Soil Compliance Monitoring Annual Report 2013 and 2014

Part II: Restoration sites

0 Summary

This report presents results from soil sampling carried out by SEPA as part of the 2013 and 2014 soil compliance monitoring campaigns, which investigated the impact of spreading organic materials to land. This report focuses on the result of waste application as part of the restoration of derelict land. A separate report is available on waste application to agricultural land.

Sites requiring restoration often completely lack any natural soil. The substrate present pre-restoration is usually poor in organic matter and nutrients, its structure is often impaired, and the substrate shows low biological activity.

Organic waste materials can provide the organic matter and nutrients needed to transform poor substrate often present at restoration sites to a viable growing medium/soil. However, care has to be taken that not too much material is applied, which can result in excessive nutrient and/or Potentially Toxic Element (PTE) concentrations in the created soil and can have negative environmental impacts.

The compliance monitoring did not check if required improvement of poor soil structure has been achieved.

SEPA-led research work subsequent to 2014 has uncovered examples of poor restoration practice, in particular sewage sludge being buried below 30cm of substrate. This has resulted in the sewage sludge not only failing to improve topsoil quality but also posing an environmental risk. The soil sampling method followed during the 2013 and 2014 campaigns did not pick up on issues involving buried waste material at restoration sites as sampling depth was not sufficient to do this.

Results from the 2013 and 2014 soil compliance monitoring campaigns provide evidence supporting the recommendation in the Sludge Review[1] to replace the current exemptions with a “whole project life” licence.

Recommendations:

- More detailed inspections during restoration activity would be useful to prevent poor practices, such as burying sewage sludge.
- Introduce “Whole project life” licences for long-term site restoration projects (replacing the current exemptions).
- Include visual evaluation of soil structure (VESS) in future regulatory evidence monitoring.
- Include soil inspections at depths greater than 25cm in future regulatory evidence monitoring.

1 Introduction and background

In 2013 and 2014 SEPA included restoration sites in the soil monitoring programme.

At restoration sites, organic material is applied for the purpose of ‘ecological improvement’ of derelict or abandoned land, such as disused quarries and opencast mines, under paragraph 8(2) or paragraph 9 exemptions (schedule 1 of the Waste Management Licensing Regulations 2011). Restoring an old habitat that previously existed before it was destroyed or degraded by human activity such as quarrying or mining qualifies as ecological improvement under the legislation, thus returning land back to agricultural use is regarded as ecological improvement. The activity must

[1] Review Of The Storage and Spreading Of Sewage Sludge on Land In Scotland (The Sludge Review): Final Recommendations

comply with the relevant objectives stated in Schedule 4 of the 2011 Regulations, as amended and must not endanger human health or harm the environment.

Sites to be restored often completely lack any natural soil. The substrate present pre-restoration is usually poor in organic matter and nutrients (nitrogen (N), phosphorous (P), to a lesser extent potassium (K) and magnesium (Mg)). Its structure is usually impaired through previous heavy machinery movement, and the material generally shows low biological activity. The pH might also be unfavourable for vegetation growth.

The application of organic waste materials is intended to
- create a fertile soil for potential various later land uses;
- incorporate sufficient organic matter, which will help to improve soil water retention, soil structure, nutrient holding capacity, and biological activity;
- provide sufficient nutrients to establish a stable vegetation cover;
- establish a favourable soil pH for the intended land use.

The use of organic waste material in restoration projects also has additional benefits such as
- recovery of resources from waste materials;
- reduction of environmentally unsustainable disposal routes such as landfilling;
- reduction in the use of virgin resources.

In order to produce a soil with reasonably high organic matter content, a substantial amount of organic material is needed, which is usually applied at much higher rates than on agricultural land. Material used for site restoration, such as raw sewage sludge and off-spec compost, is also often less suited for agricultural use. Most organic materials used are high in available nutrients, which can be transferred to watercourses or groundwater through leaching or erosion, leading to downgrades in water quality since nutrient uptake is limited within the first year of restoration.

Therefore, concerns have been raised about the impact of this activity on soil quality and the wider environment. This report presents the findings of SEPA soil monitoring.

2 Sites

Soil samples were taken at four restoration sites in 2013 and 2014 (for more details see annex 1 Table 1).

Sites 1-3 are previous opencast coalmines situated in the central belt. The present substrate has a high clay and stone content and shows signs of severe compaction from heavy machinery. Raw sewage sludge was used at all three sites for restoration at an application rate between 150 and 420t/ha fresh weight.

Site 4 was a former industrial site in Ayrshire. Here the substrate is sandy. About 10,000t/ha of off spec compost was used to restore the site.

3 Methods

Soil sampling followed the sampling method developed for soil compliance monitoring of agricultural sites based on the method described in the Sludge use in Agriculture Regulations 1989. Restoration sites were divided into discrete areas for sampling and a representative soil sample was collected in each area by using a soil auger to take 25 subsamples in a W-shaped pattern across the whole of this area, then reducing to a suitable volume for bagging by mixing and coning and quartering. Maximum sampling depth was 25cm, but some samples were taken to shallower depths due to high stone content preventing penetration of the auger.

Samples were analysed by UKAS accredited external laboratories for:

- pH;
- total carbon[2] and total nitrogen;
- extractable[3] phosphorous, potassium and magnesium;
- total cadmium, chromium, copper, lead, nickel, zinc and mercury;
- microbial biomass carbon.

At a sub-set of sites earthworm were collected separately and analysed by SEPA.

4 Results

At each site two or three treated areas (where organic waste material was applied) and one non-treated reference area were sampled. At site 2 an area with suspected unauthorized sludge application was also sampled.

The results from the treated areas are compared with the non-treated (reference) areas at each site. It is assumed that the treated and reference areas were similar in their characteristics before waste application and therefore if soil properties in the treated areas differ from those in the reference areas these differences were caused by spreading. However, because some of the sampling took place once most or all of the site had been restored, it is not always clear how representative reference areas are of the whole site before restoration.

Analytical results for all parameters and sites are provided in Annex 2.

Soil pH

At two of the four sites (site 1 and 4) the pH of the reference area was unfavourably low; pH in spread areas was higher, indicating that waste application generally improved the situation.

Soil organic matter

Only one of the four reference areas had a low organic matter content and this was the former industrial site (site 4). The compost application increased the soil organic matter content of the soil to unnaturally high levels, especially for a sandy soil.

The reference areas of the three coalmine sites already had soil organic matter concentrations of 7.7% or higher. This amount is already relatively high, given that the average soil organic matter concentration in agricultural soils in Scotland is within a similar range[4]. However, the substrates at coalmine sites often contain small particles of waste coal, which increases the carbon concentration and thus the calculated organic matter results. The coal carbon does not have the same properties as organic matter has and therefore the higher concentration is not necessarily a sign that no additional organic matter is required to create a viable soil. Of the three opencast coalmine sites, site 1 was the only one where the application of sewage sludge increased the organic matter concentration in the soil, at site 2 and 3 this was not observed for most of the treated areas sampled.

Soil nitrogen

[2] Carbon measurement is a surrogate for measuring the soil organic matter content since soil organic matter consists of around 58% carbon.
[3] Extractable nutrients were measured in modified Morgan's extract (SAC method).
[4] According to SEPA's soil compliance monitoring results 8% is the average soil organic matter content of all sampled agricultural fields.

There is a statically significant relationship between total carbon and total nitrogen concentrations in soils sampled at the restoration sites. This is because most of the soil nitrogen is bound in the organic matter and therefore its concentration in the soil is related to the amount of organic matter in the soil.

Extractable phosphorous

All four reference areas have a low extractable phosphorous content. The waste application increased the extractable phosphorous content of almost all treated areas. However only site 1 achieved a reasonable concentration in the restored soil. At site 2 extractable phosphorous was still below optimum in soil in the restored areas, site 3 shows some areas with too high and some with too low extractable phosphorous levels, and at site 4 the restored areas show excessively high amounts of extractable phosphorus. The latter is a clear indication of over-application, posing a risk of phosphorus leaching to groundwater and/or being transported to surface water, which could have negative impacts on water quality.

Extractable potassium

Two of the four reference sites have a low extractable potassium content. Waste application generally increased extractable potassium content to favourable levels. At site 4 compost application resulted in extremely high extractable potassium levels – again indicating over-application.

Potential toxic elements (PTE)

Soil PTE concentrations are compared to limits from the Sludge (Use in Agriculture) Regulations 1989. Although these limits are not legally binding for restoration sites, it is important to prevent soil PTE concentrations reaching levels close to or above these limits, especially where the land is to be returned to agricultural use.

At site 4, which received off-specification compost, copper and zinc concentrations are both well in exceedance of the limits set out in the 1989 Regulations. The soils also contain substantially higher cadmium and lead concentrations in the treated area than the reference area; however these PTE do not exceed the soil limits. These high soil PTE concentrations are likely a result of elevated concentrations in the compost combined with excessive spread rates.

For the three former opencast coalmine sites, there is no consistent evidence of PTE enrichment resulting from sewage sludge spreading to land. Often the reference area has the highest PTE concentration for certain elements. This could be because of low input of such elements and natural variability.

Microbial biomass

At two of the four untreated areas (sites 1 and 4) microbial biomass was low. At these two sites organic waste application increased the microbial biomass significantly in tandem with increased carbon content. At the other two sites (sites 2 and 3) microbial biomass also reflected soil carbon concentration. Since the carbon concentration did not follow any pattern, none can be seen for microbial biomass either.

Despite the fact that microbial biomass is related to carbon content in the soil, the ratio between those two (microbial biomass carbon to soil carbon (Cmic/Ct)) provides further insight into the availability of the soil carbon present. Low Cmic/Ct ratios (<1) indicate that the carbon is not easily available to the microorganisms. This can be seen at site 4, where large amounts of compost were applied. Although the microbial biomass has increased significantly the Cmic/Ct ratio is low, indicating that the carbon present in the compost is very stable. The high concentration of some PTE could also have a negative impact on the Cmic/Ct ratio.

On the other hand, at site 1 the increased carbon content also resulted in increased Cmic/Ct ratio, indicating that the applied raw sewage sludge is likely providing easily available carbon. No clear pattern in the Cmic/Ct ratio can be detected for site 2 and 3. At all open coalmine sites, the presence of coal particles has likely an impact on the Cmic/Ct ratio by lowering it by an uncertain amount. This limits the conclusion that can be drawn from the results.

Earthworms

Earthworms were only sampled at areas from site 1 and 2. The species number was surprisingly high at most sampled areas, however the abundance and biomass were (very) low.

At site 1 the abundance, biomass and number of species present were extremely low in the reference area but were significantly higher in the restored areas. Species composition in treated areas was very unusual, not reflecting natural species composition. Remarkably high numbers of species favouring wet soils were found in the treated area, potentially reflecting the ongoing wet site condition of these areas.

At site 2 the earthworm numbers (abundance, biomass and species numbers) of the reference area doesn’t differ much from the restored areas, indicating no obvious impact from the sewage sludge application. Again, most species present prefer moist to wet soils.

5 Conclusions and recommendations

Using organic waste materials can provide the organic matter and nutrients required to transform poor substrate often present at restoration sites into a viable growing medium/soil. Site 1 is a good example for this.

Care has to be taken that not too much material is applied. Site 4 is a good example where waste application resulted in extremely high concentrations of organic matter and nutrients and even exceeding some of the PTE levels specified in the Sludge (Use in Agriculture) Regulations 1989. This emphasises the need for application rates to be checked by (qualified) soil scientists before a paragraph 8 or 9 exemption is registered.

Results from sites 2 and 3 are very inconclusive and don’t show any obvious improvements from the waste application. Based on the analytical results it was not possible to establish for certain if area 2e received sewage sludge or not. More detailed examination of these sites as part of a later research project established that the majority (if not all) of the applied sewage sludge has been buried below 30cm of substrate and was not mixed properly within the top 30cm. This resulted in the sewage sludge not only failing to improve the topsoil but also posing an environmental risk. <u>Recommendation 1:</u> More detailed inspections during restoration activity would be useful to prevent poor practices.

The use of “poor-quality” organic materials, such as raw sewage sludge or off specification compost, in restoration projects in large quantities needs particular care to ensure no environmental harm occurs and restoration success is achieved. <u>Recommendation 2</u>: Introduce “Whole project life” licences for long-term site restoration projects (replacing the current exemptions), to enable effective long-term planning of projects and tighter, closer, more resource-efficient regulation of these projects.

The compliance monitoring only included soil chemical and biological parameters, and did not take into account the need to improve soil physical properties, especially soil structure, at most of the sites. It is generally assumed that this will automatically be achieved by adding organic material. However, depending on the properties of the organic material added this might not be the case. Raw sewage sludge, for example, generally has a relatively high water content making it difficult to mix it properly with clayey substrates, resulting in a highly variable distribution of the sludge in the created soil. Recommendation 3: Include visual evaluation of soil structure (VESS) in future regulatory evidence monitoring.

The applied soil sampling method does not necessarily pick up bad restoration practice such as burying waste material at depths greater than 25cm. Recommendation 4: Include soil inspections at depth greater than 25cm in future regulatory evidence monitoring.

Claudia Erber on behalf of the SEPA Soil Science Working Group, July 2018

Annex 1: Sites

Table 1: Information on restoration sites sampled in 2013 and 2014.

Site	Site characteristics	Material applied	Areas sampled
1	opencast coal mine	raw sewage sludge; applied 2-15 months prior to sampling application rate: 150-450t/ ha	1a reference area, 1b & 1c treated area
2	opencast coal mine	raw sewage sludge, unknown application time, application rate:150-450t/ ha	2a reference area, 2b, 2c & 2d treated area, 2e area suspected of receiving unauthorised sludge application
3	opencast coal mine	raw sewage sludge, applied approximately 8 months prior to sampling, application rate: 152t/ ha	3a reference area, 3b, 3c & 3d treated area
4	former industrial site	off-specification compost, applied 1 year (site 4d) and >4 years (site 4b & 4c) prior to sampling application rate: 10,000t/ ha (site 4d), unknown for site 4b and 4c	4a reference area, 4b, 4c & 4d treated area

Annex 2: Results

Table 2: Data for chemical parameter and microbial biomass

area	ha	pH	P* (mg/l)	K* (mg/l)	Mg* (mg/l)	C† (%)	SOM# (%)	N† (%)	C:N	Cd† (mg/kg)	Cr† (mg/kg)	Cu† (mg/kg)	Hg† (mg/kg)	Ni† (mg/kg)	Pb† (mg/kg)	Zn† (mg/kg)	Cmic~ (mg/kg)	Cmic: Ct
1a	3.9	7.4	0.8	123	410	4.5	7.7	0.11	40.8	0.11	42.1	32.8	<0.05	41.7	25.5	77.5	186	0.41
1b	8.3	7.1	20.1	123	398	5.9	10.1	0.27	21.7	0.21	44.3	54.7	<0.05	41.5	43.5	101.6	476	0.81
1c	2.6	5.8	8.9	150	430	13.0	22.4	0.55	23.6	0.20	38.7	41.3	<0.05	38.4	37.3	82.3	1022	0.79
2a	0.35	5.2	1.1	59	94	4.7	8.0	0.27	17.3	0.27	36.4	86.7	0.40	18.8	202.3	74.6	571	1.23
2b	0.75	6.2	1.6	112	310	3.8	6.5	0.18	21.2	0.13	48.2	28.8	0.15	37.0	38.2	66.3	440	1.15
2c	0.3	5.8	1.7	89	146	10.2	17.5	0.43	23.8	0.26	45.1	31.7	0.20	23.7	63.6	69.6	798	0.78
2d	0.05	5.4	2.5	63	183	3.5	6.0	0.21	16.8	0.10	50.6	26.0	0.15	25.1	32.7	50.9	540	1.53
2e	0.25	5.4	3.2	115	540	9.4	16.2	0.32	29.2	0.13	45.0	30.1	0.08	48.3	23.6	73.7	755	0.81
3a	0.6	4.7	1.9	55	139	14.4	24.8	0.66	21.8	0.27	30.6	21.8	0.06	31.0	13.7	67.1	985	0.68
3b	9.6	6.6	42.8	107	317	4.4	7.6	0.31	14.3	0.17	36.5	32.8	0.05	34.7	21.2	90.6	906	2.04
3c	1.25	5.4	3.0	86	237	7.3	12.6	0.34	21.5	0.11	28.8	21.6	0.06	25.0	21.2	44.7	794	1.09
3d	0.6	6.2	1.4	96	412	7.8	13.4	0.32	24.4	1.35	32.1	23.9	0.10	31.5	18.4	189.7	542	0.69
4a	No data	7.9	3.7	87	61	1.1	1.9	0.06	18.2	0.32	35.6	150.9	0.23	37.7	132.5	153.1	257	2.35
4b	No data	7.4	126.0	730	563	18.2	31.3	1.54	11.8	0.65	97.4	60.4	0.16	25.6	158.6	258.8	1044	0.57
4c	No data	7.5	102.0	772	393	18.1	31.1	1.54	11.8	1.09	67.8	154.7	0.31	28.0	256.1	466.8	1368	0.75
4d	No data	7.8	39.1	587	339	14.7	25.3	0.75	19.6	0.62	33.8	55.0	0.21	26.1	442.8	811.8	1420	0.96
min		4.7	0.8	55	61	1.1	1.9	0.06	11.8	0.10	28.8	21.6	<0.05	18.8	13.7	44.7	186	0.41
max		7.9	126.0	772	563	18.2	31.3	1.54	40.8	1.35	97.4	154.7	0.40	48.3	442.8	811.8	1420	2.35
median		6.2	3.1	110	328	7.6	13.1	0.32	21.3	0.24	40.4	32.8	0.13	31.2	37.8	79.9	774	0.81
mean^		6.4	22.5	210	311	8.8	15.1	0.49	21.1	0.37	44.6	53.3	0.14	32.1	95.7	167.5	756	1.04

* extractable, † total, # SOM = soil organic matter, calculated from total carbon by multiplying with 1.72, ~ microbial biomass carbon, ^ The mean concentration was calculated by assigning a value of half the detection limit to all results where measured concentration was below detection limit.

Table 3: Earthworm sampling results

area	ha	species number	total abundance	total biomass	species
1a	3.9	3	27	5.8	Allolobophora chlorotica (green morph), Lumbricus castaneus, Lumbricus rubellus
1b	8.3	12	250	45.4	Allolobophora chlorotica (green and pink morph), Aporrectodea caliginosa, Aporrectodea longa, Aporrectodea rosea, Dendrobaena octaedra, Dendrodrilus rubidus,Eiseniella tertraedra, Lumbricus castaneus, Lumbricus festivus, Lumbricus rubellus, Satchellius mammalis
1c	2.6	9	396	74.2	Allolobophora chlorotica (pink morph), Aporrectodea caliginosa, Aporrectodea rosea, Dendrobaena octaedra, Dendrodrilus rubidus,Eiseniella tertraedra, Lumbricus castaneus, Lumbricus rubellus, Octolasion tyrtaeum
2a	0.35	9	190	45.6	Allolobophora chlorotica (green morph), Aporrectodea caliginosa, Aporrectodea longa, Aporrectodea rosea, Dendrobaena octaedra, Lumbricus rubellus, Lumbricus terrestris, Octolasion cyaneum, Octolasion tyrtaeum
2b	0.75	5	125	38.5	Allolobophora chlorotica (green morph), Aporrectodea caliginosa, Aporrectodea rosea, Octolasion tyrtaeum
2c	0.3	9	242	71.7	Allolobophora chlorotica (green and pink morph), Aporrectodea caliginosa, Aporrectodea longa, Aporrectodea rosea, Dendrobaena octaedra, Dendrodrilus rubidus, Lumbricus castaneus, Lumbricus rubellus
min		3	27	5.8	
max		12	396	74.2	
median		9	216	45.5	
average		8	205	46.9	