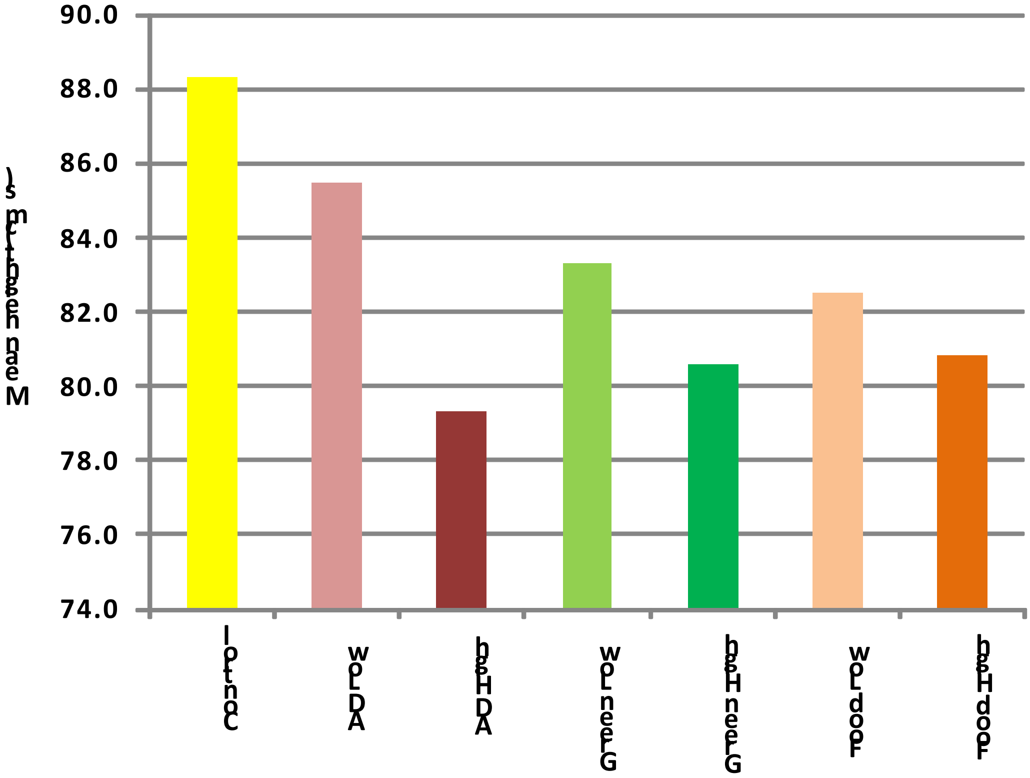


Figure 13. The mean height of rowan growing in each of the blends of compost or biofertiliser and quarry waste.

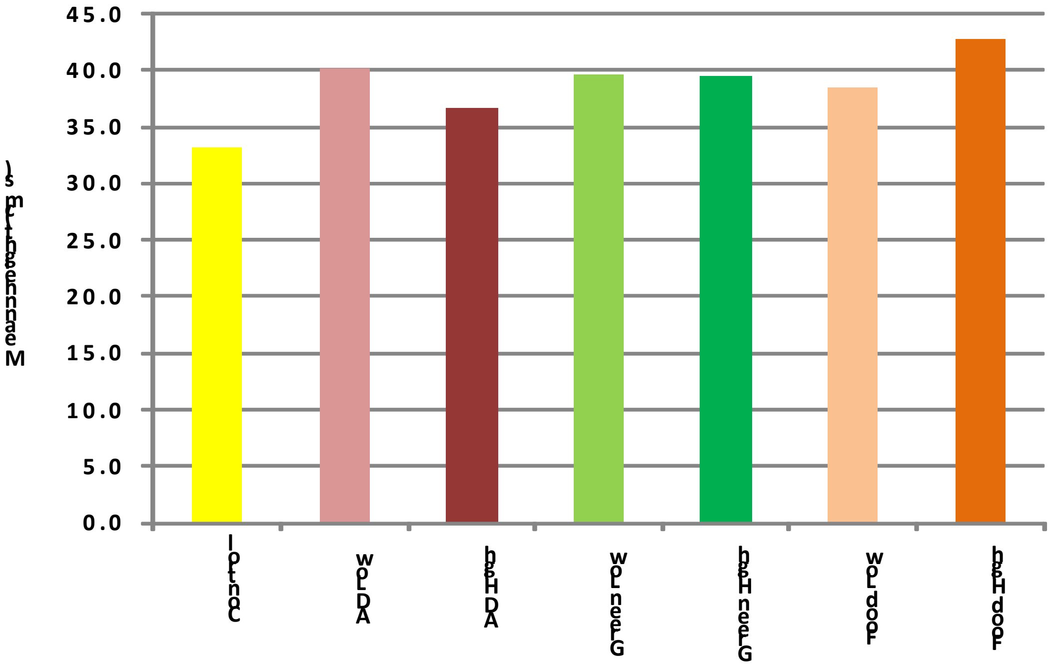


Figure 14. The mean height of English oak growing in each of the blends of compost or biofertiliser and quarry waste.

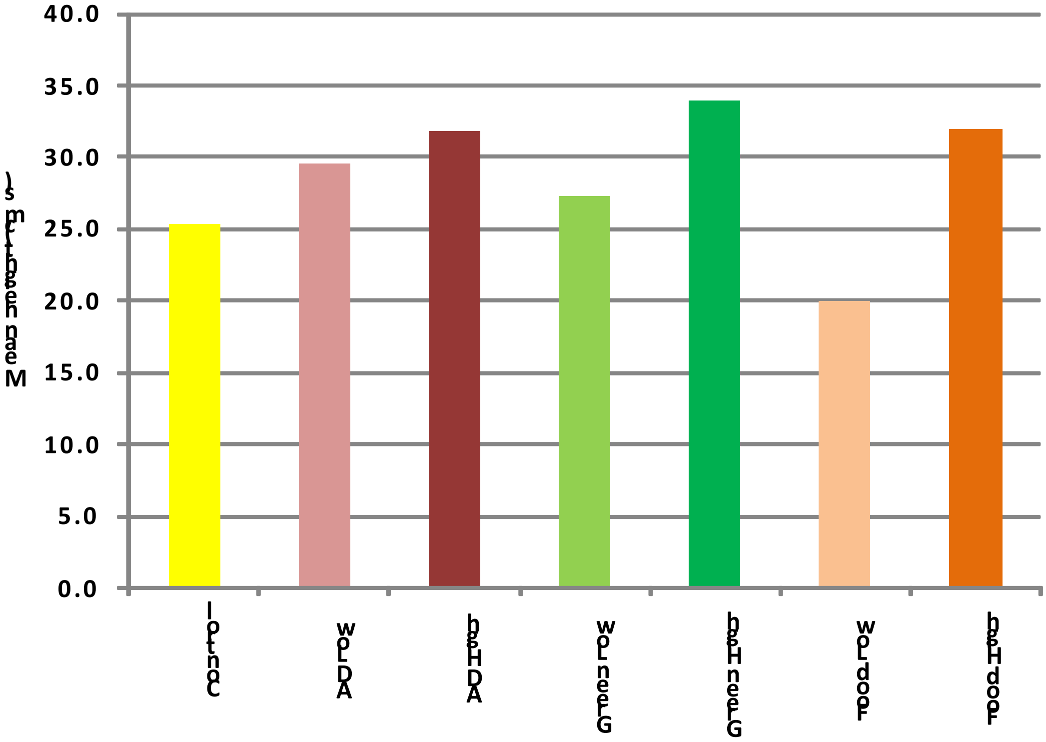


Figure 15. The mean height of grey willow growing in each of the blends of compost or biofertiliser and quarry waste.

An Analysis of Variance of tree heights for each species and pooled over all species showed that there was no significant difference between the compost:quarry waste soil blend treatments. Differences in mean height between species just reflected height differences at the time when the trees were planted. The only species for which the soil blend treatment effect was almost significant was rowan. However, the tallest rowan trees were in the control treatment and the shortest were in the biofertiliser high rate treatment, whilst height growth was also retarded in the green compost and food-included high rate treatments.

In the first growing season there was an inadequate time span for the growth of trees to respond to the different soil treatments. The trees were planted in early summer and experienced (after an initial rainfall) a period of drought lasting more than two weeks. It will be necessary to monitor tree growth through the 2011 growing season in order to obtain comparative tree growth data for the various compost and biofertiliser treatment blends with quarry waste.

5.0 Conclusions and Recommendations

5.1 Setting up the trial

If we consider first the mechanical aspects of preparing compost: quarry waste blends and using these to set up the trial, the preparation of the compost: quarry waste blends was a straightforward process of mixing in-situ quarry waste with the two composts (Gwynedd Council, food-included compost and Waste Recycling Group, green compost). In practice the use of a bucket attached to a 360° excavator produced a visually homogenous blend. One important factor which contributed to the success of mixing was that the raw quarry waste contained relatively few stones. It would cost less in large scale practice to spread compost using an agricultural muck spreader and then plough in and rotavate or just rotavate. This method would be satisfactory for establishment of grassland but would provide an inadequate depth of incorporation for trees.

For the purpose of setting up the trial, mixing liquid biofertiliser with the quarry waste and green compost was undertaken using a two-stage method suitable for small trial plots, which would not be replicated on a large scale. For the trial, compost and quarry waste were premixed and biofertiliser was added afterwards into a central pocket, capable of holding the biofertiliser liquid to be mixed into the treatment. Mixing was then undertaken. Incorporation of biofertiliser on a large scale would normally involve either spreading the liquid using agricultural machinery followed by rotavation or ploughing or using direct liquid injection equipment as used for incorporation of liquid sewage sludge.

Physically setting up the trial was straightforward. The most important requirement was that the mixed materials should be loose-tipped and that there was no cross-contamination of blends or compaction caused by machinery prior to planting of trees and seed of meadow grassland. This was achieved successfully because the excavator moved progressively backwards, or around the sides of the trial plot area, as the different mixes were placed in their assigned position in the trial. Painted stakes were placed to provide the excavator driver with accurate positioning of the trial plots.

Once the trial had been set up and planted with trees and wild flower seed mixture, the area was fenced with rabbit proof fencing which was essential to safeguard trees and prevent surface disturbance. The fenced area was also protected from accidental damage by machinery which may be active in the immediate vicinity.

5.2 Impact of compost and biofertiliser on soil properties

The quarry waste was physically and chemically unsuitable for final site restoration. The material contained a relatively high content of clay and silt and if compacted will impede drainage and impede infiltration of rainfall when dry. The quarry waste was deficient in available nitrogen, phosphorus and potassium and in an unamended state would not support good tree growth or an adequate cover of wildflower-rich meadow grassland. However, the raw subsoil contained minimal potentially toxic (metal) elements and very low concentrations of organic contaminants. The quarry waste was also deficient in organic matter and thus, potential mineral plant nutrients from this source. It was clear that incorporation of organic matter in the form of compost, biofertiliser or both was an essential requirement for development of a healthy soil system which would deliver a sustainable grassland or woodland landscape.

Chemical analysis of PAS 100 composts and biofertiliser demonstrate certain contrast between these materials, which will influence the fertility of blends of quarry waste with compost and biofertiliser. Anaerobic digestate was particularly high in total concentration of phosphorus and potassium and as expected contained a high concentration of ammonium-nitrogen. The concentration of phosphorus and potassium in both food-included compost and green compost was relatively much lower. However, these two materials contained a higher concentration of nitrate-nitrogen at the time of application. The pattern of release of these major nutrients influenced the establishment and growth of meadow grassland but not planted trees except for rowan.

The concentrations of all metals tested were low in all three organic materials. Total zinc was at a higher concentration in biofertiliser in comparison with food-included and green composts but the range of absolute values, 180-190mg/kg was unlikely to influence plant growth and did not pose an environmental hazard. The two metalloids, arsenic and boron were at low (or very low) concentrations in all materials. The concentrations of TPH (C10-C40) and PAH (total EPA 16) were also very low. Thus all materials used in the trial were innocuous.

In both July and September 2010 the amount of compost or biofertiliser mixed with quarry waste in the differing treatments was reflected in the percentage organic matter content of the manufactured soil. A higher proportion of food-included or green compost in the blend generally produced a soil with higher organic matter content. This effect also occurred with total content of soil nitrogen but available nitrate-nitrogen was higher in the blend of biofertiliser, green compost and quarry waste. There was greater mineralisation of nitrogen (more rapid release) despite the lower total soil nitrogen in the biofertiliser high and biofertiliser low treatments. This rapid availability of soil nitrogen probably explained the high plant biomass (measured as vegetation height) in the biofertiliser high treatment. The concentration of both ammonium and nitrate-nitrogen had fallen to low values when measured in early October 2010, particularly in the soil mixes containing compost. A combination of slow mineralisation, plant uptake and leaching of nitrogen in soil solution probably accounted for this situation.

Despite the initial high concentrations of phosphorus and potassium in fresh biofertiliser the addition of 2.2% of this material in the mix plus 5% or 10% green compost, gave a soil concentration of P and K in October 2010 slightly below the values achieved using higher rates of incorporation of food-included or green compost.

Soluble P and K in biofertiliser may have been more readily leached in soil water. However, the cautious approach was justified because meadow wildflower growth in the biofertiliser high and biofertiliser low treatments was at least as vigorous as the high rate green compost and high rate food-included compost treatments. At the end of the 2010 growing season soil fertility was more than adequate to support good growth of meadow vegetation and trees in all biofertiliser and compost blends with quarry waste.

5.3 Establishment of growth of meadow grassland

Ultimately the 'success' of habitat creation within the wider quarry landscape is a measure of biological 'success'. A significant aim of restoration is to encourage biodiversity and locally distinct types of habitat. At Fron Haul quarry this includes meadow grassland and woodland including birch and oak as significant species and naturally colonising grey willow in unmanaged areas. A single growing season is much too short a period over which to judge 'success'. Monitoring over a period of three or four years will provide a reasonable indication of successful restoration of meadow grassland.

The incorporation of green compost with quarry waste promoted the most rapid germination and early establishment of meadow grassland. In mid summer (20th July) the treatment with low rate of green compost supported the greatest plant species density (number of species per unit area) of both sown and meadow wildflowers and unsown ruderal colonising species. This effect persisted to 23rd September although the other compost treatments also supported greater species densities than the control treatment. Clearly, blends of quarry waste containing PAS 100 green compost and food-included compost were favourable to the establishment and growth of meadow grassland during the first growing season after sowing. The key to success was using no more than 20% green compost in the blend with quarry waste and no more than 17% food-included compost. Excessive soil fertility is a problem for successful grassland habitat creation (Marrs and Gough, 1989; McCrea et al., 2004; Critchley et al., 2002). A previous WRAP Trailblazer Project (OBF-009-002) on a former landfill site in Cumbria (Trials for the Restoration of Broughton Craggs Former Landfill Site, March 2011) clearly demonstrated the deleterious impact on meadow grassland of an excessively fertile soil where food-included compost caused luxuriant growth of dominant grasses which outcompeted meadow wildflowers.

5.4 Survival and growth of trees

Unfortunately, there was a delay in planting the trees which did not go into the trial plots until 8th-9th June 2010. This was two months past the prime planting period. The trees experienced two days rainfall followed by more than two weeks continuous drought. The subsequent soil moisture stress caused increased mortality, during the first growing season in grey willow (51.6%) and hairy birch (15.9%). In contrast English oak and rowan experienced very low mortality (1.6% and 4.8% respectively). The average survival of oak and rowan was well above normal for woodland planting on brownfield land (Rawlinson et al., 2004).

During the first growing season there were no statistically significant differences in height growth between the compost: biofertiliser: quarry waste mixes, for any tree species. The height growth of oak was consistently greater in all of the compost or biofertiliser treatments and the same occurred with grey willow (except for the low rate of food-included compost). There was an inadequate length of time between planting and the end of the first growing season for treatment differences to take effect. It is expected that treatment differences will become clear cut by the end of the 2011 growing season, when height growth between autumn 2010 and 2011 will provide a sensitive indicator of tree performance.

5.5 Economic factors and the choice of recycled organic materials for the creation of in-situ manufactured soils in a quarry setting.

An economic assessment of recycled organic materials that are available for use in creation of new landscapes in quarries is an essential prerequisite for determining the optimum strategy for restoration of quarry wastes. Residual mineral substrates in quarries are normally very infertile materials often with a physical structure that is poor for a potential soil-forming material and an important initial decision is to determine whether in-situ manufacture of soils is the best option or whether the cost of importing topsoil is the best economic option.

Thus the in-situ manufacture of soils should be assessed in comparison to the cost of importing topsoil (BS 3882: 2007) assuming that it would be available in sufficient quantity and with a specification suitable for individual landscaping requirements. If imported organic materials can be used for direct in-situ manufacture of soil at a quarry close to the site where new landscape works are required and the total cost per m3 of manufactured soil is less than imported topsoil, this becomes the first option of choice. This assumes that the quarry site contains no topsoil, or inadequate amounts, that has been stored and is available for landscape works.

At Fron Haul Quarry the waste derived from washing aggregates, collected in a lagoon and then removed to storage areas, has unsuitable physical and chemical properties for rapid or even medium-term soil development. Unfavourable physical characteristics include high bulk density, poor infiltration and permeability to water and very low organic matter content. The main chemical problem is a very low content of available major nutrients such as nitrogen and phosphorous. Thus the material provides a serious impediment for colonization and growth of plants.

Soil organic matter plays a key role in supporting good physical quality of soil and in the provision of major and micro plant nutrients over an extended period of time. Table 8 provides a summary of the various types of organic materials that may be available for blending with quarry waste, in order to create manufactured soils. Four main factors will determine the choice of organic material which can be used in soil manufacture. These are;

- The cost of the product per m3 delivered to the site.
- Easy availability of the organic product.
- Haulage distance from the nearest producer site.
- Suitability of the organic product for blending with quarry waste and creation of sustainable landscapes.

At Fron Haul Quarry it is too early in the development of the trial to determine the most suitable organic material (or mix of materials) for landscaping purposes based on the performance of trees or meadow grassland. Therefore, the organic amendment material of choice will be the one that can be sourced from the nearest location bearing in mind the ex-site producer cost of the material. Three different organic materials were tested in the trial and PAS 100 green compost is available from a producer located near Wrexham but the nearest location for PAS 100 food-included compost is Gwynedd Council's site at Harlech and the nearest location for biofertiliser is the Biogen Greenfinch digester near Ludlow, Shropshire. Thus currently the best option for soil manufacture is PAS 100 green compost. However, if alternative materials become available at sites closer to Fron Haul at some future time, a combination of reduced input of PAS 100 green compost combined with biofertilser would provide a useful alternative probably at lower cost.

Table 8. The main characteristics of recycled organic materials and comparative chemical, physical and cost benefits.

Characteristic	PAS 100 food-included compost	PAS 100 green compost	Sewage sludge cake	Thermally dried sewage pellets	Biofertiliser	CLO
	Physical properties					
Bulk density fresh	+	+	++	++	++	++
Organic matter content (dry) percentage	40-50%	25-30%	40-60%	50%	ND	50-55%b
C : N ratio	++	++	++	+	++	+
	Chemical analysis					
pH	7.0 -8.0	7.0 – 8.0	6.0 – 8.0	ND	6.5 – 8.0	6.5 – 7.5
Total nitrogen	++	+	++	+++	+++	+
Total phosphorus	+	+	++	+++	++	+
Total potassium	+++	+++	+	+	+++	+
Total magnesium	++	+	+	+++	+	+

Metals content	**Generally low**	**Generally low**	***Can contain higher concentrations of Zn, Cu, Pb, Ni, Cr**	**Generally acceptable**	***Generally acceptable**	**ND**
Moisture content percentage	**Variable**	**20 -35%**	**5-95% depending on type**	**5%**	**Depends on whether liquor, whole or fibre**	**ND**
Comparative cost on a volume basis ex-site	**Variable medium cost**	**Variable medium cost**	**Low free + transport**	**High**	**High**	**Low free + transport**

Notes: + low ND: no data available

++ medium

+++ high

* depends on producer site and feedstock - variable

5.6 General conclusions

- The first year of the trial located at Fron Haul Quarry has demonstrated that satisfactory establishment of most species of trees and good establishment of meadow grassland was achieved on the majority of the blends of quality composts and biofertiliser.
- Some of the willows and birch died due to a combination of late planting and drought and these should be replaced as soon as possible.
- The full benefit of manufacturing soil in-situ using blends of quarry waste and PAS 100 green compost, PAS 100 food-included compost and biofertiliser, will not be revealed until tree growth and meadow vegetation development have been monitored for a period of three years.
- The method of blending quarry waste with the organic materials was satisfactory in practice, although on a large scale, application of biofertiliser would be achieved more effectively and at a lower cost by spreading, followed by mechanical incorporation into quarry waste or using direct liquid injection equipment.
- If the method of mixing quarry waste and organic materials, used in the trial, was implemented on a large scale, the cost of in-situ manufacture of soils would be less than the cost of importing topsoils. The estimated cost of production of 100m3 of manufactured soil incorporating 20% green compost by volume is £7.50 per m3 but this would reduce to £5.00-£6.00 per m3 for substantially larger volumes. This would be competitive with imported topsoil at Fron Haul Quarry and probably at the majority of quarry locations in North Wales.
- A reduced cost method for incorporating compost would be to spread using an agricultural rear discharge muck spreader or a wide track 360° excavator followed by incorporation using a rotavator or plough plus power harrow. This will be suitable for meadow grassland and shrubs but less suitable for trees where a greater depth of incorporated organic material would be required.
- The biodiversity and nature conservation role of the restored trial area will start to be revealed during 2011. The site will become more favourable for many invertebrate species and small mammals but will require a few years development before becoming useful habitat for passerine bird species. The wider setting will develop into a valuable grassland and woodland landscape in the medium to long term and will provide the basis of a valuable informal recreation area with access to nature, following eventual closure of the quarry.

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7.0 Glossary of terms

Term	Definition
Analysis of variance	Provides a statistical test of whether or not the mean values of a particular variable in a set of experimental treatments are all equal or whether significant differences occur at a particular level of probability.
Annual	A plant that usually germinates, flowers and dies within a single season or year.
Biennial	A plant that takes two years to complete its biological life cycle. Germinating, flowering and dying within the two- year period.
Biodiversity	The measure of total species diversity within an ecosystem.
Biofertiliser	In the context of this report is the residual material remaining after anaerobic digestion, which is normally in the form of liquid slurry. This material increases the supply and availability of nutrients and therefore encourages plant growth.
Biomass (plants)	The accumulative mass of all living plants in a given unit area. Can also be applied to a single species.
BS3882 : 2007	The BSI specification for topsoil including multipurpose topsoil and specific purpose topsoil grouped as acid, calcareous and low fertility topsoil.
BSI PAS 100	A Publicly Available Specification (PAS) for compost, published by the British Standards Institute. The specification for compost covers the entire process of compost production; from raw materials and production method, through to quality control and lab testing. BSI PAS 100 is certified by the Association for Organic Recycling in order to assure quality, traceability, safety and reliability.
Domin Score	Value assigned to a plant species within a sampling area using the Domin Scale. The Domin Score denotes the species quantitative contribution to the vegetation by estimating its percentage overall abundance.
Forb	An herbaceous flowering plant that is not a graminoid (grasses, sedges and rushes).
Kolmogorov-Smirnov Test	Nonparametric statistical test for the equality of continuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution. In the context of this report it is used to test for normality of distribution as a requirement for the Analysis of Variance model.
Mineralization	Transformation of an element from a form bound in soil organic matter to an inorganic, plant-available form.
National Vegetation Classification (NVC)	The British National Vegetation Classification or NVC is a system of classifying natural habitat community types in Britain according to the vegetation they contain.
Naturalistic	Imitating or reproducing the effect or appearance of semi-natural habitats. A man-made replica of a semi-natural habitat is described as 'naturalistic'
Nitrification/Nitrifying	Oxidation of ammonia in a two step process to nitrate via nitrite by autotrophic bacteria.
PAH EPA-16	Organic pollutants consisting of polycyclic aromatic hydrocarbons (PAHs) generated by incomplete combustion. PAHs are often mutagenic and carcinogenic and can accumulate in food webs.
Perennial	Referring to a plant that lives for more than two years.
Phytotoxic	Poisonous to plants.
Provenance	The origin or source of a species population (eg. origin of planted trees imported from a nursey).
Pseudo-random	The appearance of statistical randomness but not truly random. Location of sample areas by blind throwing of a sample quadrat is pseudo-random sampling.

Quality Compost	Compost which will not pose any risks to the environment or human health in the quantities or frequencies in which it is used. Quality composts conform to BSI PAS 100 accreditation.
Quality Protocol	Criteria for the production of a product from a particular waste type. The protocol is required to ensure use of such a product does not pose any risk to the environment or to human health.
Ruderal	Plant species that are first to colonise disturbed lands. The disturbance may be natural (e.g. forest fires or avalanches), or due to human activities (e.g. agriculture, mining, road or building construction or post-industrial derelict land). Ruderal species usually dominate the disturbed area for a few years, gradually succumbing to competition from other species.
Soil Organic Matter/SOM	Well decomposed remains of plants, animals, organic manures or other forms of decomposed organic matter.
Soil Texture	Descriptive classification reflecting the proportions of mineral fractions (sand, silt and clay sized particles).
Species Richness	The number of different species within a given area also known as species density. Often used to determine the conservation value of ecosystems and their species.
Species Diversity	An index that incorporates species richness and also the relative abundance of species weighted in various ways.
TPH	Total petroleum hydrocarbon (TPH) relates to any mixture of hydrocarbons that are found in crude oil. TPHs are a component of petroleum products which can contaminate the environment.
Volatilised	Process where a substance is converted into gas or vapour.

Appendix Tables

Table 1. Suppliers of BSI PAS 100 composts and anaerobic digestate.

Material	Supplier	Certification
BSI PAS 100 green compost	Waste Recycling Group Wrexham Recycling Park Wales	Quality Protocol BSI PAS 100
BSI PAS 100 food-included compost	Gwynedd Council Fridd Rasus Harlech Wales	Quality Protocol BSI PAS 100
Biofertiliser	Biogen Greenfinch Ludlow Shropshire	Working towards PAS 110

Table 2. Neutral grassland species seed mix sown at Fron Haul Quarry on 2nd June 2010 at a sowing rate of 4.5 grams per m^2.

% by wt	Latin name	Common name
5	*Achillea millefolium*	Yarrow
6	*Centaurea nigra*	Common knapweed
3	*Crepis capillaris*	Smooth Hawksbeard
3	*Daucus carota*	Wild carrot
5	*Gallium verum*	Lbiofertiliseries bedstraw
4	*Geranium molle*	Dove's-foot cranes-bill
5	*Hypochaeris rbiofertilisericata*	Cat's ear
4	*Knautia arvensis*	Field scabious
5	*Lathyrus pratensis*	Meadow vetchling
5	*Leucanthemum vulgare*	Oxeye daisy
4	*Leontodon hispidus*	Rough hawkbit
4	*Lotus corniculatus*	Birdsfoot trefoil
3	*Plantago lanceolata*	Ribwort plantain
3	*Primula veris*	Cowslip
5	*Ranunculus acris*	Meadow buttercup
5	*Rumex acetosa*	Common sorrel
3	*Trifolium repens*	Creeping white clover
4	*Vicia cracca*	Tufted vetch
3	*Agrostis capillaris*	Common bent grass
5	*Anthoxanthum odoratum*	Sweet vernal-grass
5	*Cynosurus cristatus*	Crested dogstail grass
2	*Dactylis glomerata*	Cock's foot grass
3	*Poa trivialis*	Rough-stalked meadow grass
5	*Phleum bertolonii*	Smaller cat's-tail

Table 3. Suppliers of native Welsh species of tree species nursery stock with provenance if known.

Supplier of nursery stock	Species	Provenance
Tree Haven Nursery Llandrindod Wells LD1 5UN	*Betula pubescens* *Quercus rubur* *Sorbus aucuparia*	304 305 Welsh
Johnsons of Whixley Whixley York YO26 8AQ	*Salix caprea*	Welsh

Table 4. Percentage frequency of wildflower meadow species in each trial plot plus a mean value per treatment assessed on 20th-23rd July 2010.

Experimental treatment	Plot number	*Achillea millefolium*	*Centaurea nigra*	*Galium verum*	*Leucanthemum vulgare*	*Lotus corniculatus*	*Plantago lanceolata*	*Rumex acetosa*	*Vicia cracca*
biofertiliser high	1	10	10	6	10	14	10	12	10
	9	46	4	6	12	20	20	16	10
	17	62	6	6	20	8	30	28	6
Mean		39.3	6.7	6.0	14.0	14.0	20.0	18.7	8.7
biofertiliser low	2	26	6	6	6	24	18	22	6
	15	28	0	2	14	18	16	24	6
	18	40	12	0	12	12	16	18	6
Mean		31.3	6.0	2.7	10.7	18.0	16.7	21.3	6.0
Food high	5	64	8	0	14	0	26	10	4
	12	40	0	0	12	8	0	24	0
	21	66	12	8	20	14	24	44	0
Mean		56.7	6.7	2.7	15.3	7.3	16.7	26.0	1.3
Food low	6	70	6	6	18	16	24	48	12
	16	26	4	6	8	18	26	42	0
	20	40	4	2	16	10	28	20	8
Mean		45.3	4.7	4.7	17.3	14.7	26.0	36.7	6.7
Green high	3	68	10	0	22	8	18	4	0
	10	70	10	8	26	18	34	32	4
	19	72	4	6	18	18	20	10	6
Mean		70.0	8.0	4.7	22.0	14.7	24.0	15.3	3.3
Green low	4	54	6	2	12	12	14	26	2
	13	52	0	0	14	16	20	18	2
	22	82	4	6	26	20	56	54	8
Mean		62.7	3.3	2.7	17.3	16.0	30.0	32.7	4.0
Control	7	4	0	0	8	16	8	0	8
	14	40	6	6	8	36	32	4	12
	23	80	12	12	12	20	16	46	26
Mean		41.3	6.0	6.0	9.3	24.0	18.7	16.7	15.3

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