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Organics Trailblazer Project

Lambton Former Coke Works

Work Packages 4 and 5.

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Executive summary

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1 Introduction

1.1 Background

This report details the findings of a nine month trial undertaken from 2007 to 2008 at the former Lambton coke works site to assess the benefits o fusing PAS100 compost with a soil manufacturing programme.

Manufactured soils were needed at the site for the creation of 23 hectares of woodland and 10 hectares of grassland (Figure 1). A total of 59500 m^3 of topsoil and 402500 m^3 of subsoil were calculated to be required for the planned landscaping. Sufficient stockpiled topsoil resources were identified on site for the restoration of 25 cm depth of soil for grassland (25000 m^3) and to top-dress woodland soil profiles (34500 m^3). However, previous research indicated (Moffat, 1995) a soil depth of 2 metres (402500m^3) would be needed for the successful establishment of woodland, and insufficient natural subsoil material existed on the site. Following experimental testing of the physical, chemical and biological function of available on-site materials, colliery shale amended with imported organic matter materials was found to be the most appropriate soil forming material for the creation of woodland subsoils.

The trial described in this report was undertaken to evaluate different strategies for creating artificial woodland soil profiles, namely alternative methods of soil emplacement and different mixes of organic materials added as ameliorants to manufactured subsoils. The unique feature of this sites manufactured soil is the use of PAS100 compost with paper mill crumb. A design to supply nutrients, control their release and also supply moisture.

In summary, the rationale for the soil profile design is based on sufficient depth and added organic matter, in place of clay, to hold water with a lower subsoil mainly designed to hold water and an upper subsoil designed to hold water but also to release nutrients. This design is site specific in terms of plants to include, climate and available on-site soils. Aesthetic factors such surface appearance and practical issues relating to site logistics and materials handling are also site specific and need consideration.

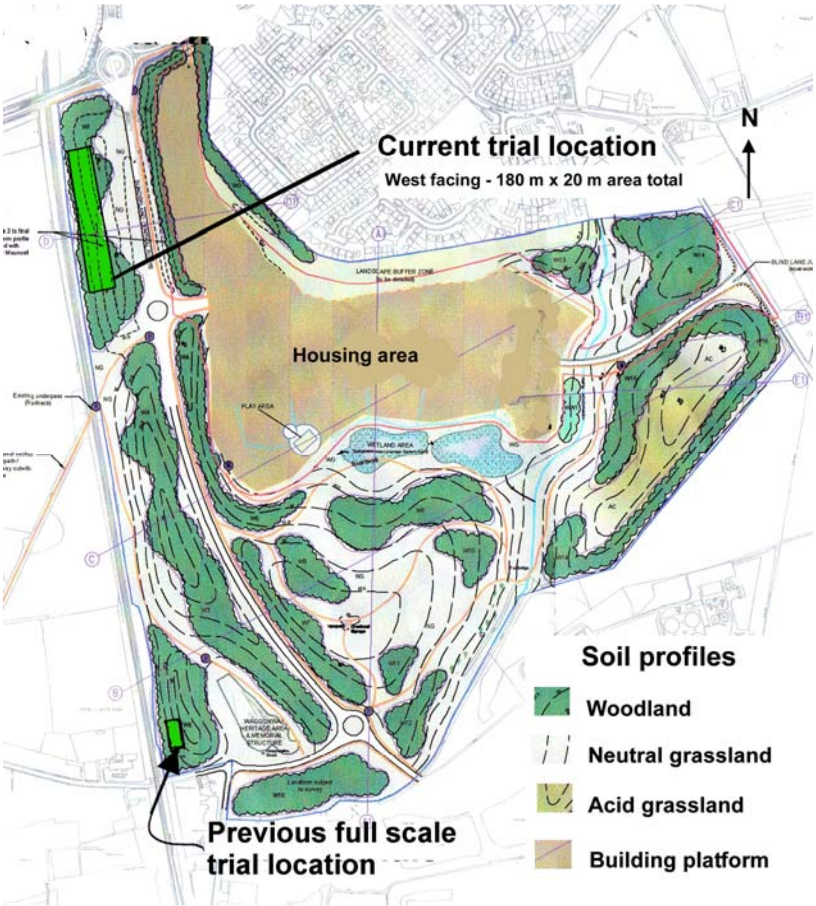

Figure 1: Trial location

1.2 Trial design

Trial plots were constructed in May 2007 in the north west of the Lambton former coke works site (Figure 1, Current trial location).

Of major importance was the need for very clear unambiguous instructions for site consultants, contractors and particularly the actual plant operators. Careful monitoring is also need in the early stages to ensure procedures are followed. Careful monitoring is also needed of the PAS100 compost being imported. Although a compost manufacturing site's material may have passed the PAS100 test, any opportunity to 'offload' sub-grade material onto a large site may be taken.

- Each plot received 2 metres of manufactured soil (Figure 2): All ratios for measurement are on a volume basis as this proved the most suitable to scale up to dumper truck size quantities for mixing (Plate 1).
    - All plots received the same 1 metre of reduced subsoil mixture:

      2 parts paper mill crumb (PMC) to 5 parts colliery shale.

    - 90 cm of upper subsoil was then emplaced and composed of a 2:5 ratio of organic amendments to colliery shale (Plate 2).

      Two organic amendments mixes were compared:

      1. 50% green waste compost (GWC) to 50% PMC
      2. 80% green waste compost (GWC) to 20% PMC.

    - All plots were top-dressed with 10 cm of site-won topsoil (clay loam texture).

- Three methods of soil emplacement were tested:

  1. Conventional narrow track bulldozer (NT) emplacement (Plate 2)
  2. Low bearing wide track (WT) bulldozer emplacement
  3. Loose tip (LT) emplacement (Plate 3).

- Plots were hand planted with a mix of native tree species (Plate 4).

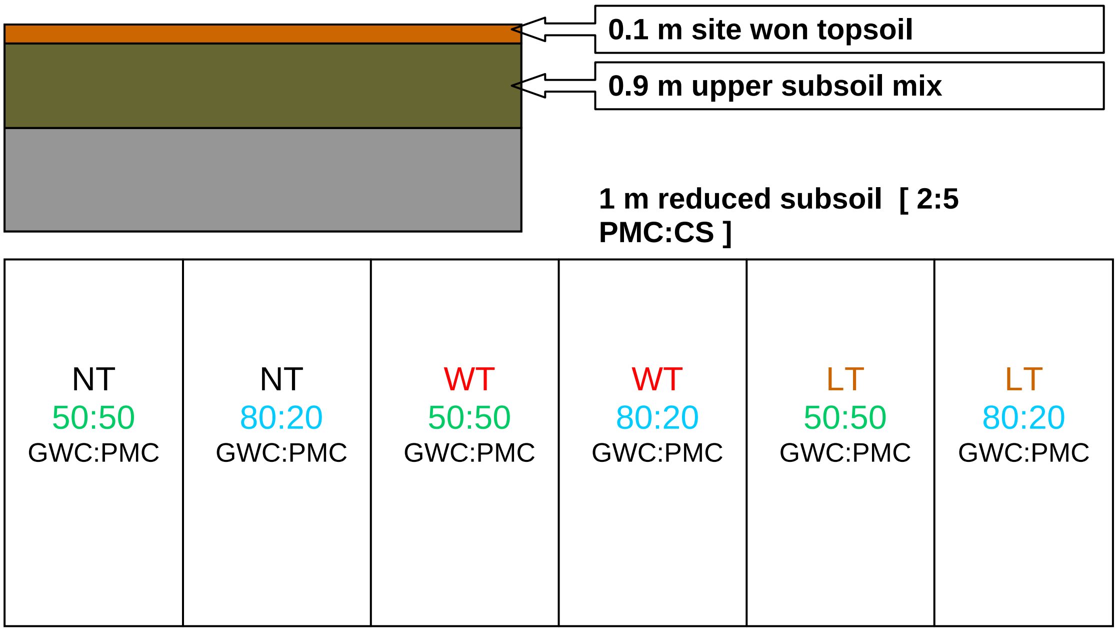

Figure 2: Trial layout

Plate 1: Soil material blending

Plate 2: Bulldozer emplacement

Plate 3: Loose tip emplacement

Plate 4: Completed trial plots

1.3 Trial monitoring

1.3.1 Soil physical parameters

- **Bulk density** This is a fundamental property in relation to restored soils, and can influence all other physical parameters. Bulk density was measured at two sample depths of 50 and 150 cm using a U38 sampling tube following site preparation in May 2007.

- **Soil penetration resistance** Layers with elevated penetration resistance can limit natural root extension and adversely affect plant growth. Soil penetration resistance was measured in upper and reduced subsoils (50 cm and 120 cm) following site completion in May 2007 and again at 50 cm at the end of the trial period in February 2008, using a proving ring penetrometer.

- **Moisture content** This has been assessed using gypsum blocks placed at 50 cm and 150 cm depths to track moisture changes during the growing season. Soil density and structure effect the availability of water to plants, and plant growth can in part be linked to these changes

- **Structural development** Manufactured soil may be ameliorated over time through structural redevelopment due to natural formation processes. Soil structure in surface layers (to 50 cm) was assessed qualitatively in test pits in February 2008.

1.3.2 Soil chemical parameters

- **N transformations** Plant available nitrogen concentrations (NO_3 and NH_4,) were monitored monthly between site construction in May 2007 and the end of the trial in January 2008. Samples were taken from upper subsoils (50 cm) and reduced subsoil (150 cm). A combination of on-site and commercial laboratory analysis was used.

- **Other macronutrients and key chemical properties** potassium, phosphorus, magnesium, soil electrical conductivity (salinity) and pH were measured following initial soil placement in May 2007 and at the end of the trial period in January 2008. Samples were collected on two occasions from topsoil (0-10 cm) upper subsoil (50 cm) and reduced subsoil (150 cm) in May 2007 and from subsoils and reduced subsoils in January 2008.

- **Phytotoxins (Bo, Cu, Ni and Zn)** These metals are common in soils at Lambton and although uncontaminated materials have been specified for the construction of the trial, measurements were undertaken as a check should any unexplained plant deaths occur. Samples were collected from topsoil (0-10 cm) upper subsoil (50 cm) and reduced subsoil (150 cm) in May 2007 and from subsoils and reduced subsoils in January 2008.

1.3.3 Leachates

- **Nitrogen.** Total, NO_3 and NH_4 nitrogen were monitored in groundwater extracted from borehole monitoring wells. Samples were collected in June, August, October and December 2007, and at the end of the trial in January 2008.

1.3.4 Soil gas composition

- **Carbon dioxide** This provides an indication of microbial activity (aerobic respiration) within the soil.

- **Methane** Methane production occurs due to microbial digestion under anaerobic conditions and is harmful to plant growth.

- **Oxygen** Oxygen concentrations are linked to rates of microbial respiration (CO_2 , CH_4) and may indicate rates of gas diffusion through subsurface soil layers.

Permanent gas wells were installed to depths of 50 cm and 150 cm in each plot in May 2007, and monitoring of all gas parameters was conducted monthly between May 2007 and January 2008.

1.3.5 Plant growth

- **Tree height** Ten trees of four species (oak, birch, hawthorn and hazel) were randomly selected in each plot and their height measured from the base of the trunk to the top of the leading shoot. The height of each tree was recorded monthly between May 2007 and January 2008.

- **General observations on plant health.** Visual assessment of all trees was made on a monthly basis to monitor any visible signs of disease.

- **Tree root development.** At completion of the trial (February 2008) qualitative assessment of root profiles of randomly selected trees from each of the treatments was undertaken by excavating a section in a soil pit.

1.3.6 Statistical analysis

Analysis of variance was used to test differences between land emplacement methods, organic amendment mixtures, treatment interactions (combinations of land emplacement and organic mixtures, 1-6) and sample depths of soil, leachate and gas parameters with a blocked general linear model using Mintab 15 statistical software. Tree growth data was also tested for differences between species. Data was tested for normality using Anderson-Darling test. Tree growth and soil nitrate data was normalized using square root transformation. Tukey's test was used to test for differences between individual treatments.

2.0 Results

2.1 Soil physics

2.1.1 Bulk density

Stoniness of the soil material caused difficulties in bulk density sampling, and resulted in a elevated degree of variability in treatment means. However, results did confirm that bulk density was significantly greater in plots emplaced with a narrow track bulldozer than those emplaced by loose tipping, with intermediate concentrations in plots emplaced by wide track bulldozer (Figure 3).

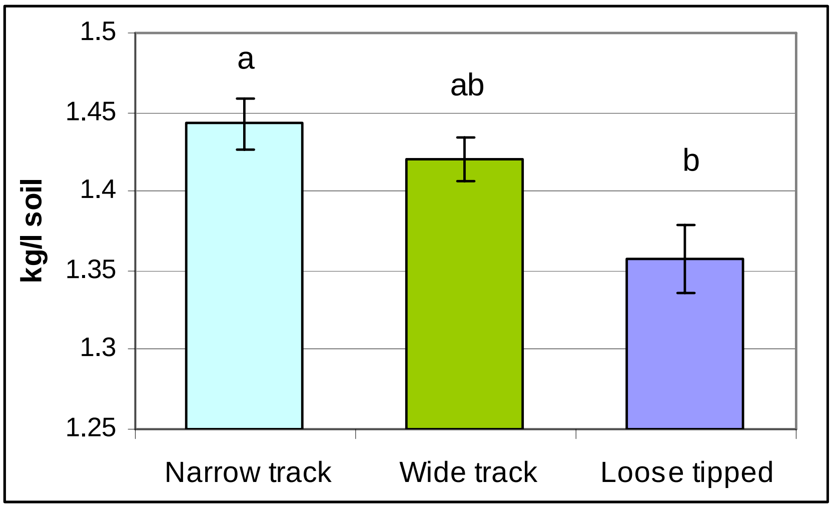

Figure 3: Soil bulk density May 2007
Same letter indicates no significant difference between emplacement methods ($p<0.05$).

2.1.2 Penetration resistance

Bulldozer emplacement resulted in significantly greater penetration resistance than loose tip emplacement (Figures 4-6). Penetration resistance of plots emplaced using a wide track bulldozer did not differ from use of a narrow track bulldozer. There was a no decline in resistance concentrations over the 9 month monitoring period (Figures 5 and 6).

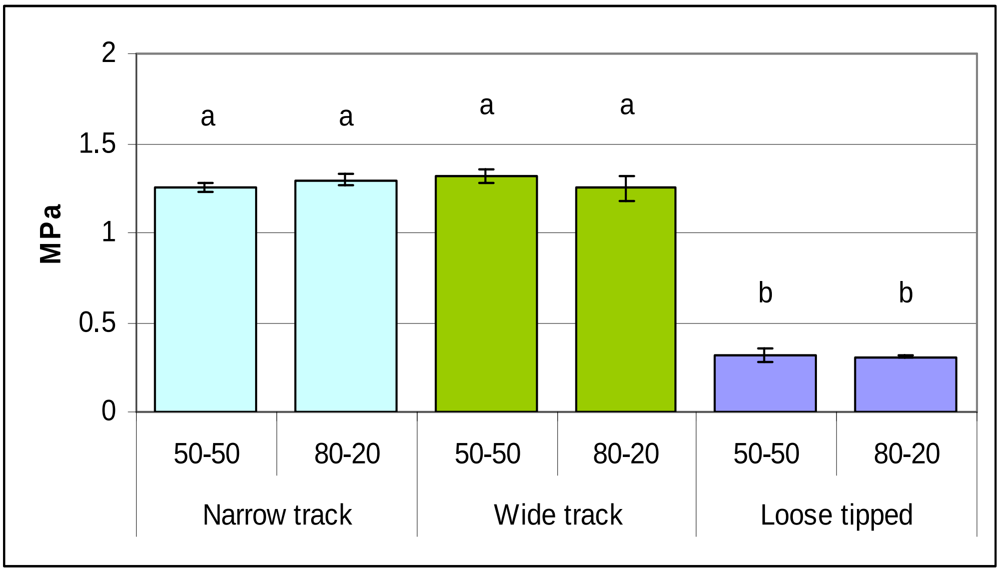

Figure 4: Penetration resistance (150 cm depth) May 2007
Same letter indicates no significant difference between treatments ($p>0.05$).

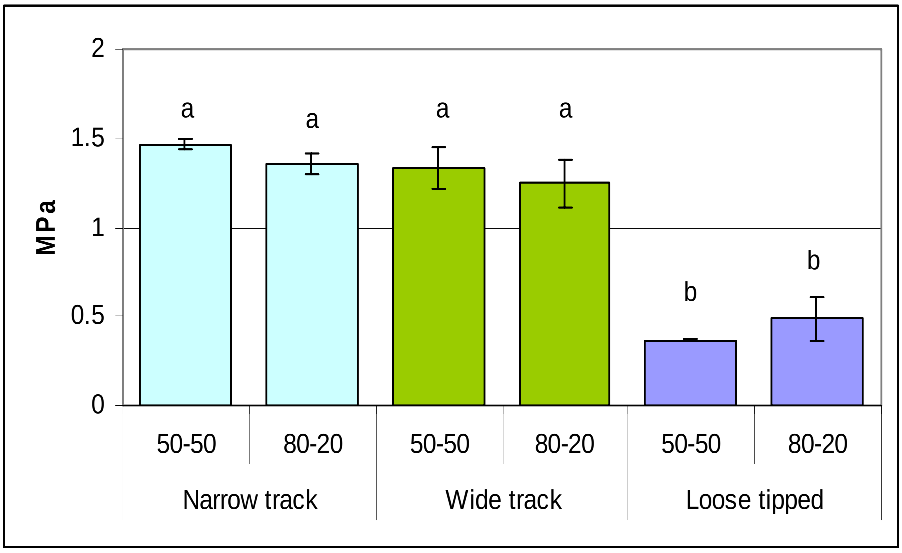

Figure 5: Penetration resistance (30 cm depth) May 2007
Same letter indicates no significant difference between treatments ($p>0.05$)

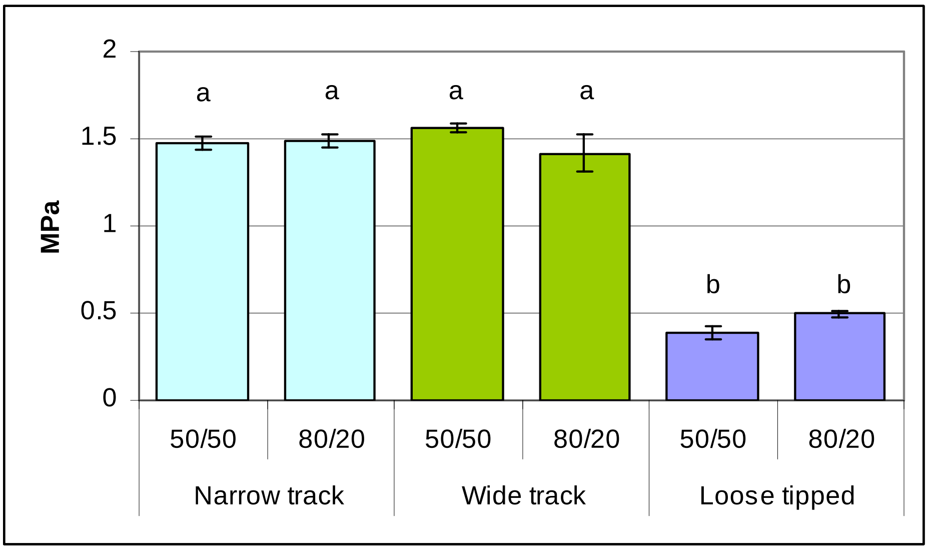

Figure 6: Penetration resistance (30 cm depth) Feb 2008
Same letter indicates no significant difference between treatments ($p>0.05$)

2.1.3 Structural development

Qualitative assessment of soil structural development conducted in February 2008 demonstrated that topsoil emplacement with bulldozers resulted in a much greater concentration of compaction, and a reduced degree of structural integrity, with poorly structured topsoil (site-won clay loam) and heavily compacted subsoil material. In marked contrast, loose tip emplaced plots displayed a much reduced degree of structural damage to the topsoil, with retention of natural soil structures, and a much less compacted underlying subsoil.

Soil emplacement method	
Loose tipped	**Bulldozer**
0-15 cm Moderately stony coarse-medium sub-angular blocky clay.	0-5 cm Moderately stony coarse – medium sub-angular blocky clay.
	5-15 cm Compacted poorly structured, moderately stony clay forming very coarse clods or platy aggregates.
15-50 cm Loose structureless colliery shale.	25-50 cm Elevatedly compacted structureless colliery shale

Generalised soil profiles to 50 cm depth

2.1.4 Soil moisture

Results of soil moisture monitoring proved inconclusive during the trial monitoring period, as elevated rainfall resulted in soil saturation at all monitoring times (see appendix 3).

2.2 Soil chemical parameters

2.2.1 Nitrogen

Upper subsoil nitrate concentrations were not found to be affected by rate of compost application. However, there was a significant effect of land preparation; loose tipped plots were found to have greater nitrate concentrations than either of the bulldozer emplaced plots (Figure 7). Nitrogen in the bulldozer plots appears to have been preferentially mineralized to the ammoniumcal form. Ammonium concentrations were found to be significantly greater in the upper subsoil of the bulldozer emplaced than the loose tipped plots (Figure 8).

There was also an effect of rate of compost application on ammonium concentrations in the bulldozer prepared plots; application of compost at the reduced rate (50:50 mix) resulted in significantly greater ammonium (Figure 9). Ammonium concentrations in the loose tipped plots were unaffected by choice of organic amendment.

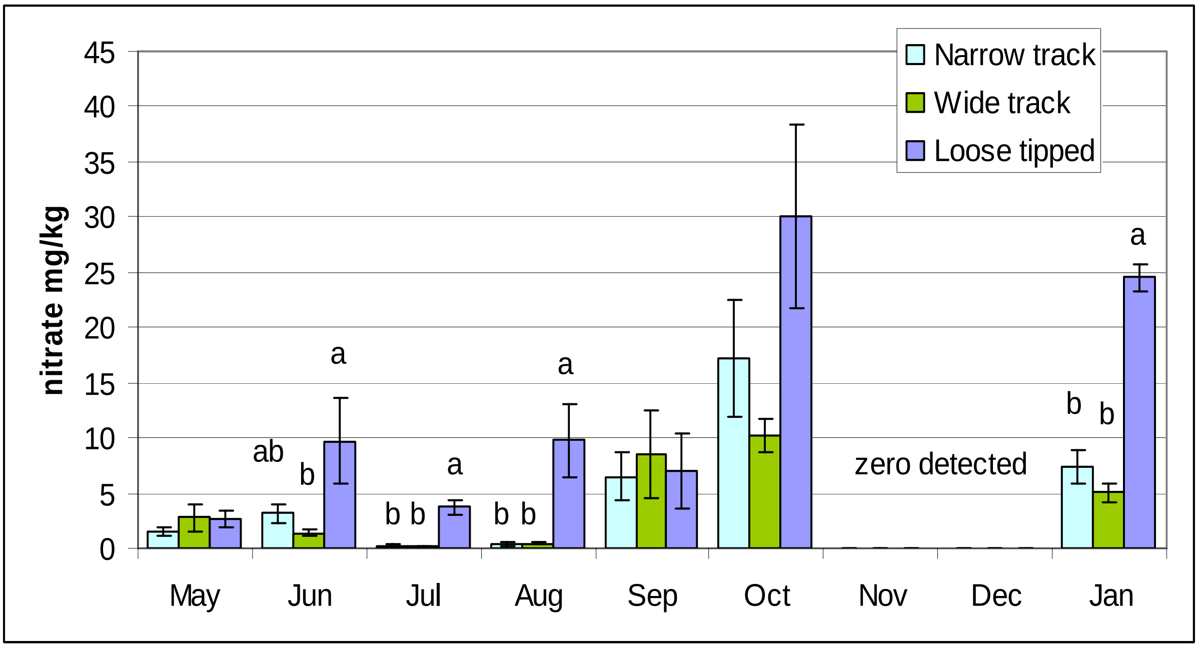

Figure 7: Upper subsoil nitrate concentration
Same letter or no letters indicate no significant difference between emplacement methods (p>0.05)

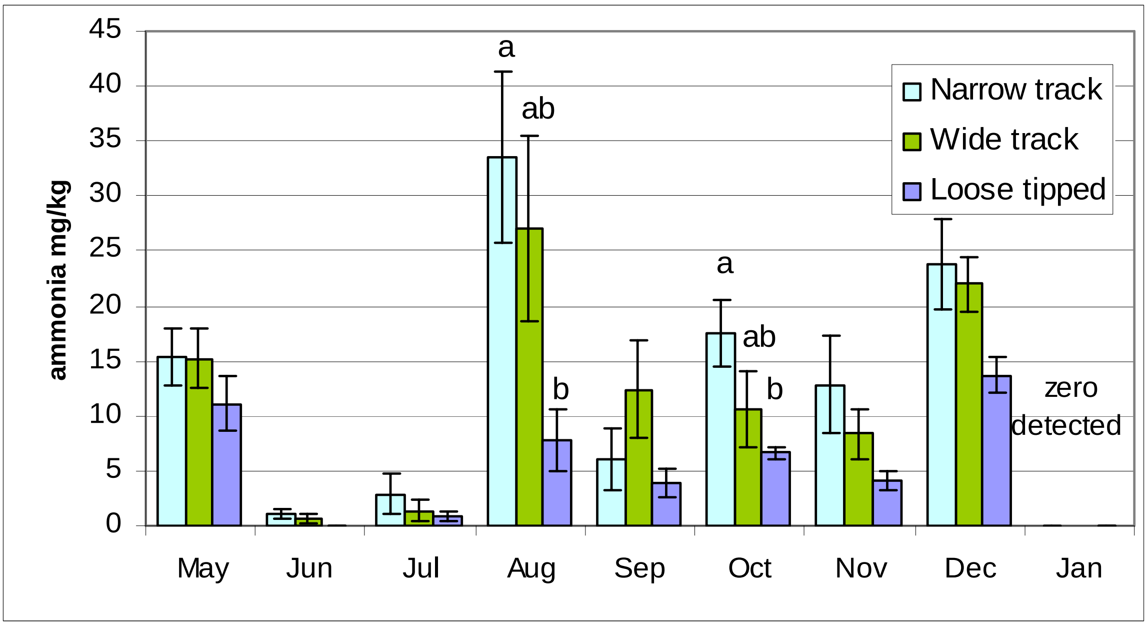

Figure 8: Upper subsoil ammonium concentration by land preparation
Same letter or no letters indicate no significant difference between emplacement methods (p>0.05)

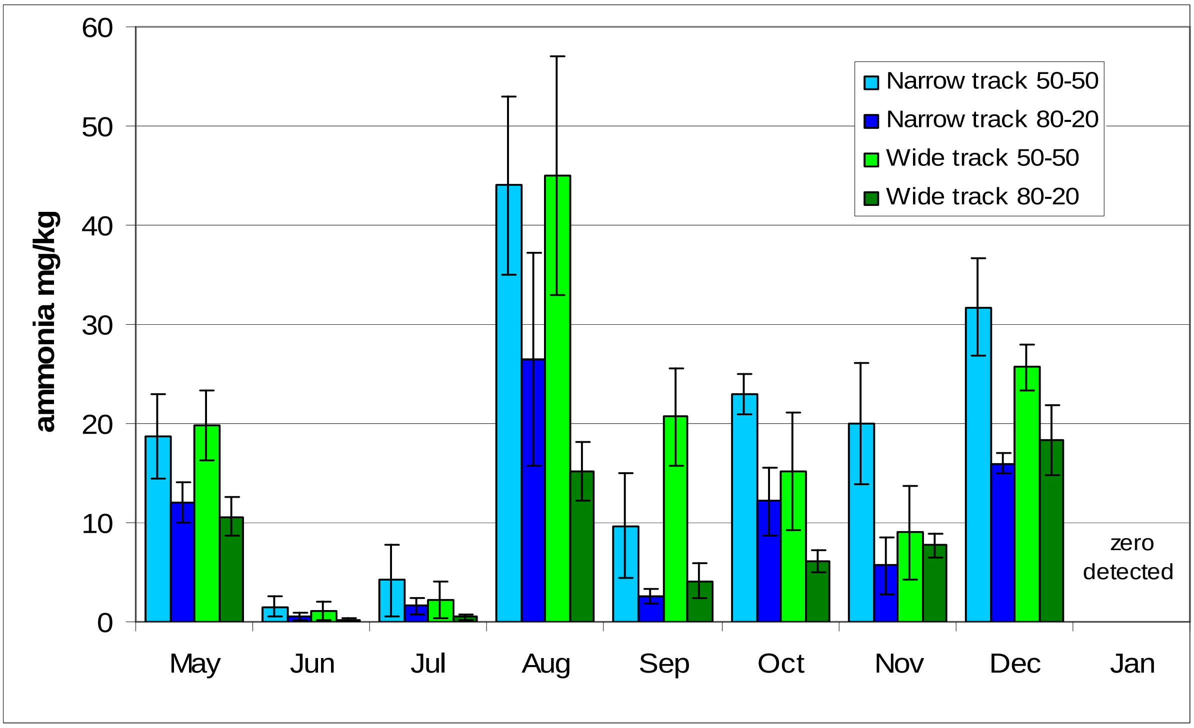

Figure 9: Upper subsoil ammonium concentration by treatment (bulldozer plots only)

2.2.2 Nutrients and phytotoxins

Soil analysis shortly after soil profile construction (May 2007) revealed application of compost to the upper subsoil resulted in significantly greater available P and K and a decrease in Cu, Ni and Zn concentrations relative to those in the reduced subsoil (receiving paper mill crumb only)(Table 1).

Comparing the two upper subsoil organic amendments, application of the reduced compost rate (50:50 mix) resulted in significantly greater total nitrogen, phosphorous and potassium (Table 1). However this rate also increased boron concentrations and electrical conductivity.

Emplacement	GWC:PMC	N%	NO_3	NH_4	P	K	Cu	Ni	Zn	Bo	EC(Us/cm)	pH
Topsoil (0-10 cm)												
Narrow track	**50:50**	0.29	31.4	8.8	1.4	105	47.7	18.7	116.7	1.1	507	7.9
	80:20	0.38	5.2	9.4	2.5	127	47.3	18.7	111.3	1.0	367	7.9
Wide track	**50:50**	0.36	16.9	9.7	3.8	138	45.3	17.7	105.0	1.2	590	7.8
	80:20	0.37	23.7	10.4	3.1	528	50.7	16.7	97.3	1.1	840	7.7
Loose tipped	**50:50**	0.38	23.4	7.4	2.9	263	55.7	17.7	106.7	1.1	697	7.9
	80:20	0.43	19.3	7.3	1.9	152	60.7	20.0	113.3	1.3	520	8.0
Upper subsoil (50 cm)												
Narrow track	**50:50**	0.48	1.7	13.6	3.6	1153	66.3	20.7	135.0	1.1	1300	7.7
	80:20	0.44	1.4	8.3	3.5	697	64.3	20.3	101.3	0.7	1233	7.6
Wide track	**50:50**	0.58	4.2	13.4	8.2	1147	65.0	19.7	136.7	1.5	1467	7.6
	80:20	0.48	1.3	7.4	3.2	840	63.7	18.3	112.3	0.9	1300	7.7
Loose tipped	**50:50**	0.49	4.0	7.8	7.0	1173	67.0	19.7	102.7	1.2	1466.7	7.7
	80:20	0.45	1.2	7.7	2.6	390	75.0	18.0	102.7	0.9	1233.3	7.8
Reduced subsoil (150 cm)												
Narrow track	**50:50**	0.51	0.5	10.4	1.2	140	88.0	23.7	182.3	0.8	1200	8.1
	80:20	0.58	0.6	5.7	1.2	113	78.0	23.7	203.0	0.8	1300	7.8
Wide track	**50:50**	0.43	0.4	6.5	1.0	114	78.3	24.7	299.0	0.6	1300	7.7
	80:20	0.53	0.5	6.2	1.4	163	74.7	22.7	170.0	0.7	1466	7.8
Loose tipped	**50:50**	0.50	0.5	6.6	1.0	243	79.0	22.3	175.3	0.9	1400	7.9
	80:20	0.42	0.4	6.5	3.2	470	84.0	25.0	156.7	0.9	1333	7.8

Table 1: Soil chemical analysis May 2007 (all figures mg/kg unless stated)

Chemical analysis in January 2008 did not indicate any differences in measured soil chemical parameters between compost application rates (Table 2). However, greater concentrations of available phosphorous occurred in the loose tipped plots than the bulldozer emplaced plots. Concentrations of available phosphorous, potassium and magnesium were greater in the (compost amended) upper subsoil while zinc and nickel were greater in the reduced subsoil (no compost added).

Emplacement	GWC:PMC	P	K	Mg	Ni	Zn	Bo	EC(Us/cm)	pH
Upper subsoil (50 cm)									
Narrow track	**50:50**	9.3	813	280	18	120	0.7	1320	8.3
	80:20	7.3	820	300	17.3	90	0.7	1467	8.3
Wide track	**50:50**	10.7	1127	313	15	85	0.8	1367	8.2
	80:20	7.7	1133	337	17.3	103	1.0	1633	8.2
Loose tipped	**50:50**	23.3	1020	377	20	133	1.0	1500	8.3
	80:20	15.3	987	360	20	133	0.8	1567	8.3
Reduced subsoil (150 cm)									
Narrow track	**50:50**	4.0	793	243	25.3	210	0.9	2333	8.2
	80:20	5.7	643	247	23.0	147	0.6	1400	8.3
Wide track	**50:50**	7.0	730	260	20.3	180	1.1	1183	8.2
	80:20	3.3	700	247	38.7	187	0.6	1500	8.3
Loose tipped	**50:50**	3.3	623	287	44.0	180	0.9	1400	8.4
	80:20	4.3	633	273	20.7	123	1.3	1310	8.3

Table 2: Soil chemical analysis Jan 2008 (all figures mg/kg unless stated)

2.3 Leachates

Results indicate that loose tip emplaced plots experienced greater rates of leaching of mineral nitrogen (Figures 10, 11), particularly ammonium. This greater rate was also reflected in total nitrogen leaching rates (Figure 12).

There were no significant differences in leachate nitrogen concentration between compost mixes within the loose tip plots. However there is some evidence to suggest leaching rates of ammonium and total nitrogen are greater with the reduced rate of compost application (50-50 mix) from the bulldozer prepared plots (Table 3).

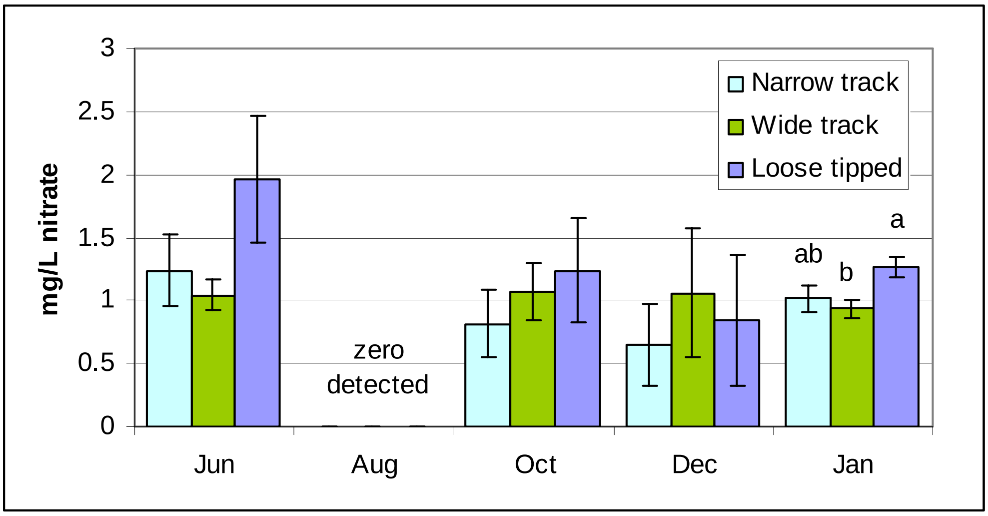

Figure 10: NO_3 leachate concentrations

Same letter or no letters indicate no significant difference between emplacement methods ($p > 0.05$)

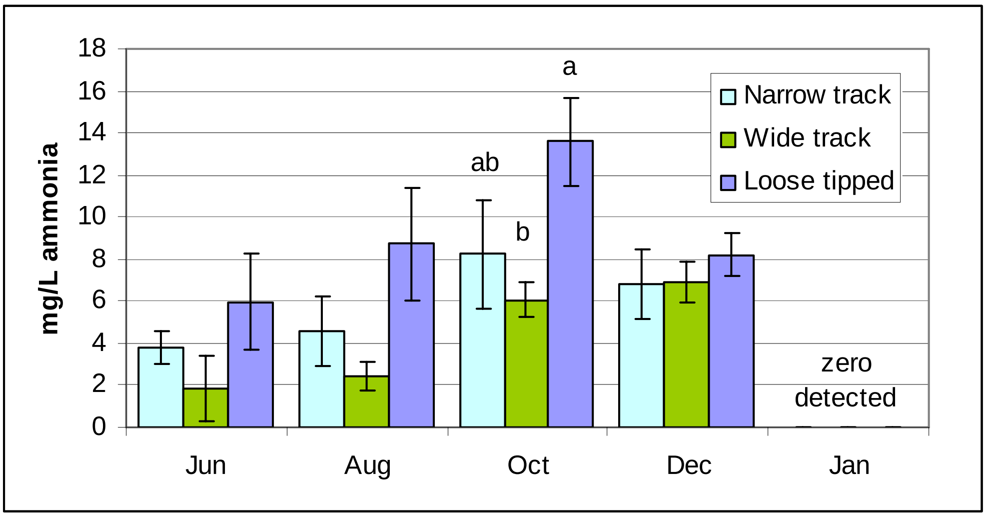

Figure 11: NH_4 leachate concentrations

Same letter or no letters indicate no significant difference between emplacement methods ($p > 0.05$)

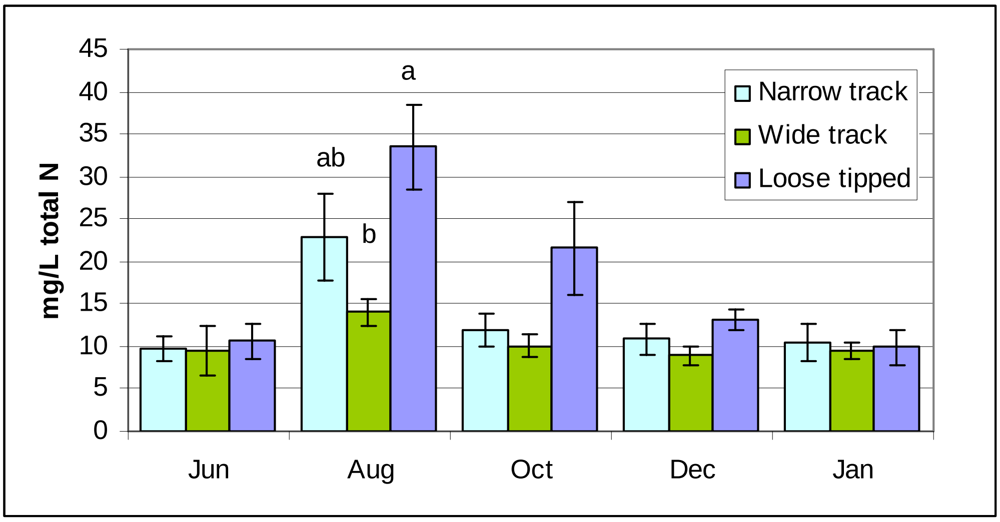

Figure 12: Total nitrogen leachate concentrations

Same letter or no letters indicate no significant difference between emplacement methods ($p > 0.05$)

		Jun	Aug	Oct	Dec	Jan
Emplacement	**GWC:PMC**		**NO_3**			
Narrow track	**50:50**	1.6	0	0.9	0.9	0.9
	80:20	0.9	0	0.8	0.5	1.1
Wide track	**50:50**	0.9	0	0.9	0.9	1.0
	80:20	1.2	0	1.3	1.2	0.9
Loose tipped	**50:50**	2.5	0	1.3	0.8	1.3
	80:20	1.4	0	1.1	0.8	1.2
			NH_4			
Narrow track	**50:50**	5.1	6.9	10.7	8.9	0
	80:20	2.6	2.2	5.7	4.7	0
Wide track	**50:50**	2.8	3.2	7.1	7.9	0
	80:20	0.5	1.6	5.0	5.9	0
Loose tipped	**50:50**	5.6	8.4	13.2	8.9	0
	80:20	6.4	9.0	14.0	7.5	0
			Total N			
Narrow track	**50:50**	9.2	26.3	13.9	12.9	11.9
	80:20	10.3	19.3	9.8	8.8	8.9
Wide track	**50:50**	10.2	16.0	11.2	9.8	10.8
	80:20	8.5	12.1	8.9	8.1	8.1
Loose tipped	**50:50**	9.5	28.7	25.6	14.0	9.5
	80:20	11.7	17.3	17.3	12.3	10.3

Table 3: Nitrogen leachate concentration (mg/l)

2.4 Soil gas concentrations

2.4.1 Carbon dioxide

Carbon dioxide concentrations in the reduced subsoil were significantly reduced than those in the upper subsoil from August to January. There were also large differences between land preparation methods. Loose tipped plots exhibited reduced carbon dioxide concentrations than bulldozer prepared plots during the monitoring period (Figures 13 and 14). There was no significant difference in carbon dioxide concentration between different rates of compost addition (Table 4).

Emplacement	**GWC:PMC**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**
				Upper subsoil (50 cm)						
Narrow track bulldozer	50:50	44.4	23.4	50.3	35.0	27.7	21.3	13.6	8.4	6.5
	80:20	40.9	49.7	58.3	38.6	35.3	19.5	21.8	18.1	17.7
Wide track bulldozer	50:50	65.1	43.7	63.3	50.2	32.7	23.7	16.0	18.4	19.8
	80:20	16.7	36.5	33.8	32.6	26.5	34.8	11.4	14.3	17.5
Loose tipped	50:50	15.4	12.0	13.4	10.1	1.8	8.1	3.1	2.9	2
	80:20	20.1	14.0	12.9	9.7	0.5	7.8	3.5	2.1	1.1
				Reduced subsoil (150 cm)						
Narrow track bulldozer	50:50	28.6	38.7	38.3	42.5	39.8	40.0	21.0	22.8	18.0
	80:20	8.9	51.0	60.0	47.4	45.8	39.1	26.9	35.9	26.0
Wide track bulldozer	50:50	35.2	53.3	44.7	57.8	54.4	48.3	34.1	36.6	29.2
	80:20	15.3	26.7	31.0	46.0	38.9	27.6	29.3	29.6	13.2
Loose tipped	50:50	24.0	12.9	20.0	28.1	23.9	20.6	9.6	9.9	7.7
	80:20	25.2	30.3	43.2	20.9	19.1	17.8	9.1	8.7	7.3

Table 4: CO_2 gas concentration (%)

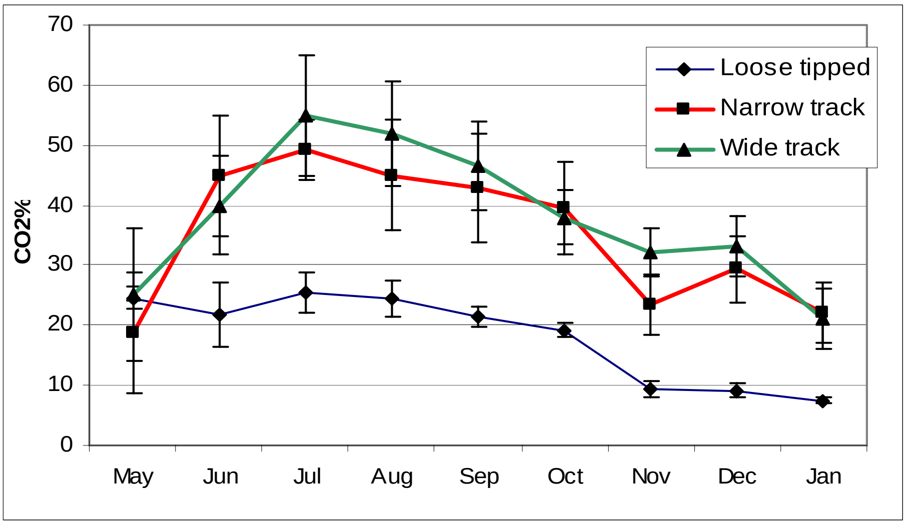

Figure 13: CO_2 gas concentration (50 cm depth)

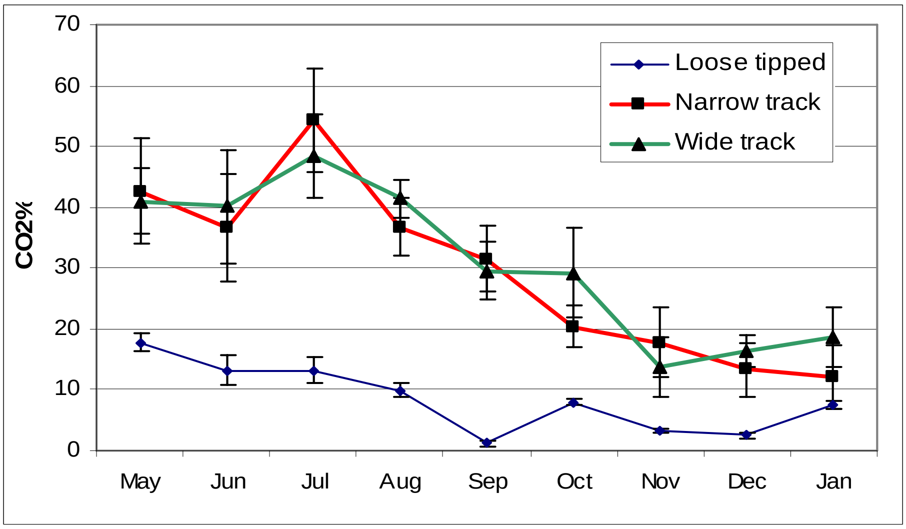

Figure 14: CO_2 gas concentration (150 cm depth)

2.4.2 Oxygen

Soil oxygen concentrations were found to be greater at the shalreduced sampling depth from September to January. Concentrations were not affected by organic amendment type (Table 5). However, they were affected by land preparation; loose tip emplaced plots had greater oxygen concentrations than bulldozer emplaced plots from September onwards at 50 cm depth, and from November onwards at 150 cm (Figures 15 and 16).

soil emplacement	GWC:PMC	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
					Upper subsoil (50 cm)					
Narrow track bulldozer	**50:50**	6.9	12.0	6.1	9.7	11.2	8.8	9.9	15.4	17.6
	80:20	8.8	3.3	1.9	6.5	8.0	11.2	9.1	10.7	10.4
Wide track bulldozer	**50:50**	1.7	6.3	2.5	4.1	9.6	6.1	8.0	7.5	6.5
	80:20	15.2	6.8	8.0	7.2	10.2	2.8	9.5	12.0	10.4
Loose tipped	**50:50**	10.0	11.2	12.3	13.4	19.4	13.1	16.6	17.0	18
	80:20	7.4	9.4	10.9	13.7	20.6	12.8	16.0	17.8	18.5
					Reduced subsoil (150 cm)					
Narrow track bulldozer	**50:50**	11.4	7.3	9.1	5.3	5.5	0.8	8.0	4.8	8.5
	80:20	17.9	3.9	2.0	3.2	3.9	2.2	4.9	0.4	7.0
Wide track bulldozer	**50:50**	10.3	5.2	3.7	2.6	2.5	0.4	5.9	1.9	5.1
	80:20	14.5	10.6	5.8	4.2	6.4	6.8	6.4	0.4	11.5
Loose tipped	**50:50**	6.0	11.6	3.6	2.8	3.6	1.7	11.4	10.6	14.2
	80:20	6.9	2.6	7.9	6.2	5.5	3.6	10.5	11.1	13.9

Table 5: 0_2 gas concentration (%)

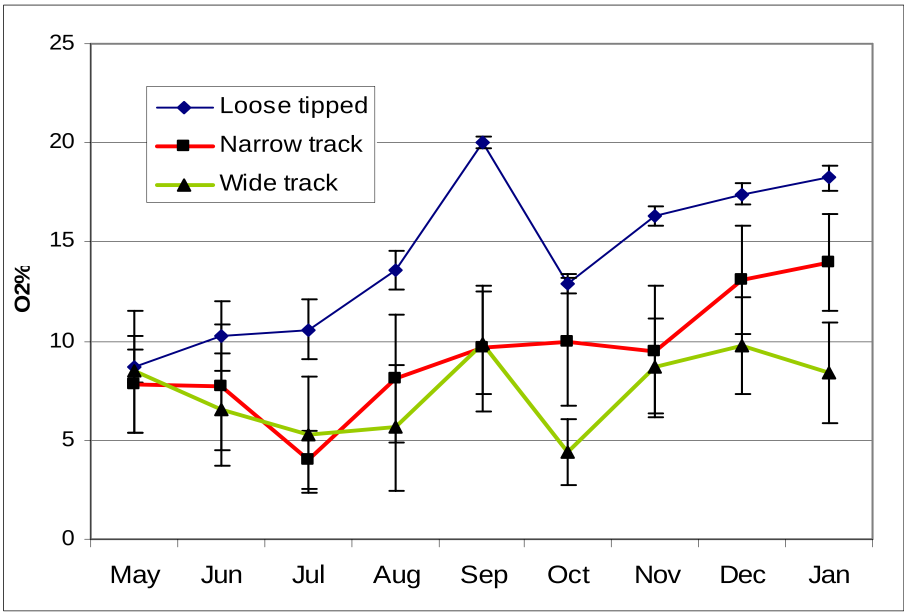

Figure 15: 0_2 concentrations (50 cm depth)

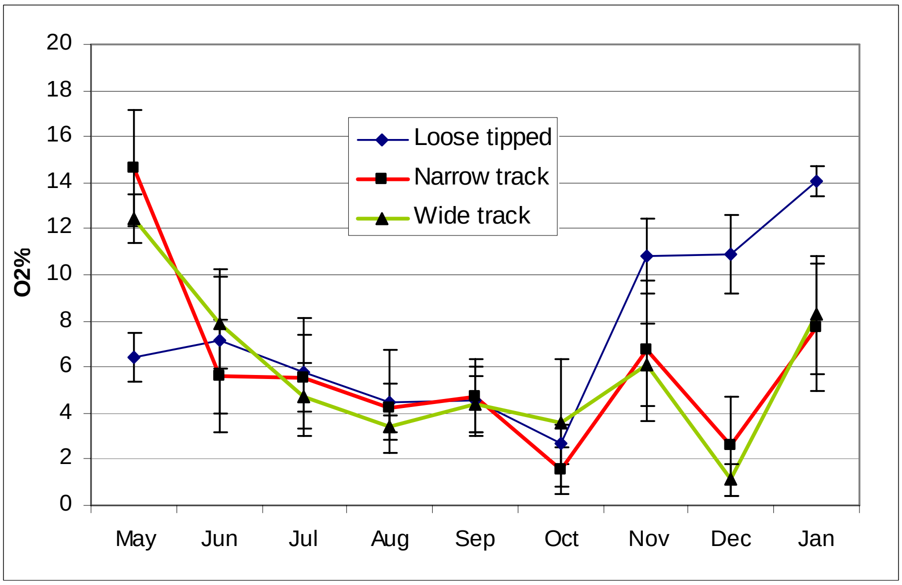

Figure 16: O_2 concentrations (150 cm depth)

2.4.3 Methane

Methane generation was very low or zero at both sample depths in the loose tipped plots and significantly reduced than the bulldozer placed plots (Figures 17 and 18) Rates of methane production differed little between compost treatment rates, although results indicated that production rates were greater from the upper subsoil when a wide track bulldozer was used in combination with 50:50 organic amendment mix (Table 6).

Emplacement	GWC:PMC	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
Upper subsoil (50 cm)										
Narrow track bulldozer	50:50	21.8	14.0	18.7	13.2	11.2	12.0	28.6	7.5	4.9
	80:20	10.3	29.8	35.2	25.1	21.0	20.5	24.4	20.7	17.9
Wide track bulldozer	50:50	10.3	29.8	35.2	25.1	21.0	20.5	24.4	20.7	17.9
	80:20	26.4	21.2	24.8	17.2	10.0	8.1	22.1	16.9	15.9
Loose tipped	50:50	2.8	21.5	26.4	23.7	15.9	16.6	22.8	17.1	17.3
	80:20	0	0.1	0.4	0	0	0	0.1	0	0
Reduced subsoil (150 cm)										
Narrow track bulldozer	50:50	21.8	14.0	18.7	13.2	11.2	12.0	28.6	7.5	4.9
	80:20	10.3	29.8	35.2	25.1	21.0	20.5	24.4	20.7	17.9
Wide track bulldozer	50:50	26.4	21.2	24.8	17.2	10.0	8.1	22.1	16.9	15.9
	80:20	2.8	21.5	26.4	23.7	15.9	16.6	22.8	17.1	17.3
Loose tipped	50:50	0	0.1	0.4	0	0	0	0.1	0	0
	80:20	0	0.3	0.1	0	0	0	0	0	0

Table 6: CH4 gas concentration (%)

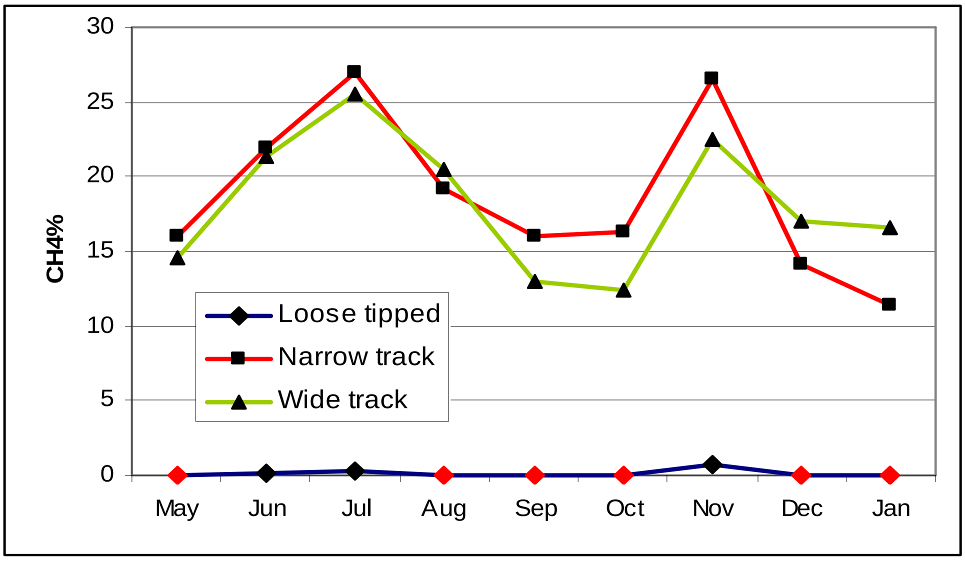

Figure 17: CH4 gas concentrations (50 cm depth)

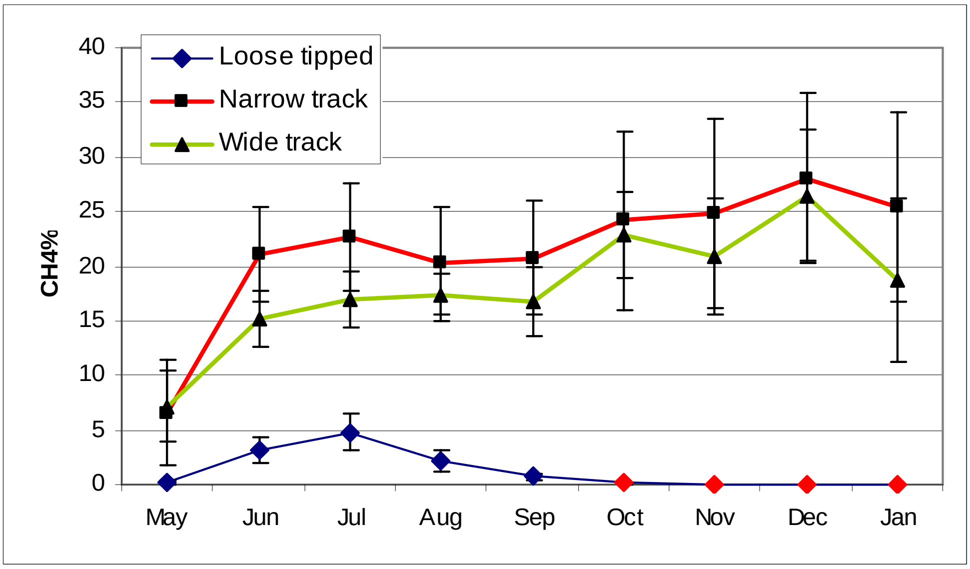

Figure 18: CH4 gas concentrations (150 cm depth)

2.5 Plant growth

Tree growth rates differed between land preparation methods and tree species, but were not significantly affected by upper subsoil organic amendment mix (Figure 19). Tree growth was significantly greater for loose tipped plots than either of the bulldozer emplaced plots. Using a wide tracked instead of a conventional bulldozer for emplacement did not result in any tree growth improvement. All tree species grew better on the loose-tipped plots (Table 7).

There was a notable pattern in the monthly growth rates between May and October 2007; the major difference in growth rates occurred between June and August when trees on the loose tipped plots grew significantly better than those on the bulldozer prepared plots (Figure 20).

	Tree Species				
Emplacement	**Hazel**	**Birch**	**Oak**	**Hawthorn**	**Mean**
Loose- tipped	45.5	45.2	8.2	19.5	30.9A
Narrow Track	41.4	25.3	6.7	6.3	19.1B
Wide Track	33.9	30.5	6.5	11.0	20.7B
Mean	40.1a	34.7a	7.1b	11.31b	

Table 7: Mean tree growth (cm) May-Oct 2007

Column means (species) and row means (emplacement method) with same letters are not significantly different (P>0..05)

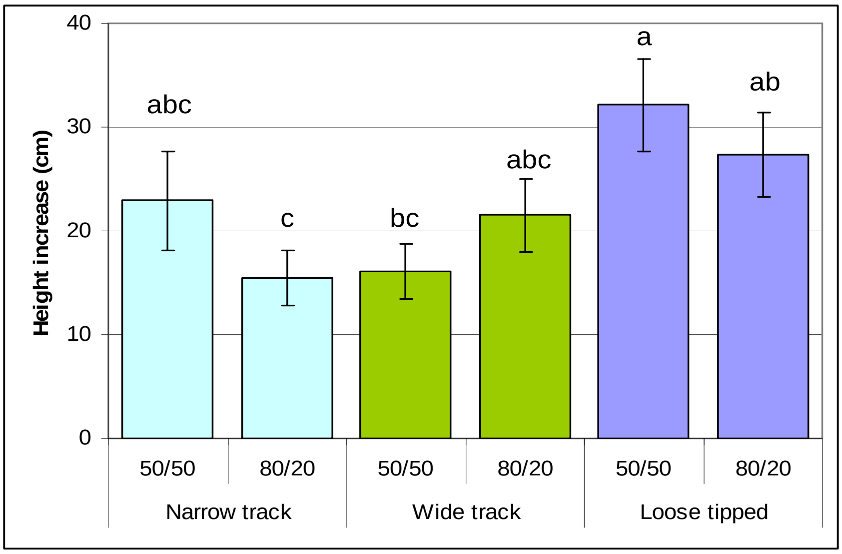

Figure 19: Total tree height growth May-Oct, 2007

Different letters indicate significant differences between emplacement methods (p<0.05).

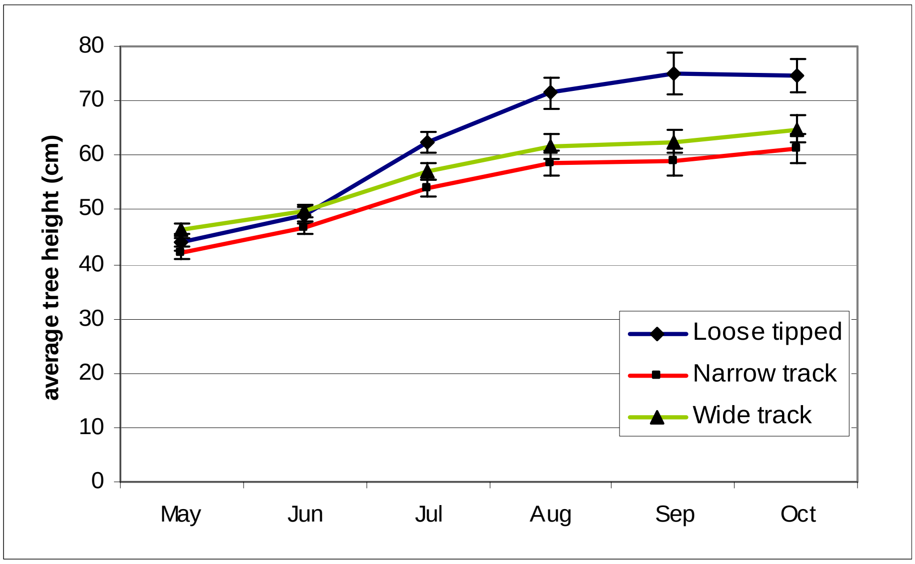

Figure 20: Tree height growth by land preparation May-Oct 2007.

2.5.1 General visual observations on plant health

No significant visual differences such as chlorosis were noted. Trees on the bulldozer emplaced soils appeared stunted in comparison to those on the loose tipped (Plate 5).

Plate 5. Loose tip plot in the foreground with all other plots in view being bulldozer placed.

Most roots on these bulldozer placed plots had not grown beyond the original planting holes and formed dense root balls. In some cases lateral extension had occurred through the site-won natural topsoil, but roots did not appear to have extended into the upper subsoil colliery shale material below approximately 20 cm (Plate 6). In contrast rooting was observed to at least 1 m in the loose tip emplaced plots (Plate 7).

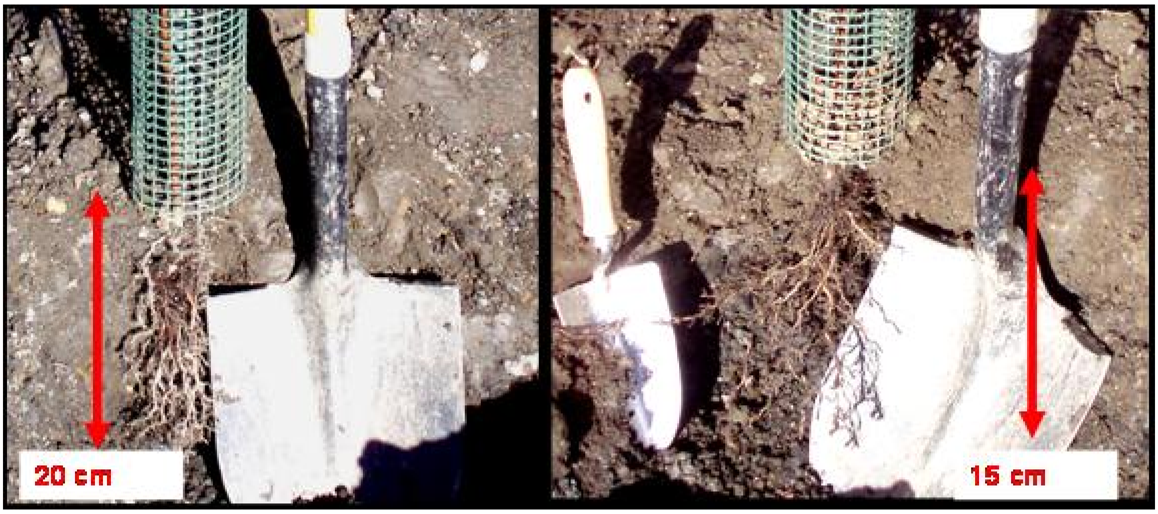

Plate 6: Tree root profiles wide track bulldozer emplaced (left) and narrow track bulldozer emplaced (right)

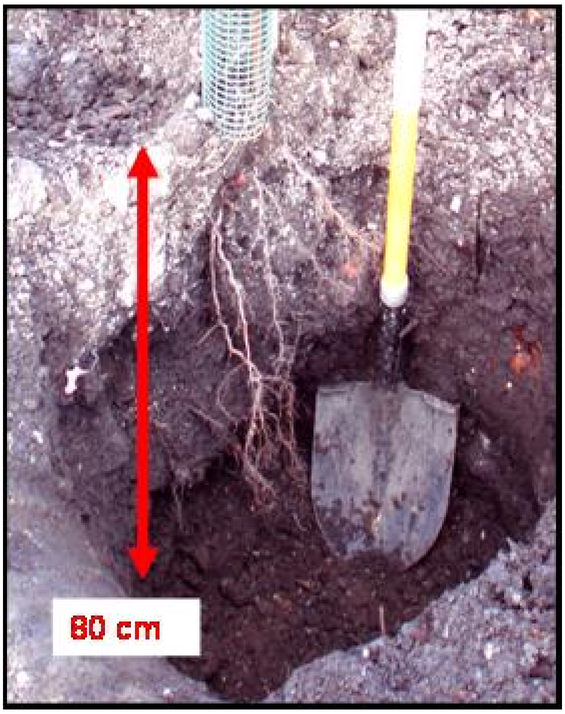

Plate 7: Tree root profile loose tip emplaced

2.6 Cost benefits of using PAS100 compost

To be assessed over winter 2007/2008.

Tree replacement verses cheaper method

3.0 Discussion of results

Tree growth

Direct comparison of trial tree growth rates with published figures is difficult due to variability between species, planting age, and density, soil type and climate. However, growth rate of tree seedlings on land prepared by loose tip emplacement are regarded as satisfactory. Although tree mortality was not observed on the bulldozer emplaced plots, rates of growth were relatively poor in all species. Observations at the end of the trial (Plates 5 and 6) indicated that stunted above-ground growth of trees on the bulldozer emplaced plots could be explained by restricted root extension.

Penetration resistance concentrations in the bulldozer emplaced plots were all at concentrations regarded as moderate in agricultural soils. Recorded concentrations in the loose tip emplaced plots were low (Table 8). Russell (1988) cites the evidence of numerous studies, and reports that resistance readings measured by penetrometer indicate impedance to plant root development at concentrations between 0.5 and 4MPa dependent on species. Evidence from this study indicates that tree root impedance occurred at concentrations above 1MPa. Loose tip emplaced plots exhibited resistance concentrations generally below the reduced threshold of 0.5 MPa.

The fact that elevated penetration resistance concentrations were not observed to ameliorate over the trial period (Figs 5 and 6) indicates a long term problem on bulldozer emplaced land. Soil ripping may provide an initial solution, but as previous studies have indicated, natural resettling over time, and limitations to maximum depth of sub-soiling operations (approximately 60 cm) make it unsatisfactory for long term establishment of woodland (Moffat, 1997; Moffat and Bending, 2000).

Class	Penetration resistance (MPa)
Small	<0.1
Extremely low	<0.01
Very low	0.01-0.1
Intermediate	0.1-2
Low	0.1-1
Moderate	1-2
Large	>2
Elevated	2-4
Very elevated	4-8
Extremely elevated	>8

Table 8: Soil penetration resistance classes
Source: Soil Survey Staff, 1990

Initial tree growth rates (May to July) did not appear to be affected by the restricted rooting on the bulldozer emplaced woodland (Figure 20). There are several likely explanations; firstly root extension in all plots would have taken some time, and translations into above-ground growth would be delayed. Secondly soil nutrient concentrations in the reclaimed topsoils were abnormally elevated, particularly mineral nitrogen (Table 1), a widely reported phenomenon in stockpiled topsoils (Davies et al., 1997). Thirdly the early summer of 2007 was unusually wet, experiencing moe than double the expected rainfall (Figure 21). These factors probably meant that water and nutrient deficiency which might otherwise occur due to restricted rooting on the bulldozer emplaced soils were not limiting during this period. The latter two variables are unusual situations unlikely to persist in the future. Elevated soil nutrient availability would be expected to decline relatively rapidly as available nutrients are fixed by soil organisms, extracted by vegetation or leached below the rooting depth (Davies et al., 1997). Soil moisture deficits in the summer are predicted to increase in the summer in the UK. It appears elevatedly likely that the concentrations of subsoil compaction caused by bulldozer emplacement observed in this trial will cause periodic nutrient and water stress affecting long term tree growth and survival rates due to a greatly reduced effective rooting depth. In the longer term, increased wind-throw hazard as a result of shallow rooting is a further likely problem.

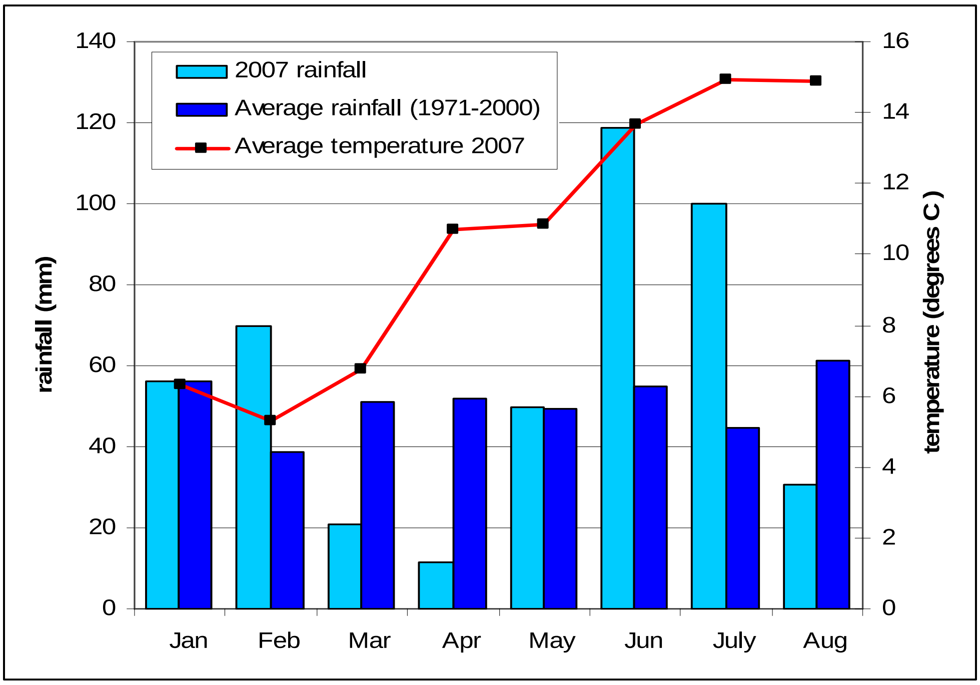

Figure 21: 2007 weather compared to long-term climatic average

Source: Durham Met office

Nutrient supply

Stockpiled topsoils commonly contain relatively elevated concentrations of available nutrients due to natural organic matter decomposition during the storage period. This appears to have occurred in the site-won topsoils used in this trail (see Table 1). Although this process increases short term availability, it commonly leads to a reduced capacity to supply these nutrients in the longer term (Davies et al., 1997). This reduced capacity will take a number of years to be ameliorated by the restoration of the natural nutrient cycle under woodland vegetation. Consequently the supply of nutrients provided by the upper subsoil is likely to be important to facilitate optimum vegetation growth in the medium term without future additions of artificial fertiliser.

Soil compaction by bulldozer emplacement appears to have had a negative effect on macronutrient availability. Despite greater vegetative growth (and nutrient uptake) coupled with greater rates of leaching, loose tipped subsoils were found to contain greater concentrations of nitrate and available phosphorous. The most likely explanation is that greater rates of aerobic soil microbial activity in the un-compacted upper subsoil of the loose tip emplaced plots resulted in greater mineralisation of added organic amendment materials. As the compaction problem is likely to persist in the bulldozer emplaced plots, it also appears likely that nitrogen and phosphorous supply will continue to be greater in the subsoils of the loose tipped plots. Although it is difficult to estimate the actual nitrogen supply potential of the loose tip plots, the tree growth rates, coupled with the appreciable concentrations of soil nitrate detected during later growing season indicate that supply was adequate to support optimum tree growth. Whether these concentrations will be sufficient to meet tree requirements for optimum growth in coming years as the available nitrogen in the topsoil declines, and the demands of the growing saplings increases is difficult to predict. However, what is clear is that the loose tip emplaced soil is much more efficient at meeting these requirements than that emplaced by bulldozer.

The greater concentration of ammoniumcal nitrogen in the subsoils of the bulldozer emplaced plots is further evidence of the adverse impacts of compaction. Mineralisation of organic nitrogen to ammonium is evidence of anaerobic soil microbial activity (Davies et al., 1995). The persistence of these elevated concentrations indicates an absence of nitrifying bacterial activity, which only occurs aerobically. Plant uptake of ammonium is much less efficient than that of nitrate, added to the fact that elevated penetration resistance will minimise plant root access to subsoil nitrogen reserves.

Although concentrations of ammonium in subsoils of the bulldozer emplaced plots were greater, rates of leaching of ammonium, nitrate and total nitrogen were significantly greater in the loose tipped plots. This indicates greater deep drainage in the less compacted loose tipped soils. However, as previously stated, nitrogen availability in loose tipped plots appeared to be adequate, and not adversely limited by leaching rates.

The choice of upper subsoil organic amendment did not have any significant impact on the rate of tree growth. However application of the 50:50 rate of compost to PMC to the upper subsoil resulted in significantly greater total nitrogen, available phosphorous and potassium than the 80:20. This evidence, combined with the greater ammonium concentrations in the upper subsoil of the bulldozer emplaced profiles indicates that this mix supplied greater amounts of mineral nitrogen. Although nitrate concentrations were not found to differ between amendments in the LT plots, it may well be the case that greater nitrate concentrations occurred using the 50:50 mix and were subsequently taken up by plants or lost as gaseous emissions. These findings indicate a greater available or readily transformed pool of these macronutrients in the paper mill crumb than in the compost. However as these differences appeared to have dissipated by the end of the first growing season without an impact on tree growth this cannot be viewed as a true advantage of this organic amendment.

Phtotoxins

Initial site analysis of colliery shale suggested zinc concentrations may be above reported phytoxic threshold concentrations of 300mg/kg (Moffat and McNeil, 1994). Following colliery shale mixing with organic materials to form subsoil materials zinc concentrations fell significantly, as the organic amendment materials employed were reduced in zinc than the colliery shale. Other potentially phytotoxic metals were well below threshold standards (Moffatt and McNeil, 1994).

Pollution of controlled waters

Although loose tip emplacement resulted in elevatedest leaching rates, monthly nitrate concentrations observed in groundwater borehole wells did not suggest that loose tip emplacement is likely to result in nitrate pollution problems using these soil forming materials. However measured ammonium concentrations were above the upper indicator threshold for river ecosystem classification of 9 mg/l^{-1} (RE5 Statutory instrument No. 1057, 1994) particularly using loose tip emplacement (Figure 11). Although these borehole well figures are not directly comparable with river water quality standards, concentrations appear sufficiently elevated given the proximity of planned woodland creation sites at Lambton to a stream and planned wetland creation scheme to justify further investigation and monitoring.

Gas generation

Elevated methane gas concentrations in the subsoils of the bulldozer emplaced plots further supports the assertion that soil compaction caused by this emplacement method resulted in anaerobic conditions The methane concentrations generated may have been able to cause ‘flash-over’ conditions as often found on restored landfill sites. This can result in spontaneous combustion and severe damage to newly established vegetation. Low or zero methane concentrations in the loose tip emplaced plots coupled with reduced CO_2 concentrations and greater O_2 indicates reduced anaerobic microbial activity in these plots.

Loose tip emplacement has been shown in previous studies to be an effective form of land emplacement on reclaimed industrial land, particularly well suited to woodland creation due to the avoidance of soil compaction in subsurface layers (refs? ….).

COST IMPLICATIONS?

4.0 Conclusions and recommendations

Loose tip costs more than
Compost costs more than

1. Using loose tip soil emplacement avoided the problems of compaction associated with bulldozer land preparation, resulting in much better tree root system development, superior soil aeration and greater supply of nitrate and phosphorous. The long term result of bulldozer compaction is likely to be poor tree growth and a elevated likelihood of tree fatality. Loose tipping emplacement method is strongly recommended to ensure optimum tree sapling growth.

2. Nitrogen leaching is greater with loose tipping as a result of more effective drainage. Concentrations of ammonium leaching may present an environmental risk and justify further monitoring and assessment.

3. Subsoil methane concentrations may present flash risks when land is compacted by bulldozer preparation, but are negligible using loose tip emplacement.

4. Overall, the organic amendments used as soil forming materials proved satisfactory for woodland establishment, but are not suitable without the loose tip emplacement method.

5. Either 50:50 or 80:20 organic mixes of green waste compost and paper mill crumb are suitable organic amendments for woodland soil manufacture (added to mineral material in ratio 2 parts organic matter to 5 parts colliery shale).

6. Overall benefits are more speed
    1. Less replacement
    2. Long term success

7. Further monitoring is recommended in particular to evaluate in the longer term:
    - Tree health
    - Soil annual moisture regimes
    - Nitrogen leaching rates
    - Phytotoxic metal availability
    - Soil development, particularly soil biological health indicators (organic matter, fungal mycorrhizal and microbial activity)

References

- Davies R. Hodkinson R. Younger A. and Chapman R, 1995. Nitrogen loss from a soil restored after surface-mining. *Journal of Environmental Quality* 24, 1215-1222.

- Davies R. Younger A. and Hodgkinson R. 1997. Soil nitrogen depletion: the threat from soil stockpiling. *Journal of the Institute of Environmental Sciences* 6, 7-10.

- Moffat A.J. 1995. Minimum soil depths for establishment of woodland on disturbed ground. *Arboricultural Journal 19*, 19-27.

- Moffat A.J. and Bending N.A.D. 2000. Replacement of soils and soil forming materials by loose tipping in reclamation to woodland. *Soil use and Management* 16, 75-81.

- Moffat A.J. and McNeil J.D. 1994. *Reclaming disturbed land for forestry*. Bulletin 110. HMSO, London.

- Russell E. W. (1988). *Russell's soil conditions and plant growth*. 11th. edition. A. Wild (ed.). Longmans Scientific and Technical.

- Soil Survey Divisions Staff, 1990. *Soil Survey Manual*. USDA-NRCS, Washington D.C.