Forestry Trials of Compost & AD in Central Scotland

Greenoakhill (S) trial site March 2008

Year 5 growth at June 2013

Dalquhandy compost plot LP/SS Planting May 2009

450 tph Compost (year 7) October 2015

Summary

Experience gained through forestry reclamation trials in Central Scotland has shown that green compost and fibre anaerobic digestate organic amendments are likely significantly to improve the survival, health and growth of trees on reclaimed land, provided that key limiting factors are addressed.

Complete cultivation of the soil profile to relieve compaction is usually essential and will be required for mixing the amendment into the upper soil profile. Operations should, wherever possible, be carried out during drier weather. Particular care must be given to providing good drainage, without which tree performance will be severely limited on wetter sites such that the desired benefits of the treatment will not be achieved.

Improved soil conditions will also favour weeds, which are very likely to be vigorous, so it is important to allow for a robust protection and early maintenance specification including tree shelters and strimming in case of poor chemical weeding weather. Rushes can be a particular problem on wet, clay sites and may smother trees, especially softer species.

The optimum application rate of organic amendment will be influenced by site conditions and the chemical analysis of the amendment itself, which can be variable. In the case of green compost a rule of thumb would be around 200 tph (loose, wet sites) to 450 tph (firm, dry sites) fresh weight, but this will be at least a third less in the case of fibre anaerobic digestate.

An increase in application rate, even if possible within environmental constraints, will not result in improved growth beyond a limit for each site. Issues of physical weed competition and tree instability owing to excessive top-growth for the wind conditions will be exacerbated by higher application rates. It is recommended that soil and amendment analyses are carefully considered, together with drainage, exposure and species choice, to minimise the quantity of amendment used. This is because very rapid early growth can in fact be detrimental to the tree stand even in the establishment phase.

Successful reclamation of land to forestry involves the balancing a number of potentially complex interactions, so specialist advice is recommended.

This report is a basic summary of the trial conditions and main forestry growth and establishment results.

Full details of the analyses of the compost and AD used, soils and of the scientific appraisal of analysis and growth data generated, are given in the respective project reports listed in the References section, which also includes details of related reports on operational practice.

Using this report

In this report key statements are given in highlighted boxes:

Green: Information

Blue: Practice

Suggested action Warning Consider

Introduction

This report summarises the results of six forestry establishment trials planted between 2008 and 2011 on three sites in Central Scotland and then maintained and measured for two to five years until 2015. The trials were intended to reveal the effect of mixing organic amendment with soil forming materials on the growth of forest trees on disturbed sites. The sites were reclaimed from former industrial uses, with characteristics of 'brownfield' or 'vacant and derelict' land having **very poor 'soils'** with low nutrient status and little - or no - organic matter and soil structure (**Plate 1**).

Dalquhandy (Greenoakhill (S) is similar) **Addiewell**

Plate 1. Heavy clay (left) and Burned shale (right)

This operational research was supported by the Waste Resources Action Programme, Zero Waste Scotland, Forestry Commission Scotland and the Central Scotland Green Network.

The trials have largely be written up in full scientific reports as described in the References section, so this report is designed to collate and present a summary of the main issues for forestry practice.

Detailed operation guidance is available on the use of British Standard green compost in land reclamation for forestry which this report does not repeat[1]. The same *principles* apply to the use of fibre anaerobic digestate.

Organic amendments

The **organic amendments** tested were green compost, formed only from plant material excluding any other types of organic wastes, and anaerobic digestate (**Plate 2**). Both materials can be produced and certified according to British Standard specifications: PAS 100-Compost and PAS 110-Anaerobic Digestate and are also the subject of 'quality protocols'[2]. If PAS accredited and used according to best practice they are not classified as a waste and can be used without additional licensing.

Plate 2. Green compost (left) and Fibre AD (right), Addiewell January 2011

Anaerobic digestate and compost have quite different characteristics (**Figure 1**).

Note the potential for variation within sources of both AD and compost, which can have significant effects on quantities of nutrients and other important characteristics of the organic amendments when applied to a site.

[1] Wall, M., (2014). Using quality compost to reclaim land for forestry and biomass. Forestry Commission, Forest Research, Technical Development FCJR104

[2] See PAS 100 and PAS 110 and Quality Protocol references

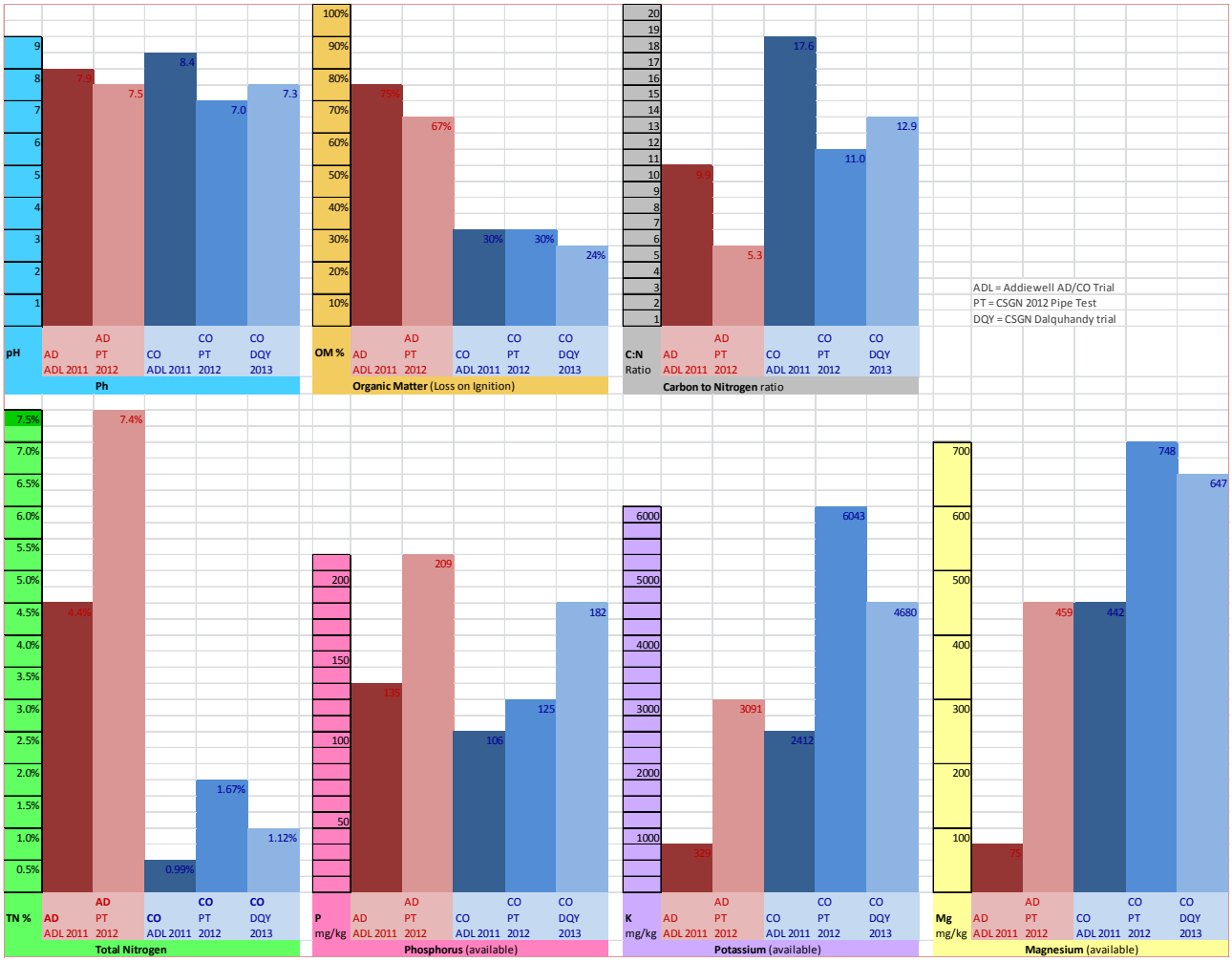


Figure 1. Analyses of Fibre AD and Green compost used 2011 to 2013

Anaerobic digestate (AD) is one of the products resulting from dewatering of the slurry left after digestion of food waste in the absence of air e.g. over 15 days at 35C. Carbon dioxide and methane gasses are also produced and the latter may be used to power engines for electricity production. The de-watered AD, known as 'fibre', may have the general appearance and consistency of compost, although characteristics vary depending on the process, plant and feedstock used. It should be noted that AD can initially have a very pungent and lingering odour, which needs to be considered when planning.

Anaerobic digestate has a very much higher concentration total nitrogen, particularly of the ammonium form of nitrogen, so less AD would be used than green compost for a given application rate of total nitrogen.

The ammonium nitrogen in AD is initially very mobile in the environment through loss to the atmosphere, leaching and oxidation. Thus anaerobic digestate releases a large quantity of ammonium nitrogen in the first few months after application, which can be taken up by plants both directly and in oxidised forms, but will also be dissipated into the environment.

Although high in readily available[3] organic matter, the high total nitrogen concentration limits the quantity that can be applied to avoid over-application. On a fresh weight basis anaerobic digestate tends to have much more total nitrogen and readily available organic matter, and more phosphorus, than **green compost**. Conversely, green compost may have more potassium and magnesium. Both amendments have high pH (alkalinity) and acceptable Carbon : Nitrogen ratios.

Green compost is the term used to describe compost that originates solely from composting vegetation such as tree and shrub residues. In contrast to AD, it has a low concentration of ammonium nitrogen and releases nitrogen by mineralisation of organic matter over time, which is mobilised and available to plants as nitrate nitrogen. Compost has a more 'slow release' effect than AD, yielding nitrate nitrogen for both uptake by plants and loss in water.

Objectives

The general objectives of the field trails were to:

1. Provide visual and data evidence of the effect of mixing organic amendment into poor quality soils during cultivation on tree establishment and early growth.
2. Indicate the range of amendment application rates that may be appropriate in differing conditions by comparing growth and other effects.
3. Investigate the use of PAS 100 green compost and PAS110 anaerobic digestate, separately and in combination at different application rates, using a range of conifer and broadleaved tree species appropriate to the sites.
4. Reveal practical issues that may promote or hinder successful forest tree establishment on the sites and to generate method and cost information where possible.

[3] Analyses refer to fine sieved material, so exclude large fragments of wood etc. and hence underestimate the total organic matter content of green compost.

The trials included comparisons of amendment treatments with others having no amendment added, but **all plots were cultivated to relieve compaction**, as this was a basic requirement of the sites.

Work method

The trials followed a standard format as follows:

- Complete cultivation by excavator to 1 m depth (**Plate 3**)
- Five or six ground treatments replicated three or four times on each site
- Treatments randomised within replications *(except the SRF trial)*
- Compost or anaerobic digestate sourced from local suppliers working towards, or having achieved, PAS quality certification and applied in accordance with regulations
- Organic amendment spread over the cultivated surface immediately following cultivation and mixed in by excavator bucket to c. 50 cm depth
- Method ensured that there was no re-compaction of cultivated plots by machine traffic
- Transplants or cell grown forest trees planted immediately following ground preparation in spring at regular square spacing and protected by 60 cm or 75 cm tube guards
- Trial areas fenced against deer and rabbits as required (all but one trial)
- Tree height measurement immediately after planting and again thereafter at the end of each growing season for the duration of up to five years
- Details of tree survival and growth, weeds and other impact factors were recorded at each measurement
- Weeding (mostly slashing) and staking carried out as required
- Trial reports completed for WRAP and Zero Waste Scotland funding partners including statistical data and resulting conclusions and recommendations.

Plate 3. Complete cultivation by excavator at Addiewell (left) and Dalquhandy (right)

This work involved the support and advice of specialists shown in the Acknowledgments section of this report.

Sites

Three sites were located across central Scotland (**Figure 2**), offering differing reclamation challenges but representing typical conditions in the region (**Table 1**).

Figure 2. Trial locations

Table 1. Site details

Location & i.d.	Funder	Amendment / *Substrate*	Conditions
Greenoakhill Landfill Site, Glasgow: 'GoH'	WRAP	Green compost / *1 of Clay loam pH 8.1 & 1 of Silty fine sand pH 8.3*	Altitude 30 m Rainfall 890 mm Exposure: Moderate
Dalquhandy former opencast coal site, South Lanarkshire: 'DQY'	WRAP, ZWS, FCS, CSGN	Green compost & anaerobic digestate / *Sandy clay loam with peat pH 4.8 - 5.0*	Altitude 230 m Rainfall 1250 mm Exposure: Severe
Addiewell former oil shale spoil bing, West Lothian: 'ADL'	WRAP, ZWS	Green compost & anaerobic digestate / *Oil shale pH 7.2 - 8.1*	Altitude 175 m Rainfall 1016 mm Exposure: Moderate

Note: CSGN - Central Scotland Green Network, FCS - Forestry Commission Scotland, WRAP - Waste Resources Action Programme, ZWS - Zero Waste Scotland

Trials

A total of six forestry field planting trials were established between 2008 and 2013 to investigate the effects of applying compost and AD **(Table 2)**, and were subsequently maintained and measured.

Table 2. Compost & AD field trials in Central Scotland

Site Year[a] / soil forming material	Site Type	Compost/AD[b] Quantity (fresh t/ha)	Nitrogen Added[c] (kg/ha)	Species
Greenoakhill N 2008 / Sandy	Landfill	Compost at 0, 300, 600 & 1200	2,500 - 10,000	Silver birch
Greenoakhill S 2008 / Clayey	Landfill	As above	As above	Silver birch
Dalquhandy 2009 / Clayey	xOCCS[d]	Compost at 0, 450 & 750	3,000 - 5,000	Silver birch, Lodgepole pine & Sitka spruce
Dalquhandy 2011 / Clayey	xOCCS	Compost, AD & both at 100 to 300	1,250 - 3,000	Silver birch
Addiewell 2011 / Shaley	Oil shale	As above	As above	Silver birch
Dalquhandy 2013 / Clayey	xOCCS	Compost at 340	1,600	Downy birch, Sitka spruce Willow[e], Common alder

Notes:
a. All sites planted in spring of year
b. CO - PAS100 green compost, AD - pPAS110 Anaerobic Digestate fibre
c. Estimated Total Nitrogen within compost / AD applied
d. 'xOCCS' = former Open Cast Coal Site, restored
e. *Salix dasyclados* Loden, *S. viminalis* Jorr, *S. viminalis* Thorhill as cuttings singled after 1 year, alternate rows

Experience showed that the factors which influence the characteristics of the organic amendment, and therefore the rate of application of nitrogen (or any other constituent) are variable. Therefore, in the absence of advance analysis, the prior estimation of application rate may sometimes only be made in general terms. The main influencing factors are:

- bulk density - linked to moisture content and degree of compaction: c 0.6-0.7 t/m^3 for fresh compost and 0.7-0.8 t/m^3 for AD used in the trials and
- % total nitrogen in laboratory samples: 1-1.7% and 4.7-7% for compost and AD respectively.

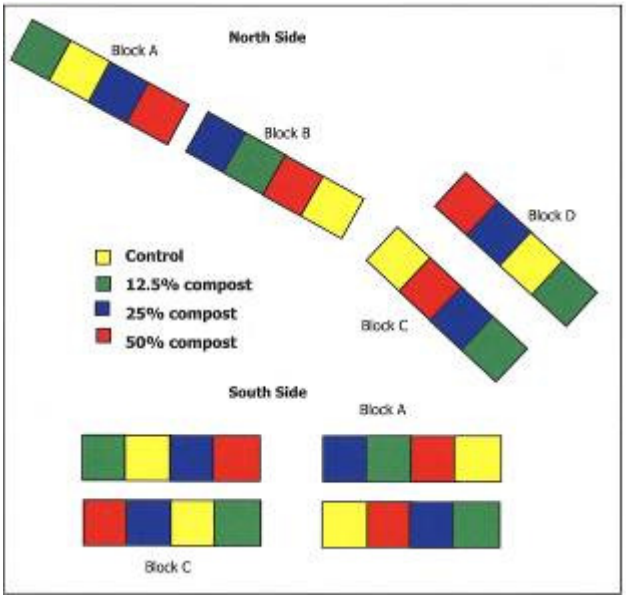
It should also be noted that the laboratory analysis figures exclude all material over 2 mm such as stones and larger fragments and so is not a direct representation of the whole compost.

The trials and their measurement results are described below and further details are at **Appendix 1**.

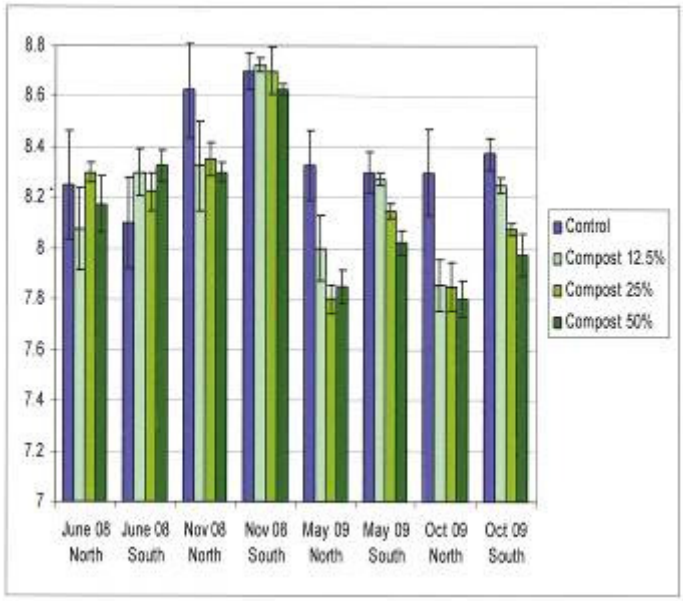
Greenoakhill compost trials 2008

The first trial, funded by the Waste Resources Action Programme and Forestry Commission Scotland, was carried out in spring 2008 at Patersons Quarries' Greenoakhill landfill site in Glasgow, using green compost (**Figure 3**). The two locations were on silty fine sand and clay loam substrates. The trials were of identical design, albeit that the plots were randomised separately, and were planted with Silver birch. The more exposed, clay loam plots, were provided with 60 cm tree tubes.

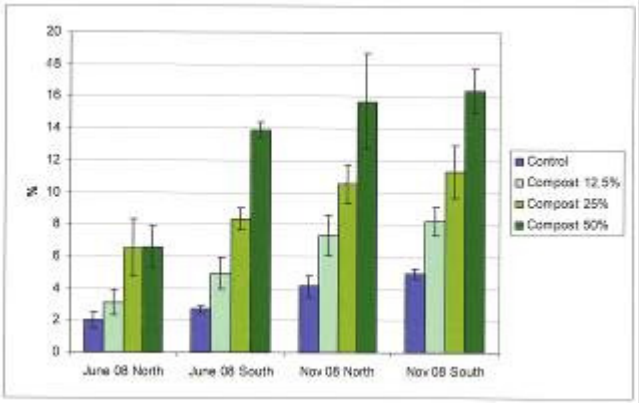
The Greenoakhill trials were intended to demonstrate the potential for planting at this site using compost, owing to plans for community woodland on the reclaimed land in the future.

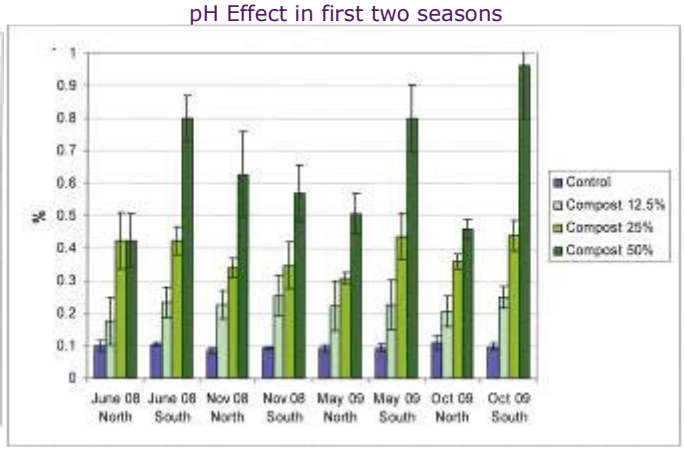


Layout: North (Sandy silt), South (Clay)



pH Effect in first two seasons





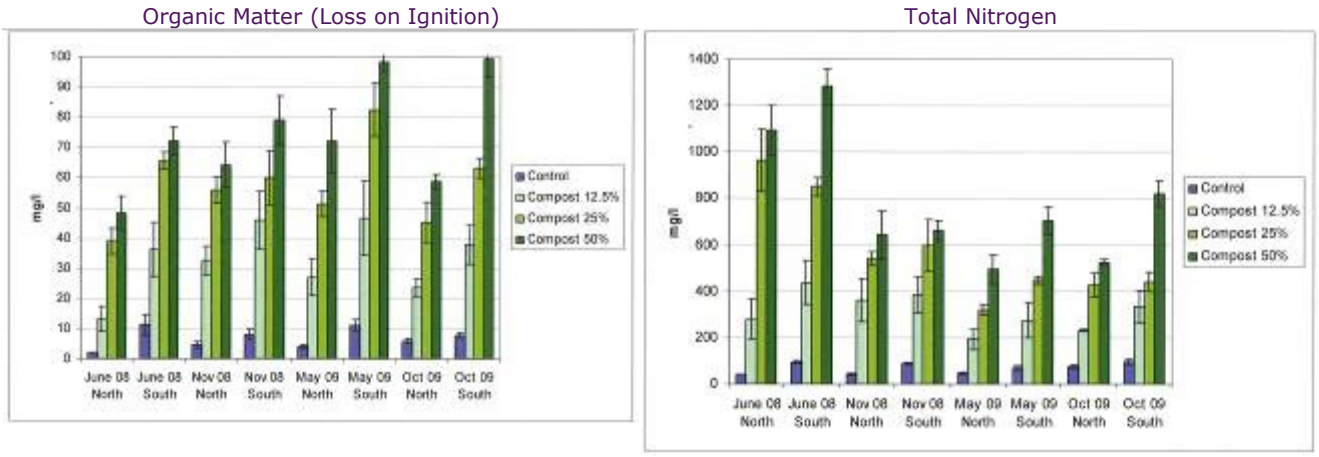


Figure 3. Greenoakhill trials layout and Year 2 results[4]

The **results** demonstrated the significant beneficial effects of mixing compost (into the upper 50 cm of soil profile) during cultivation on both soil types.

Soil **organic matter and major nutrients were all significantly increased** compared to the control (cultivation without compost). Organic matter and nitrogen, particularly, increased over the short term, probably owing to mineralisation of the compost.

The Silver birch crop growth reflected the improvement in soil properties (**Plate 4**).

May 2009 (after 1st season) September 2011 (4 seasons)

Plate 4. Greenoakhill south trial

[4] Figures from: Hipkin, A., (2010). The Greenoakhill Trailbalzer Project: the use of compost to manufacture top soils for brownfield regeneration with tree planting at the Greenoakhill Landfill Site, SE Glasgow. Waste Resources Action Programme.

The increase in application rate also increased growth up to somewhere between the '15%' and '25%' rates but **there was no improvement beyond that**, indicating that other limiting factors were involved.

Pioneer broadleaved weed growth was very significant, especially in the higher application rate plots and required urgent slash weeding in mid first season.

Dalquhandy compost trial 2009

The second trial was established in spring 2009 at the Scottish Coal Dalquhandy former opencast coal site, Coalburn, South Lanarkshire (**Figure 4 & Plate 5**).

The 2009 Dalquhandy trial was intended to investigate the effect of using compost on a wet and very exposed heavy clay site.

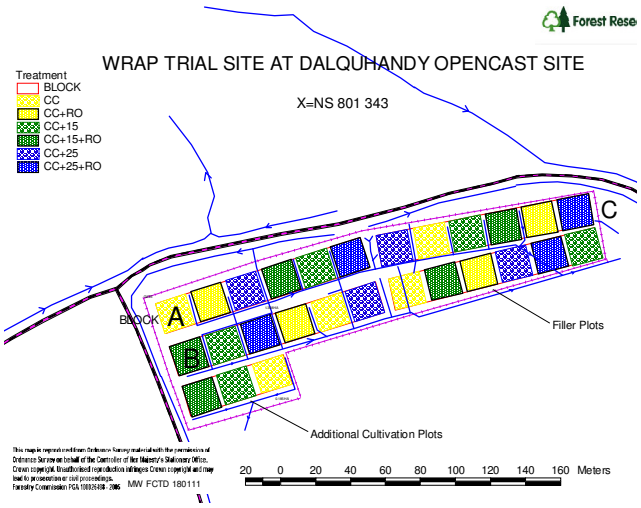


Figure 4. Trial layout

Plate 5. July 2015 (7th season)

An additional aim was to test improvement in survival, if any, which might result from extra cultivation to break up clay 'clods' more effectively, thereby creating a better tilth and improved early root contact with compost.

The additional cultivation was carried out by excavator bucket, intended to mimic 'rotovation'. Weather conditions were very challenging during both cultivation and planting, initially very wet and then, during the latter stages of planting, comprising harsh drying winds.

In spring 2010, an additional three plots known as 'Rep 5' were added, one without compost and two with '15%' compost. One of the compost plots was treated by intensive rotovation by a powered garden rotovator to test the effect of this high degree of surface cultivation in relatively benign and dry conditions.

Three replications of the 2009 trial were planted with an intimate 50/50 mix of Lodgepole pine and Sitka spruce forest transplants, and a fourth block of treatments was planted with bare root Silver birch. The Silver birch were provided with 60 cm tree tubes to ensure that they were visible for weeding and measurement through rush growth that rapidly emerged on the site. Trees that died within the first two years were beaten up (replaced) using Hybrid larch transplants, to avoid any possibility of confusion with the original 2009 plants.

The three 2010 plots were planted with an intimate 50/50 mix of Sitka spruce and Hybrid larch. No beating up was required owing to the excellent survival in these extra plots.

Site variability, attributed in part to varied presence of peat in the soil, reduced the degree to which statistically significant growth effects were evident. However, differences were becoming more pronounced after five years as tree growth started to accelerate during the later establishment phase.

Growth results for the first five seasons for Sitka spruce are shown in **Figure 5**.

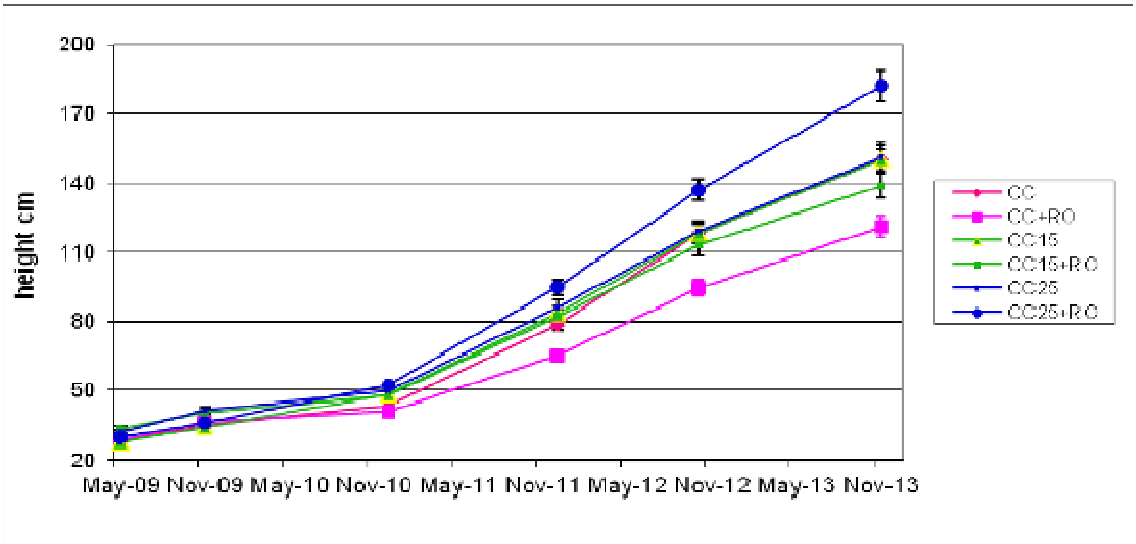


Figure 5. Dalquhandy 2009 compost trial growth after 5th season – Sitka spruce[5]

[5] From Hipkin, A., Salt, C. & Wall, M. (2014). Dalquhandy Compost Forestry Trial, 2009: Five year results, 2014. Zero Waste Scotland

- Growth of Sitka spruce in compost treatments was often significantly greater than in the cultivation-only treatments and appeared to increase further from 15% to 25%[6]. Silver birch also grew faster after five years but there was no clear difference between the 15% and 25% application rates. Similarly, growth of Larch was also improved by compost treatment.

Growth of Lodgepole pine did not appear to respond to addition of compost, over and above cultivation, which probably reflects the nitrogen fixing characteristic of this pioneer species.

June 2009 (after planting in May)

October 2015 (7th season)

Plate 6. Dalquhandy compost trial

Significant growth of rushes as well as Sitka spruce in Block B, Plot CC25RO (25% rotovated compost) in October 2012

Poor growth and nutrient deficiency in Sitka spruce in Block C, Plot CC (untreated control) in October 2012

Plate 7. Crop and weed growth responses

[6] The compost application rate was described on the basis of the notional volume of compost to be mixed into the upper 50 cm of the cultivated soil profile i.e. a 50% treatment would comprise equal proportions by volume of compost and receiving soil forming material in the completed mix.

The key silvicultural results from the trail were that compost will exacerbate **rush growth and wind instability** and that **effective drainage** from cultivated areas **is crucial**.

Combined Anaerobic digestate and compost trials 2011

The two trials, funded by the Waste Resources Action Programme and Forestry Commission Scotland, were located on a previously levelled area of a former oil shale spoil tip at Addiewell near Edinburgh in West Lothian (owned by West Lothian Recycling) and at the Dalquhandy former opencast coal site in South Lanarkshire (owned by Scottish Coal, and latterly by Hargreaves Quarries).

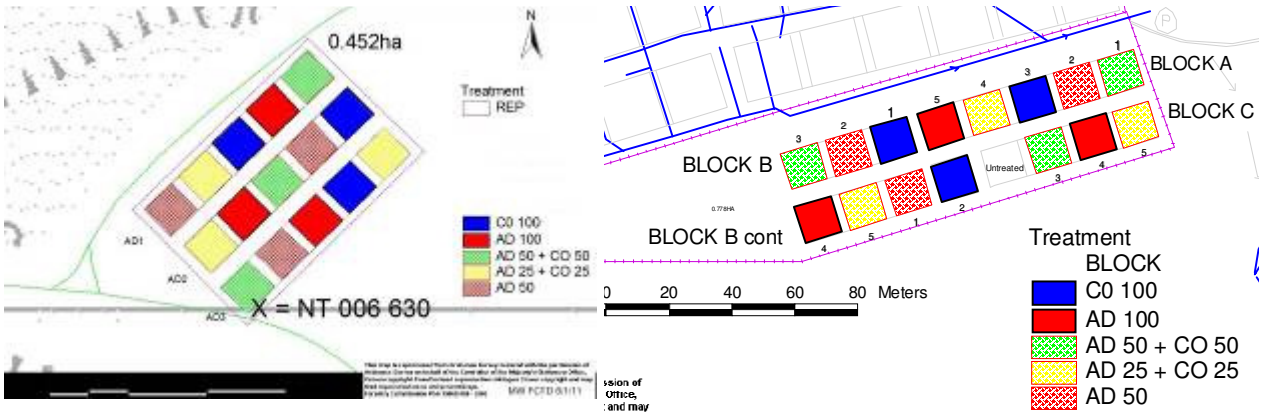
These trials, of almost identical design, were intended to reveal the effect of using anaerobic digestate (AD) as an alternative to, and in combination with, green compost.

The conditions on these two sites were very different (**Plate 8**):

Plate 8. Addiewell (left) and Dalquhandy (right) in January 2011

- **Addiewell** - platy and fine fragments of red and black shale
- **Dalquhandy** - 'clods' of heavy clay with rock and peat.

The trials were of similar design (**Figure 6**), planted with cell grown Silver birch and were protected by 60 cm tree tubes to ensure that they were visible for weeding and measurement through broadleaved weed growth that rapidly emerged on the sites. A 'DoT Verge' grass seed mix was sown after planting on both sites to promote relatively manageable grass growth for competition with aggressive broadleaved and rush weeds encountered on the oil shale and clay respectively.



Addiewell Dalquhandy

Figure 6. 2011 Fibre anaerobic digestate / green compost trial layouts

The Dalquhandy trial made use of free space for an extra un-replicated treatment plot comprising cultivation only, with no organic amendment added. This 'control' plot proved to be a very useful demonstration of the benefit of applying amendments.

The trials were designed to compare AD and green compost on the basis of the application rate of total nitrogen in the amendments e.g. an equivalent contribution of **c 3,000 Kg / ha total nitrogen** from compost compared to the same contribution from AD.

The tonnage of anaerobic digestate applied was lower than that of compost because of its greater total nitrogen concentration.

Both trails were measured for the first two seasons and funding was then provided by FC Scotland for measurement after five years. Unfortunately, the Addiewell trial was badly affected by a spring grass fire which prevented meaningful measurement results, although the Dalquhandy trial five-year results were obtained.

Growth results did not show significant differences between the various AD and compost treatments, even after five years at Dalquhandy. Growth in the first year was good but reduced markedly in the second year, although still very much better than the single 'untreated' plot at Dalquhandy, illustrating the advantage of adding compost or AD (**Plate 9** and **Figure 7**).

Addiewell Rep 1 | Dalquhandy Rep 1 | Dalquhandy control

Plate 9. AD 50%/CO 50% plots (100 tph/150 tph) & untreated 'control', October 2015

Addiewell after Season 2 (2012

Dalquhandy after season 2 (2012)

Not measured owing to grass fire damage

Dalquhandy after season 5 (2015)

Figure 7. 2011 AD / Compost trial growth

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