# 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

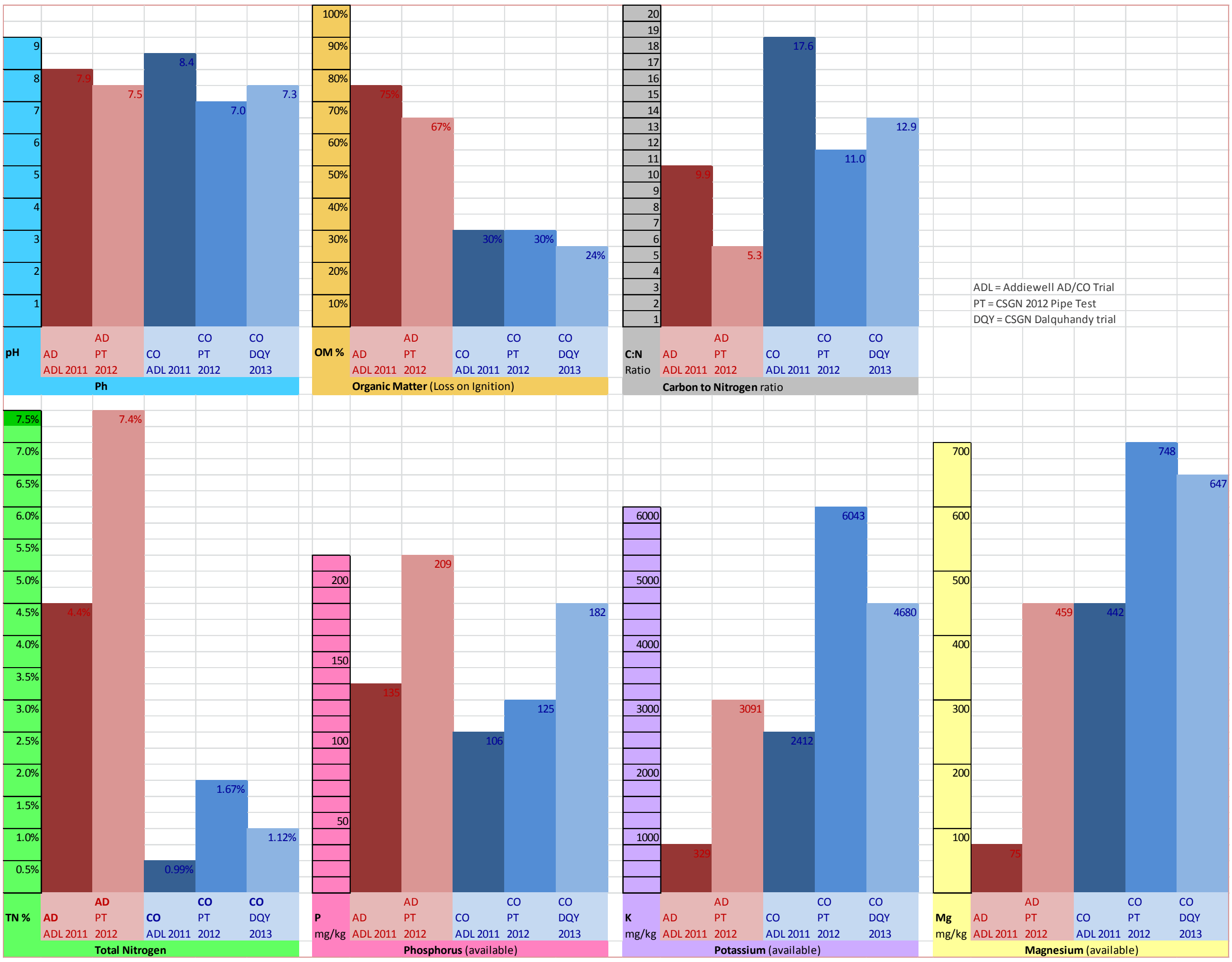


**Figure 1.** Analyses of Fibre AD and Green compost used 2011 to 2013

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

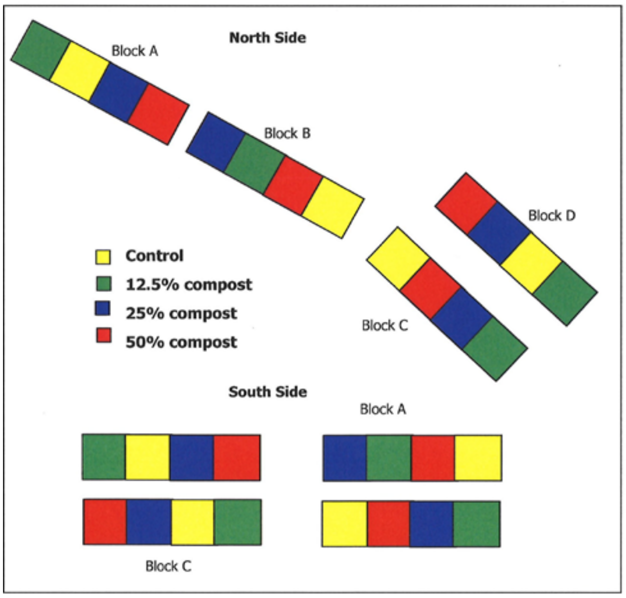
It should also be noted that the laboratory analysis figures exclude all material over 2 mm such as stones and larger fragments and so is not a direct representation of the whole compost.

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

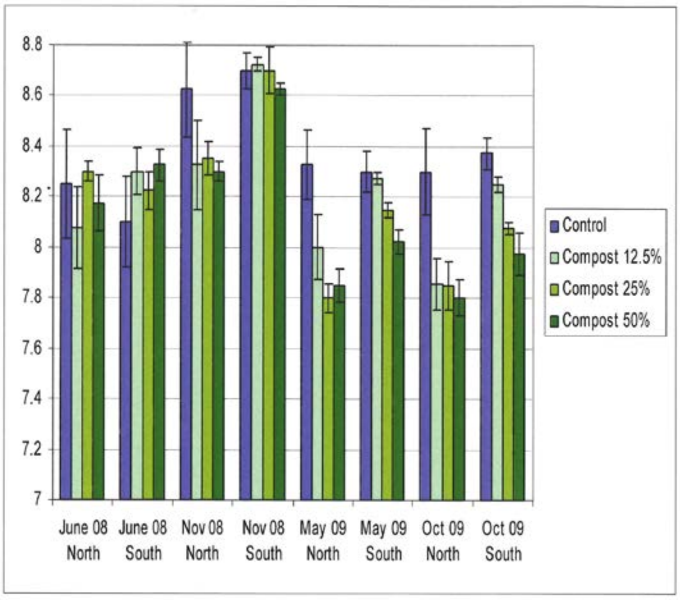
## Greenoakhill compost trials 2008

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.

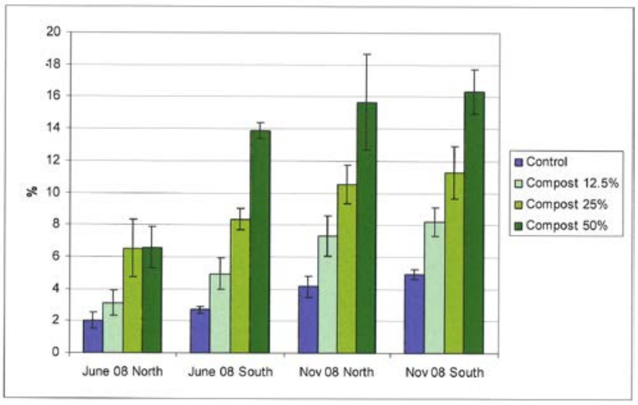
> The Greenoakhill trials were intended to demonstrate the potential for planting at this site using compost, owing to plans for community woodland on the reclaimed land in the future.

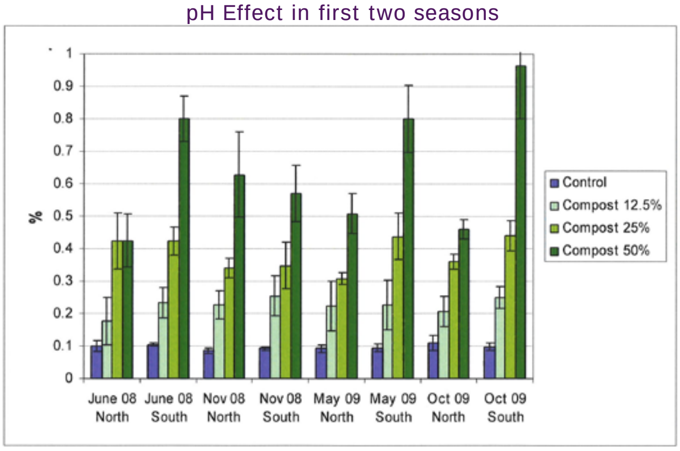



Layout: North (Sandy silt), South (Clay)

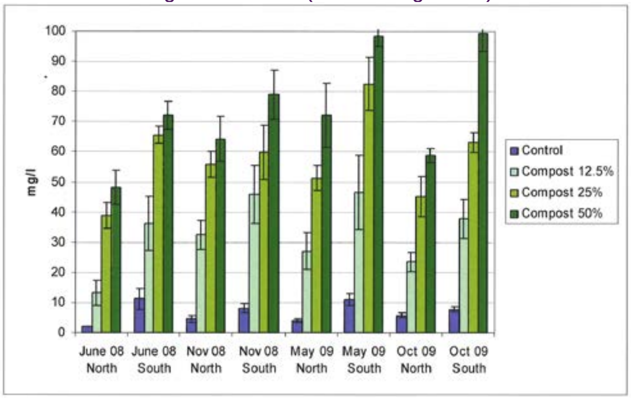



pH Effect in first two seasons

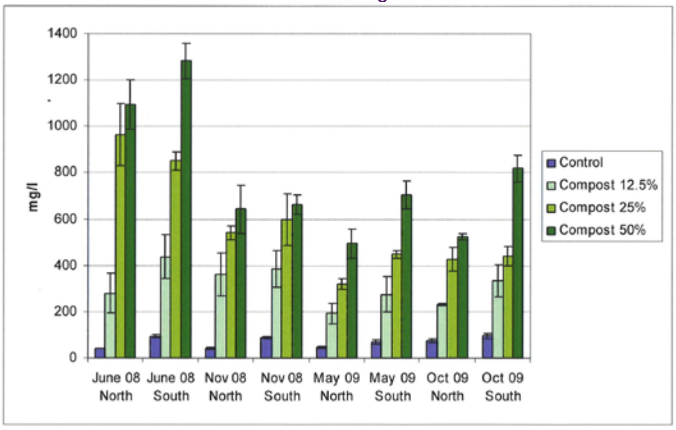


Organic Matter (Loss on Ignition)




Total Nitrogen




Phosphorus (available)

Potassium (available)

**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.

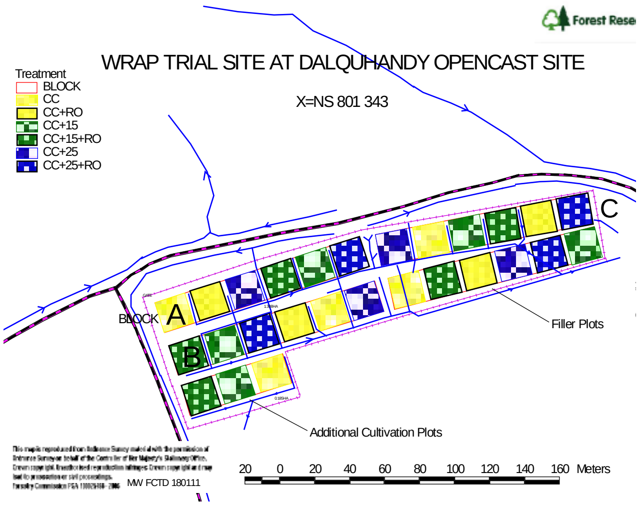



**Figure 4.** Trial layout

**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**.

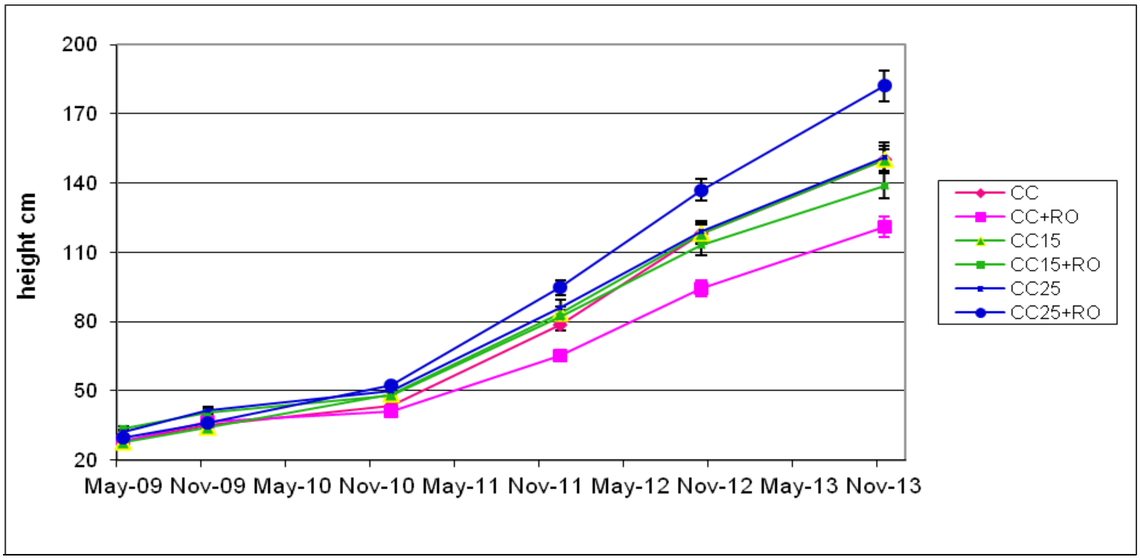



**Figure 5.** Dalquhandy 2009 compost trial growth after 5th season – Sitka spruce[5]

[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

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[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).

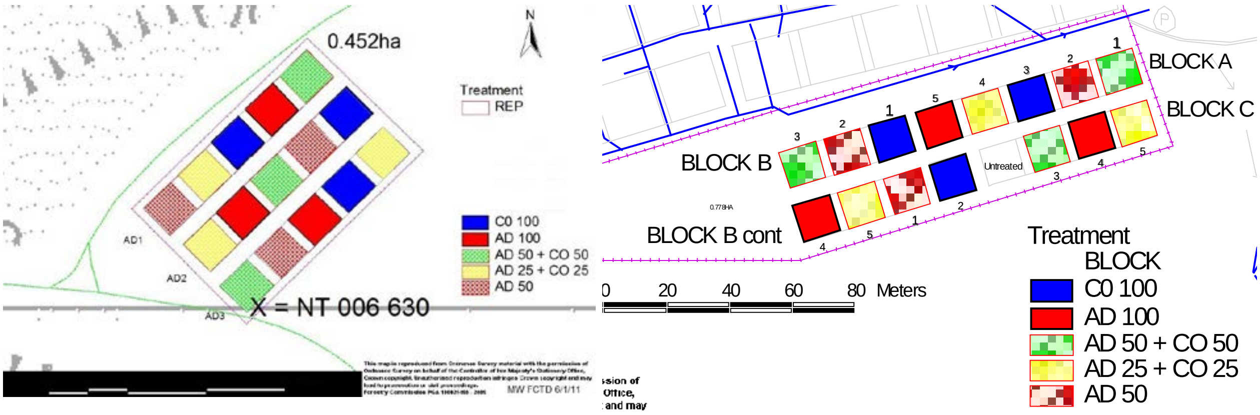
These trials, of almost identical design, were intended to reveal the effect of using anaerobic digestate (AD) as an alternative to, and in combination with, green compost.

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.

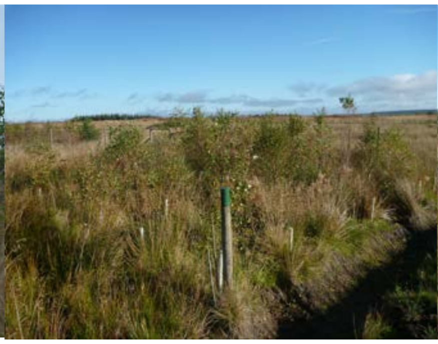
> The trials were designed to compare AD and green compost on the basis of the application rate of total nitrogen in the amendments e.g. an equivalent contribution of **c 3,000 Kg / ha total nitrogen** from compost compared to the same contribution from AD.

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**).

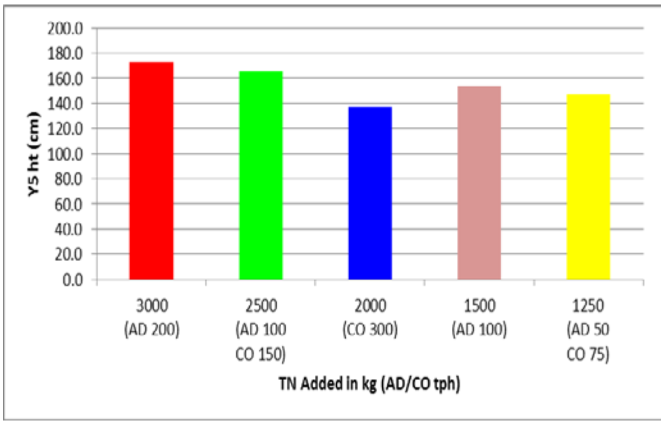
Addiewell Rep 1



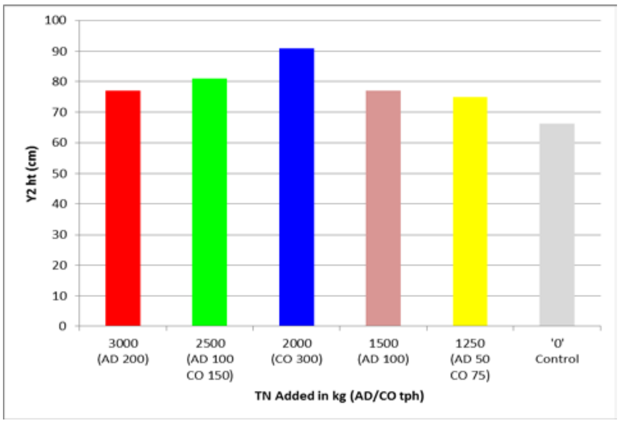
Dalquhandy Rep 1

Dalquhandy control

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

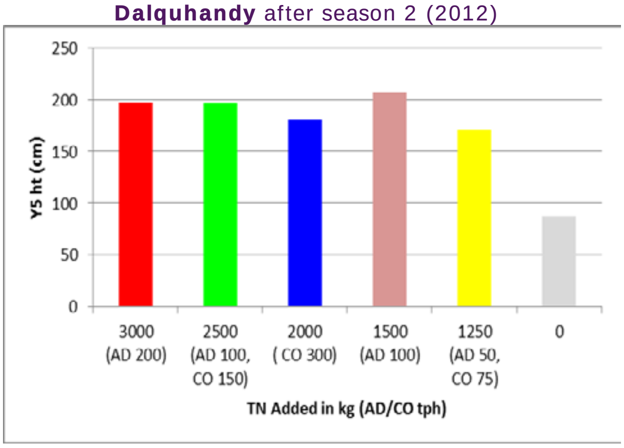



**Addiewell** after Season 2 (2012




**Dalquhandy** after season 2 (2012)

**Not measured owing to grass fire damage**

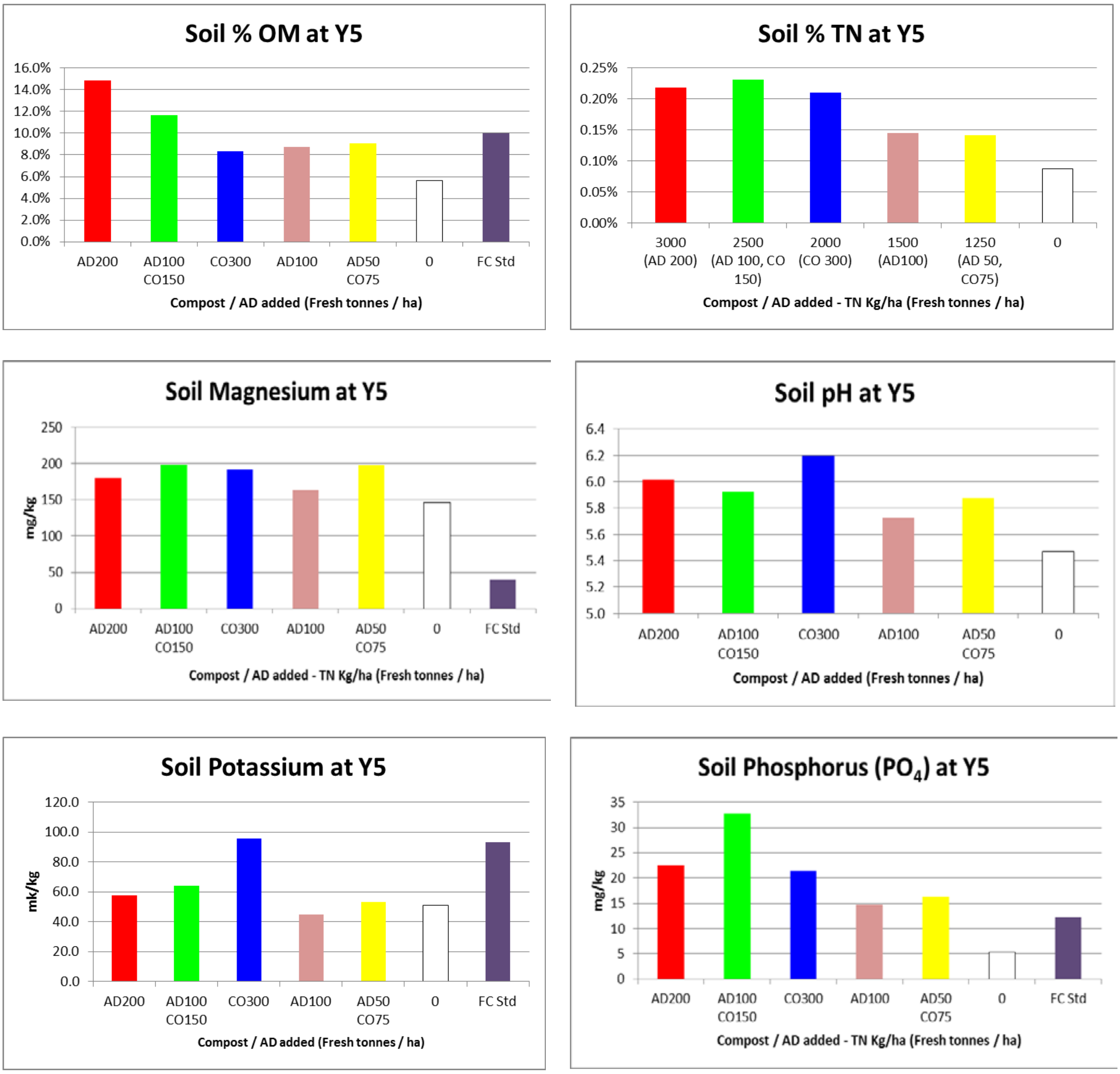



**Dalquhandy** after season 5 (2015)

**Figure 7.** 2011 AD / Compost trial growth

Soil analyses after five years showed that **treatments had improved the main soil characteristics**.

Organic Matter, Total nitrogen, pH and major nutrients were all improved compared to the pre-treatment soils (shown as '0') by some or all treatments. Details for Dalquhandy are shown in **Figure 8**, together with FC minimum standards where applicable.




Note: OM – Organic Matter, TN – Total nitrogen

**Figure 8.** Dalquhandy 2011 AD / compost trial soil results at Y5

Owing to the exceptionally wet conditions at Dalquhandy, additional drainage was installed in early 2015, comprising drainage 'taps' into open 'V' drains, which proved very effective and are now expected to release additional growth potential (**Plate 10**):

July 2015

Drainage tap, September 2015

**Plate 10.** Additional drainage at Dalquhandy

Soil sampling showed the notable apparent improvement in soil structure, with amendment treatments resulting in a looser structure with better aeration and root penetration (**Plate 11** for Dalquhandy). Soil structure was similarly improved at Addiewell.


Soil with no amendment treatment from the 'control'


Soil / AD at 200 tph ('AD100%')

**Plate 11.** Soil development, from no treatment 'control' to 200 tph AD at Dalquhandy in October 2015

Growth at Addiewell was around twice that of Dalquhandy after the second season, and after five seasons was still significantly greater (**Plate 12**). This was attributed largely to the much drier conditions at Addiewell:

Addiewell: Rep 1 Plot 1 (October 2015)

Dalquhandy: Rep 1 Plot 1 (September 2015)

**Plate 12.** AD 100 / CO 150 tph at Year 5

## Compost and 'short rotation forestry' trial, spring 2013

The trial utilised experience gained in respect of intensive drainage, individual tree protection and grass seeding.

> This trial was conceived as a demonstration of the potential for using a compost application rate matched to site for growing a close spaced tree crop for short rotation biomass production.

Two methods of cultivation by excavator were used in each plot (**Figure 11**):

- **Complete inversion** results in the surface being buried during cultivation and is suitable for sites where there is little or no benefit in retaining the original profile at the surface.
- **Partial inversion**, in contrast, is a two stage process in which the ground surface is retained in the upper half of the cultivated profile: this can be slower but may be worthwhile if upper soil layer is clearly better.

These methods were the subject of work / time study to provide operation productivity and cost information (reported separately[7]).

[7] Saunders, C.J. & Wall, M. (2014). Dalquhandy former opencast compost cultivation trials. Technical Development Report TDJR110. Forestry Commission, Forest Research.

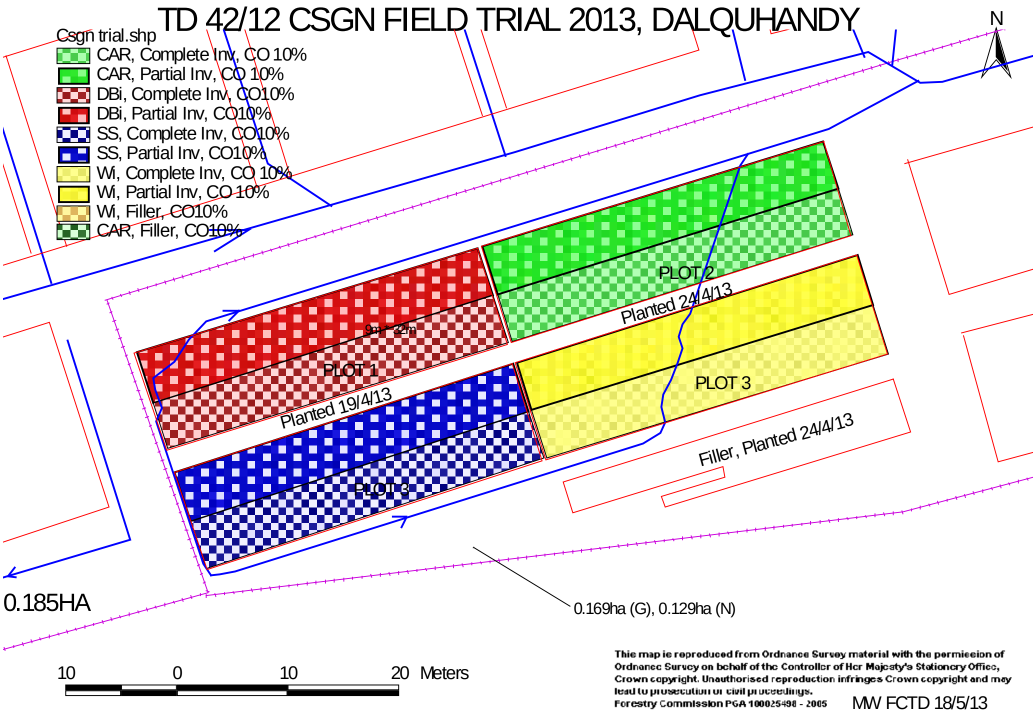



**Figure 11.** Dalquhandy compost and SRF trial layout

Results after three seasons of growth show that Partial inversion provides a slight increase in growth on this site, except for Sitka spruce (**Figure 12**).

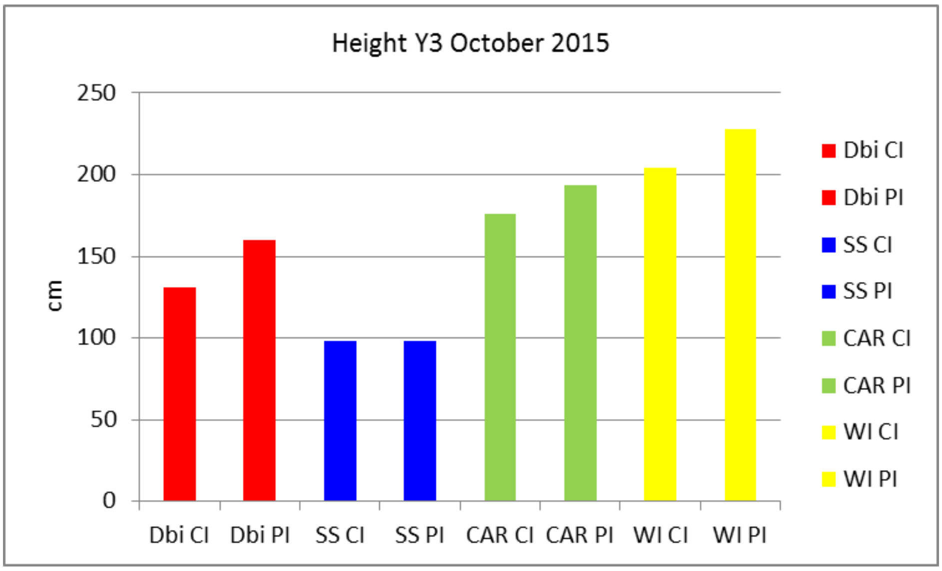



**Figure 12.** Dalquhandy compost and SRF trial result at Y3

Height growth and health of all species was good after three seasons, with all species performing well (**Plate 13**).

After only three seasons height growth alone is not likely to be a true reflection of the potential for SRF biomass production, where volume production is the crucial result. The greater height growth of single stemmed willow may not provide the greatest overall biomass production in the longer term.

**3rd season**, Willow & Common alder

**3rd season**, Downy birch & Sitka spruce

**Plate 13.** Compost SRF trial 3 season's growth at October 2015

It is **recommended** that the Compost / SRF trial at Dalquhandy is maintained and **measured for at least five years** to yield volume production results.

# Conclusions

Planning, implementation and analysis of the suite of forestry field trails have provided an invaluable opportunity to improve understanding of the practice of using green compost and anaerobic digestate for reclamation to forestry in Central Scotland. The main issues identified and lessons learned are summarised here (and the main conclusions from the individual trial reports are given in **Appendix 2**).

- Prior to reclamation, the concentrations of major plant nutrients – nitrogen, phosphorus and potassium - in the site soil-forming materials were frequently well below the minimum standards.

- Application of amendments during cultivation, even at 15% by volume, raised nutrient levels well above the minimum standards.

- Use of organic amendments in land reclamation can potentially alleviate the impact of the main constraints of soil forming materials for woodland establishment, in particular low organic matter content and deficiency in major nutrients.

- Cultivation with amendments will mitigate compaction, which is often the single greatest constraint on tree growth on restoration sites.

- The optimum application rate of organic amendment will be influenced by a combination of initial tree growth response, potential environmental constraints and financial considerations.

- The 'optimum' application rate will:

⚠ Enable prolonged and healthy growth of trees that can compete with weeds unaided within 5 years ('establishment'), using the minimum quantity of amendment

⚠ Avoid excessive weed competition and early tree growth (which causes stem bending and tree toppling) and associated tree deaths

⚠ Avoid pollution of the water environment, particularly with nitrate and phosphate, which can lead to eutrophication of water bodies.

- In general, a higher application rate will be suitable for firmer and drier soils, reflecting better stability and utilisation of nutrients and organic matter in aerobic conditions. In wet, anaerobic conditions, applications beyond the optimum will provide no growth benefit, but may contribute to pollution risk over time.

- An organic amendment’s nitrogen content will limit its application rate.

- Higher nitrogen applications should generally be avoided because they may reduce the stability of faster growing tree species and are likely to stimulate excessive weed growth.

- AD fibre provides up to twice the total nitrogen of compost on a fresh weight basis (more if dry weight) but the amount that can be applied to increase organic matter is restricted by its high potential to rapidly loose soluble nitrogen – with a consequent potential for pollution.

- Compost provides proportionally more organic matter than AD fibre and a lower amount of slow release nitrogen having longer-lasting effect.

- Soil wetness reduces tree growth on all treatments for the conditions studied. Addition of organic amendments to wet sites at higher rates could have negative impacts on soil function and may not improve tree growth. Adequate drainage on wet sites is essential to reduce negative effects and increase the tree performance benefit of organic amendments.

- Compost incorporation reduced compaction (bulk density) of the soil and its re-compaction after cultivation.

- The beneficial effects of organic amendment addition in increasing pH value and plant nutrient levels were still significant after 5 growing seasons.

# Recommendations

## Reclamation

The key points to note from the field trials when reclaiming land for forestry using green compost and fibre AD are:

- Complete cultivation is essential on most sites to relieve compaction. Undertake reclamation operations in dry weather, wherever possible, to improve cultivation and mixing and to minimise both soil damage and pollution risk.
- Cultivate to at least 1 m depth where possible and consider a partial inversion technique if the soil surface layer is better quality than the lower layer and it is desirable not to bury it during cultivation.
- Provide good drainage by installing open 'V' drains or wider 'swales' within the cultivated area (not separated by and uncultivated barrier) and / or drainage 'taps' that breach uncultivated barriers to enable soil water to drain away. Good drainage is essential.
- Use soil and amendment analysis to *inform* the amendment application rate, where possible given other factors, to achieve nutrient and other criteria in the FC 'Minimum standards for soil forming materials for acceptable woodland establishment' (**Appendix 3**).
- Different organic amendments have different nutrient characteristics, so analysis of the source to be used is recommended in order to allow determination of an appropriate application rate.

As a rough guide: firmer/drier sites are likely to benefit from application rates of around 200 to 450 t/ha of fresh **green compost**; wet sites should benefit from lower application rates 100 to 300 t/ha. **Fibre anaerobic digestate** will be one third to one half less, depending on nitrogen content.

## Forestry operations

Reclaimed soils will usually have a poor soil structure and may still be poorly drained and have unusual chemistry. The application of green compost and / or fibre AD will provide a marked initial nutrient boost, particularly of available nitrogen, which can cause problems if not anticipated.

However, it is important that foresters are aware of the characteristics of soils reclaimed using quality compost so that the silvicultural benefits are maximised whilst the potential problems are minimised. Issues to be considered are summarised in **Table 3** for green compost, but the same principles apply to other organic amendments including AD fibre.

**Table 3.** Key issues for planting and establishment on sites reclaimed with compost[8]

| Issue | Implication | Comment |
|---|---|---|
| Ground preparation | | |
| Ground is already cultivated | Mounding is not advisable or necessary | Wet sites might benefit but machinery compaction risk and cost likely to preclude |
| Drainage already installed | Additional surface drains usually unnecessary. Avoid compaction by machines | Armoured drain, berm & swale spacing may differ from forestry drain norm |
| Grass seeding | Ideally sow grass seed to minimise initial annual weed growth | Physical competition by grass is much less than broadleaved weeds |
| Planting & protection | | |
| Fallow period | Preferably avoid fallow owing to vigorous weed growth in 1st season | Annual weed growth can be limited if site is grass seeded early |
| Planting date | Normal constraints apply but loose soil can dry / re-wet quickly | Consider wind-scorch and desiccation risk |
| Plant type | Sites may justify more expensive plug plants over bare root transplants. Avoid 'J' rooting | Bushy bare roots can be difficult to plant properly in heavy, wet clods and plug plants |
| Species | Fast, pioneer species will reduce weed risk but may also topple after 2 - 3 years if exposed | Slower growing climax species will be at risk from weeds for longer |
| Protection | Tubes aid chemical and strimmer weeding, give protection against voles and weeds smothering soft conifers | Tubes also protect against hares (75 cm) and rabbits (60 cm). Taller tubes (120 cm) can be more liable to vandalism / wind toppling |
| | Taller (120 cm) tubes can exacerbate etiolation and poor stem strength. Use shorter tubes except where some protection from Roe deer is needed | Exterior deer fencing may also be advisable. |

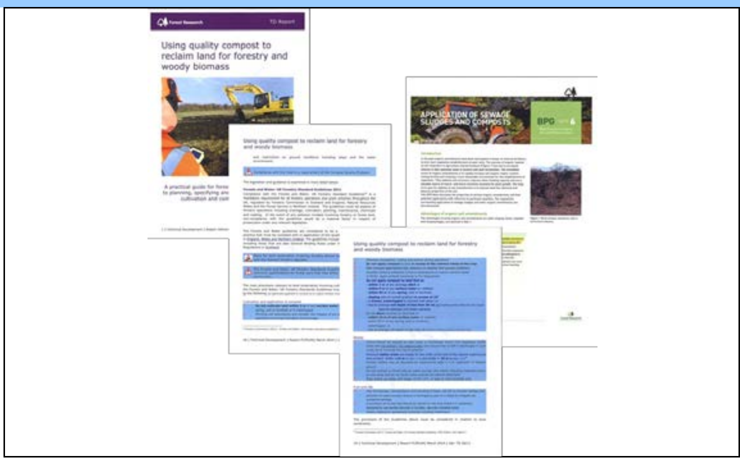
[8] From: 'Using quality compost to reclaim land for forestry and woody biomass'. Wall, M. (2014). FCJR104. Forest Research, Technical Development

| | Establishment, weeding & maintenance | |
|---|---|---|
| Weeding | Expect vigorous early annual / pioneer weed growth. Chemical weeding alone may not suffice, allow for strimming etc | Allow for 3 - 4+ years weeding. Excessive 'arable' weeds can swamp trees and tubes, especially in first year; less thereafter |
| | Expect rush infestation on certain wet sites, spreading within 2 - 3 years onwards. Readily swamp trees over winter, especially softer species | Very difficult to control chemically and may need strimming, so consider tubes as trees are otherwise difficult to see and easily damaged |
| Staking | Potential very rapid stem / crown growth in first two years. Can lead to stem drooping / lodging or snapping at root collar. Consider additional staking of faster growing species | Flush of major nutrients in first two years that will then subside, but tree instability may occur soon thereafter, especially on windy sites |
| Beating up | Apply normal practice for replacement of dead trees | Initial survival should be good, but weeds and etiolation are threats. |

The nutrient enrichment of soils reclaimed with compost need a robust establishment specification and often probably also an extended maintenance period.

Plan to overcome possible problems of excessive early stem growth (by minimising application rate) and prevalence of weeds. Post planting care is crucial. **Do not get caught out!**

Reclamation to forestry poses particular challenges for which guidance is available. A successful outcome may involve balancing a complex factors so specialist advice should be considered.



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# Appendix 1

## Trial details

| Site / Planted spring | Reps of / Treatment Plots | Species / Plot trees @ *Spacing* | Treatments Compost (CO) / Anaerobic digestate (AD) |
|---|---|---|---|
| GoH ('Sand') / 2008 | 4 of 5 treat's | SBi<br>*64 @ 1.5 $m^2$* | CO (0-20 mm) @ 0%, 12.5%, 25% & 50% by volume in upper 50 cm |
| GoH ('Clay') / 2008 | As above | As above | As above |
| DQY / 2009<br><br><br>2010 | 3 of 6 treat's<br>1 of 6 treat's<br><br>1 of 3 treat's | LP/SS[1] (HL)[2]<br>SBi (HL)[2]<br>*144 @ 1.5 $m^2$*<br>SS/HL @ 1.5 $m^2$ | CO (0-40 mm) @ 0%, 15% and 25% by volume in upper 50 cm, each single and double cultivated-in<br>CO @ 0%, 15% & 15% double cult'n |
| DQY 2011 ('Clay') | 4 of 5 treat's (+ 0 'control') | SBi<br>*64 @ 1.5 $m^2$* | AD @ c 3k & 1.5 Kg N / ha<br>CO (0-20 mm) @ 3k Kg N / ha<br>CO & AD @ c 3k & 1.5 Kg N / ha |
| ADL 2011 (Oil shale) | As above | As above | As above |
| DQY 2013 | 1 of 4 treat's | CAR, DBi, SS, Wi[3.]<br>*279 @ 1$m^2$* | CO @ c 1.5k Kg N / ha<br>Each plot $^{1}/_{2}$ complete & $^{1}/_{2}$ partial inversion |

Notes: Greenoakhill - GoH, Dalquhandy - DQY, Addioewell - ADL
SBi - Silver birch, DBi - Downy birch, CAR - Common alder, Wi - Willow (clones), LP - Lodgepole pine, SS - Sitka spruce, HL - Hybrid larch
1. LP / SS alternate trees
2. HL beatups (replaced dead trees)
3. *Salix dasyclados* Loden, *S. viminalis* Jorr, *S. viminalis* Thorhill, alternate rows

# Appendix 2

## Main conclusions from each field trial

### Greenoakhill compost trial 2008 & 2009

- Compost application rates of 12½% (300 t/ha), 25% (600 t/ha) and 50% (1200 t/ha) by volume gave proportionate increases in soil **organic matter**.

- The 12½% application nearly doubled the **total nitrogen** in the soil from an adequate level, and this was doubled by the 25% and the 50% rate, although the nitrogen supply appeared excessive.

- Concentrations of extractable **phosphorus** and **potassium** were greatly increased by compost application but there was some early loss of potassium, probably due to leaching.

- **pH values** of the control plots were slightly over the target maximum for trees of pH8, and this was reduced slightly by addition of compost to below the ceiling.

- The 12½% application more than doubled (237%) **tree growth** over three seasons compared to the cultivated control plots, in which trees also had small and yellowish leaves. The 25% application further increased growth by 25 - 30%. There was no statistically significant increase in growth with the increased application rate to 50%.

- 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 - 2013

- **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 of **rush weeds** was significant, and particularly heavy and damaging in the compost treatment plots. Planting regime such as tubes for broadleaves and establishment operations such as weeding must cater for significant and damaging rush growth.

- Tree **survival** was lowest in compost treatments and in Lodgepole pine, which was attributed largely to rushes smothering this 'soft' conifer species and problem which also affected Larch, but les so the 'harder' Sitka spruce.

- **Growth** of Sitka spruce, larch and Lodgepole pine accelerated by the fourth and fifth years as would be expected in normal forestry establishment. That of Silver birch started to reduce at the fifth season, possibly owing to the impact of the heavy, wet conditions.

- Growth of Sitka spruce in compost treatments was significantly greater than in the cultivation-only treatments and appeared to increase further from 15% to 25%. 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.

- An effective and relatively intense surface water **drain network** is important to help maximize the benefits of complete cultivation and compost addition and to reduce the effect of rushes.

- **Species choice** has an important impact. Larch and Lodgepole pine are, as would be expected, more tolerant of the poor nutrient conditions than Sitka spruce. Choice of broadleaves should allow for both rushes and water-logging on heavy soils.

- In the exposed, heavy, wet conditions tested some larger Lodgepole pine, and to a lesser extent some Sitka spruce, showed some **instability** as they tended to develop a lean owing to 'wind socketing' and in such cases selected staking could be considered to help roots develop.

- **Compost addition can improve tree growth and health**, at least for larch, birch and Sitka spruce but also promotes rush competition, so a lower dose of compost (e.g. 15% / 450 tonnes / ha or less) is to be preferred to a higher dose (e.g. 25% / 750 tonnes / ha) for this reason. There was no apparent improvement in the growth of Lodgepole pine

- **Secondary cultivation to improve compost mixing is not justified** by improved survival or growth

## Dalquhandy and Addiewell AD / compost trial 2011 - 2012

Dalquhandy:

- After two seasons of **growth** there were no significant differences between the various AD and compost treatments. Growth in the first year was good but reduced markedly in the second year, although still very much better than the single 'untreated' plot, illustrating the advantage of adding compost or AD.

- After two seasons, average **growth** of the Silver birch was between $^{1}/_{2}$m and c $^{3}/_{4}$m which was considered reasonable for the initial site conditions and allowing for the cool, wet second season. Although not measured, the growth in the third and fourth seasons to 2014 has markedly increased.

- The lack of clarity in growth data is not entirely unexpected, in that tree establishment generally takes around five years, especially on the more challenging sites.

- Field observations suggest that the **wet conditions** on the Dalquhandy site, probably exacerbated by a remarkably wet second growing season, act as a constraining factor on tree growth by impeding availability of nutrients.

- One important possible implication of a lack of clear treatment differences on the wet Dalquhandy site is that the utilisable amount of organic amendment should be reduced compared to more freely draining sites.

- **Survival** at 82% to 93% was good, especially considering the extremely wet and exposed conditions of the site. The increased mortality in the higher nitrogen plots appears, from field observations, to be linked to weed competition, especially to grass growing within tubes, and possibly also to water-logging whereby weak trees then succumb more readily.

Addiewell:

- Growth differences between the various AD and compost treatments were not statistically significant. However, there appeared to be a trend of higher growth in the most of the AD plots and slightly lower growth in the compost only and lowest mixed rate plots.

- After two seasons, average **growth** of the Silver birch was between 1 m and c $1^{1}/_{3}$ m which was considered very good for the initial site conditions.

- Tree **survival** was good at 88-97%.

- Both survival and tree health were affected by significant broadleaved **weed growth**, especially in the first season, and fast top growth as compared to lower stem strength which resulted in a few **excessively leaning trees**.

- The optimum application rate may not therefore be the highest owing to the problems of weeds and tree instability.

Both sites:

- The AD had nearly twice the **organic matter** content of green compost on a fresh weight for weight basis but was also considerably wetter at 70% compared to 40% moisture content (wet basis) respectively.

- For a given application rate of total nitrogen, the AD supplied approximately half the organic matter of green compost owing to its much higher total nitrogen content in dry matter. Field observations indicated increased organic matter in the compost and AD treatments and improved soil conditions compared to the control plot.

- AD provided approximately 50% more **total nitrogen** than green compost on a fresh weight for weight basis, so conversely about a third less AD would be used than green compost for a given application rate of total nitrogen.

- Most of the nitrogen supplied by the AD was in the available ammonium form which can be rapidly dissolved and leached from the soil and could be volatalized and lost to the atmosphere. In contrast, nitrogen in compost is mostly in slow release organic form.

- Owing to the **chemical composition**, on a fresh-weight for weight basis compost provides more phosphorus and magnesium and much more potassium than AD, which conversely has much more sulphur. The pH of AD at 8.0 was slightly higher than that of the compost at 7.6.

- On poorly draining, high rainfall sites conditions could result in the formation of sulphides from AD that could restrict the growth of roots.

- **Health** of both trees and ground vegetation was very markedly better in all treated plots compared to 'control' plot that had no compost or AD applied. In the control plot (only present at Dalquhandy) tree leaves were relatively small even at the end of the first season, indicating that they were struggling.

- Overall, AD fibre has a **good potential** as a fertilizer, but it has more constraints than compost.

## Dalquhandy compost / SRF demonstration trial planted 2013

- Survival and growth in the first two seasons have been good in all treatments, and this is expected to be confirmed by end of season data.

- Growth and health of Common alder has been notable, with Downy birch also performing well. A few alder have required staking owing to fast top-grow and exposure.

- Growth of Sitka spruce has been variable but generally good, the main issue being lack of shoot stiffness leading to stems tending to droop within the tree tubes used for weed protection. Growth of the willow clones has been generally good but with some variation apparently linked to ground disturbance caused by essential draining through the plot.

- The grass sward sown has proved very effective after two seasons with few broadleaved weeds or even rushes. The white clover element of the seed mix has thoroughly occupied the ground surface and appears to be out-competing invasive weeds.

- There appears visually to be a slight growth benefit within the partial inversion area of the alder plot and this will be checked by end of season measurements.

# Appendix 3

## Minimum standards for soil forming materials for acceptable woodland establishment[9]

| Parameter | Standard | Comments on method |
|---|---|---|
| Texture | No limitations; however, the placement location of materials of different texture on site should be related to site factors e.g. topography | Texture (% sand, silt and clay) should be determined by pipette method. Preferred textures include materials with > 25% clay |
| Bulk density (after placement) | <1.5 g / cm$^3$ to at least 50 cm depth<br><1.7 g / cm$^3$ to below 1 m depth | |
| Stoniness: Clay or loam | <40% by volume of material greater than 2 mm in diameter and <10% by volume of material greater than 100 mm in diameter | Measure mass of stone >2 mm and >100 mm in a known mass / volume of soil; divide each value by 1.65 to calculate the volume |
| Stoniness: Sand | <25% by volume of material greater than 2 mm in diameter and <10% by volume of material greater than 100 mm in diameter | |
| pH | Within the range 4.0 to 8.0 | Based on a 1:2.5 soil: $CaCl_2$ (0.01 M) suspension |
| Electrical conductivity | <0.2 S m-1 (2,000 uS/cm) | Based on a 1:1 soil:water suspension |
| Iron pyrite content | <0.05 % | British Standard 1016 method |
| Topsoil nutrient and organic content | N >1500 kg N/ha [10]<br>P >16 mg/l (ADAS Index 2)*<br>K >121 mg/l (ADAS Index 2)<br>Mg >51 mg/l (ADAS Index 1)<br>Organic matter content >10% | Standard ADAS methods |
| Specific metal and organic contaminants | These should fall between the Soil Guideline Values (DEFRA and EA, 2002) for residential without plant uptake and industrial / commercial. Where no SGVs are available acceptable limits should be derived using a risk based approach for human health. Levels of copper and zinc should not exceed 130 or 300 mg/kg respectively. | Determination according to substance using a method comparable with the Soil Guideline Values being used. Approval should be sought from Forest Research on the guideline concentrations being used before soil placement begins. |

Note: * > 16 mg/l and < 25 mg/l to reduce risk of phosphate pollution. Litterick, A. Pers. Comm. (2014)

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