MIRO - FINAL REPORT

Combination of Basaltic Quarry Fines with Organic Process Residues for the Development of Novel Growing Media

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SUMMARY

This project aimed to identify and assess potential combinations of four quarry fines with five composts for the development of growing media, aimed mainly at horticulture in the short term, and land restoration in the long term.

Grass and tomato plant pot trials were set up against corresponding quarry soil and reference control (good agricultural soil and tomato grow-bag) to assess blends' performance. According to composts, the two blends which performed the best and medium, within the grass pot trial experiment, were selected, and tested further on a larger scale: lysimeters were set up to assess physical properties (infiltration, shear strength, water holding capacity), and leaching potential from blends for ground and surface water potential contamination. (Two compost and four rock fines that is eight blends). Two rock fines and composts were then selected according to the above grass trials, and tested on a larger scale in field plot trials set up on a site to be restored within a local quarry.

Results included the grading of tomato plants after two weeks, the monitoring of the plants' heights and tomato yields, the grass growth of grass pot trials and lysimeters, the leachability of nutrients and potential contaminants, and physical properties (infiltration, water holding capacity, shear strength) of blends tested in lysimeters. Field plot trials were then set up at a local quarry, with grass on one half of the plots, and trees on the other half; their set-up revealed the difficulty encountered by the machinery to blend the two materials together, suggesting a poor trafficability and workability. Results of pot trials suggested that any type of the rock fines tested in this project did not reduce the compost quality but enhanced in most cases, especially those with low nitrogen. Tomato fruits were as acceptable for the consumer as any other tomato fruits. All the rock fines were tested further, with the selection of two composts (low and high nitrogen). Tests suggested that nitrate leaching might be an issue to be addressed, whereas the ecotoxicity test (Enchytraeid worm test) suggested that all the blends tested in lysimeter trials were suitable for soil invertebrates. Basaltic rock fines also improved infiltration rate and shear strength of composts.

It can be concluded that most quarry fines interact positively (at least) with composts, and vice versa, to give potential novel growing media suitable for horticultural and land restoration uses. Though, further research should be undertaken in the ratio of compost: quarry fines to potentially reduce the initial level of nitrogen in some blends, and therefore reduce nitrate leachability. Moreover, other potential utilisations of such growing media should be further investigated such as applications in sylviculture.

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1. INTRODUCTION

Soil, like peat, is a valuable and non-renewable resource. Traditional sources of topsoil and of soil-forming materials are becoming less able to meet demand for soils for landscaping and for container-grown plants. Demand for soils and soil-forming materials extends from land restoration that might have a recreational or urban landscape outcome, through agricultural applications to compensate for erosion or removal of nutrients, to horticultural production and leisure gardening. In this context, the identification of alternative sources of organic matter and mineral matter represents a commercial opportunity on two counts: (1) markets exist for soil forming materials, and (2) suitable materials arise as wastes (composted materials) and by-products (quarry fines).

Many quarry sites, landfills and spoil heaps in the UK suffer from a lack of topsoil in order to undertake a suitable restoration to current expected standards. When soils are removed prior to quarrying or any other engineering activity, their properties change as a consequence of compaction and restricted aeration. Chemical changes affect the form of key nutrients such as nitrogen. Stockpiled soils are often not suitable for land restoration work (Davies, 1998). The material available for final restoration may often consist of only poor quality subsoil or merely the rock fines or coarser material remaining as spoil from the mineral extraction operation. A major problem with such materials is the poor water holding capacity and/or low plant nutrient content. In addition to the problems for the use of such materials for restoration at the quarry, there also exists the potential for the utilisation of the fines as a mineral supplement for organic waste materials for final use within the horticultural sector. This is particularly the case for potassium as a nutrient for tomato production.

Within a quarry, after soil has been removed and stockpiled on site during quarry operations (typically 10 years), excavation takes place and rocks are crushed and sieved for a particular end use. However, many fines do not have uses as they do not meet processing criteria for existing uses (e.g. road, construction). These are stockpiled on site, and can become an increasing issue for quarries, which have difficulty disposing of them.

A potential solution to this lack of suitable topsoil is to manufacture a soil at the particular site. In addition, the quarry fines offer the potential to be blended with organic waste residues to be marketed as novel growing media.

Two key factors have underpinned the rationale behind this study. First, the Landfill Directive requires putrescible matter within municipal solid waste and from other sources to be treated in ways that do not require landfill. This has led to a significant growth in composting activity as part of a normal waste management system. Secondly, the amount of fine aggregate produced as a normal consequence of crushed rock aggregate production is increasing due to changes in design specifications for road construction and for technical reasons (Mineral Solutions, 2004a). This study addresses technical aspects of the use of the two materials in combination as soil-forming materials. Key issues concern:

1) The availability of nutrients from (a) compost and (b) crushed rock sources

2) The performance of blended materials for horticultural and land restoration applications
3) The potential environmental impact of the blended materials.

Commercial aspects of blending quarry fines with composts have been considered in a separate study (Mineral Solutions 2004b).

Manufactured soil use (the use of combined soil forming materials) on aggregate extraction sites has traditionally been undertaken whenever a shortage of soils has arisen. The term ‘soil-forming materials’ has been in existence for many years and refers usually to on-site overburden materials which can be used to help form a profile within 1 m depth of the surface, ultimately for plant growth. The overburden can consist of various mineral matter drift deposits suitable for making soils, with those of a silty or sandy texture usually the most easily handled.

Following placement on an area to be restored, a soil forming material, usually, would then be augmented with some form of organic matter, very often some form of sewage sludge which would need to be imported into the site. Many other different organic matter sources are however now increasingly available to help in the production of synthetic soils for land restoration (Bending, 1999; WRc & ADAS, 1999).

Typical materials available include:

- Green waste or other composts
- Paper waste sludge
- Food waste
- River or canal dredgings
- Water treatment sludge
- Farmyard manure
- Wood waste
- Various sewage sludges
- Animal by-product wastes

A number of issues must be addressed before a synthetic soil can be manufactured.

The entire operation would normally need to fall within exception criteria listed within the Waste Management Licensing Regulation 1994 as the Environment Agency will in most cases consider the imported material a ‘waste’. The main points to note are that:

- The organic waste amendment must fall within the categories listed within Table 2 of the Regulations
- Only specific quantities of certain wastes can be spread on land.
- If soil is manufactured on the site, up to 20 000 cubic metres can be spread on land.
- The material results in agricultural or ecological benefit.

In addition to the legislative aspects of synthetic soil manufacture and application, practical aspects relating to environmental pollution, plant nutrient management and physically dealing with the materials involved have to be considered.

A crucially important point is the ability to manufacture a soil on-site and hence increase the volume of material that can be applied if needed. This clearly distinguishes between operations where materials can simply be spread directly on the land surface or those used for soil manufacture on-site.

In general, two different ‘limiting’ criteria may restrict the amount of waste that can be spread on land which is being restored. The Waste Management Licensing Regulation 1994, which are the same for any site, and the Contaminated Land Regulations 2000 which would be site-specific. If the land is being restored to agriculture and once the land had passed beyond the 5 year aftercare period, the Nitrates Directive would need to be adhered to.

If a quarry site does not have a Waste Management License, the Environment Agency will need a Waste Management Licence exemption application to be lodged prior to land-spreading of waste. Within the application, details relating to pollution issues such as nitrogen and metal content of the waste and site specific details such as proximity to receptors such as streams will be needed.

To satisfy the Waste Management Licensing regulations, agricultural or ecological benefit will need to be proved and therefore information on the plant nutrients to be supplied to agricultural plants or mainly soil structural improvements to be imparted for ecological benefit must be quantified. Careful management of plant nutrients and soil structural conditions will be needed for any commercial cropping programme also.

The physical condition of both on-site soil making materials and the imported organic or mineral matter will need to be such that they are able to be applied to land or relatively easily mixed prior to application. Mixing can prove difficult with heavy clay substrate material and wet organic matter. Some pre-drying or other preparation, such as screening or shredding, of either the substrate and/or the organic amendment may be needed.

If a material is being spread directly onto a site then a solid or liquid spreader can apply material which is then mixed into the substrate on the ground with various agricultural machinery to achieve specific desired results such as mixing to depth. If a soil is to be manufactured, this must be undertaken prior to any material being placed on the site surface. The simplest methodology would involve adding a quantity of organic material to a muck spreader followed by a quantity of inert mineral matter, such as sand, and mixing will take place as these are spread onto the land.

With all synthetic soil manufacturing, whether done on the ground or prior to application, some degree of initial testing and then trial and error pilot studies are essential to satisfy both the regulatory authorities and the site operators’ practical achievable goals.

Manufactured topsoil has been of growing interest for the last couple of years and is still under development and research by a number of organisations. This project aims to identify and assess potential combinations of four quarry rock fines combined with five typically available composts for the development of growing media, for land restoration at the particular site and for marketing within the horticultural sector.

1.1. Aims and Objectives

The aim of the project was to develop potential growing media from the combination of compost with quarry fines for horticulture in short term uses (such as container growing), and land restoration on a long term basis, but also aiming at other potential uses, such as sylviculture. Because previous work had considered fines from sand and limestone production units in the English Midlands (Keeling, unpublished), this study focussed on igneous rock sources in Northern England and Southern Scotland.
The study had the following objectives:

- Reviewing, selecting and analysing appropriate fines (basalt, dolerite and felsite) arising from quarries operated by Tarmac Northern ;

- Reviewing, selecting and analysing appropriate composts (anaerobic digested, food industry, green wastes processed indoors and outdoors, and kerbside collection compost);

- Testing and analysing all blends combinations of the composts and quarry fines and then selecting best potential performing blends for further investigations.

The variability of different sites requiring restoration in terms of properties, such as soil type, nutrient and metal content, and richness of local vegetation and biodiversity was considered. The results were interpreted to produce recommendations based on high, medium and low nutrient requirements for land restoration purposes.

1.2. Project Partners

The project has involved a number of partners to ensure that appropriate materials were used and that the outcomes were appropriate:

Sources of compost:
A. & E. Thompson
Alternative Waste Solutions
Newcastle City Council: City Works and Parks and Countryside Training
SENREC (South East Northumberland Recycling)

Sources of quarry fines:
Tarmac Northern Ltd

Land restoration:
Glen Kemp Ltd
Soil Environmental Services Ltd
University of Newcastle
Harper Adams University College

1.3. Background

Previous work by Tarmac in collaboration with Harper Adams University College, and landscape restoration work undertaken by Glen Kemp Ltd at various locations in northern England and Scotland, have determined that there is a shortage of soil forming materials at many upland quarries for restoration purposes. Keeling *et al.*

(unpublished) have studied the development of synthetic soils by combining sandstone and limestone quarry residues with composted green wastes, which could present a solution for recycling difficult wastes and produce high quality synthetic topsoils. Vegetation growth and survival have been used as indicators in addition to chemical and physical properties for monitoring the quality of growing media for many years. Keeling *et al.* (unpublished) concluded that synthetic soils could be produced from a range of composts and quarry wastes, and that the optimum performance achieved was with sand-based materials, and relatively higher nitrogenous compost. They also concluded that "synthetic soil blends containing one third by volume of compost and two third by volume of quarry fines consistently resulted in optimum plant growth."

Production of aggregate leads to the generation of fine material (<5mm) as a result of the crushing and screening process. There are currently little or no significant market applications for this material (Mineral Solutions, 2004a). However, these quarry fines represent an important nutrient source for the growth of plants, with the exception of nitrogen. By combining quarry fines with sources of nitrogen (in this case organic waste compost), a well balanced nutrient source for plant growth can be created.

Vegetation requires a nutrient balance for optimum growth: in total, sixteen elements are involved, from which eleven are trace elements. Nitrogen, phosphorus and potassium are the three most important elements, together with magnesium, calcium, and manganese. All the sixteen elements are required for healthy plant growth. If one is missing or is present in insufficient amount, vegetation growth is restricted (Bradshaw and Chadwick, 1980).

Composted materials all provide some nitrogen, but usually lack potassium and/or phosphorus. Combining quarry rock fines and compost could provide a growing medium, with a nutrient balance appropriate to most plants, ranging from low to high nutrient requirements depending on local vegetation, and targeted uses.

For restoring quarries, it is important in the first instance to assess the vegetation growth in surrounding soils of the quarry, such that it is possible to "mimic" as close as possible the local soils.

1.4. Composts/ Organic Residues

The definition of compost varies slightly depending on the regulating organisation (e.g. The Composting Association, WRAP). A general definition of compost or composted material can be:

Organic material, classed as waste, that has been recycled into material for re-use.

Table 1.1 lists the main types of available compost, feedstocks and nitrogen levels.

Table 1.1. Types of composts available. (Definitions from The Composting Association, 2001)

Compost Types	Feedstock	Nitrogen (N)
Food Industry (FI)	Food industry wastes (from restaurants, etc.)	Medium to high
Green Waste processed indoors (GW)	Garden waste such as grass clippings, tree prunings, leaves, etc.. Synonymous with 'garden wastes', 'yard trimmings', 'botanical wastes' or 'garden trimmings'. They can arise from domestic gardens, public areas, private parks or gardens, or landscaping activities.	Low to medium depending on the composting process used, such as maturation of the composted material outdoors (low in key nutrients n, P, K), or indoors (higher in key nutrients N, P, K)
Anaerobic Digested (AD)	Any feedstock, including animal by-products (carcasses, blood, etc.)	Depends on feedstock used, but the digestion process reduces greatly the initial high nitrogen and E-coli contents.
Municipal Solid Waste (MSW)	Household waste plus any other wastes collected by a Waste Collection Authority, or its agents, which may include municipal parks and gardens waste, beach cleansing waste, commercial or industrial waste and waste from the clearance of fly-tipped materials" MSW generally refers to household wastes.	Depends on feedstock used.
Kerbside Collection (KC)	Organic wastes, or other recyclables, which are regularly collected from commercial and industrial premises and households.	Low to medium

1.4.1. Composting methods and processes

The most commonly used process is an open air windrow-style composting system. There are three basic stages of the composting process:

1) High rate composting phase
This is "the first stage in composting process characterised by high rates of biological activity, oxygen demand and of heat generation" (The Composting Association, 2001).

2) Stabilisation
This is "the bio-oxidative process of degrading feedstocks into stable humic substances following the high rate-composting phase" (The Composting Association, 2001).

3) Maturation (Curing)
A "process whereby phytotoxic compounds in composts formed during the active composting phase are metabolised by micro-organisms into compounds that do not harm plants. This is generally characterised by a drop in pH (from alkaline towards neutral), the conversion of ammonium compounds into nitrates and the re-colonisation

of the compost by beneficial soil micro-organisms destroyed during the active composting phase" (The Composting Association, 2001).

Maturation is an important process such that if the compost is not mature and that the ammoniacal nitrogen level is still very high from the composting process, this can cause hindrance to plant growth, and can contaminate the ground and waters through leaching of nitrate and/or ammonium. As compost matures, nitrogen and other compounds stabilise over time. Depending on the feedstock and the composting process used, the maturation period of composted materials varies greatly between three weeks to one year.

Other processes include:
- Enclosed "in-vessel" system for composting small amounts on-site.
- Vermi-composting processes (using selected species of worms)

1.4.2. Compost standards

Composted materials must meet certain specifications to ensure a sustainable, safe, high quality and performance end-product. Compost/rock fines blends that perform in pot experiments and meeting the BSI PAS 100 (British Standards Institution Publicly Available Specification 100) should be selected as materials suitable for site restoration or horticultural use.

1.4.3. Uses and benefits of composts

Composts are used for various purposes and have various benefits (BSI PAS 100: 2002. The Composting Association, 2001):

Agriculture, landscaping, land restoration, forestry, horticulture, sylviculture, gardening, etc.

- Agriculture, landscaping, land restoration, forestry, horticulture, sylviculture, gardening, etc.

- Composts are not only useful for plant growth, their structural stability, microbial activity and calorific value can be used in engineering, biotechnology and energy generation, as well as bioremediation, construction and bio-filtering, amongst other uses.

- The largest potential use of composts, covering nearly all market sectors is for soil improvement. Benefits include increase of SOM (Soil Organic Matter), fertility and water-holding capacity, improvement of soil structure, reduction of acidity (liming effect), and suppression of disease.

1.5. Rock Fines

Finely crushed rock represents an important nutrient source for plants (K, P and many trace nutrients), which varies according to rock type.

The different rock types available from crushed rock aggregate production are dominated by basalt, dolerite, felsite, limestone, greywacke and sandstone.

Rock fines can be highly variable, but can be generally defined as fractions produced by hard rock crushing that is below 3, 4, 5 or 6 mm, or fractions typically below 0.075 mm, produced by screening unconsolidated aggregates (sand and gravel).

The EN definition though is as follows:

Fine aggregate is below 4 mm or below 2 mm; fines suitable for use as a filler is the fraction below 0.063 mm. (The Quarry Products Association, 2003)

For the purpose of this study material finer than 5 mm was classed as rock fines. Finely crushed rock represents an important nutrient source for plants (K, P and many trace nutrients), which varies according to rock type.

Crushed rock aggregates are produced from three main types of rocks:
1. *Igneous*- Solidified molten or partly molten rocks (e.g. basalt, granite).

2. *Sedimentary*- Resulting from consolidation of loose accumulated sediment (e.g. gritstones), or chemical precipitation, or organic remains (e.g. limestone).

3. *Metamorphic*- Recrystallized pre-existing rocks due to a change in pressure, temperature, and/or volatile content (e.g. quartzite, gneiss).

Material developed in quarries are used for various purpose, such as road construction, bricks, building, land restoration, landfill cover and capping, sculpture depending on the rock type. (The Geological Society, 1993).

2. MATERIALS AND METHODS

Overall, five composts and five rock types were selected, analysed and included in various experimental trials.

Raw materials intended for use in trials were sent for appropriate analysis (material characteristics helping to determine suitability for environmental utilisation and applications) to UKAS accredited and university laboratories. Analytical results are given in full in Appendix 2.1.

2.1. Materials

2.1.1. Composts (organic residues)

Composts selected for the trials were:

1. Mature and semi-mature food industry compost, made from chicken, fish and straw.
2. Anaerobic digested compost originating from a local farm, made from abattoir waste and manure.

3. Green waste compost processed outdoors from a local authority
4. Green waste compost processed indoors from a local composting company
5. Kerbside collection compost originating from a local authority

Table 2.1. Selected composts

Compost Types	Wastes	Nitrogen (N)
Food Industry (FI)	Fish bones, chicken carcasses and feathers, cardboard, paper, sawdust	High
Green Waste processed indoors (GW 2)	Green wastes	Medium to high
Green Waste processed outdoors (GW 1)	Green wastes	Low to medium
Anaerobic Digested (AD)	Farmyard manure, abattoir wastes	Medium: digestion reduces initial high nitrogen level
Kerbside Collection (KC)	Household wastes	Low to medium

Composts were analysed for nutrient and heavy metal contents, physical contaminants, *E. coli* and *Salmonella*, physical properties such as plastic, stones, glass, following the British Standard Institution Publicly Available Specification for composted materials (BSI PAS 100).

2.1.2. Rock fines

Basalt and dolerite were selected for being iron sources, rich in magnesium, and effective sources of potassium as K_2O; they weather easily, possessing therefore more iron, magnesium and potassium available to vegetation and crops. Rock fines selected and their source are summarised in Table 2.2.

Quarry rock fines were analysed for total major and trace elements (using X-Ray Fluorescence), and particle size distribution.

Table 2.2. Selected rock fines and sources.

Source (quarry)	O.S. grid reference	Rock type	Rock fine type	Characteristics
Bannerbank	NS495525	Carboniferous Clyde Plateau Lavas	<5 mm “type 1 sub base” basalt	Iron source, rich in magnesium, and effective source of potassium as K_2O, weathers easily.
Craighouse	NT600362	Basalt	<2 mm “dust” basalt	
Harden	NT959085	Felsite	<2 mm “S2 Fines”	
Ravelrig	NT130665	Quartz dolerite	<75 µm “dust residue”	
Barrasford	NY914745	Dolerite (Whin Sill)	<75 µm “dust residue”	

The chemical analyses of the Barrasford material has a high CaO content compared with published analyses of the Whin Sill dolerite (Robson, 1980), suggesting that the fines in this case are a mixture of limestone (present at the same quarry) and dolerite.

Corresponding quarry soils properties, summarised in Appendix 2.2, vary from peaty soil (waterlogged, low nutrient) to well-drained and nutrient-rich soils.

2.2. Methods

2.2.1. Tomato plant pot trials

The purpose of this trial is to assess whether or not the igneous rock types present in the fines are suitable for use in commercial growing media. Fines from Barrasford quarry were not used for the tomato trials because of their high lime content. Four rock types were tested:

1. Carboniferous Clyde Plateau Lavas (i.e. basalt) B1

2. Basalt B2

3. Felsite F

4. Quartz dolerite D1

Each rock fine was blended with each of the five available compost types to a 70:30 (% w/w) compost: rock fine ratio. The five compost types were also tested without added rock fines to compare their performance. The reference used was a widely available ‘Grow Bag’ compost purchased from a gardening centre.

Each tomato plant was potted in a 6 litre pot containing the compost blend, and placed randomly on benches in a green house (Plate 2.1).

After two weeks, the tomato plants were generally graded from 1 to 10 for their height and general health (1: very small and unhealthy, 10: very high and healthy) (general subjective qualitative test).

To assess the performance of the treatments, the following were monitored:

- Plant height was measured weekly.
- Fruit yield: fresh and oven-dried fruit were weighed, and analysed for heavy metal content to determine whether they met British standard food specifications (Commission Regulation (EC), 2001).
- A taste panel was set up to assess the difference between controls and treatments, and within treatments.

Plate 2.1 – Tomato pot trials

2.2.2. Grass experiments

The use of composts: fines blends for restoration work has been assessed in grass trials. Pot trials have been carried out for a range of composts and rock types, and the results of these were used to design a smaller number of lysimeter trials, prior to field trials.

Grass experiments included pot trials to identify appropriate composts: fines blends to test suitability for land restoration, and lysimeter trials to assess performance of selected blends (from the grass pot trial) to a larger scale, and to assess leachability of possible contaminants derived from the compost.

2.2.2.1. Pot trials

Four rock types were tested:

1. Carboniferous Clyde Plateau Lavas (i.e. basalt) B1
2. Basalt B2
3. Felsite F
4. Dolerite (Whin Sill) D2

Each rock was blended with each of the five available compost types in a 50:50 compost: rock fine ratio (% v/v).

The reference control used was a well drained sandy loam good agricultural soil from the Rivington series (major soil group Brown soils) (Properties described in Appendix 2.2). In addition, the topsoil from each quarry was individually used to give an indication of the expected plant growth with the on-site materials usually available.

Grass was sown into 1 litre pots containing the blends (Plate 2.2). The grass seed mixture *Land reclamation PRO 95 (with ryegrass)* supplied by Perryfield, was selected as it is a land reclamation mixture suitable for landfill and/or quarry sites and spoil heaps, characterized by poor fertility, drought and acid to alkaline conditions. It is composed of:

- 20% Tivoli perennial ryegrass late tetraploid25% Merlin/Jupiter slender creeping red fescue10% Quatro sheep's fescue10% Triana hard red fescue;
- 20% Canon flattened meadow grass;
- 10% Highland browntop bent;
- 2.5% Kent wild white clover (Nitrogen fixer)2.5% Birdsfoot trefoil (Nitrogen fixer);

Plate 2.2 – Grass pot trials

To assess blend performance, grass was cut twice, weighed when fresh and oven-dried. The composts: fines blends from this trial were sent for chemical analysis, to include nutrients, pH, and heavy metals.

2.2.2.2. Lysimeter trials

A lysimeter is an instrument used to assess hydrological data of a known growing medium area, such as rainfall, evapo-transpiration, run-off, infiltration, and leachate. The purpose of this trial was to assess the possible leaching of contaminants from composts within the blends, and soil physics of a plot large enough to reflect a field situation.

Using data from the grass pot trials, compost specifications, and potential development of compost processes, eight lysimeters were built and set-up to assess anaerobic digested (AD) and food industry (FI) composts, each blended with the following rock fines:

1. Carboniferous Clyde Plateau Lavas (i.e. basalt) B1

2. Basalt B2

3. Felsite F

4. Dolerite (Whin Sill) D2

Each lysimeter had a volume capacity of about 1m^3. At the base was a layer of sand (10 cm depth with a slight slope towards the leachate drain surrounded by gravel) covered by a permeable geotextile, to allow drainage for leachate collection and prevent root penetration in the sand drainage layer. Each lysimeter was filled with 60cm of each selected blend (Figure 2.1, Plates 2.3, 2.4, and 2.5). The blends were left to settle for two weeks, and grass seed (*Land reclamation Pro-95 mixture*) added.

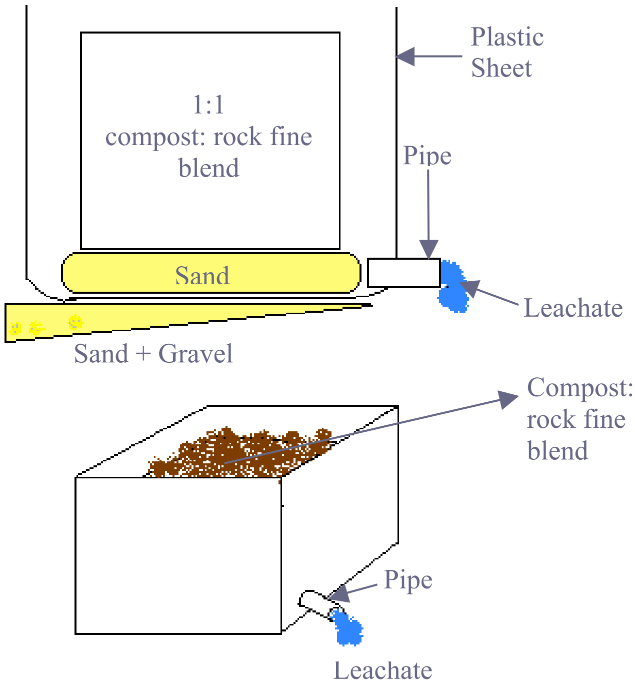

Figure 2.1 - Profiles of lysimeter System

- Leachate from each lysimeter was collected monthly from August through to December 2003 to monitor the contamination potential of tested blends from summer conditions to land reaching field capacity. Collected leachate was analysed monthly for ammonium, nitrite, nitrate, total nitrogen, pH, and electrical conductivity.

- Soil mechanical and physical properties (shear strength using a hand-held shear vane, available water capacity using pressure plates and tension tables, and infiltration rates using a double-ring infiltrometer) were determined within each lysimeter.

- Grass yield was also determined from each lysimeter, and recorded as total fresh grass weight.

Plate 2.3 – Lysimeter for leachate collection with 10 cm sand.

Plate 2.4 – Leachate collection drain at the bottom corner of one lysimeter

Plate 2.5 – Lysimeters filled with blends of composts and rock dust (1:1 v/v)

2.2.3. Ecotoxicity

The principle of the method used was to determine whether the growing media were toxic to living organisms. This was undertaken by placing a known number of enchytraeid worms in a growing media for a period of time, and counting the number of surviving adult worms, and later, the number of juvenile worms. The more (adult and juvenile) worms recovered, the less toxic the growing medium.

The ecotoxicity of the selected blends was assessed by Dr Alan Keeling, Harper Adams College. The aims, methods, results and interpretation of the test can be found in Appendix 2.3.

2.2.4. Field trials

Field trials were established at Barrasford Quarry, with the design being influenced by results from the lysimeters for the selection of blended material to be tested. The blends selected were based on anaerobic digested compost (as it is coarse grained compost that is likely to be widely produced in rural and urban areas) and food industry compost (as it is high nitrogen compost with potential to be produced in large quantities). Materials and the procedure for construction of field plots are detailed below.

2.2.4.1. Site details

Barrasford Quarry (OS grid reference NY914745) was selected for the field plot trials as it was easy of access and would provide some of the materials required.

4,000m^2 space was allocated by the quarry manager for field plot trials. The allocated space had also been levelled by Tarmac with various quarry fine residues, including asphalt-bound materials, etc. as it was intended to be restored in the future.

Consequently, the surface material where the plots were designed to be located, was firstly analysed for Total Petroleum Hydrocarbons (TPH) (Appendix 2.4), to determine whether or not the material used to level the site would influence the trial results.

2.2.4.2. Field plot design

Four field plots of 10m x 3m x 0.50m (depth) were delineated according to the plan (Figure 2.2), in a manner to represent as closely as possible materials and procedures to be used in restoration on a full scale area.

Plots were 3 m wide to allow machines to “spread” rock fines directly and then to spread and blend composts.

Plots were located on the site so that potential leachate did not run-off onto neighbouring plots. (Figure 2.2)

A reference plot of similar size was also set up using shale, subsoil, and topsoil.
Figure 2.2 and Plate 2.6 show the suggested and applied design for the field trial.

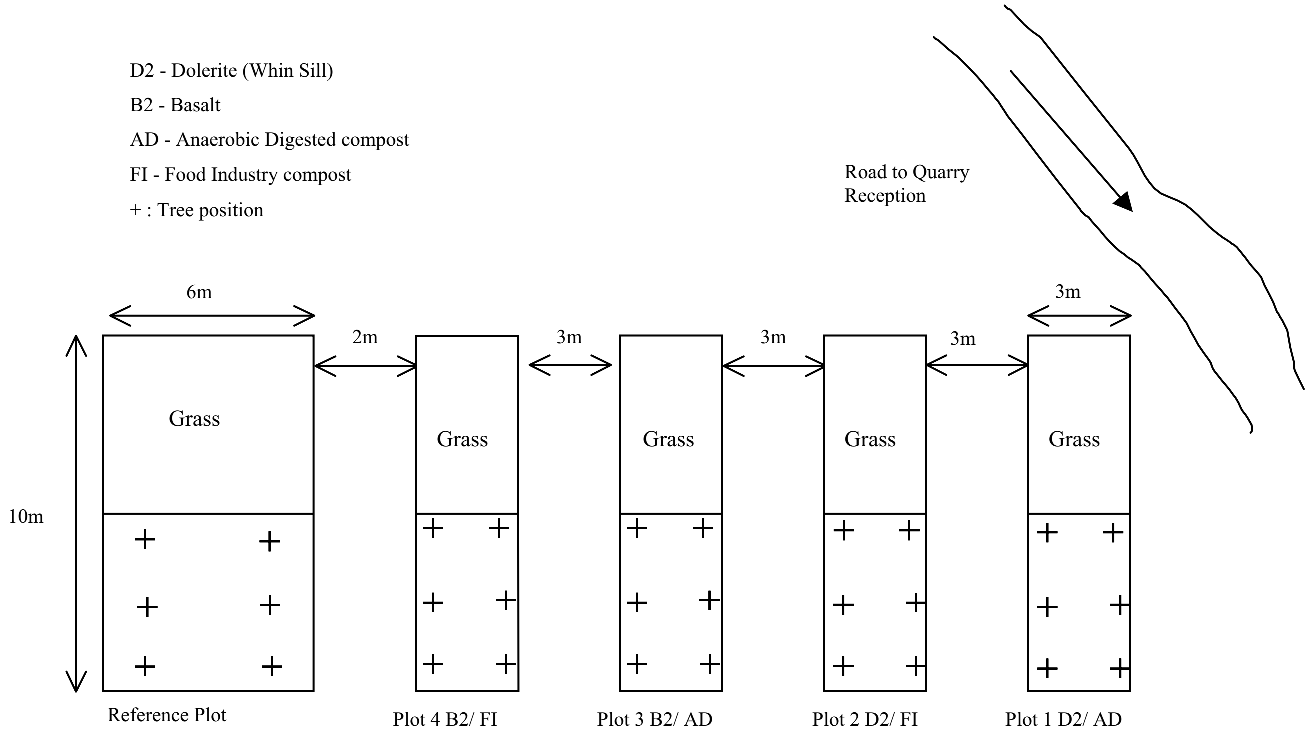

Figure 2.2 - Design for field plots trial at Barrasford Quarry

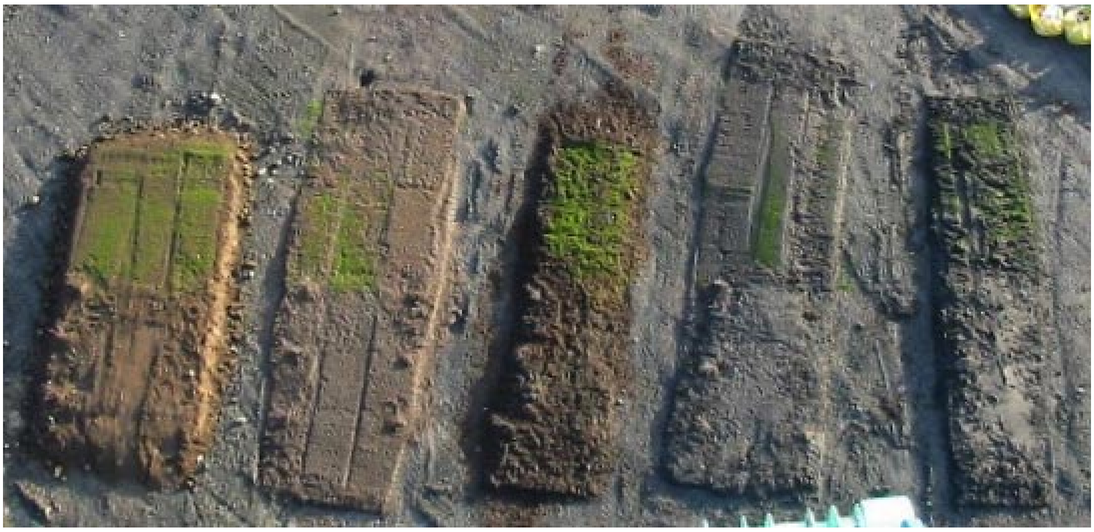

Plate 2.6 – Field plots trial at Barrasford quarry taken from height of 35 metres.

2.2.4.3. Plot treatments

The following treatments were applied to the plots:

1) Anaerobic Digested compost + Basalt B2

2) Anaerobic Digested compost + Dolerite (Whin Sill) D2

3) Food Industry compost + Basalt B2

4) Food Industry compost + Dolerite (Whin Sill) D2

Table 2.3 shows the treatments applied to each plot.

2.2.4.4. Procedure

- *Experimental plots*

Table 2.3. Density and PSD of composts and rock fines selected for field trials.

Material	**Density** (t/ plot)	**Particle Size Distribution PSD**
Anaerobic Digested compost AD	3.0	-
Food Industry compost	3.5	-
Dolerite (Whin Sill) D2 "dust residue – 75µm"	4.25	2 mm-75 µm: 4.00% 75 µm-63 µm:4.80% <63 µm: 91.20%
Basalt B2 "dust"	8.0	6 mm-3.35 mm: 11.00% 3.35 mm-2.36 mm: 21.36% 2.36 mm-600 µm: 54.28% 600 µm-75 µm: 13.25% <75 µm: 11.00%

Analytical results for composts and fines used are given in Appendix 2.1.
Each plot was covered with:

a. The selected quarry fine to be applied within the blend to a depth of 0.25m, using a spreader
b. The selected compost to be applied to a depth of 0.25m, using a spreader

Compost on each plot was blended with quarry fines, using an agricultural "rotara"
Each plot was sown with grass seed cultivars (40% Allegro, 30% Score, 30% Concerto), used also for land reclamation of landfill, quarry sites and spoil heaps, but also for landscape use. The application rate was at 350 kg/ha, i.e. 1.05 kg/plot, over the lower half of each plot.

- *Trees*

Hardwood transplants (Small plants less than 1.2m in height, up to 4 years old) of 2 years of age are normally used for land restoration. The common tree species used for restoration of derelict land are (Keeling *et al*., unpublished; James, 1955):

- Birch (*Betula Pendula*) as it is a resilient pioneer species, and grows in most places.
- Alder as it is capable of fixing nitrogen,
- Willow (*Salix Fragilis*) as it is resistant to waterlogging

As no alder species were available, three birches and three willows were selected for each plot.

Three bare rooted transplants of birch and willow were planted in notches, at 2m intervals over half (3m x 5m) of each large plot.

- *Reference/control plot*

A reference control plot was built to compare and monitor performance of experimental plots against current methods of restoration. Some shale from the quarry site was spread on the ground to restore as close as possible the original landscape. 0.6m of available subsoil followed by 0.3m of available topsoil from quarry site was then spread to cover the shale.
A control plot was set-up in the same way, with three birches and three willows planted, as on the experimental plots.

3. RESULTS AND DISCUSSION

The results of tomato plant pot trials (grade, height, yield and taste panel) are presented and discussed first, followed by results of the grass experiments (grass yield, nutrient analysis from pot trial; grass yield, leachate, soil mechanics and physical properties from lysimeter trial; and field trial respectively).

3.1. Tomato Plant Pot Trials

The tomato plant trial was graded at two weeks old, then monitored by MSc student M. Bartlett for height and yield. Data and interpretation are outlined below.

3.1.1. Grade

This test was undertaken at an early stage in the trial as differences in plants were noticeable within two weeks of potting (Data in Appendix 3.1.1). This grading helped to better assess any observable differences between treatments. These grades allowed a quick and general comparison of the various treatments applied.

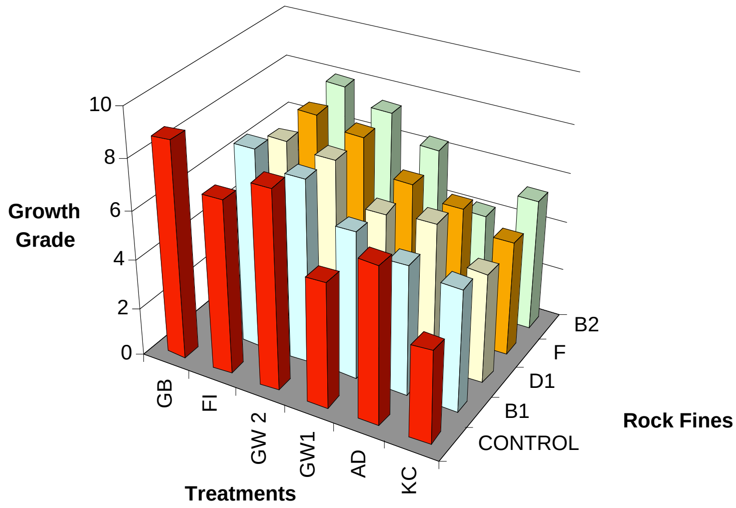

Figure 3.1 – Averages of tomato plants growth grade after two weeks.

Growth grades of plants showed that (Figure 3.1) the grow bag reference (GB) gave plants all graded above 8, followed by GW2, FI and AD controls. All rock fines appeared to enhance the plant growth with FI, GW1 and KC composts; both basalts B1 and B2 resulted in taller and more vigorous plants than their respective control. However, rock fines seemed to hinder the initial growth with GW2 and AD composts.

3.1.2. Plant height

Plants height was measured by MSc student M. Bartlett, as part of his MSc thesis. An abstract of his thesis can be found in Appendix 3.1.2.

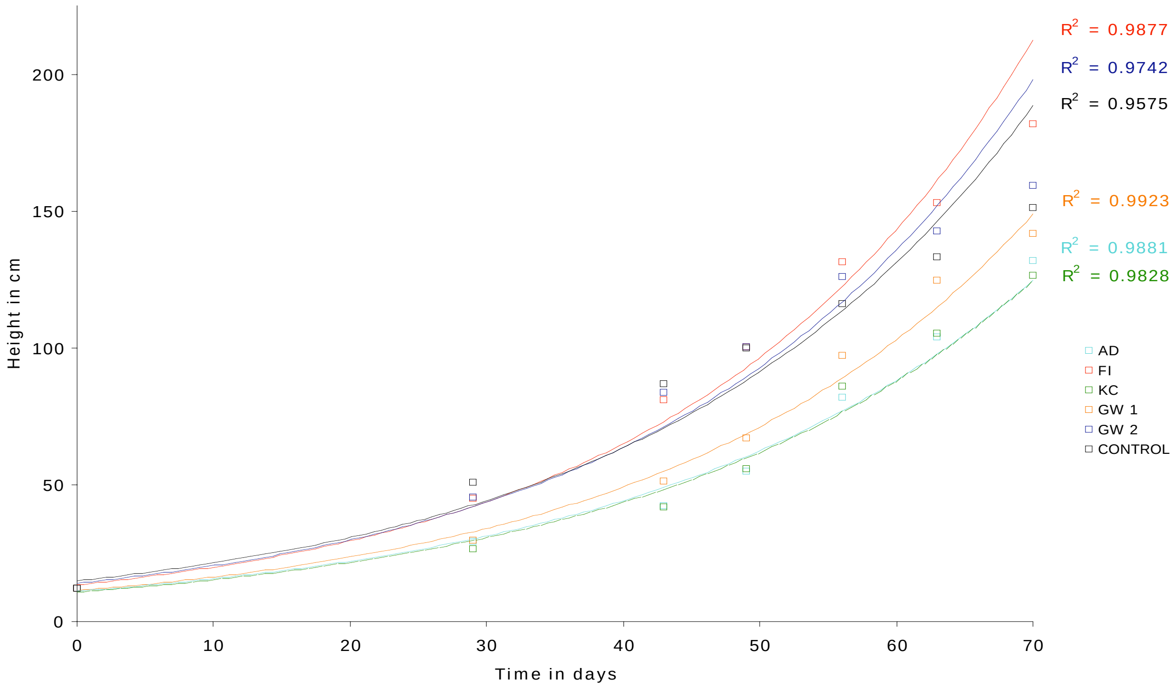

Figure 3.2 – Average heights of tomato plants by treatment (Bartlett, 2003)

Bartlett (2003) discussed that there was a significant difference between the compost type and the rate of plant growth, but no difference was assessed between the rate of plant growth and the rock type. Factors that influenced plant growth were suggested to be the C: N ratio and electrical conductivity.

3.1.3. Tomato Yield

Total tomato yield from four trusses was determined, and total yield compared to assess any significant difference of yield between treatments.

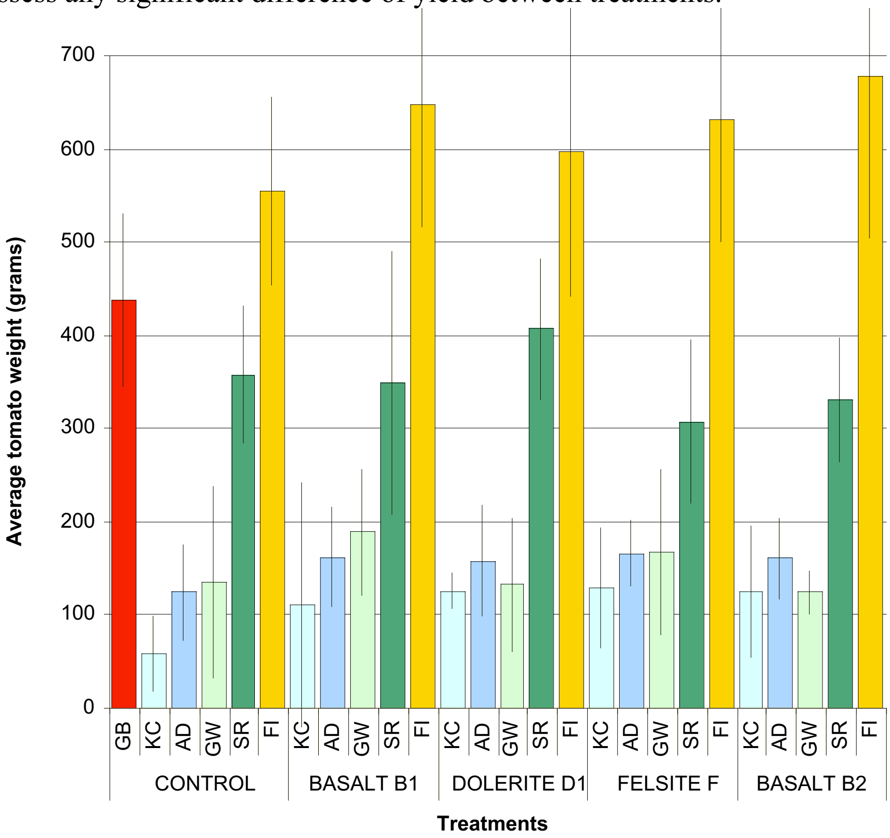

Figure 3.3 - Plot of average tomato weight by treatment

Figure 3.3 shows that all FI treatments and the FI control gave significantly greater tomato yields than the other treatments, and similar yields to the reference grow bag (GB). All GW 2 treatments and the GW 2 control gave similar tomato yield to the reference grow-bag, but significantly ($p < 0.05$) lower than FI treatments, with the exception of GW 2/D1 and GW 2/B1 blends.

All GW 2 treatments and the grow bag GB produced significantly greater tomato yield than GW 1, AD and KC treatments, with the exception of GW 2/F giving statistically similar fruit yield as GW 1 treatments and KC/B1 treatments.

With the exception of KC/D1, which produced noticeably ($p > 0.05$) greater yields than the KC control, compost: rock fine blends gave statistically similar results to their respective control.

The results of these trials suggest that the addition of rock fines to composts does not significantly ($p > 0.05$) alter the quality of compost in general. However, results from the KC/D1 blend and respective KC control suggest that the initial quality of the compost and the rock type added may contribute to the quality of the corresponding blend, as rock fines may supply the nutrients and elements required to make the compost a “more complete” growing medium for horticulture.

Anaerobic digested (AD), kerbside collection (KC) and green waste (GW 1) treatments gave statistically similar tomato yields. Although, the kerbside collection compost (KC control) ($p > 0.05$) gave a lower fruit yield than when blended with dolerite (D1), and than green wastes compost (GW 1) blended with basalt (B1 and B2). This suggests that the addition of quartz dolerite rock fines enhances the kerbside collection (KC) compost quality, providing nutrients and allowing a similar yield to other typical compost types.

One-way ANOVA tests were undertaken on the data to assess and confirm results from Figure 3.2 (Corresponding data and details of statistical results can be found in Appendix 3.1.3)

3.1.3.1. Comparison of all treatments including controls and reference.

The following table summarises the statistical one-way ANOVA results:

Table 3.1 – Summary of one-way ANOVAs of tomato weight versus variables, considering blends and controls.

Source	DF	Fexp	Fcrit	p	Significance
Compost	5	47.74	2.28	<0.005	SD
Rock fines	5	1.81	2.28	>0.005	NS
Truss	3	6.01	2.62	<0.005	SD

Results from Table 3.1 suggest that rock fines do not have a significant impact on tomato yields. However, the composts show significant differences which are reflected in tomato yields.

Truss results suggests that tomato yield per truss significantly decreases with plant height, and truss age. Trusses 1 and 2 give similar yields, however truss 1 is significantly greater than trusses 3 and 4.

3.1.3.2. Comparison of blends only (no controls)

The following table summarises the statistical one-way ANOVA results:

Table 3.2 – Summary of one-way ANOVAs of tomato weight versus variables, considering only blends.

Source	DF	Fexp	Fcrit	p	Significance
Compost	4	122.04	2.46	<0.005	SD
Rock fine	3	0.08	2.70	>0.005	NS
Replicates	4	0.59	2.46	>0.005	NS

FI and GW 2 performance are statistically different from all of the other composts, and from one another. GW 1, KC and AD blend performance are not statistically different, and can thus be suggested to be of similar performance, giving similar tomato yield. Replicates did not significantly differ from one another, confirming the validity of the trial.

To conclude, no significant (p> 0.05) difference between rock blends within each treatment suggests that rock blends do not alter significantly any of the composts included in the blends. However, an insignificant difference is still observable between composts tested separately, and composts blended with rock fines. This suggests that rock fines interact with compost to increase, even by very little, compost quality.

3.1.3.3. Comparison of control and reference treatments only

The following table summarises the statistical one-way ANOVA results:

Source	DF	Fexp	Fcrit	p	Significance
Control	5	30.99	2.54	<0.005	SD

Table 3.3 – Summary of one-way ANOVAs of tomato weight versus variables, considering only control and reference treatments.

With the controls used for comparing treatment performance, the statistical results show that FI compost and the grow bag gave statistically the same yield, significantly (p <0.05) greater than GW 1, KC and AD composts. Yields from GW 1, KC and AD composts were similar (p> 0.05) from one another. Yield from GW 2 compost was significantly different (p <0.05) from all of the other composts, but similar (p> 0.05) to the grow bag used as a reference.

Thus, it can be suggested that the increasing order of treatment performance, including the reference control is as follow:

FI ≥ GB ≥ GW 2 > AD = GW 1= KC

With FI > GW 2, and GB ≥ GW 2.

3.1.3.4. Conclusions of tomato yield

Rock fines were assessed to have an insignificant effect on the composts they were blended with. However, observable differences within blends, between blends and controls are noticeable, suggesting that rock fines interact with composts.

AD, GW 1, and KC compost treatments gave similar tomato yields, significantly lower than FI, GB, and GW 2 composts.

FI and GW 2 composts control and blends were found to give similar tomato yield as the reference grow bag; however, FI compost control and blends gave significantly greater yield than the GW 2 compost control and blends.

Thus, when assessing which blend or compost is similar to the reference grow bag, with respect to taste, it is suggested that food industry (FI) compost alone, or blended with any rock fines, is as good (or potentially greater) as a common grow bag.

3.1.4. Tomato taste panel

Results of the tomato taste panel are included in Appendix 3.1.4.

The taste panel results are listed below in the following order:

1. FI blends and control, and grow bag reference graded by male
2. FI blends and control, and grow bag reference graded by female
3. GW 2 blends and control, and grow bag reference graded by male
4. GW 2 blends and control, and grow bag reference graded by female
5. FI and GW 2 Controls, and reference grow bag graded by male and female.

The results show the average grades for juiciness (J), tenderness (T), fruit flavour (F), and overall acceptability (OA), plotted against the tomatoes grown in a particular blend.

One-way ANOVA tests were undertaken on data to assess and confirm results from Figures 3.3 to 3.7 (Corresponding data and details of statistical results can be found in Appendix 3.1.4).

3.1.4.1. Tomato grading of FI blends and control, and grow bag reference graded by males and females

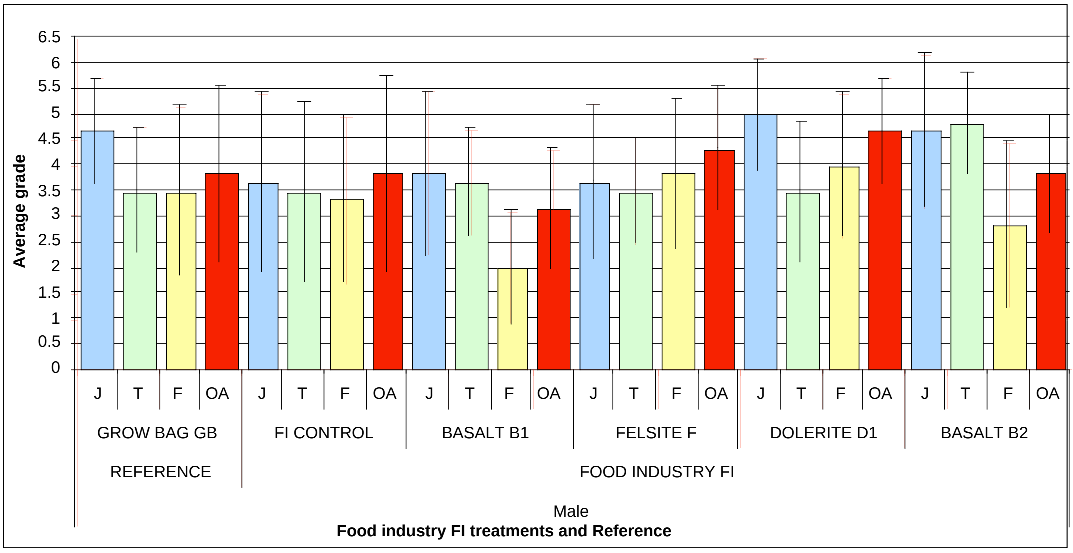

Figure 3.3 – Average grade of all parameters tested, on FI blends and control, and grow bag as graded by males.

According to the male taste panel (Figure 3.3), all FI blends and control gave similar ($p > 0.05$) tomato taste to the grow bag reference (J, T, F, and OA). All the blends resulted in tomatoes tasting the same as the FI control.

However, it can be noticed that the food industry compost when blended with basalt (B1) resulted in the lowest fruit flavour (F) and overall acceptability (OA), but potentially greater juiciness (J) and tenderness (T) than the food industry compost (FI control) alone and when blended with felsite F (FI/F). Apart from tenderness, the blends that appeared to enhance the tomato taste were food industry (FI) compost blended with dolerite (D1). The FI compost with felsite (F) appeared to enhance fruit flavour and overall acceptability, whereas when blended with basalt (B2), the FI compost enhanced juiciness and decreased fruit flavour. Basalts (B1 and B2) appeared to enhance tenderness, whereas dolerite (D1) and felsite (F) did not appear to have any effect.

Overall, it can be suggested that rock fines do not significantly alter the taste of tomatoes. However, they consistently appear to reduce the fruit flavour and overall acceptability of tomatoes.

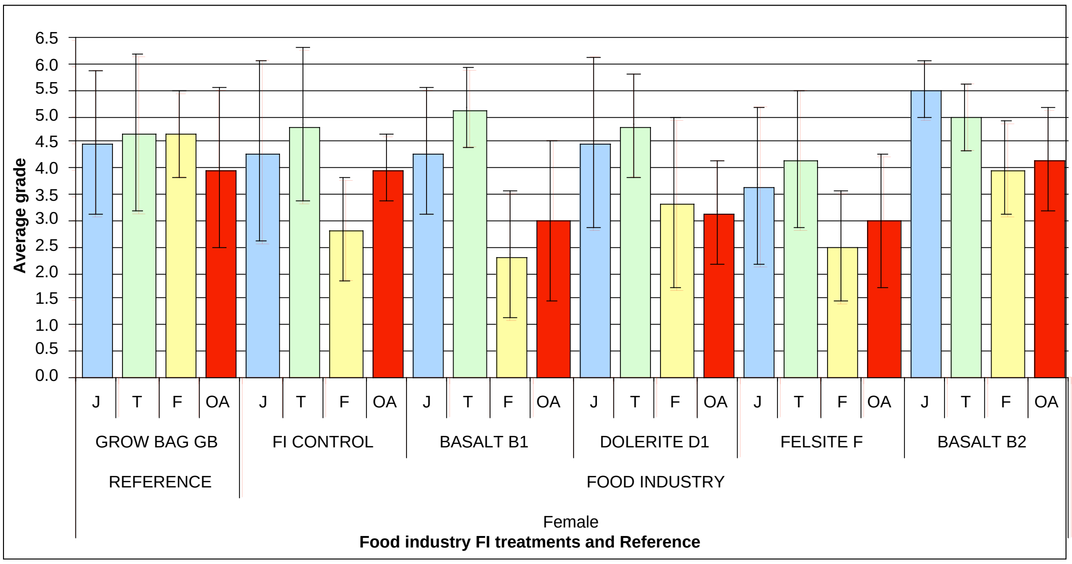

Figure 3.4 – Average grade of all parameters tested, on FI blends and control, and grow bag as graded by females.

Generally, according to the female taste panel (Figure 3.4), all food industry (FI) blends and control gave similar ($p > 0.05$) tomato taste as the grow bag (GB), and to one another, as they did according to the male results. However, the tomato taste was significantly reduced by basalt (B1) and felsite (F), resulting in tomatoes significantly less "fruity", "juicy", and "tender" (only with felsite F) than tomatoes from the grow bag (GB). Basalt B1 appeared to enhance the fruit tenderness, whereas basalt B2 appeared to enhance most of the taste parameters. The taste panel grades of tomatoes from the grow bag (GB) are suggested to be lower than those from the food industry (FI) compost blended with basalt (B2) in all cases, apart from the fruit flavour.

For males and females grading, tomatoes from food industry treatments, dolerite (D1) appeared to increase juiciness as well as fruit flavour and overall acceptability followed by felsite (F) for males, and basalt (B2) for females. Both basalts (B2 and B1) appeared to enhance the fruit tenderness according to male and female results. Male candidates appeared to prefer food industry blends, particularly with felsite (F) or dolerite (D1), rather than the FI compost; whereas females preferred the food industry (FI) compost blended with dolerite (D1) or basalt (B2), as well as the grow bag (GB), which male candidates liked less.

3.1.4.2. Tomato grading of GW 2 blends and control, and grow bag reference graded by males and females

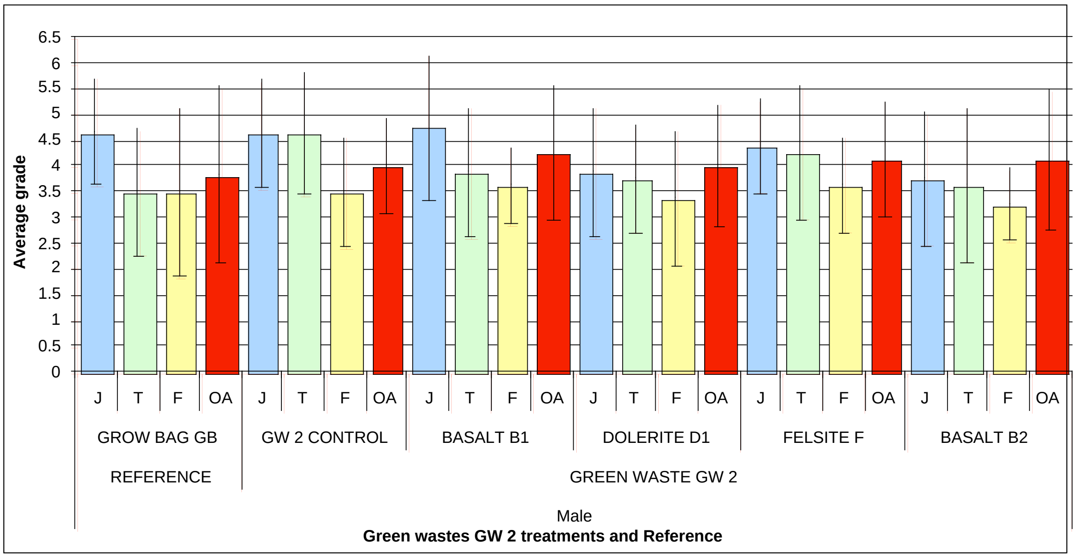

Figure 3.5 – Average grade of all parameters tested, on grow bag, GW 2 blends and control as graded by males.

Figure 3.5 suggests that all green waste (GW 2) blends gave similar (p> 0.05) tomato taste as the green waste compost (GW 2 control) and the grow bag (GB).

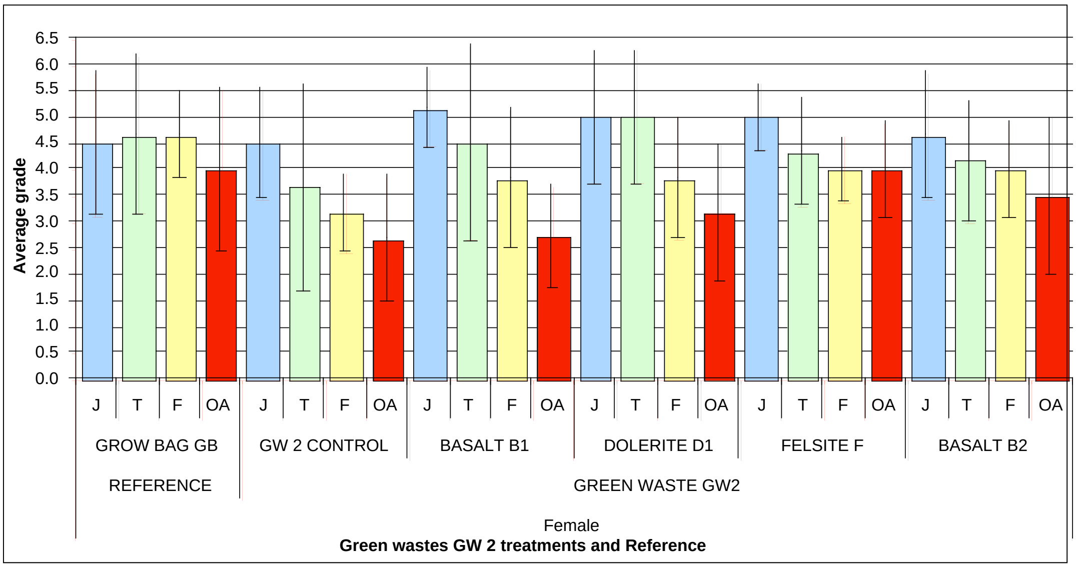

Figure 3.6 – Average grade of all parameters tested, on grow bag, GW 2 blends and control as graded by females.

Figure 3.6 shows that all blends gave similar (p> 0.05) tomato taste as the grow bag (GB) and the green waste compost (GW 2 control). The green waste compost (GW 2) with dolerite (D1) appeared to improve the grading of the fruit flavour and overall acceptability compared to the grow bag (GB). Females appeared to appreciate more tomatoes from GW 2 blends, whereas males generally appreciated more tomatoes from the green waste compost (GW 2 control) alone and with felsite (F).

In general, felsite (F) and basalt (B1) appeared to increase the juiciness, tenderness, fruit flavour, and overall acceptability of tomatoes grown in green wastes (GW 2) blends, compared to dolerite (D1).

3.1.4.3. Tomato grading of FI, GW 2 controls and the grow bag reference graded by males and females

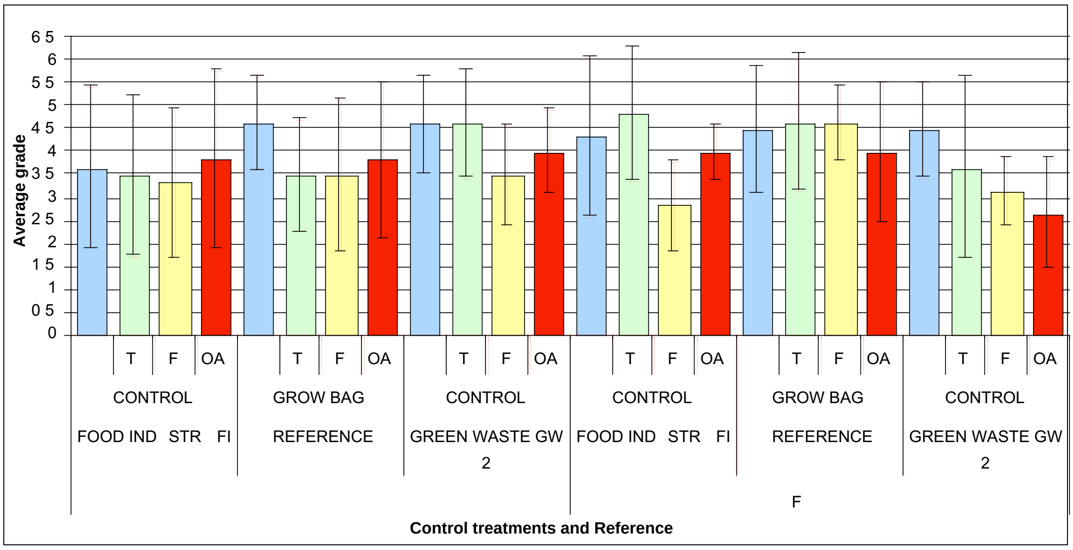

Figure 3.7 – Average grade of all parameters tested, on FI control, grow bag, and GW 2 control as graded by males and females.

Figure 3.7 shows that tomatoes from all controls were graded similarly, and were not found significantly ($p > 0.05$) different from one another. However, overall, females gave a higher grade to tomatoes from the food industry compost (FI control) and the grow bag (GB) than males, and graded the green waste compost (GW 2 control) lower than the other control and reference.

Overall, it can be suggested that females preferred tomatoes from the grow bag and the food industry compost (FI control), whereas males preferred tomatoes from the green waste compost (GW 2 control), followed by the grow bag (GB).

All the controls gave similar grading by males and females, apart from the fruit flavour from FI and GW 2 which appeared to be well below the grow bag, according to female results.

Results suggest that overall, females appear to prefer tomatoes from food industry (FI) treatments, whereas males generally preferred tomatoes from green waste (GW 2) treatments.

3.1.4.4. Conclusions of the taste panel

According to males grading tomatoes from food industry (FI) blends, basalt (B2) and quartz dolerite (D1) appeared to improve at least one aspect of the tomato compared to the food industry compost (FI control), dolerite for juiciness (equal to the grow bag) and basalt for tenderness (greater than the grow bag). According to females grading, felsite (F) and basalt (B1) appeared to reduce tomato taste followed by dolerite (D1). Basalt (B2) increased juiciness and tenderness of the fruit, whereas basalt (B1) increased the fruit tenderness. The food industry (FI) compost with basalt (B2) appeared to be the only blend that can result in tomatoes as “tasty” as those from the grow bag, and “tastier” than those from the food industry compost (FI control).

The green waste compost (GW 2 control) appeared to result in “tastier” tomatoes when blended with felsite (F) or basalt (B1).

These results, although not statistically significant, indicated that composts consistently appeared to be generally enhanced by the presence of basalt (B2) or quartz dolerite (D1) to a potentially similar level of quality as a widely available grow bag. Moreover, it can be suggested that depending on the compost, appropriate rock fines (especially basalt B2 and dolerite D1) may be blended to enhance the juiciness, tenderness and fruit flavour of the tomato.

Most importantly, the trials show that these blends of compost and fines have no detrimental effect on the acceptability to the consumer of the fruit.

3.2. Grass Mixture Experiments

3.2.1. Pot trial

This trial compared grass growth, nutrients in blends.

Grass yield from all the quarry soils were below or as good as the yield from the Rivington reference. The treatments that significantly enhanced composts appeared to be B1 followed by B2 for GW 2, and F for FI compost. (Corresponding data and statistical results can be found in Appendix 3.2.1).

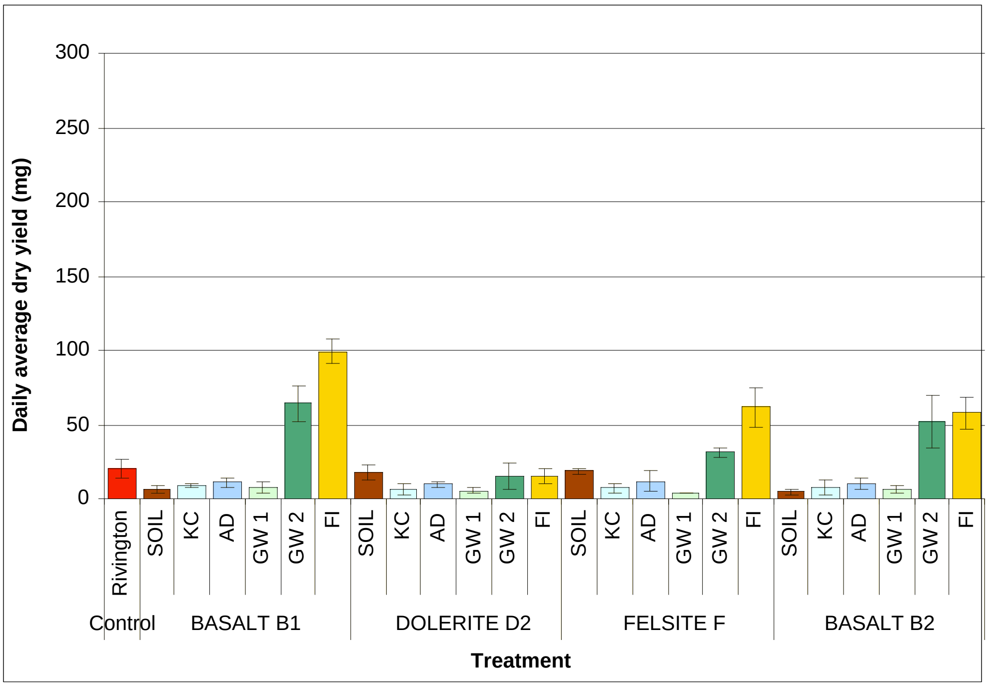

Figure 3.8 – Daily average dry grass mixture growth (Cut 1: 1 month after grass sown) for all treatments and controls.

Figure 3.8 shows that most of the treatments, controls and reference resulted in similar ($p > 0.005$) dry grass weight gains. The green wastes (GW 2) and food industry (FI) composts with basalts (B1 and B2) and felsite (F) resulted in the highest dry weight gains per day at the first cut. This was due to high nitrogen content of GW 2 and FI composts. Dolerite (D2) with the green waste (GW 2) and food industry (FI) composts had reduced the dry weight gains per day possibly due to the fine particle size resulting in poor structural conditions for seed germination, and also because this dolerite (D2) is mixed dolerite and limestone.

Most of the FI and GW 2 blends resulted in too low grass growth to be used as a replacement soil for restoration at these four quarries.

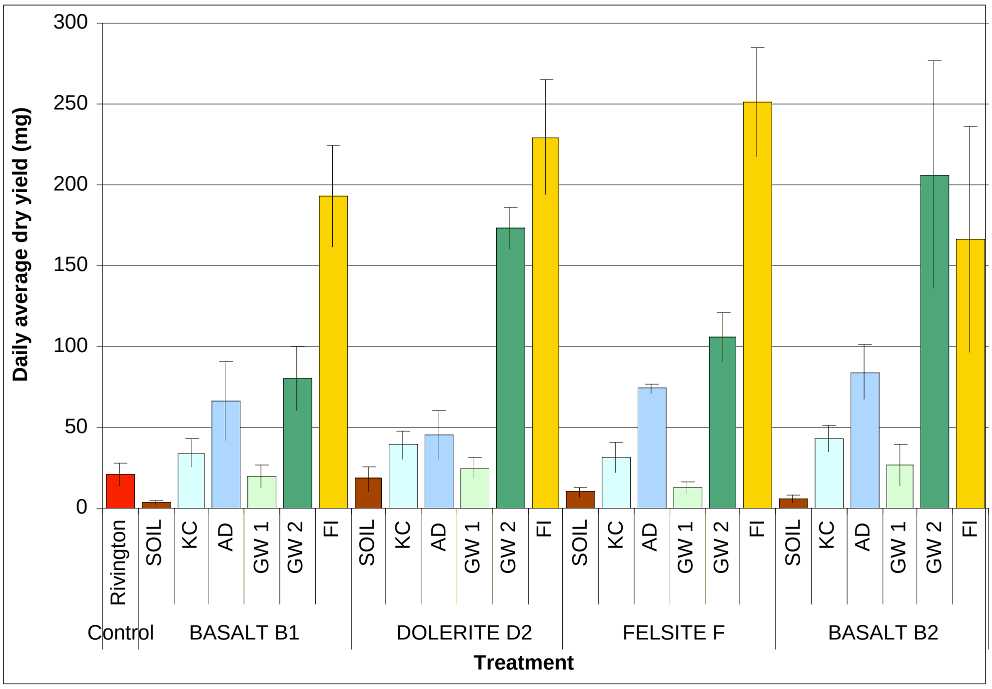

Figure 3.9 – Daily average dry grass mixture growth (Cut 2: 2 months after grass sown) for all treatments and controls.

Results from the second grass cut (Figure 3.9) showed that FI compost with D2 and F rock fines resulted in a high grass weight gain, whereas FI compost blended with B1 and B2 rock fines gave lower grass weight gains, especially B2 rock fines. GW 2 compost with D2 and B2 resulted in higher dry grass weight gains than with B1 and F. The AD compost with all rock fines also gave high grass weight gain, except with D1 reducing the grass weight gain. This was possibly due to the fine particle size resulting in poor structural conditions. Results from FI and GW 2/D2 blends suggest that the grass will be able to access most of the nitrogen available with time allowing the settlement of the compost/rock fine blend. KC compost with all rock fines resulted in higher weight gain than quarry soils. Soils B1 and B2 resulted in a lower grass weight gain than soils D2, F and Rivington. The GW 1 compost with any of the rock fines resulted in dry grass weight gains as low as the quarry soils.

Figures 3.8 and 3.9 show that the grass growth rate has increased after the first grass cut. This may be due to the duration of the rock fines presence, having had more time to blend with the compost, and therefore interact more efficiently.

By the second cut, the daily dry weight gain had increased compared to the first cut except for the soil only treatments. Notably, the daily dry weight gain from D2 rock fines with GW 2 and FI had significantly increased compared to the first cut. This was probably due to the grass being able to access the nitrogen.

Plate 3.1 – Grass mixture: on the left, nitrogen-fixing plants dominate in a low nitrogen medium (B1/KC blend), whereas on the right, ryegrass dominate in a high nitrogen medium (B1/FI blend).

The seed mixture used contains a variety of grasses and nitrogen-fixing plant species. The performance of these varied within this trial. Low nitrogen composts/rock fine blends resulted in the growth of nitrogen-fixing plants (clover) dominating the sward (Plate 3.1), whereas grasses predominated on high nitrogen blends.

Plate 3.1 and results of grass nutrient analysis (Appendix 3.2.2) showed which compost or blend lacked nitrogen, as the nitrogen level in grass from low nitrogen composts was similar or higher to the nitrogen level in grass from high nitrogen composts. This confirms that grass "traps" the nitrogen available from the air and transforms it to its own requirement: as nitrogen supply from the atmosphere is unlimited, nitrogen fixing plants develop and grow further than in other nitrogen-rich composts. Although some of the blends were rich in nitrogen, basalt appeared to restrict the nitrogen supply to the grass mixture, whereas dolerite enhanced it.

Generally, the first dry grass cut results (Figure 3.8) did not reflect any influence from any of the rock fines or composts applied, apart from the food industry (FI) and green waste (GW 2) composts which varied positively with both basalts (B1 and B2) and felsite (F).

It can be suggested that dolerite (D2) did not initially have a high grass weight gain, and significantly reduced FI and GW 2 grass weight gain. However, over time, D2 rock fines with food industry (FI) and green wastes (GW 2) composts appeared to significantly increase the grass growth. Felsite (F) rock fines with the food industry (FI) compost, and basalt (B2) with the green waste (GW 2) compost appeared to also significantly ($p < 0.05$) increase the grass growth. In all cases, food industry (FI) treatments resulted in significantly higher grass growth than others, followed by green wastes (GW 2) treatments, except FI compost with B2 rock fines which resulted in a lower grass weight gain than GW 2/B2 blend.

Figures 3.8 and 3.9 show that dolerite (D2) with all composts resulted in significantly lower grass dry weight gains than basalts (B1) and felsite (F) with all composts. The other blends were not significantly different from one another. Thus, it can be suggested that any of the blends can be used for quarry restoration, apart from blends with food industry (FI) and green wastes (GW 2) composts, irrespective of the rock fines present in the quarry.

Thus, for quarry land restoration, basalt fines originating from a quarry could be blended with green waste (GW 1, processed outdoors) compost types, resulting in a growing medium with similar nutrient and chemical properties as the natural (original) soil surrounding the area to be restored.

3.2.1.1. Grass mixture growth conclusions

For dry grass results from Figure 3.9, the best soil substitutes for the restoration of those four quarries would be:

- Green wastes (GW 1) compost with felsite (F);
- Green wastes (GW 1) compost with felsite (F) or basalt (B1 or B2);
- Green wastes (GW 1) compost with any of the rock fines tested in this trial, or kerbside collection (KC) compost with basalt (B1);

The length of time of the presence of rock fines are in the blends appeared to influence the results, suggesting that time (one month minimum) is required for the rock fines to fully interact with the compost they are blended within.

3.2.2. Lysimeters

3.2.2.1. Grass growth

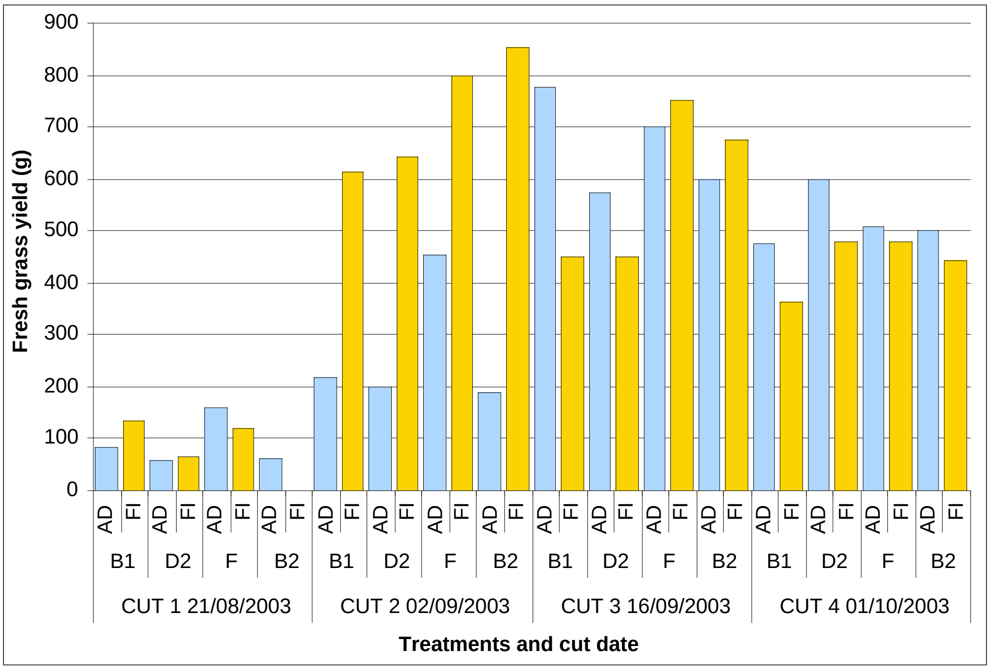

Figure 3.10 – Fresh grass mixture yields per treatment and dates.

Figure 3.10 shows that grass growth rate in the lysimeters resulted in a general trend of increasing yield up until October, following which all treatments showed a decline. Some treatments resulted in early establishment such as with Craighouse fines, whereas the very course materials with AD compost resulted in slow establishment due to excessive ammonium contents. All treatment approached similar growth rates towards Cut 4 and as such would all be suitable for land restoration in terms of grass growth potential.

3.2.2.2. Leachate

o *Nitrogen within leachate*

Leachate was analysed over a period of five moths with samples taken for analysis on the first of every month from August to December. (Data in Appendix 3.3.1)

Initially, during August and September, leachate was generated by water from artificial watering with pre-collected rain water. The initial weeks to month 3 (October) resulted in erratic patterns in the results as most of the blend material in the lysimeters was reaching a state of 'field capacity' beyond which drainage would then occur.

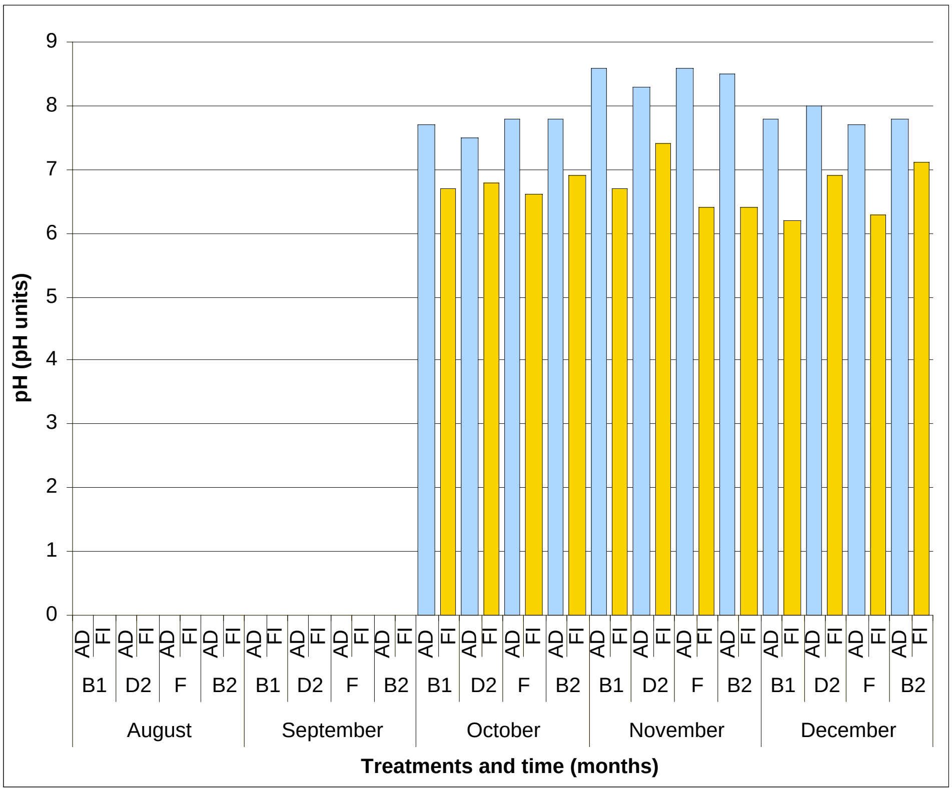

Figure 3.11 – Variation of pH of treatments over time.

In general, pH of the leachate from blends with food industry (FI) compost was 6.5 and those with the anaerobic digested (AD) compost were 8.

From about September onwards, some major patterns appeared to emerge, although lysimeters with basalt (B1) blends periodically demonstrated erratic results with relatively high values for all determinants.

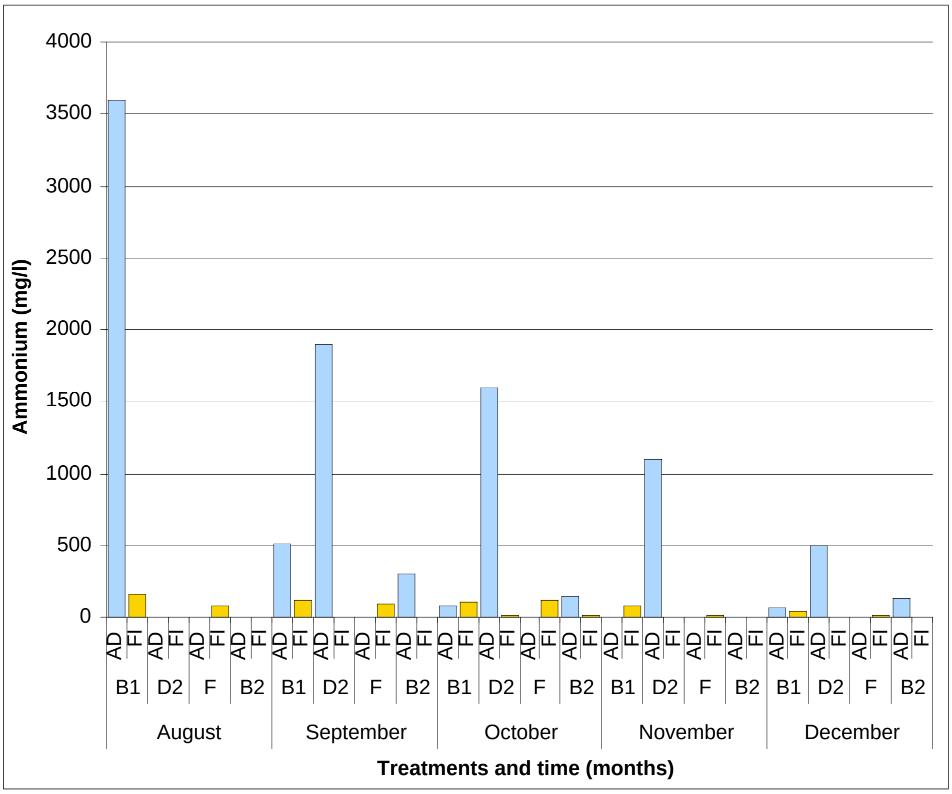

Figure 3.12 – Variation of ammonium concentrations in collected leachate against treatments over time.

During September, ammonium was detected in the leachate at concentrations up to 2000 mg/l, and particularly so in that emerging from blends with anaerobic digested compost. Over subsequent months ammonium concentrations consistently declined in all leachates.

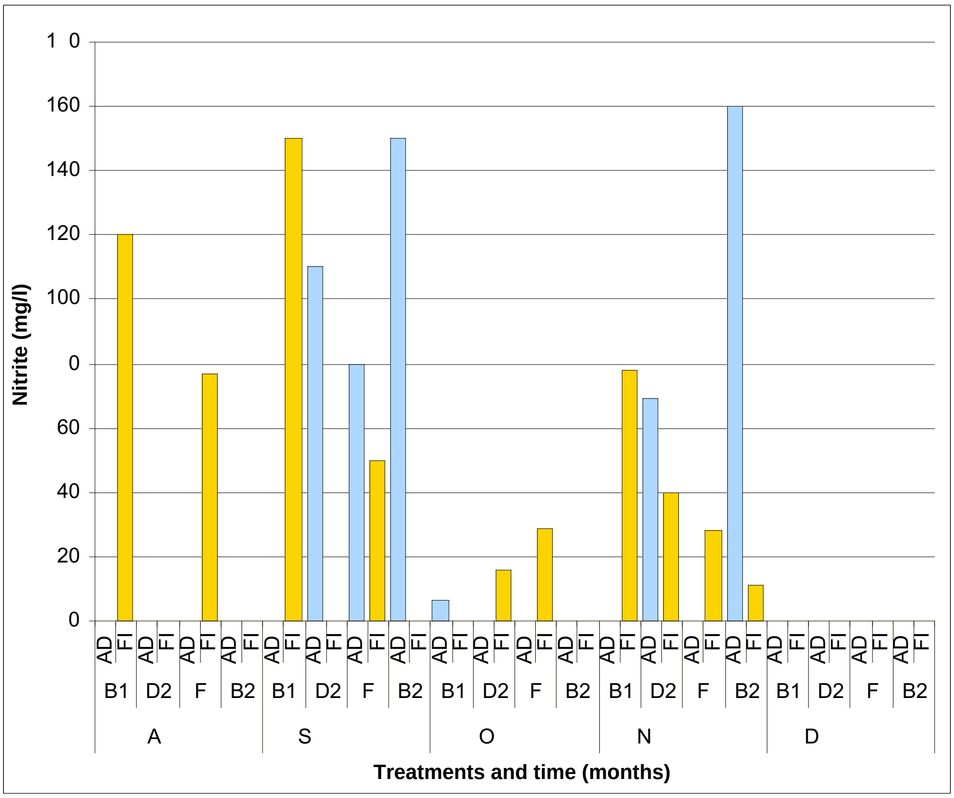

Figure 3.13 – Variation of nitrite concentrations in collected leachate against treatments over time.

As ammonium was transformed, nitrite appeared during September and then November. Following each of these pulses of nitrite, nitrate featured more prominently in each of the subsequent months, October and December, respectively. Nitrite is very transient and concentrations in general did not exceed 1000 mg/l.

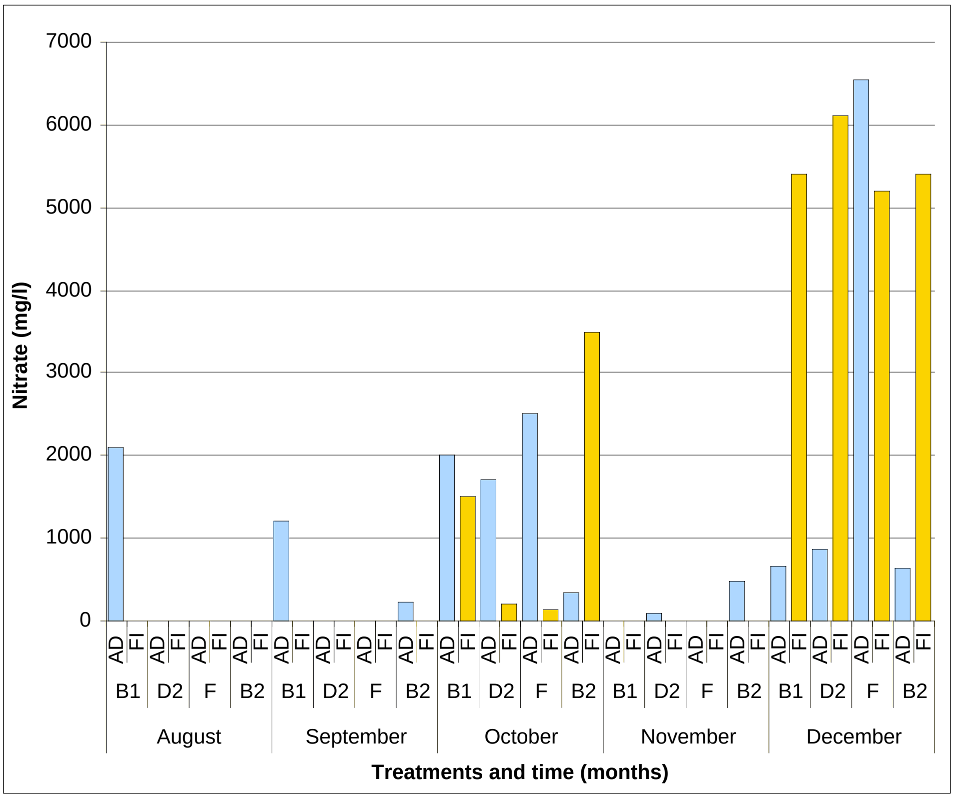

Figure 3.14 – Variation of nitrate concentrations in collected leachate against treatments over time.

However, nitrate after 5 months, during December, reached over 5000 mg/l for leachate from most food industry compost treatments and some anaerobic digested leachates.

Overall, the two major points to emerge from this work are that:

1) nitrogen appeared to be following natural patterns of transformation within the manufactured soils and anaerobic bacteria are operating effectively,

2) The concentration of nitrate in the leachate after five months is prohibitively high and that much reduced quantities of both these composts would need to be employed in field conditions.

o *Chloride and metals within leachate*

Bramwell (2003) studied, as part as her MSc thesis, chloride and metal leachability for the two high nitrogen composts: food industry (FI) and green waste (GW 2) composts blended with the various types of rock fines.

Results suggested that metal leachability was negligible. Chloride concentrations in the leachate from blends were significantly higher in green waste (GW 2) treatments than in food industry (FI) treatments.

An abstract of her MSc thesis can be found in Appendix 3.3.2.

3.2.2.3. Ecotoxicity test

Data from the ecotoxicity test undertaken by Dr Alan Keeling (Harper Adams College) were interpreted and discussed on the report in Appendix 2.3, concluding that compost-rock fines blends tested in the lysimeter trials are not harmful to soil invertebrates.

3.2.2.4. Blend physical properties

- *Infiltration*

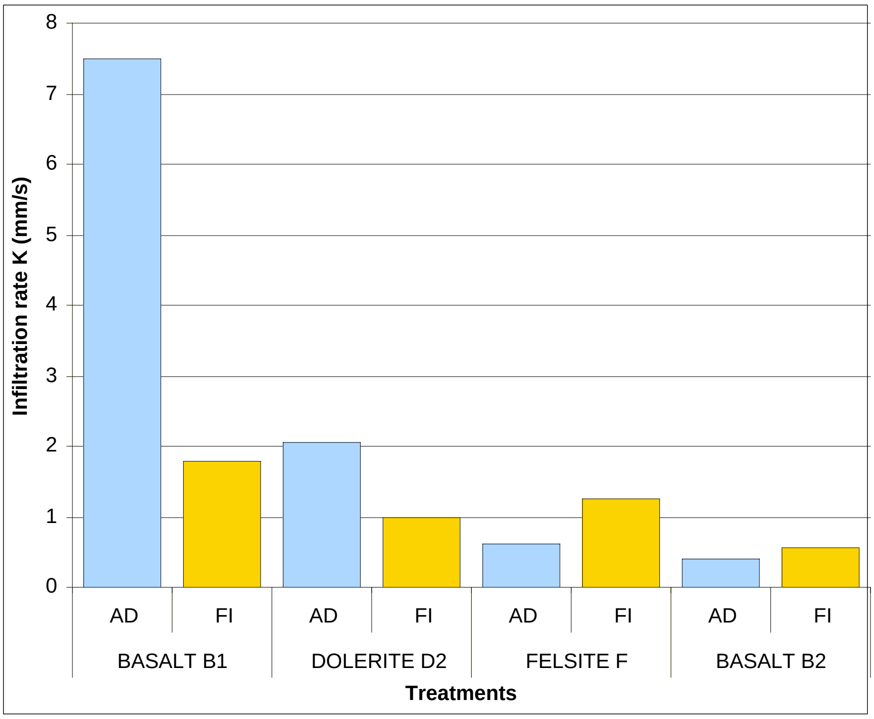

Figure 3.15 – Infiltration K (mm/s) results from lysimeter trials.

Figure 3.15 shows that infiltration rates (Corresponding data in Appendix 3.3.3) vary according to rock types and composts. Basalt (B1) and dolerite (D2) help improve the drainage, especially for the AD compost. Drainage of FI and AD composts were enhanced by basalt (B1), which can be explained by the higher content of larger rock compared to other rock fines tested. Felsite (F) and basalt (B2), which are of similar texture (gravely), resulted in similar infiltrations.

To summarise, infiltration results can be placed into the following order:

For FI compost: B2 <D2 ≤F <B1

For AD compost: B2 ≤F < D2 <B1

o *Shear strength*

The shear strength helps predict the erodibility of any growing media, as the lower resistance encountered means that the medium is weaker and more subject to erosion than a medium with a higher shear strength. For example, sandy materials are more erodible than some composts, or clay soils.

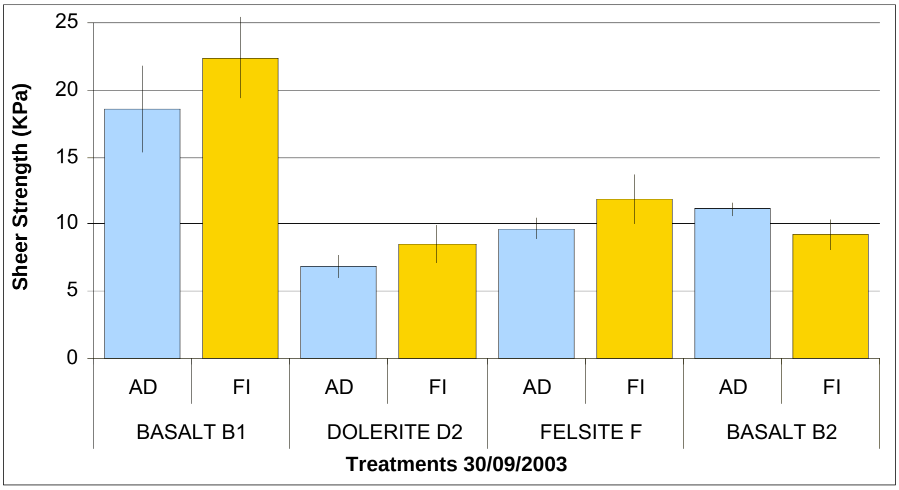

Figure 3.16 – First set (end September 2003) of shear strength results from lysimeter blends.

Figure 3.16 (Corresponding data in Appendix 3.3.4) shows that basalt (B1) blends have the highest shear strength followed by felsite (F), basalt (B2), and dolerite (D2) blends. The rock fines analysis in Appendix 2.1 confirmed these results. Even if blended with compost, the shear strength results of the blends corresponded to the sand content of the rock fines alone. Thus, it can be suggested that dolerite (D2) blends are possibly more than or as erodible as basalt (B2) and felsite (F) blends, whereas basalt (B1) blends are less erodible.

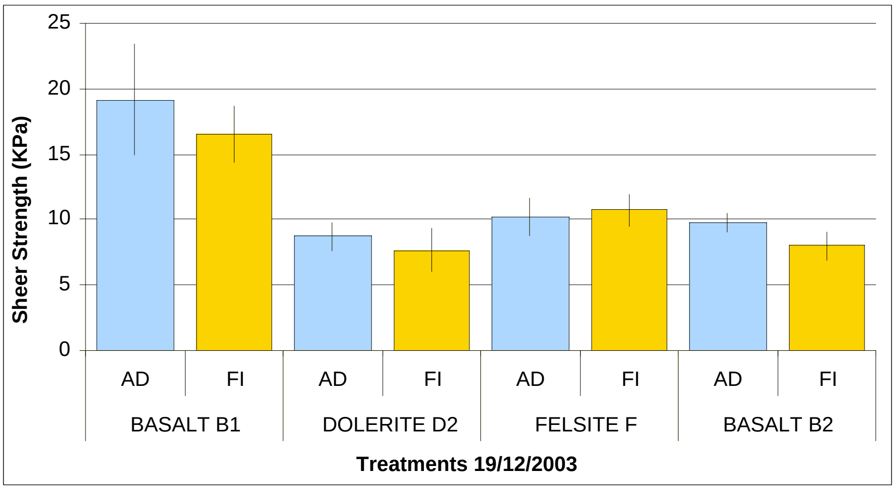

Figure 3.17 – Second set (two months and a half after first set, mid-December 2003) of shear strength results from lysimeter blends.

Figure 3.17 (Corresponding data in Appendix 3.3.4) shows similar results as Figure 3.16, however, it appears that the shear strength varied with time, increasing or decreasing depending on the blends. Most of the blends had stable or decreasing shear strength with time, apart from the anaerobic digested (AD) compost blended with dolerite (D2), which had a shear strength which increased with time. This increase may have been due to the settlement of the rock fines in the compost, resulting in compaction of the growing medium, as dolerite (D2) rock fines are very fine in texture. Also, grass and plant roots should be taken into consideration as vegetative cover can increase the stability of a growing medium by up to 500% (Keeling *et al.*, unpublished).

- *Bulk Density*

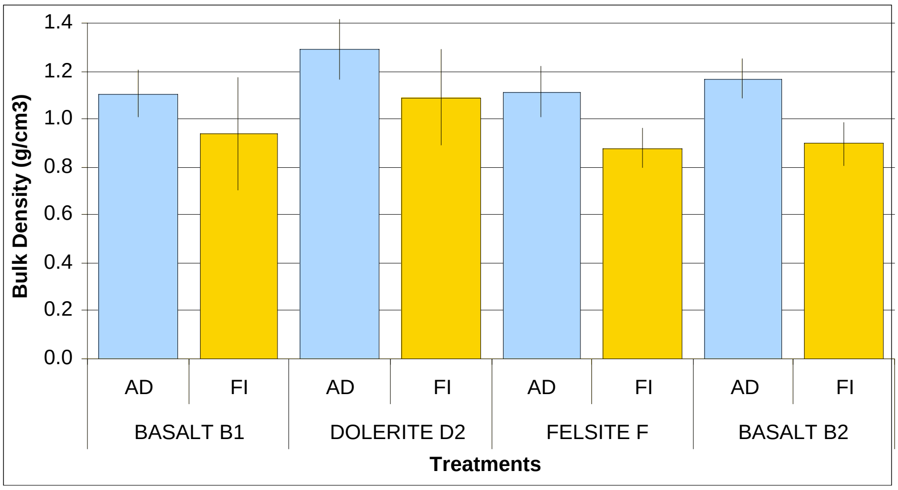

Figure 3.18 – Bulk density of lysimeter blends.

Figure 3.18 (Corresponding data in Appendix 3.3.5) shows that all the FI blends and all the AD blends gave the same bulk density. All the AD blends generally gave a higher bulk density than the FI blends. This suggests that the AD compost has a higher density, and may be more subject to compaction than the FI compost.

Moreover, it can be noticed that the bulk density of dolerite D2 rock fines with AD or FI compost was higher than the rest of the blends, confirming the fine particle size of D2 rock fines, and the compaction of the material, even when blended with compost.

Only dolerite (D2) and basalt (B1) with the FI compost gave a similar high density as AD blends, suggesting that basalt (B1) and dolerite (D2) increase the density of blends. Felsite (F) and basalt (B2) rock fines did not increase the density of the blends, which can be explained by their gravely texture.

- *Water holding capacity*

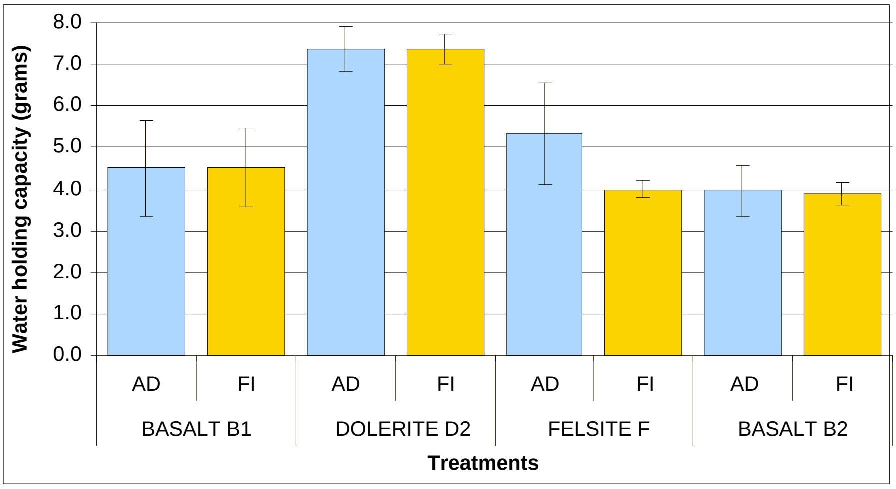

Figure 3.19 – **Water holding capacity of lysimeter blends.**

Figure 3.19 (Corresponding data in Appendix 3.3.6) shows that dolerite (D2) with AD and FI composts resulted in a higher water holding capacity than the other blends. This can be potentially explained by the higher bulk density of dolerite (D2) with any of the two composts, having the potential to retain more water than the other blends as the medium has a finer particle size. All of the other blends resulted in similar water holding capacity.

3.3. Field Plot Trials

The plot trial set-up was based on lysimeter results: A high and a low nitrogen compost were blended with dolerite and basalt fines.

Issues were encountered when blending the materials together on-site, suggesting that trafficability and workability of blends, especially with dolerite (D2) are a potential problem when applying those materials for land restoration.

4. CONCLUSIONS

The work carried out in this study has demonstrated that fines from igneous rock aggregate quarries can be blended successfully with composts of differing type and source to give growing media that can be used in horticulture and land restoration.

Grass trials suggested that, for land restoration purposes, quarry soils B1 and B2 could be matched in their potential for plant growth by the blend felsite/green waste compost processed outdoors. Quarry soils D2 and F could significantly be matched by the green waste compost processed outdoors and blended with basalt or felsite. Considering results from the second dry grass cut, the food industry compost with felsite and dolerite resulted in the greatest grass growth of the food industry treatments. Green waste compost processed indoors with basalt (B2) and dolerite resulted in the greatest grass growth of the green waste (GW 2) treatments. The response of a restoration mix of seeds will vary according to the compost type; nitrogen-fixing species will predominate in a nitrogen poor compost, whereas grasses will predominate for a nitrogen-rich compost.

Lysimeter trials showed that:

- The shear strength and infiltration of the manufactured soil are increased by basalt (B2) fines with a greater particle size.
- Basalt (B1) fines with a finer particle size and dolerite (D2) increase the density and water holding capacity of manufactured soil.

The lysimeter trials showed that initial runoff or through drainage will be rich in ammonium (up to 2000 mg/L), whereas later runoff or through drainage will be rich in nitrate (up to 5000 mg/L). These levels exceed regulatory limits.

In contrast, tests using enchytraeid worms have shown that the compost-rock fines blends used in the lysimeter trials are not harmful to soil invertebrates.

Field trials at Barrasford Quarry emphasise the importance of achieving blends that can be worked using appropriate machinery. Fines with a high proportion of silt grade material are more difficult to mix in place, compared to those with a higher sand or grit content.

For blends intended for horticultural use, all combinations gave similar results in terms of taste and consumer acceptability. The greatest yields of fruit were obtained when high-nitrogen food industry compost was used alone, or blended with any rock fines.

The food industry compost with basalt (B2) appeared to be the only blend that resulted in tomatoes as “tasty” as those from a reference grow bag, and “tastier” than those from the food industry compost alone. The green waste compost processed indoors appeared to result in “tastier” tomatoes when blended with felsite or basalt (B1).

The results of the taste panel, although not statistically significant, indicated that composts consistently appeared to be generally enhanced by the presence of basalt (B2) or quartz dolerite (D1) to a potentially similar level of quality as a widely available grow bag. Moreover, it can be suggested that depending on the compost, appropriate rock fines (especially basalt B2 and dolerite D1) may be blended to enhance the juiciness, tenderness and fruit flavour of the tomato.

Overall:

- Rock fines can contribute positively to the quality of compost, especially of low nitrogen compost;

- Rock fines and compost do not appear to alter significantly tomato taste, and blends can be selected for enhancing juiciness and/or tenderness of fruit;

- Compost and rock fine blends are suitable for land restoration uses, but consideration of leachate is needed.

Further research to this project could include ecological surveys as a long term monitoring method on field trials, including trees and weed appearance considering that the seed mixture of grass is initially known, confirming indication of low (nitrogen-fixing plants growing) and high (normal healthy grass) nitrogen blends. Moreover, testing blends with varied ratios of compost: quarry fines would allow identifying the most promising ratio for blends, depending on compost and rock fine types used, and on the potential application of the growing medium. Also, the variation of compost: rock fines blend ratio would help assessing the influence on vegetation, crops, contaminants leachability and toxicity, and physical properties such as erodibility.

Potential applications of such growing media or rock fines are numerous, and include various ways to help remediate to various environmental issues, such as an additive to natural soil).

Mineral Solutions Ltd have worked on two further MIST projects arising from this project, one researching the various potential uses of rock fines (Mineral Solutions, 2004a), and the other one developing a generic model advising which factors and parameters to consider when creating novel growing media (Mineral Solutions, 2004b).

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APPENDIX 2

Appendix 2.1. Analytical Results of Composts and Rock Fines

Appendix 2.2. Properties if Soils Used in Trials.

Appendix 2.3. Ecotoxicity Test

Appendix 2.4. Total Petroleum Hydrocarbon (TPH) Analysis Results

Appendix 2.1. Composts and rock fines analysis

Table A1. Results of compost analysis

Source			AWS, Cockle Park farm	City Works	PACTS	SENREC	A&E Thompson	Grow-Bag
Composts			Food Industry (FI)	Kerbside Collection (KC)	GreenWaste GW 1 (Outdoors)	GreenWaste GW 2 (Indoors)	Anaerobically Digested (AD)	Grow-Bag (GB)
Salmonella			Negative	Negative	Negative	Negative	Negative	Negative
E. Coli		cfm/g	167.0	88.3	<10	9923.0	12556.0	<10
PH		pH units	5.89	7.75	7.77	7.14	9.01	5.05
Electrical Conductivity		mS/cm	1262	630	880	1550	607	913
Organic matter content		% w/w	70.3	16.5	27.2	39.8	88.1	92.4
Dry Matter		%	36.0	79.2	77.6	62.5	20.2	32.1
Chloride		mg/kg	235	387	650	1555	871	78.3
C:N Ratio			8:1	18:1	18:1	13:1	24:1	36:1
Nitrate Nitrogen (NO^-_3)		mg/kg	2731.00	<0.01	<0.01	<0.01	<0.01	1168.00
Ammonium Nitrogen (NH^+_4)		mg/kg	3670.0	75.7	66.6	561.0	3404.0	745.0
Total	N	%w/w	4.630	0.585	0.892	2.130	1.740	1.430
	C	% w/w	38.7	10.6	16.4	27.7	41	50.8
	P	% w/w	0.291	0.068	0.163	0.296	4525	1658
	K	% w/w	0.585	0.379	0.690	1.290	10699.00	3552.0
	Mg	% w/w	0.175	0.400	0.473	0.365	2630.0	6609.0
	Cu	mg/kg	35.7	31.1	50.2	47.8	26.9	119
	Cd	mg/kg	0.154	0.959	2.330	0.503	0.191	0.282
	Cr	mg/kg	13.6	29.2	33.4	22.3	8.52	2.92
	Pb	mg/kg	260.0	76.7	200.0	93.4	38.3	38.9
	Hg	mg/kg	0.050	0.076	0.111	0.116	<0.05	0.071
	Ni	mg/kg	5.03	28.80	25.20	18.60	5.68	2.91
	S	% w/w	0.443	0.209	0.154	0.332	2710	4600
	Zn	mg/kg	108.0	96.3	167.0	201.0	131.0	26.8
Available (Water Soluble)	P	mg/kg	216.00	<0.01	14.70	47.00	193.00	238.0
	K	mg/kg	544	703	1618	3373	658	468
Plastic >2mm		% w/w	0.09	0.04	0.03	<0.01	0	0
Metal >2mm		% w/w	<0.01	<0.01	<0.01	<0.01	0.00	0.00
Glass >2mm		% w/w	0.00	0.03	0.21	0.05	0.00	0.00
Stones >2mm		% w/w	1.00	32.40	19.20	5.00	0.00	0.00

Table A2. XRF and PSD results on rock fines

Rock fines		Carboniferous Clyde Plateau Lavas Basalt B1	Dolerite Whin Sill D2	Quartz Dolerite D1	Basalt B2	Felsite F
Major elements [Component oxide weight percentages (wt. %)]	SiO2	48.93	45.53	53.41	44.88	67.97
	TiO2	2.76	1.85	2.04	3.30	0.36
	Al2O3	16.94	12.79	13.26	13.05	13.66
	Fe2O3	11.27	11.39	12.73	14.97	1.97
	MnO	0.22	0.15	0.23	0.18	0.03
	MgO	4.04	4.54	2.63	7.13	0.37
	CaO	3.65	13.24	6.03	7.70	0.41
	Na2O	6.25	3.10	4.97	3.34	4.51
	K2O	2.50	0.91	2.22	1.42	6.00
	P2O5	0.63	0.40	1.09	1.10	0.06
	SO3	0.48	0.43	0.12	0.10	0.07
	LOI	2.54	4.90	1.74	2.54	4.90
	Total	100.20	99.24	100.47	99.71	100.31
Trace elements (ppm)	As	4	4	4	<2	10
	Ba	665	394	449	1056	840
	Ce	103	85	97	117	153
	Co	37	48	55	39	<2
	Cr	60	280	101	74	8
	Cs	<2	5	<2	3	2
	Cu	38	84	67	36	15
	Ga	26	24	28	23	19
	La	38	30	40	51	100
	Mo	4	<2	<2	4	<2
	Nb	52	17	40	40	18
	Nd	45	33	50	58	56
	Ni	8	51	107	<2	<2
	Pb	41	14	11	20	27
	Rb	58	26	27	46	179
	Sb	<2	<2	<2	<2	<2
	Sc	18	26	20	15	4
	Se	<2	<2	<2	<2	<2
	Sn	5	<2	<2	5	5
	Sr	523	711	587	494	175
	Ta	6	<2	<2	3	<2
	Th	14	7	4	9	28
	U	5	<2	<2	3	<2
	V	148	270	158	73	19
	W	<2	<2	<2	<2	<2
	Y	39	35	42	56	22
	Zn	367	188	137	204	47
	Zr	317	196	312	334	413
Particle Size Distribution (PSD)	**Sand (% w/w)** 2.00-0.063mm	70	8	Not tested	81	88
	Silt (% w/w) 0.063-0.002mm	15	82	Not tested	7	4

Rock fines		**Carboniferous Clyde Plateau Lavas Basalt B1**	**Dolerite Whin Sill D2**	**Quartz Dolerite D1**	**Basalt B2**	**Felsite F**
Particle Size Distribution (PSD)	**Clay (% w/w)** <0.002mm	15	10	Not tested	12	8
	Fine Gravel (%) 3.4-2.00mm	7	0	Not tested	10	12
	Textural Class	Sandy Loam	Silt Loam	Not tested	Sandy Loam	Loamy Sand

Appendix 2.2. Properties of soils used in trials

Table A3. Table showing results of soils used in trials

	Soils	Parent Material/Geology	Major Soil Group	Soil Subgroup	Soil Series	Water regime	Landscape	Comments
Quarries	**Soil B1**	Drifts derived from basaltic rocks	Podzolic soils	Peaty podzols, peaty gleys, peat, some rankers	Darleith / Kirktonmoor	Permeable, well drained Moderate AWC	Hills with gentle to strong slopes; slightly rocky	Arable and permanent pastures, acid bent-fescue grassland, broad-leaved woodland
	Soil D2	Carboniferous limestone, shale and sandstone	Podzolic soils	Humo-ferric podzols	Anglezarke	Permeable, well-drained, long FC	Gently to strong slopes, and some steeper valley-sides.	Mainly used for rough grazing
	Soil B2	Drifts derived from basaltic rocks	Brown soils	Brown forest soil, some brown rankers	Darleith / Kirktonmoor	Freely drained	Hills, valleys sides, gentle and strong slopes, slightly rocky	Grassland
	Soil F	Basic igneous andesites	Podzolic soils	Typical brown podzolic soils	Malvern. Acid soils Sandy silt loam or clay loam	Permeable, well drained Moderate AWC	Lower altitude in Cheviot Hills, moderate or steep slopes, very stony	Grassland Limited availability of phosphate Short growing season
	Soil D1	Intrusive Basalt, Dolerite, and allied types	Brown soils	Brown forest soil	Darleith / Kirktonmoor	Moderately to well drained.	Hill sides, very steep slopes. Moderately rocky, with cliffs	Mainly rough grazing of grassland. Some deciduous woodlands.
	Control soil Rivington (Cockle Park Farm)	Sandstone	Brown soils	Typical brown earth	Rivington – Sandy Loam Naturally acid	Permeable, well drained Moderately small AWC	High ground, steep valley sides. Moderately stony	Good agricultural soil, intensive grassland where slope allows.

Appendix 2.3. Ecotoxicity test

Ecotoxicity report of 8 synthetic soils by Dr. A. Keeling, Harper Adams College

Aim of test: To determine the general ecotoxicity of soils using the enchytraeid worm *Enchytraeus albidus*.

Method
Dried soils were ground and sieved to 3 mm. The water holding capacity of each soil was determined using standard procedures. Dried soils (20g) were placed into 250 ml glass bottles and water added to the soil's water holding capacity. Five replicate samples were used for each test soil, and a synthetic OECD soil (8 replicates) was used as the control. 25 mg of rolled oatmeal was placed in each bottle as a food source.

Worms (10) were placed in each bottle and all bottles were placed in a controlled environment set at 18^{o}C and 90-100% humidity. Microcosms were checked weekly and extra water and food added as necessary. After 21 days, the surviving adult worms were removed from the bottles and counted.

After a further 3 weeks, the soils were stained to reveal the juvenile worms. The number of juveniles within each bottle was then counted.

Results
A table of results is shown on the following page. There were no significant differences in the number of surviving worms for each soil, both compared with each other and with the control OECD soil. A 2-way analysis of variance was also carried out which showed there was no difference between results from each quarry source and each compost ($P > 0.05$).

The number of juveniles present during the latter half of the experiment was inconsistent. There were significant differences between the treatments but it most be noted that the coefficient of variation was high.

The BFD soil showed, irrespective of compost type, both low survival rates and the lowest numbers of juveniles.

Discussion
This assay measures both acute toxicity (survivors at 21 days) and chronic toxicity (juveniles at 42 days). The experiment did not show any significant differences between the synthetic soils and the control in terms of acute toxicity.

The numbers juveniles were low in this experiment. A count of 25 would normally be expected in the control soil, however we are not aware of any unusual environmental conditions which may have caused these results.

Most of the synthetic soils tested in the experiment compared favourably with the OECD control soils. The BFD soil did give poorer results than all the soils, irrespective of compost type, but these results are not significantly different from the control soil.

It is concluded that all media provided a satisfactory environment for the survival and reproduction of *Enchytraeus albidus*, indicating acceptable levels of heavy metals or other toxins in the soils tested.

Table A4. Effects of synthetic soils on the survival and juvenile production of *Enchytraeus albidus* in controlled microcosm conditions.

SOIL SAMPLE	SURVIVORS (/10)	JUVENILES
BB / FI	7.25	5.75
BFD / FI	4.60	0.40
CHSE / FI	7.80	3.60
HDN / FI	9.20	5.00
BB / AD	6.40	12.8
BFD / AD	5.20	0.00
CHSE / AD	8.20	5.00
HDN / AD	8.60	10.6
CONTROL	6.62	2.25
LSD ($P < 0.05$)	3.68	8.50
Coefficient of variation (%)	36.4	122.6

Appendix 2.4. Total Petroleum Hydrocarbon (TPH) analysis results

Raw data tables follow.

TES ID Number CL/	Client Sample Description	TPH GCFID (AR)
	Units :	mg/kg
	Method Codes :	TPHFID
	Detection Limits :	10.0
0333709	Plot 1	467
0333710	Plot 2	317
0333711	Plot 3	743
0333712	Plot 4	933

TES Bretby

PO Box 100, Bretby Business Park, Burton-on-Trent, Staffordshire, DE15 0XD

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Client Name	Mineral Solutions Limited
Contact	Ms G Guillou

Mineral Solutions

Soils Sample Analysis

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Report Number	EFS/034876
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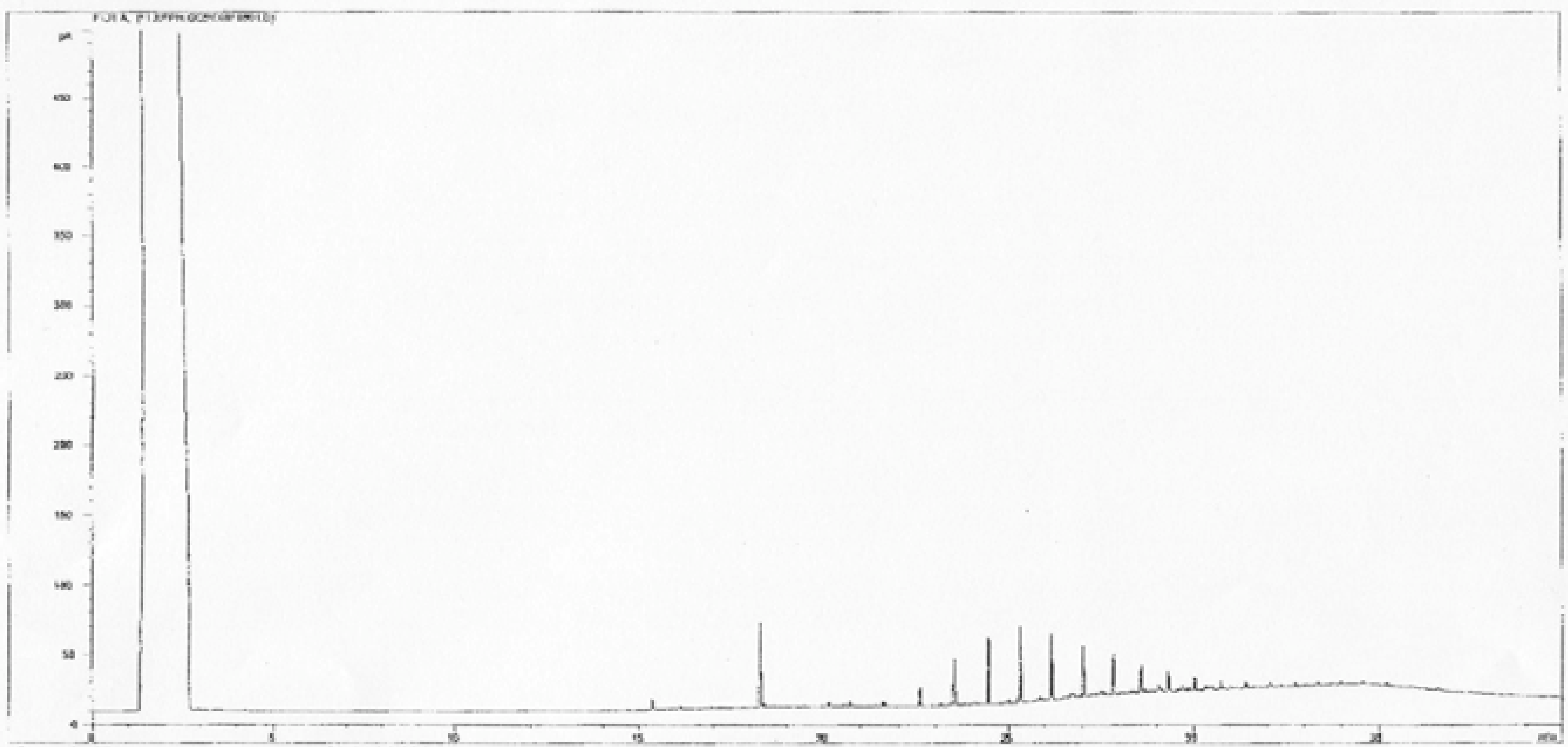
Petroleum Hydrocarbons (C8 to C37) by GC/FID

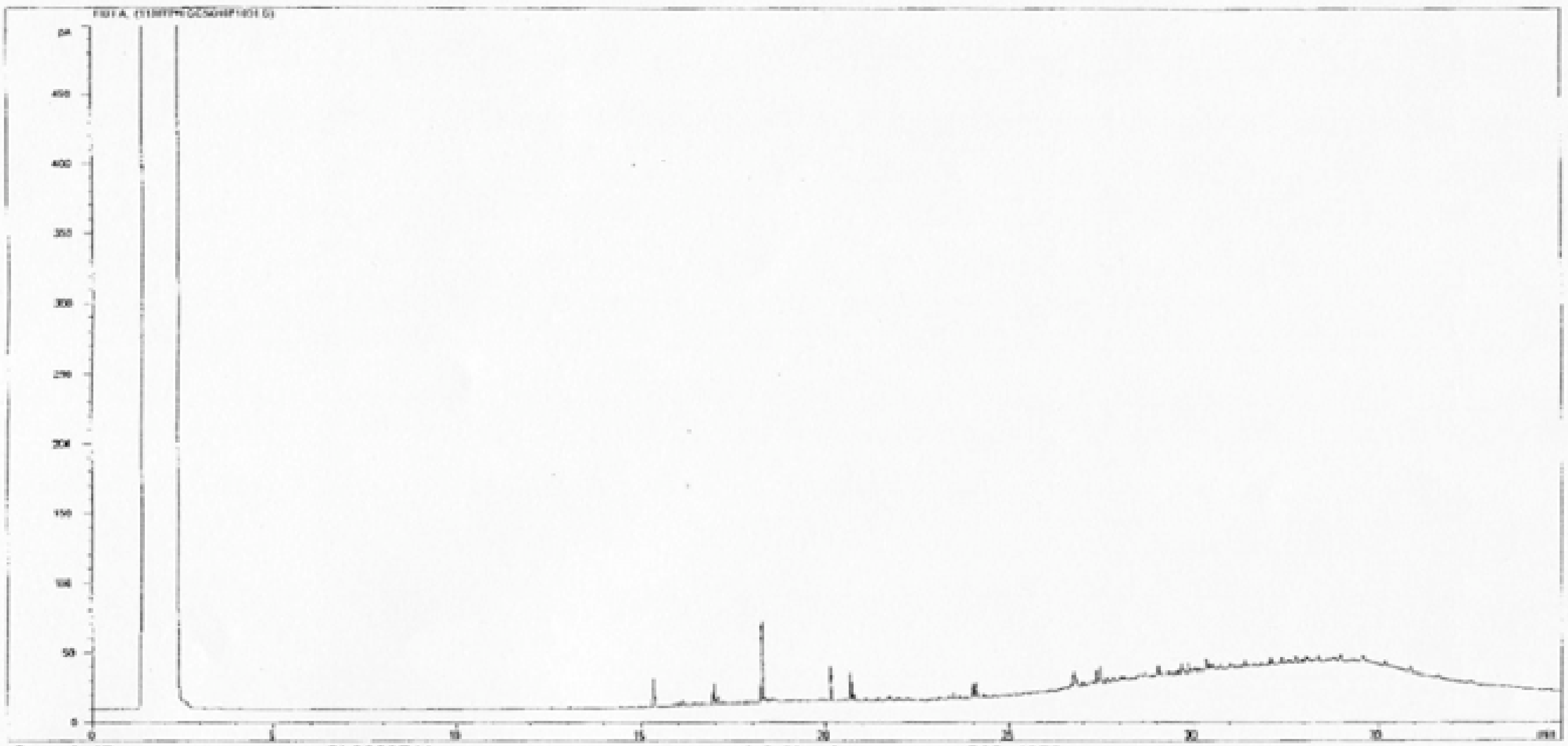


Sample ID:	CL0333709	**Job Number:**	S03_4876
Multiplier:	0.1	**Client:**	Mineral Solutions Limited
Dilution:	5	**Site:**	Mineral Solutions
Acquisition Method:	WMF_RUNF.M	**Client Sample Ref:**	Plot 1
Acquisition Date/Time:	12/01/03 00:35		
Datafile:	D:\TES\DATA\1130TPH.GC5\008F0801.D		

Petroleum Hydrocarbons (C8 to C37) by GC/FID

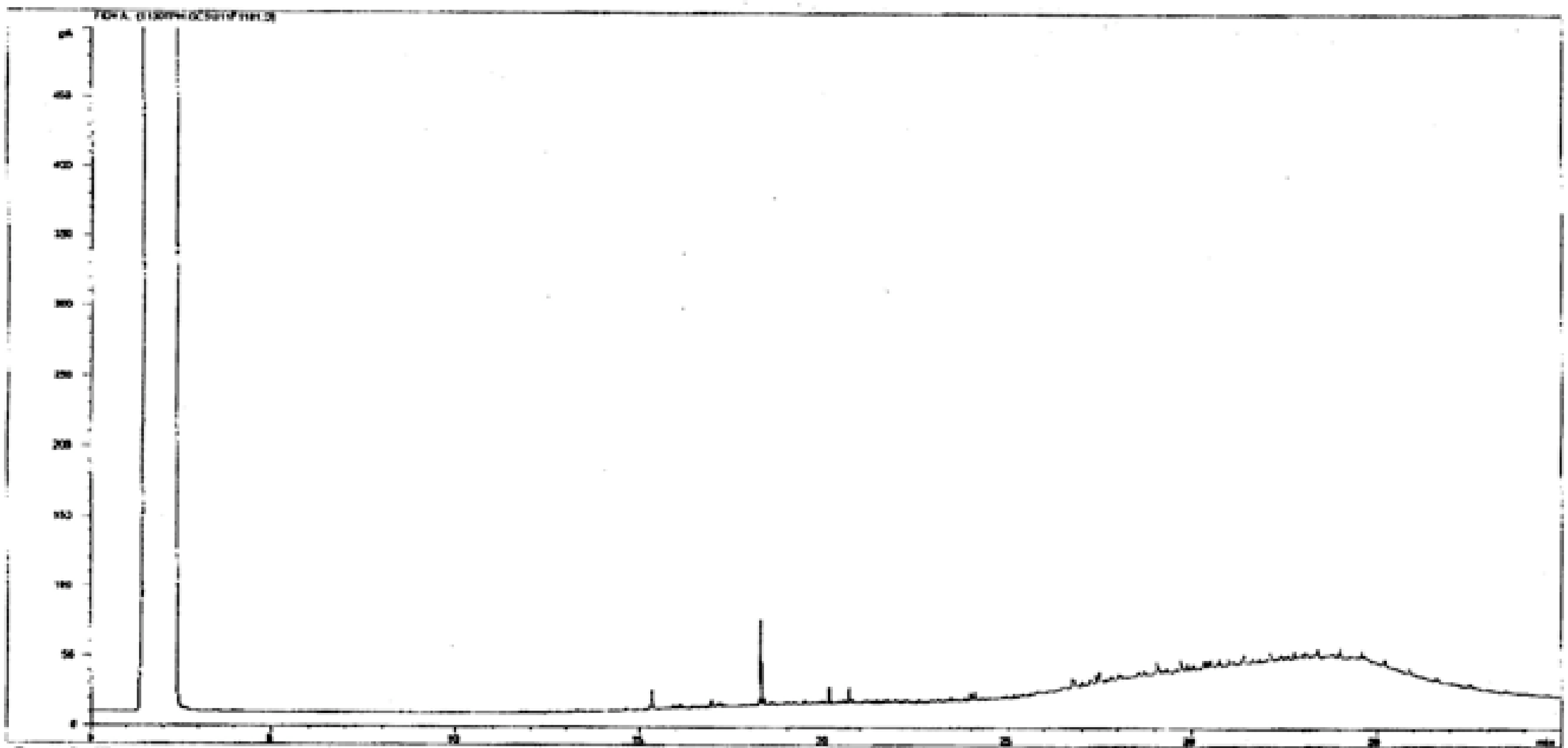
Sample ID:	CL0333710	**Job Number:**	S03_4876
Multiplier:	0.1	**Client:**	Mineral Solutions Limited
Dilution:	5	**Site:**	Mineral Solutions
Acquisition Method:	WMF_RUNF.M	**Client Sample Ref:**	Plot 2
Acquisition Date/Time:	12/01/03 01:26		
Datafile:	D:\TES\DATA\1130TPH.GC5\008F0901.D		

Petroleum Hydrocarbons (C8 to C37) by GC/FID



Sample ID:	CL0333711	**Job Number:**	S03_4876
Multiplier:	0.1	**Client:**	Mineral Solutions Limited
Dilution:	5	**Site:**	Mineral Solutions
Acquisition Method:	WMF_RUNF.M	**Client Sample Ref:**	Plot 3
Acquisition Date/Time:	12/01/03 02:17		
Datafile:	D:\TES\DATA\1130TPH.GC5\010F1001.D		

Petroleum Hydrocarbons (C8 to C37) by GC/FID



Sample ID:	CL0333712	**Job Number:**	S03_4876
Multiplier:	0.1	**Client:**	Mineral Solutions Limited
Dilution:	5	**Site:**	Mineral Solutions
Acquisition Method:	WMF_RUNF.M	**Client Sample Ref:**	Plot 4
Acquisition Date/Time:	12/01/03 03:08		
Datafile:	D:\TES\DATA\1130TPH.GC5\011F1101.D		

APPENDIX 3

APPENDIX 3.1. TOMATO PLANT POT TRIALS

Appendix 3.1.1. Tomato grade data
Appendix 3.1.2. Abstract MSc Thesis, Bartlett (2003)
Appendix 3.1.3. Tomato fruit yield data and statistics
Appendix 3.1.4. Tomato taste panel data and statistics

APPENDIX 3.2. GRASS POT TRIALS

Appendix 3.2.1.Grass growth data and statistics
Appendix 3.2.2.Nutrient analysis data

APPENDIX 3.3. LYSIMETERS

Appendix 3.3.1. Grass cuts and leachate data
Appendix 3.3.2. Abstract MSc Thesis, Bramwell (2003)
Appendix 3.3.3. Infiltration data
Appendix 3.3.4. Shear strength data
Appendix 3.3.5. Bulk density data
Appendix 3.3.6. Water Holding Capacity (WHC) data

APPENDIX 3.1. TOMATO PLANT POT TRIALS

Table A5. Tomato grade data

COMPOST TYPE	CONTROL	ROCK TYPE			
		BASALT B1	DOLERITE D1	FELSITE F	BASALT B2
	8.5				
	10				
GROW BAG GB	8.5				
	8.5				
	8.5				
	8	8	7.5	7	7
	6	7	6	8	10
FI	7	9	9	8	7.5
	6.5	8.5	7	7	8
	8	8	8	8.5	7.5
	7.5	7	7	7	8
	9	7	9	7	6.5
GW 2	8	9	8	7.5	8
	9	7.5	6	8	7
	7	7	6.5	7	7.5
	4	7	6	6	5.5
	5	6	5.5	7.5	7
GW 1	5.5	5.5	6.5	6.5	7
	5.5	5	3	6	6
	5.5	6.5	7.5	3.5	6.5
	7	5	6	5	5
	4	6	7	5.5	5
AD	7	4.5	5	5.5	3.5
	8	6	6	6	4
	6	5	5.5	5.5	3.5
	5	4.5	4.5	4	6
	1.5	5.5	4.5	5	5.5
KC	4.5	5	4.5	5	6
	4.5	5	3.5	5	5
	3.5	5	5.5	4.5	4.5
Average	**CONTROL**	**B1**	**D1**	**F**	**B2**
GB	8.8				
FI	7.1	8.1	7.5	7.7	8
GW2	8.1	7.5	7.3	7.3	7.4
GW1	5.1	6	5.7	5.9	6.4
AD	6.4	5.3	5.9	5.5	4.2
KC	3.8	5	4.5	4.7	5.4
STDEV	**CONTROL**	**B1**	**D1**	**F**	**B2**
GB	0.7				
FI	0.9	0.7	1.1	0.7	1.2
GW 2	0.9	0.9	1.2	0.4	0.7
GW	0.7	0.8	1.7	1.5	0.7
AD	1.5	0.7	0.7	0.4	0.8
KC	1.4	0.4	0.7	0.4	0.7

Growth Grade: 1=poor, 10= high and healthy

Appendix 3.1.2. Abstract MSc Thesis, Bartlett (2003)

‘The combination of crushed quarry fines and organic process residues for the development of a novel growth media.’

1 Abstract

Recent changes to EU and UK law mean that there must be a 35% reduction in the amount of waste that is disposed of in landfill sites by 2020. This means that other ways of disposing these by-products must be found. This project aims to produce a Novel Growth Medium (NGM) from quarry waste streams: crushed quarry waste and organic process residue (compost)

Four geologically distinct quarry wastes and five different sources of compost were selected to make NGMs for growth trials, conducted at the University of Newcastle-upon-Tyne experimental facility at Close House, Northumberland. In these experiments cherry tomatoes (*Lycopersicon esculentum* Mill cvs “Sungold”) were grown in separate 10 litre pots, 26 different classes, with 5 replicates, including controls were used. The quarry waste and compost were mixed at approximately 75:25 w/w. After transplantation each plant had its height measured at regular intervals for 10 days. After this time the plants were terminated above their 4th truss and the mean fresh weight of fruits was recorded per truss per week.

Using 2 way analysis of variance results indicate that there is no significant difference between the rock type used in the NGM and the rate of growth ($p = 0.165$) or with mean fresh weight yield ($p = 0.218$) or the photosynthetic health of the plants ($p = 0.943$). Analysis of variance also showed a highly significant difference between compost types used in the NGM with reference to both growth rate and mean fresh weight yield ($p > 0.0005$). Regression analysis indicates that the most important factor for both variables is the C:N ratio ($r^2 = 0.895$ & 0.851, growth rate and mean fresh weight yield respectively). Other factors such as pH, electrical conductivity and total % nitrogen w/w of he NGM also had an effect on the growth patterns of the plants. The photosynthetic health of the plans was also shown to have some dependence on the compost used ($p = 0.026$) however regression analysis fails to indicate any significant relationships with known variables from the compost.

Analysis showed all composts used to contain metals that are potentially toxic to human health (e.g. Hg, Pb, As, Cd). Metal content analysis of the fruits showed that there is no significant difference between tomatoes grown on growbags ant those grown on the NGM. Fruits from NGM plants were shown to have less lead and cadmium than the growbag fruits by approximately 35%. All fruits produced are safe for human consumption.

KEYWORDS: WASTE REDUCTION, ROCK FINES, QUARRY WASTE, COMPOST, GREEN WASTE, GROWTH TRIALS, TOMATOES

Appendix 3.1.3. Tomato Fruit Yields Data And Statistics

- ***Fruit yield data (Bartlett, 2003)***

Notes on tables 3.1.3.1 to 3.1.3.4:

(2) All weights measured in grams.
(3) All fruits harvested, irrespective of their state of ripeness.

Table 3.1.3.1: Fresh weight yield of tomatoes from 1st truss (07/07/03)

	Weight		Weight		Weight		Weight		Weight		Weight
HDN ad 1	55.5	RR ad 1	43.8	BB ad 1	34.5	CHSE ad 1	73.7	ad C 1	51.5	Growbag 1	115.5
HDN ad 2	46.9	RR ad 2	31.6	BB ad 2	63.4	CHSE ad 2	19.4	ad C 2	31.1	Growbag 2	254.3
HDN ad 3	49.1	RR ad 3	31.1	BB ad 3	30.4	CHSE ad 3	42.4	ac C 3	31.0	Growbag 3	135.9
HDN ad 4	29.1	RR ad 4	26.5	BB ad 4	71.9	CHSE ad 4	40.9	ad C 4	50.1	Growbag 4	141.5
HDN ad 5	70.2	RR ad 5	41.8	BB ad 5	34.3	CHSE ad 5	26.9	ad C 5	21.3	Growbag 5	257.5
Mean	**50.2**	**Mean**	**35.0**	**Mean**	**46.9**	**Mean**	**40.7**	**Mean**	**37.0**	**Mean**	**180.9**
HDN fi 1	160.3	RR fi 1	135.3	BB fi 1	101.4	CHSE fi 1	183.5	fi C 1	111.9		
HDN fi 2	154.6	RR fi 2	171.0	BB fi 2	255.1	CHSE fi 2	150.1	fi C 2	230.1		
HDN fi 3	237.1	RR fi 3	435.2	BB fi 3	299.9	CHSE fi 3	202.2	fi C 3	187.4		
HDN fi 4	195.1	RR fi 4	190.2	BB fi 4	165.8	CHSE fi 4	383.1	fi C 4	149.5		
HDN fi 5	173.2	RR fi 5	122.1	BB fi 5	82.0	CHSE fi 5	108.8	fi C 5	123.0		
Mean	**184.1**	**Mean**	**210.8**	**Mean**	**180.8**	**Mean**	**205.6**	**Mean**	**160.4**		
HDN kc 1	49.5	RR kc 1	20.9	BB kc 1	17.6	CHSE kc 1	43.0	kc C 1	3.7		
HDN kc 2	27.9	RR kc 2	26.7	BB kc 2	25.5	CHSE kc 2	49.0	kc C 2	26.9		
HDN kc 3	29.1	RR kc 3	39.2	BB kc 3	30.8	CHSE kc 3	83.2	kc C 3	5.3		
HDN kc 4	24.1	RR kc 4	32.2	BB kc 4	15.5	CHSE kc 4	59.9	kc C 4	9.2		
HDN kc 5	66.5	RR kc 5	47.2	BB kc 5	14.9	CHSE kc 5	18.1	kc C 5	24.9		
Mean	**39.4**	**Mean**	**33.2**	**Mean**	**20.9**	**Mean**	**50.6**	**Mean**	**14.0**		
HDN pact 1	96.4	RR pact 1	61.3	BB pact 1	61.4	CHSE pact 1	15.2	pact C 1	8.4		
HDN pact 2	54.1	RR pact 2	24.8	BB pact 2	23.3	CHSE pact 2	31.0	pact C 2	20.5		
HDN pact 3	70.6	RR pact 3	13.9	BB pact 3	32.0	CHSE pact 3	48.3	pact C 3	11.7		
HDN pact 4	34.3	RR pact 4	8.4	BB pact 4	27.8	CHSE pact 4	101.5	pact C 4	78.2		
HDN pact 5	51.6	RR pact 5	45.8	BB pact 5	32.1	CHSE pact 5	39.0	pact C 5	37.0		
Mean	**61.4**	**Mean**	**30.8**	**Mean**	**35.3**	**Mean**	**47.0**	**Mean**	**31.2**		
HDN senrec 1	118.2	RR senrec 1	92.0	BB senrec 1	71.7	CHSE senrec 1	130.0	senrec C 1	63.7		
HDN senrec 2	52.6	RR senrec 2	115.3	BB senrec 2	126.4	CHSE senrec 2	101.1	senrec C 2	142.9		
HDN senrec 3	61.3	RR senrec 3	182.6	BB senrec 3	193.6	CHSE senrec 3	78.5	senrec C 3	71.2		
HDN senrec 4	87.5	RR senrec 4	150.4	BB senrec 4	96.6	CHSE senrec 4	126.2	senrec C 4	181.2		
HDN senrec 5	170.2	RR senrec 5	193.9	BB senrec 5	130.0	CHSE senrec 5	109.9	senrec C 5	100.4		
Mean	**98.0**	**Mean**	**146.8**	**Mean**	**123.7**	**Mean**	**109.1**	**Mean**	**112.0**		

Table 3.1.3.2: Fresh weight yield of tomatoes from 2nd truss (08/07/03)

	Weight		Weight		Weight		Weight		Weight		Weight
HDN ad 1	54.9	RR ad 1	38.8	BB ad 1	49.3	CHSE ad 1	6.2	ad C 1	36.6	Growbag 1	76.9
HDN ad 2	36.5	RR ad 2	48.0	BB ad 2	44.0	CHSE ad 2	31.4	ad C 2	0.0	Growbag 2	115.7
HDN ad 3	54.2	RR ad 3	20.2	BB ad 3	38.2	CHSE ad 3	68.5	ac C 3	5.2	Growbag 3	93.5
HDN ad 4	41.3	RR ad 4	40.2	BB ad 4	30.0	CHSE ad 4	17.5	ad C 4	32.7	Growbag 4	96.7
HDN ad 5	85.4	RR ad 5	50.5	BB ad 5	13.5	CHSE ad 5	62.9	ad C 5	3.8	Growbag 5	78.2
Mean	**54.5**	**Mean**	**39.5**	**Mean**	**35.0**	**Mean**	**37.3**	**Mean**	**15.7**	**Mean**	**92.2**
HDN fi 1	303.8	RR fi 1	17.7	BB fi 1	130.4	CHSE fi 1	193.5	fi C 1	93.5		
HDN fi 2	85.8	RR fi 2	93.3	BB fi 2	51.2	CHSE fi 2	147.5	fi C 2	224.4		
HDN fi 3	111.3	RR fi 3	92.4	BB fi 3	119.8	CHSE fi 3	246.5	fi C 3	128.8		
HDN fi 4	281.1	RR fi 4	89.3	BB fi 4	300.9	CHSE fi 4	109.4	fi C 4	263.6		
HDN fi 5	166.3	RR fi 5	148.6	BB fi 5	149.0	CHSE fi 5	54.3	fi C 5	231.7		
Mean	**189.7**	**Mean**	**88.3**	**Mean**	**150.3**	**Mean**	**150.2**	**Mean**	**188.4**		
HDN kc 1	16.2	RR kc 1	42.6	BB kc 1	20.7	CHSE kc 1	24.4	kc C 1	55.0		
HDN kc 2	50.2	RR kc 2	39.2	BB kc 2	19.9	CHSE kc 2	32.1	kc C 2	23.0		
HDN kc 3	44.0	RR kc 3	31.1	BB kc 3	52.2	CHSE kc 3	68.9	kc C 3	13.0		
HDN kc 4	38.8	RR kc 4	37.8	BB kc 4	21.7	CHSE kc 4	47.1	kc C 4	1.1		
HDN kc 5	68.8	RR kc 5	47.0	BB kc 5	73.1	CHSE kc 5	5.4	kc C 5	40.7		
Mean	**43.5**	**Mean**	**39.5**	**Mean**	**37.5**	**Mean**	**35.6**	**Mean**	**26.6**		
HDN pact 1	114.6	RR pact 1	23.5	BB pact 1	86.0	CHSE pact 1	37.4	pact C 1	23.8		
HDN pact 2	56.8	RR pact 2	25.6	BB pact 2	38.3	CHSE pact 2	52.2	pact C 2	54.6		
HDN pact 3	26.4	RR pact 3	38.1	BB pact 3	59.0	CHSE pact 3	37.9	pact C 3	0.0		
HDN pact 4	22.7	RR pact 4	23.8	BB pact 4	43.4	CHSE pact 4	10.2	pact C 4	31.4		
HDN pact 5	41.2	RR pact 5	88.8	BB pact 5	56.1	CHSE pact 5	28.9	pact C 5	52.1		
Mean	**52.3**	**Mean**	**40.0**	**Mean**	**56.6**	**Mean**	**33.3**	**Mean**	**32.4**		
HDN senrec 1	78.7	RR senrec 1	97.5	BB senrec 1	15.5	CHSE senrec 1	79.7	senrec C 1	105.7		
HDN senrec 2	62.6	RR senrec 2	193.2	BB senrec 2	186.2	CHSE senrec 2	65.3	senrec C 2	302.9		
HDN senrec 3	23.5	RR senrec 3	176.5	BB senrec 3	74.5	CHSE senrec 3	120.8	senrec C 3	147.0		
HDN senrec 4	103.2	RR senrec 4	46.9	BB senrec 4	116.1	CHSE senrec 4	144.2	senrec C 4	75.3		
HDN senrec 5	71.3	RR senrec 5	62.3	BB senrec 5	62.5	CHSE senrec 5	130.5	senrec C 5	60.9		
Mean	**67.9**	**Mean**	**115.3**	**Mean**	**90.9**	**Mean**	**108.1**	**Mean**	**138.0**		

Table 3.1.3.3: Fresh weight yield of tomatoes from 3rd truss (15/07/03)

	Weight		Weight		Weight		Weight		Weight		Weight
HDN ad 1	16.1	RR ad 1	13.2	BB ad 1	36.6	CHSE ad 1	45.1	ad C 1	20.9	Growbag 1	61.8
HDN ad 2	29.0	RR ad 2	75.7	BB ad 2	48.3	CHSE ad 2	27.3	ad C 2	15.2	Growbag 2	90.8
HDN ad 3	27.3	RR ad 3	15.4	BB ad 3	53.1	CHSE ad 3	51.4	ac C 3	9.6	Growbag 3	101.2
HDN ad 4	22.6	RR ad 4	18.2	BB ad 4	17.9	CHSE ad 4	32.6	ad C 4	24.6	Growbag 4	110.4
HDN ad 5	0.0	RR ad 5	46.6	BB ad 5	12.0	CHSE ad 5	40.5	ad C 5	6.6	Growbag 5	105.0
Mean	**19.0**	**Mean**	**33.8**	**Mean**	**33.6**	**Mean**	**39.4**	**Mean**	**15.4**	**Mean**	**93.8**
HDN fi 1	136.4	RR fi 1	148.9	BB fi 1	165.6	CHSE fi 1	188.6	fi C 1	121.4		
HDN fi 2	113.3	RR fi 2	139.4	BB fi 2	141.2	CHSE fi 2	265.5	fi C 2	69.4		
HDN fi 3	112.6	RR fi 3	163.5	BB fi 3	159.9	CHSE fi 3	138.4	fi C 3	137.5		
HDN fi 4	151.3	RR fi 4	129.0	BB fi 4	132.9	CHSE fi 4	94.7	fi C 4	110.9		
HDN fi 5	158.9	RR fi 5	111.5	BB fi 5	148.6	CHSE fi 5	114.3	fi C 5	56.0		
Mean	**134.5**	**Mean**	**138.5**	**Mean**	**149.6**	**Mean**	**160.3**	**Mean**	**99.0**		
HDN kc 1	4.2	RR kc 1	59.5	BB kc 1	8.1	CHSE kc 1	6.8	kc C 1	11.6		
HDN kc 2	0.6	RR kc 2	18.4	BB kc 2	19.6	CHSE kc 2	5.5	kc C 2	10.7		
HDN kc 3	43.1	RR kc 3	35.2	BB kc 3	44.6	CHSE kc 3	46.9	kc C 3	1.0		
HDN kc 4	8.1	RR kc 4	13.1	BB kc 4	6.5	CHSE kc 4	34.3	kc C 4	0.0		
HDN kc 5	32.0	RR kc 5	27.2	BB kc 5	42.2	CHSE kc 5	0.0	kc C 5	22.9		
Mean	**17.6**	**Mean**	**30.7**	**Mean**	**24.2**	**Mean**	**18.7**	**Mean**	**9.2**		
HDN pact 1	41.6	RR pact 1	62.9	BB pact 1	90.1	CHSE pact 1	37.7	pact C 1	22.2		
HDN pact 2	63.2	RR pact 2	33.1	BB pact 2	70.6	CHSE pact 2	41.5	pact C 2	43.6		
HDN pact 3	9.7	RR pact 3	19.8	BB pact 3	61.7	CHSE pact 3	30.0	pact C 3	0.0		
HDN pact 4	22.0	RR pact 4	22.2	BB pact 4	28.3	CHSE pact 4	6.2	pact C 4	26.5		
HDN pact 5	45.0	RR pact 5	76.6	BB pact 5	60.6	CHSE pact 5	24.1	pact C 5	107.5		
Mean	**36.3**	**Mean**	**42.9**	**Mean**	**62.3**	**Mean**	**27.9**	**Mean**	**40.0**		
HDN senrec 1	48.0	RR senrec 1	102.9	BB senrec 1	39.8	CHSE senrec 1	96.4	senrec C 1	56.5		
HDN senrec 2	73.8	RR senrec 2	83.1	BB senrec 2	109.7	CHSE senrec 2	63.8	senrec C 2	0.0		
HDN senrec 3	62.9	RR senrec 3	63.9	BB senrec 3	167.0	CHSE senrec 3	46.9	senrec C 3	72.2		
HDN senrec 4	107.8	RR senrec 4	41.3	BB senrec 4	75.9	CHSE senrec 4	82.0	senrec C 4	86.2		
HDN senrec 5	79.6	RR senrec 5	86.4	BB senrec 5	38.8	CHSE senrec 5	61.9	senrec C 5	79.7		
Mean	**74.4**	**Mean**	**75.5**	**Mean**	**86.2**	**Mean**	**70.2**	**Mean**	**58.9**		

Table 3.1.3.4: Fresh weight yield of tomatoes from 4th truss (22/07/03)

	Weight		Weight		Weight		Weight		Weight		Weight
HDN ad 1	48.8	RR ad 1	55.8	BB ad 1	40.4	CHSE ad 1	80.9	ad C 1	24.3	Growbag 1	64.2
HDN ad 2	26.6	RR ad 2	84.8	BB ad 2	67.8	CHSE ad 2	36.3	ad C 2	31.0	Growbag 2	76.4
HDN ad 3	64.4	RR ad 3	34.0	BB ad 3	75.2	CHSE ad 3	37.2	ac C 3	21.0	Growbag 3	75.9
HDN ad 4	27.2	RR ad 4	21.1	BB ad 4	23.1	CHSE ad 4	27.7	ad C 4	58.0	Growbag 4	50.3
HDN ad 5	45.4	RR ad 5	52.5	BB ad 5	25.2	CHSE ad 5	34.3	ad C 5	149.0	Growbag 5	82.0
Mean	**42.5**	**Mean**	**49.6**	**Mean**	**46.32**	**Mean**	**43.3**	**Mean**	**56.7**	**Mean**	**70.2**
HDN fi 1	165.8	RR fi 1	229.5	BB fi 1	142.2	CHSE fi 1	263.8	fi C 1	97.7		
HDN fi 2	134.8	RR fi 2	136.1	BB fi 2	97.8	CHSE fi 2	144.7	fi C 2	147.5		
HDN fi 3	81.4.	RR fi 3	178.4	BB fi 3	93.4	CHSE fi 3	140.4	fi C 3	115.4		
HDN fi 4	144.7	RR fi 4	152.7	BB fi 4	261.8	CHSE fi 4	158.8	fi C 4	102.2		
HDN fi 5	84.5	RR fi 5	100.0	BB fi 5	241.1	CHSE fi 5	101.0	fi C 5	73.6		
Mean	**122.2**	**Mean**	**159.3**	**Mean**	**167.3**	**Mean**	**161.7**	**Mean**	**107.3**		
HDN kc 1	11.6	RR kc 1	25.5	BB kc 1	6.3	CHSE kc 1	3.2	kc C 1	3.8		
HDN kc 2	15.9	RR kc 2	44.3	BB kc 2	29.6	CHSE kc 2	44.4	kc C 2	24.7		
HDN kc 3	54.7	RR kc 3	14.5	BB kc 3	61.4	CHSE kc 3	0.3	kc C 3	0.0		
HDN kc 4	4.2	RR kc 4	14.6	BB kc 4	3.6	CHSE kc 4	43.5	kc C 4	0.8		
HDN kc 5	53.2	RR kc 5	13.1	BB kc 5	45.4	CHSE kc 5	9.2	kc C 5	14.7		
Mean	**27.9**	**Mean**	**22.4**	**Mean**	**29.3**	**Mean**	**20.1**	**Mean**	**8.8**		
HDN pact 1	44.9	RR pact 1	47.1	BB pact 1	67.9	CHSE pact 1	20.4	pact C 1	0.0		
HDN pact 2	39.3	RR pact 2	34.1	BB pact 2	43.6	CHSE pact 2	5.7	pact C 2	49.7		
HDN pact 3	0.0	RR pact 3	4.9	BB pact 3	13.3	CHSE pact 3	42.6	pact C 3	0.0		
HDN pact 4	0.0	RR pact 4	0.0	BB pact 4	28.5	CHSE pact 4	5.0	pact C 4	37.3		
HDN pact 5	0.0	RR pact 5	6.1	BB pact 5	23.6	CHSE pact 5	6.4	pact C 5	70.9		
Mean	**16.8**	**Mean**	**18.4**	**Mean**	**35.4**	**Mean**	**16.0**	**Mean**	**31.6**		
HDN senrec 1	32.2	RR senrec 1	86.1	BB senrec 1	45.4	CHSE senrec 1	61.3	senrec C 1	45.5		
HDN senrec 2	87.5	RR senrec 2	49.3	BB senrec 2	75.3	CHSE senrec 2	29.0	senrec C 2	0.0		
HDN senrec 3	47.1	RR senrec 3	89.6	BB senrec 3	49.9	CHSE senrec 3	14.9	senrec C 3	81.2		
HDN senrec 4	69.7	RR senrec 4	69.4	BB senrec 4	44.3	CHSE senrec 4	45.9	senrec C 4	61.7		
HDN senrec 5	97.3	RR senrec 5	53.2	BB senrec 5	30.2	CHSE senrec 5	67.5	senrec C 5	56.1		
Mean	**66.8**	**Mean**	**69.5**	**Mean**	**49.0**	**Mean**	**43.7**	**Mean**	**48.9**		

Statistical results

Comparison of all treatments including controls and references

Table A6. S ANO A

Source	DF	SS	MS	Fexp	Fcrit	p	Significance
Compost	5	504503	100 01	47 74	2 2	0 000	SD
Rock fine	5	5205	10412	1 1	2 2	0 116	NS
Truss	3	71071	236 0	6 01	2 62	0 000	SD
Plant Number	12	14113 2	10 41	6 0	1 24	0 000	SD

Detailed significant one way ANOVA tests:

o O ANO A

```
                                         Individual 95% CIs For Mean
                                         Based on Pooled StDev
Level        N      Mean      StDev  --------+---------+---------+--------
AD          25     41.94      15.63    (--*--)
FI          25    188.32      83.82                         (--*--)
Grow bag     5    180.94      69.12                    (------*------)
GW          25     41.14      25.87    (--*--)
KC          25     31.63      19.30  (--*--)
SR          25    117.90      42.59               (--*--)
                                     --------+---------+---------+--------
Pooled StDev =     45.98                    60       120       180
```

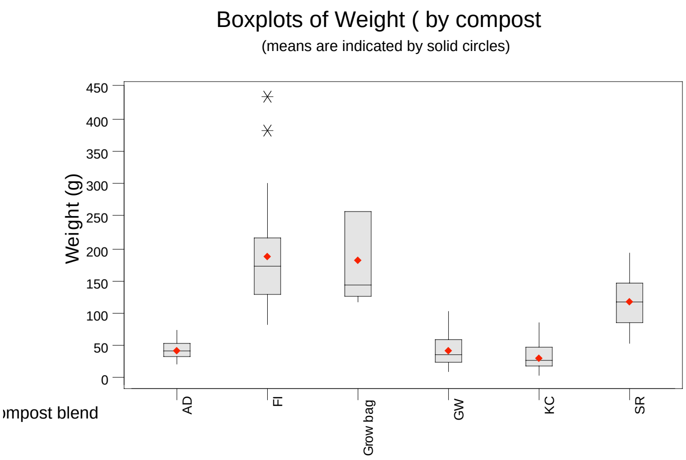


Figure A1. B W

- *One-way ANOVA: tomato weight versus rock fines*

Boxplots of Weight (by Rock ble

(means are indicated by solid circles)

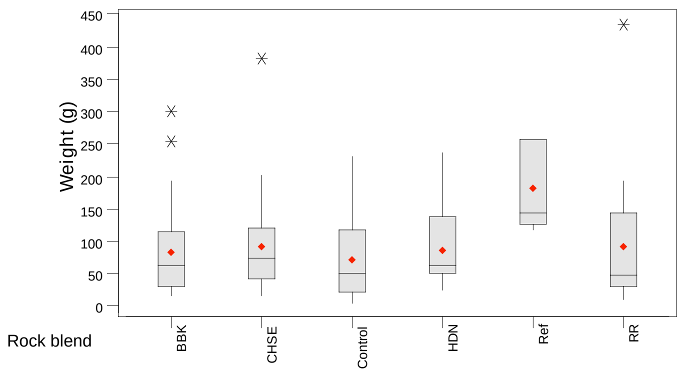


Figure A2. B

- *One-way ANOVA: tomato weight versus truss*

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level       N      Mean     StDev   --------+---------+---------+--------
1         130     87.91     77.09                      (-------*------)
2         130     75.34     66.21              (------*------)
3         130     61.23     50.19     (------*------)
4         130     58.89     54.08   (------*------)
                                    --------+---------+---------+--------
Pooled StDev =    62.79                    60        75        90
```

Boxplots of Weight (by Truss

(means are indicated by solid circles)

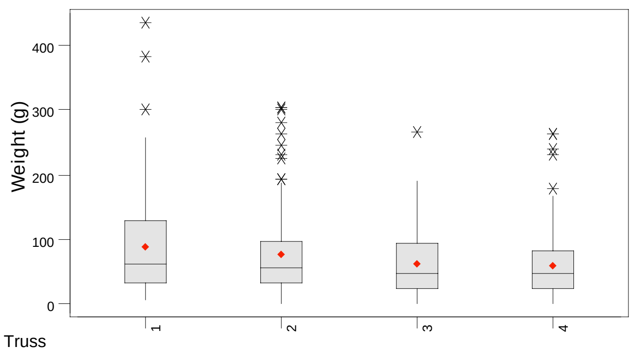


Figure A3. B

Comparison of blends only (no controls)

Table A7. S ANO A

Source	DF	SS	MS	Fexp	Fcrit	p	Significance
Compost	4	37553 2	3 4	122 04	2 46	0 000	SD
Sample number	1	3 14 65	2007 2	23 37	1 6	0 000	SD
Rock fine	3	2034	67	0 0	2 70	0 70	NS
Replicates	4	1 413	4603	0 5	2 46	0 710	NS

Detailed significant one way ANOVA tests:

- *One-way ANOVA: total weight versus compost blend*

```
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level      N     Mean     StDev  ------+---------+---------+---------+
AD        20   161.63     44.61    (-*-)
FI        20   638.28    139.94                        (-*-)
GW        20   153.20     67.35    (-*-)
KC        20   122.82     54.59  (-*-)
SR        20   348.78     96.83            (-*-)
                                 ------+---------+---------+---------+
Pooled StDev =    87.71               200       400       600       800
```

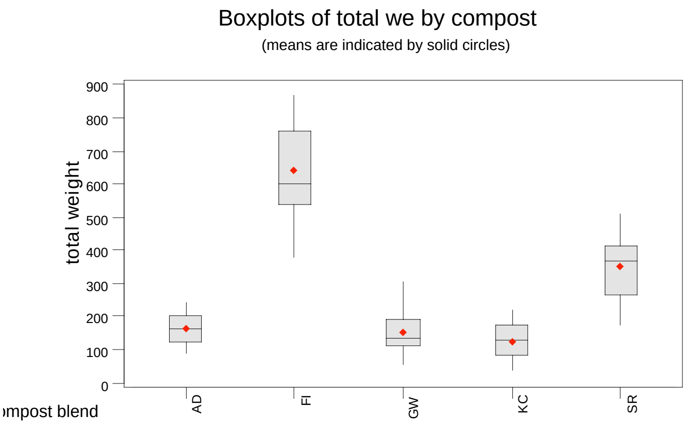


Figure A4. B

o *One-way ANOVA: total weight versus sample number*

```
                       Individual 95% CI
sample n        Mean   ---------+---------+---------+---------+--
 1               167      (---*---)
 2               307             (---*---)
 3               129    (---*----)
 4               630                             (----*---)
 5               166      (---*---)
 6               124    (---*---)
 7               125    (---*---)
 8               331              (----*---)
 9               161      (---*---)
10               678                                (---*---)
11               132    (----*---)
12               407                  (---*---)
13               126    (---*---)
14               597                            (---*---)
15               158      (---*---)
16               190       (---*----)
17               350               (---*----)
18               112   (----*---)
19               648                              (---*----)
20               162      (---*---)
                       ---------+---------+---------+---------+--
                              200       400       600       800
```

o *One-way ANOVA: total weight versus rock fines in blends*

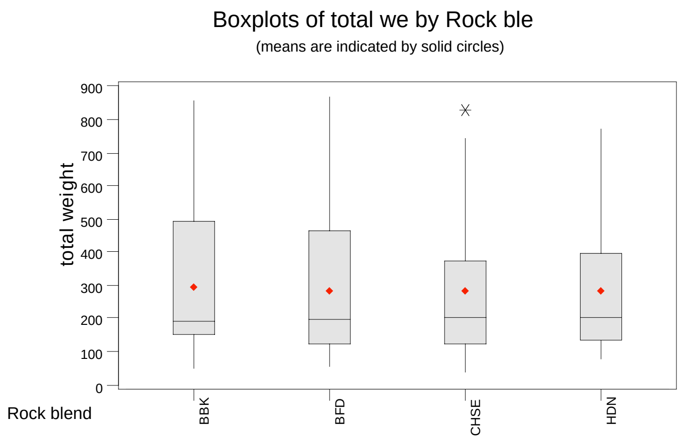


Figure A5. B

- *One-way ANOVA: total weight versus replicate*

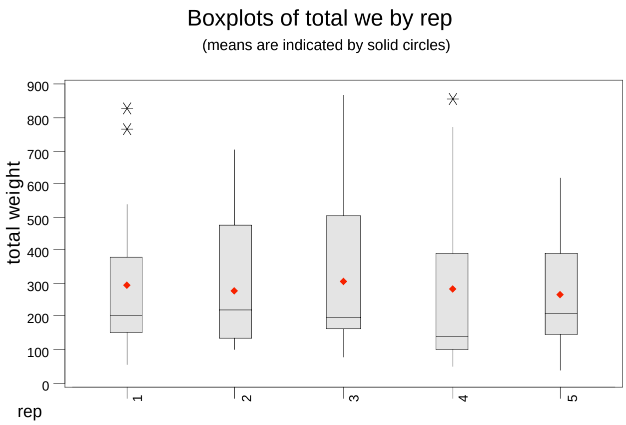


Figure A6. B

Comparison of control and reference treatments only

T

ANO A

T ANO A

Table A8. S ANO A

Source	DF	SS	MS	Fexp	Fcrit	P	Significance
Control	5	1002 14	2005 3	30	2 54	0 000	SD

Detailed significant one way ANOVA tests:

- *One-way ANOVA: total weight versus controls and reference*

```
                                          Individual 95% CIs For Mean
                                          Based on Pooled StDev
Level        N      Mean     StDev     -+---------+---------+---------+-----
AD           5    124.70     51.15         (--*---)
FI           5    555.10    101.05                              (---*--)
Grow bag     5    437.14     92.44                        (---*---)
GW           5    135.08    102.28         (---*--)
KC           5     58.60     41.06     (---*---)
SR           5    358.06     72.90                    (---*---)
                                       -+---------+---------+---------+-----
Pooled StDev =     80.45                0        200       400       600
```

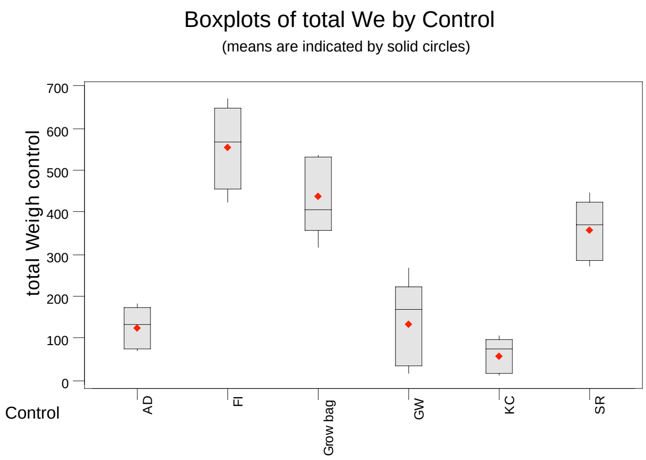

Boxplots of total We by Control
(means are indicated by solid circles)
total Weigh control
700
600
500
400
300
200
100
0
Control
AD
FI
Grow bag
GW
KC
SR

Figure A7. B

Appendix 3.1.4. Tomato taste panel data and statistics.

Table A9 C T

		Codes For Taste Panels
1	L	FI B1
2		FI B2
3		FI F
4	B	FI D1
5		FI CONTROL
6		GROWBAG GB
7		GW 2 B1
	E	GW 2 B2
		GW 2 F
10		GW 2 D1
11	A	GW 2 CONTROL

A	DATE
B	SESSION N BER
C	SE 1 ALE
	2 FE ALE
D	ANELLIST N BER
E	SA LE N BER AS ABO E
F	ICINESS
G	TENDERNESS T
	FR ITINESS FLA O R F
I	O ERALL ACCE TABILIT OA

Table A10. D T

Date	Sess. No.	Sex	Samp. No.	Juiciness	Tenderness	FruFlr	OvAccep
30 7 03	1	1	1	5	3	2	5
	1	1	2	4	5	1	3
	1	1	3	2	2	3	3
	1	1	4	6	3	5	5
	1	1	5	1	1	1	1
	1	1	6	5	4	2	1
30 7 03	1	1	5	5	6	5	6
	1	1	1	4	5	4	4
	1	1	6	5	5	6	6
	1	1	3	5	5	5	5
	1	1	2	5	5	5	5
	1	1	4	6	6	6	6
30 7 03	1	1	4	4	2	4	4
	1	1	6	6	4	5	5
	1	1	1	3	3	2	3
	1	1	5	5	4	4	5
	1	1	3	3	3	6	6
	1	1	2	6	5	4	4
30 7 03	1	1	2	5	6	3	5
	1	1	5	4	4	3	4
	1	1	4	4	3	2	3
	1	1	6	5	4	3	4
	1	1	1	5	5	2	3
	1	1	3	6	4	4	5
30 7 03	1	1	3	3	3	3	4
	1	1	4	4	4	4	5
	1	1	5	2	4	2	2
	1	1	2	2	5	1	2
	1	1	6	3	2	3	4
	1	1	1	1	3	1	2
30 7 03	1	1	6	4	2	2	3
	1	1	3	3	4	2	3
	1	1	2	6	3	3	4
	1	1	1	5	3	1	2
	1	1	4	6	3	3	5
	1	1	5	5	2	5	5
30 7 03	1	2	1	3	4	3	5
	1	2	2	5	5	4	5
	1	2	3	2	2	3	3
	1	2	4	2	3	3	2
	1	2	5	1	3	2	4
	1	2	6	2	2	4	2
30 7 03	1	2	4	3	5	2	3
	1	2	6	5	5	4	5
	1	2	1	3	5	1	2

Date	Sess. No.	Sex	Samp. No.	Juiciness	Tenderness	FruFlr	OvAccep
	1	2	5	5	6	2	3
	1	2	3	2	4	1	1
	1	2	2	6	4	3	4
30 7 03	1	2	5	5	5	3	4
	1	2	1	6	6	3	2
	1	2	6	5	5	5	5
	1	2	3	4	4	4	4
	1	2	2	6	5	4	3
	1	2	4	5	5	4	5
30 7 03	1	2	1	5	5	4	5
	1	2	2	6	5	5	3
	1	2	3	4	4	2	2
	1	2	4	6	5	5	3
	1	2	5	6	6	4	5
	1	2	6	5	6	5	3
30 7 03	1	2	2	5	6	5	5
	1	2	5	5	6	4	4
	1	2	4	6	6	5	3
	1	2	6	6	6	6	6
	1	2	1	4	5	2	2
	1	2	3	6	6	3	4
30 7 03	1	2	3	4	5	2	4
	1	2	4	5	5	1	3
	1	2	5	4	3	2	4
	1	2	2	5	5	3	5
	1	2	6	4	4	4	3
	1	2	1	5	6	1	2
30 7 03	2	1	11	3	3	3	3
	2	1	7	2	2	2	2
	2	1	8	2	2	3	3
	2	1	9	4	4	4	4
	2	1	10	3	4	2	4
30 7 03	2	1	8	3	2	2	3
	2	1	9	3	3	2	3
	2	1	10	5	3	2	2
	2	1	11	6	4	4	4
	2	1	7	6	4	4	5
30 7 03	2	1	11	4	6	3	5
	2	1	7	4	4	4	4
	2	1	8	4	5	4	6
	2	1	9	6	4	4	6
	2	1	10	3	3	5	3

Date	Sess. No.	Sex	Samp. No.	Juiciness	Tenderness	FruFlr	OvAccep
30 7 03	2	1	8	3	5	3	5
	2	1	9	5	6	5	5
	2	1	10	2	2	2	4
	2	1	11	5	5	5	3
	2	1	7	5	4	4	6
30 7 03	2	1	10	3	5	3	5
	2	1	11	5	6	2	4
	2	1	7	4	5	4	4
	2	1	8	4	5	3	4
	2	1	9	5	6	4	4
30 7 03	2	1	7	6	3	4	5
	2	1	8	6	3	4	5
	2	1	9	4	3	3	3
	2	1	10	5	4	5	4
	2	1	11	4	3	3	3
30 7 03	2	1	10	5	4	4	4
	2	1	11	6	5	5	5
	2	1	7	5	3	3	3
	2	1	8	3	2	4	2
	2	1	9	4	3	4	3
30 7 03	2	1	8	5	5	3	5
	2	1	9	4	5	3	5
	2	1	10	5	5	4	6
	2	1	11	4	5	3	5
	2	1	7	6	6	4	5
30 7 03	2	2	11	5	6	2	3
	2	2	7	6	6	2	3
	2	2	8	5	4	4	3
	2	2	9	5	4	3	3
	2	2	10	4	4	3	4
30 7 03	2	2	8	4	5	5	3
	2	2	9	6	6	4	4
	2	2	10	6	6	4	4
	2	2	11	4	3	4	4
	2	2	7	4	5	5	3
30 7 03	2	2	8	4	4	4	5
	2	2	9	4	3	4	3
	2	2	10	5	6	3	2
	2	2	11	4	1	4	1
	2	2	7	5	1	3	1
30 7 03	2	2	8	6	3	5	5
	2	2	9	5	4	4	5
	2	2	10	6	5	6	2
	2	2	11	5	3	3	2
	2	2	7	5	4	5	3

Date	Sess. No.	Sex	Samp. No.	Juiciness	Tenderness	FruFlr	OvAccep
30 7 03	2	2	7	5	5	5	3
	2	2	8	3	3	3	1
	2	2	9	5	5	5	5
	2	2	10	3	3	3	2
	2	2	11	3	3	3	2
30 7 03	2	2	7	6	6	3	4
	2	2	8	6	6	3	4
	2	2	9	5	4	4	4
	2	2	10	6	6	4	5
	2	2	11	6	6	3	4

APPENDIX 3.2. GRASS POT TRIALS

Appendix 3.2.1. Grass growth data and statistics

Dried grass growth data

	Daily dry grass cut 1				
Rock fines	Composts	Daily dry average (g)	STD	Average (mg)	STD
Control	Rivington	0 02	0 01	20 0	6 3
BASALT B1	SOIL	0 01	0 00	6 4	2 2
	KC	0 01	0 00		1
	AD	0 01	0 00	11 2	3 3
	GW 1	0 01	0 00	0	4 0
	GW 2	0 06	0 01	64 0	11 7
	FI	0 10	0 01	2	7
DOLERITE D2	SOIL	0 02	0 00	17 6	4 6
	KC	0 01	0 00	6 4	3 6
	AD	0 01	0 00	6	2 2
	GW 1	0 01	0 00	5 6	2 2
	GW 2	0 02	0 01	15 2	1
	FI	0 02	0 01	15 2	5 2
FELSITE F	SOIL	0 02	0 00	1 4	2 2
	KC	0 01	0 00	7 2	3 3
	AD	0 01	0 01	12 0	6
	GW 1	0 00	0 00	4 0	0 0
	GW 2	0 03	0 00	31 2	3 3
	FI	0 06	0 01	61 6	13 1
BASALT B2	SOIL	0 00	0 00	4	1
	KC	0 01	0 00	0	4
	AD	0 01	0 00	10 4	3 6
	GW 1	0 01	0 00	6 4	2 2
	GW 2	0 05	0 02	52 0	17 2
	FI	0 06	0 01	57 6	10

	Daily dry grass cut 2				
Rock fines	Composts	Daily dry average (g)	STD	Average (mg)	STD
Control	Rivington	0 02	0 01	21 2	7 0
BASALT B1	SOIL	0 00	0 00	3 4	1 1
	KC	0 03	0 01	34 1	5
	AD	0 07	0 02	66 6	24 6
	GW 1	0 02	0 01	1	7 3
	GW 2	0 0	0 02	0 4	20 1
	FI	0 1	0 03	1 3 3	31 3
DOLERITE D2	SOIL	0 02	0 01	1 2	7 7
	KC	0 04	0 01	3 2	0
	AD	0 05	0 02	45 2	15 3
	GW 1	0 02	0 01	24 7	6 5
	GW 2	0 17	0 01	173 3	13 0
	FI	0 23	0 04	22 5	35 5
FELSITE F	SOIL	0 01	0 00	10 2	2 7
	KC	0 03	0 01	31 6	1

	Daily dry grass cut 2				
Rock fines	**Composts**	**Daily dry average (g)**	**STD**	**Average (mg)**	**STD**
	AD	0 07	0 00	74 1	3 0
	GW 1	0 01	0 00	12 3	3 6
	GW 2	0 11	0 02	105 5	15 2
	FI	0 25	0 03	251 1	34 2
BASALT B2	**SOIL**	0 01	0 00	6 1	2 2
	KC	0 04	0 01	42 7	1
	AD	0 0	0 02	4 3	17 2
	GW 1	0 03	0 01	26	12
	GW 2	0 21	0 07	206 4	70 7
	FI	0 17	0 07	165	6

Statistics

- *Two-way ANOVA: dry grass versus Rock blend, compost blend*

```
Analysis of Variance for d grass
Source        DF        SS        MS        F        P
Rock ble       3    6.1691    2.0564    61.38    0.000
compost        4   27.7976    6.9494   207.44    0.000
Interaction   12    9.3544    0.7795    23.27    0.000
Error         80    2.6800    0.0335
Total         99   46.0011
```

- *One-way ANOVA: dry grass 2 versus Blend_1*

```
Analysis of Variance for dry gras
Source     DF        SS        MS        F        P
Blend_1     4   0.65360   0.16340    17.76    0.000
Error      20   0.18400   0.00920
Total      24   0.83760
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
Riv         5   0.50000   0.15811                         (----*-----)
Soil BBK    5   0.16000   0.05477     (-----*-----)
Soil BFD    5   0.44000   0.11402                     (-----*----)
Soil CHS    5   0.12000   0.04472   (-----*----)
Soil HDN    5   0.46000   0.05477                      (-----*----)
                                   ---------+---------+---------+-------
Pooled StDev =  0.09592                  0.16      0.32      0.48

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00722

Critical value = 4.23
```

```
Intervals for (column level mean) - (row level mean)

                   Riv       Soil BBK     Soil BFD     Soil CHS

Soil BBK      0.15855
              0.52145

Soil BFD     -0.12145     -0.46145
              0.24145     -0.09855

Soil CHS      0.19855     -0.14145      0.13855
              0.56145      0.22145      0.50145

Soil HDN     -0.14145     -0.48145     -0.20145     -0.52145
              0.22145     -0.11855      0.16145     -0.15855
```

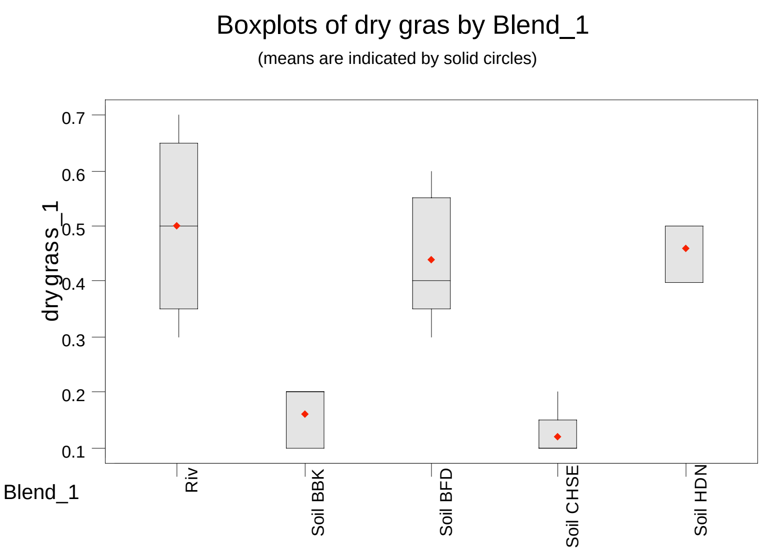


Figure A8. B 2 B 1

Appendix 3.2.2. Nutrient analysis data

Dried grass nutrient analysis

		Total (mg/kg)								
Rock fines	**Composts**	**N**	**P**	**K**	**Cu**	**Zn**	**Pb**	**Ni**	**Cd**	**Cr**
B1	**KC**	3 26	2 11	42740	5	241	0 21	0	0 05	0 2
	AD	2 31	3545	3 600	5	233	0 1	1 7	0 03	0 1
	GW 1	2 26	2 57	3 26	6 3	304	0 17	0 6	0 0	0 1
	GW 2	2 21	360	42511	6	1 3	0 14	0 5	0 07	0 1
	FI	1	2 4	272	7 3	105	0 36	0 3	0 0	0 1
D2	**KC**	2 3	3 76	50 54	3	406	0 0	2 2	0 05	0 1
	AD	2 17	3 47	3 564	7 4	1 4	0 13	0 5	0 07	0 1
	GW 1	2 07	3566	45435	7 5	27	0 13	1 1	0 06	0 1
	GW 2	2 27	3650	513 0	4	10	0 12	0 5	0 06	0 1
	FI	3 0	341	43404	13	1	0 21	0 5	0 05	0 1
F	**KC**	3 04	331	46555		176	0 2	0	0 04	0 2
	AD	2 41	433	4055	7	206	0 12	0 4	0 04	0 1
	GW 1	2 42	2742	44 03	6 6	133	0 64	1 4	0 1	0
	GW 2	2 15	3721	47542	7	5	0 26	0 3	0 04	0 1
	FI	2 35	4 4	27251	1	114	0 4	0 6	0 05	0 1
B2	**KC**	2 66	30 6	404	7 1	233	0 0	1 6	0 03	0 1
	AD	2 41	3 50	40366	2	1 2	0 0	2	0 03	0 1
	GW 1	2 35	3452	3 512	6 4	334	0 15	1 4	0 06	0 1
	GW 2	2 46	33 3	32063	4	113	0 41	1 2	0 06	0 2
	FI	2 1	3503	403 2	6	126	0 15	0 7	0 03	0 1

- ***Blends chemical analysis***

Rock fines		Basalt B1					Dolerite D2					Basalt B2					Felsite F				
Composts		**FI**	**AD**	**GW 1**	**GW 2**	**KC**	**FI**	**AD**	**GW1**	**GW 2**	**KC**	**FI**	**AD**	**GW 1**	**GW 2**	**KC**	**FI**	**AD**	**GW 1**	**GW 2**	**KC**
pH (1:6) pH units		6.82	7.22	7.37	7.22	7.58	7.84	7.86	7.8	7.76	7.92	7.17	7.8	7.8	7.53	7.92	6.69	7.31	7.81	7.64	7.83
Organic matter content % w/w		12.0	2.72	5.94	6.65	4.51	11.4	5.23	7.45	7.92	3.8	6.7	2.11	4.38	5.67	3.16	6.33	1.74	3.62	4.73	2.41
Dry Matter %		86.5	88.8	86.2	85.6	91	74.9	73	72.5	70.8	77.5	82.1	87.1	82.5	80.4	89.1	76	85.8	85.8	81.5	92.4
Cl (mg/kg)		27.2	26.8	24.5	36.1	30.2	25.2	58.8	68.1	72.8	43.8	23.5	25.6	23.4	34	17.9	25.4	24.7	15.1	26.5	12.5
C:N Ratio		9:1	14:1	17:1	11:1	12:1	10:1	19:1	15:1	15:1	20:1	7:1	11:1	14:1	12:1	17:1	9:1	4:1	19:1	13:1	14:1
Total (%w/w)	**N**	1.08	0.16	0.28	0.55	0.19	0.68	0.24	0.41	0.42	0.18	0.51	0.10	0.28	0.26	0.18	0.55	0.13	0.27	0.25	0.16
	C	10.2	2.26	4.58	6.1	2.3	6.93	4.55	6.35	6.09	3.58	3.63	1.15	3.86	3.07	3.04	4.67	0.56	5.16	3.31	2.35
	P	0.27	0.24	0.22	0.24	0.18	0.16	0.17	0.16	0.172	0.15	0.46	0.43	0.37	0.40	0.333	0.05	0.05	0.06	0.07	0.05
	K	0.18	0.23	0.22	0.23	0.20	0.09	0.12	0.15	0.18	0.13	0.04	0.06	0.10	0.13	0.10	0.08	0.09	0.10	0.10	0.10
	Mg	1.25	1.47	1.17	1.19	1.1	0.88	0.90	0.80	0.83	0.81	2.34	2.65	2.05	2.08	1.83	0.05	0.08	0.14	0.121	0.14
Available (water soluble) (mg/kg)	**P**	3.23	3.61	3.93	5.48	1.83	2.83	3.97	1.98	3.52	2.55	2.55	9.58	7.2	5.43	2.16	8	11.9	8.25	9.18	3.74
	K	15.5	48.8	159	198	57.2	10.3	71.6	275	346	142	6.62	25.1	89.3	183	42.5	12.5	24.3	86.6	160	37.9
Available CAT Extractable (mg/kg)	**Cu**	5.4	0.55	3.1	1.5	2	5.7	6.1	7.2	5.4	8.9	1.7	1.4	1.9	2.3	2.3	0.74	0.67	1.2	1.3	1.5
	Cd	0.05	0.05	0.38	0.12	0.15	0.05	0.05	0.27	0.09	0.09	0.05	0.05	0.26	0.06	0.08	0.05	0.05	0.26	0.06	0.09
	Cr	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.05	0.05
	Pb	18.1	5.2	13.5	10.8	10.9	6.4	2.8	6.9	5.8	4.8	11.1	1.4	6.1	6.5	5.7	15.4	3.8	7.7	7.6	6.4
	Hg	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Ni	0.21	0.2	0.5	0.37	0.52	0.92	1.3	1.7	1.2	1.8	1.6	1.4	1.1	1.3	1.2	0.08	0.11	0.25	0.24	0.3
	Zn	5.1	3.1	10.7	12	6.9	6.2	11.6	14.5	15	13.1	6.2	3.6	6.6	11	5	4	4.7	7.2	11.5	5.5

APPENDIX 3.3. LYSIMETERS

Appendix 3.3.1. Grass cuts and leachate data

- ***Grass cuts data***

Rock fines	Composts	CUT 1	CUT 2	CUT 3	CUT 4
Felsite F	**FI**	120	800	750	480
	AD	158	452	700	509
Dolerite D2	**FI**	66	644	450	479
	AD	59	198	575	600
Basalt B1	**FI**	134	614	450	362
	AD	85	219	775	474
Basalt B2	**FI**	0	853	675	441
	AD	61	187	600	499

cut 1 21/08/2003
cut 2 02/09/2003
cut 3 16/09/2003
cut 4 01/10/2003

- ***Leachate data***

  - *Ammonium data (mg/l)*

Rock fines	Composts	Month				
		August	**September**	**October**	**November**	**December**
Felsite F	**FI**	74	95	120	16	11
	AD	1.3	1.8	1.22	2.01	0.63
DoleriteD2	**FI**			8.45	5.19	1.65
	AD		1900	1600	1100	500
Basalt B1	**FI**	160	120	110	84	44
	AD	3600	510	80	0	64
Basalt B2	**FI**		1.4	7.29	1.57	0.31
	AD		300	150	0	130

  - *Nitrite data (mg/l)*

Rock fines	Composts	Month				
		August	**September**	**October**	**November**	**December**
Felsite F	**FI**	77	50	29	28	0.01
	AD	0.01	80	0.01	1100	0.01
Dolerite D2	**FI**			16	40	0.01
	AD		110	0.01	69	0.01
Basalt B1	**FI**	120	150	0.01	78	0.01
	AD	4800	0.01	6.6	3900	0.01
Basalt B2	**FI**		0.01	0.01	11	0.01
	AD		150	0.01	160	0.01

- *Nitrate data (mg/l)*

Rock fines	Composts	Month				
		August	September	October	November	December
Felsite F	**FI**	0.01	0.01	130	0.01	5200
	AD	0.01	0.01	2500	0.01	6540
Dolerite D2	**FI**			210	0.01	6100
	AD		0.01	1700	88	870
Basalt B1	**FI**	0.01	15000	1500	0.01	5400
	AD	2100	1200	2000	45000	650
Basalt B2	**FI**		0.01	3500	0.01	5400
	AD		220	340	480	640

- *pH (pH units)*

Rock fines	Composts	Month				
		August	September	October	November	December
Felsite F	**FI**			6.6	6.4	6.3
	AD			7.8	8.6	7.7
Dolerite D2	**FI**			6.8	7.4	6.9
	AD			7.5	8.3	8
Basalt B1	**FI**			6.7	6.7	6.2
	AD			7.7	8.6	7.8
Basalt B2	**FI**			6.9	6.4	7.1
	AD			7.8	8.5	7.8

Appendix 3.3.2. Abstract MSc Thesis, Bramwell (2003)

'Biogeochemical assessment of manufactured top soils created from composts and quarry fines for the purpose of quarry regeneration.'

Compost from food industry waste and another from green parks and garden waste were assessed for their potential as the organic matter for manufactured top soils for regeneration of four quarries in Northern England and Scotland. The rock fines from the quarries were the mineral content of the soils. Volcanic basalts, dolerite and an andesite felsite were tested. Leaching columns containing the soil mixtures had rainwater added in specific amounts as to mimic a wet summer. Soils and leachates were collected over a 2 month period and analysed for *E.coli*, Trytophan type fluorescence, pH, electrical conductivity, ammonium, nitrite, nitrate, chloride, sulphate, phosphate, lead, copper, zinc and potassium.

Results compared favourably with BSI PAS 100 manufactured top soil guidelines with autumn application advised to prevent high concentrations of nitrate, chloride and phosphate in surface run off. Salts appear to be raised to the soil surface by evaporation of soil water in between rainwater additions. Ammonium and nitrate concentrations in the soils display patterns indicating mineralization, oxidation and loss of nitrogen to the atmosphere. The soil component responsible for significant differences in analyte between soils and leachates were also investigated.

KEYWORDS
manufactured top soil, nitrogen transformation, soil water evaporation, compost, volcanic quarry fines, ground water contamination, eutrophication

Appendix 3.3.3. Infiltration data

Rock fines	Composts	Infiltration rate K (mm/s)
BASALT B1	AD	7.50
	FI	1.78
DOLERITE D2	AD	2.06
	FI	0.98
FELSITE F	AD	0.63
	FI	1.25
BASALT B2	AD	0.39
	FI	0.55

Appendix 3.3.4. Shear strength data

Rock fines	Composts	Average Shear strength 30/09/2003	STD	Average shear strength 19/12/2003	STD
BASALT B1	AD	18.55	3.19	19.15	4.21
	FI	22.38	3.04	16.52	2.22
DOLERITE D2	AD	6.82	0.82	8.74	1.07
	FI	8.50	1.38	7.66	1.64
FELSITE F	AD	9.70	0.72	10.17	1.40
	FI	11.85	1.85	10.73	1.23
BASALT B2	AD	11.13	0.46	9.82	0.74
	FI	9.22	1.06	7.98	1.07

Appendix 3.3.5. Bulk density data

Rock fines	*Composts*	*Bulk density average(g/cm^3)*	*STD*
BASALT B1	*AD*	*1.11*	*0.10*
	FI	*0.94*	*0.23*
DOLERITE D2	*AD*	*1.29*	*0.13*
	FI	*1.09*	*0.20*
FELSITE F	*AD*	*1.11*	*0.11*
	FI	*0.88*	*0.08*
BASALT B2	*AD*	*1.17*	*0.08*
	FI	*0.90*	*0.09*

Appendix 3.3.6. Water Holding Capacity (WHC) data

Rock fines	Composts	Average WHC (grams g)	STD
BASALT B1	**AD**	4.50	1.17
	FI	4.50	0.95
DOLERITE D2	**AD**	7.37	0.54
	FI	7.37	0.35
FELSITE F	**AD**	5.33	1.2
	FI	4.00	0.2
BASALT B2	**AD**	3.97	0.6
	FI	3.87	0.27