SEPA
Scottish Environment
Protection Agency

Soil Compliance Monitoring Annual Report 2009

Introduction and background

Scotland's soil is one of the nation's greatest natural assets. Soil quality is typically defined as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health.

SEPA's State of the Environment Soil Quality Report 2001 recognised the importance of soil and the functions it provides. It identified the main pressures on soils and recognised that there was a lack of data available to determine resulting impacts on soil quality. One of the main pressures identified was the application of organic materials to land, either under a Paragraph 7 exemption from the Waste Management Licensing Regulations (1994), or under the Sludge (Use in Agriculture) Regulations (1989). There is evidence of increasing application of organic material to land in Scotland in Figure 1.

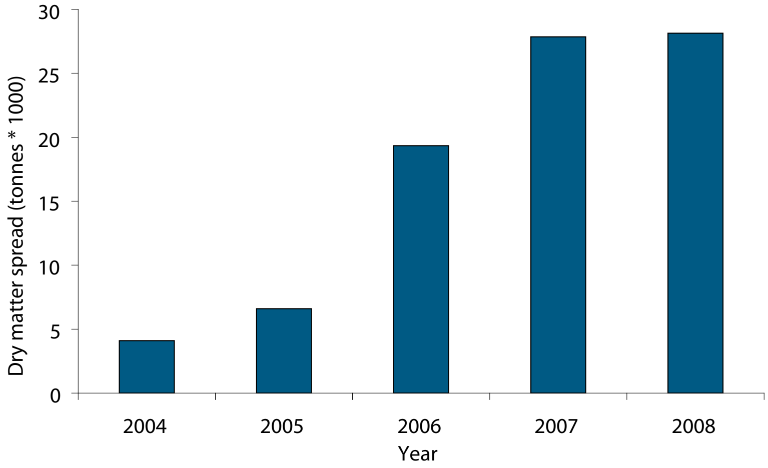


Figure 1: Amount of sewage sludge (in kilotonnes dry matter) spread to agricultural land by Scottish Water.

In order to monitor the effects of applying organic materials on soil quality, a soil compliance monitoring strategy for SEPA-regulated activities that impact on soil was developed and implemented in 2007. This monitoring allows SEPA to audit compliance with the Sludge (Use in Agriculture) Regulations (1989). This report summarises results from soil monitoring carried out in 2009.

Methods

SEPA staff sampled soils from 75 fields at 19 farms. Samples were taken from fields across Scotland to which a variety of organic materials were applied for agricultural benefit, including sewage sludge, distillery waste, food processing waste and off-specification compost[1] (Figure 2). To put this into context, SEPA sampled 22 out of about 790 fields receiving sewage sludge. Samples were analysed for:

- pH;
- total carbon and total nitrogen;
- extractable phosphorous, potassium and magnesium;
- total cadmium, chromium, copper, lead, nickel, zinc and mercury;
- microbial biomass carbon;
- earthworms (collected at a sub-set of fields).

One representative soil sample was taken from each field and analysed by external laboratories for all the above soil quality indicators except earthworms, which were sampled separately and analysed in-house.

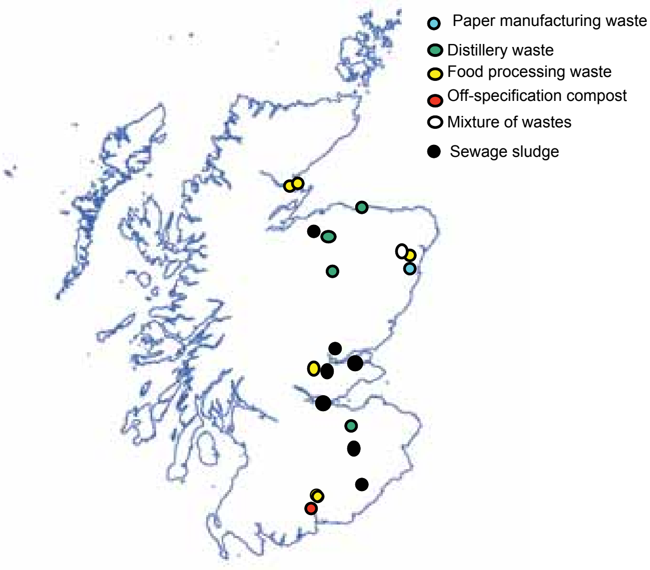


Figure 2: Locations of farms sampled in 2009 and organic material types applied.

[1] Off-specification compost is composted material which does not meet the required standard (PAS100) for it to be legally sold as a product.

Results

Mean, median, maximum and minimum values for soil quality indicators are shown in Table 1 and for earthworms in Table 2. Soil quality was generally found to be good, although there was one instance where the nickel concentration was very close to the permitted maximum set out in the Sludge (Use in Agriculture) Regulations.

Table 1: Mean, median and ranges for each parameter measured (except earthworms).

Parameter	Unit	Mean	Median	Minimum	Maximum	N
pH		6.0	5.9	5.0	7.3	75
P*	mg l^{-1}	7.0	6.2	1.0	23.3	75
K*	mg l^{-1}	144	129	39	368	75
Mg*	mg l^{-1}	150	131	33	411	75
C†	%	4.3	3.7	1.4	16.6	75
N†	%	0.35	0.30	0.12	1.43	75
C:N		12	12	9	17	75
Cd†	mg kg^{-1}	0.17^	0.22	<0.10	0.45	75
Cr†	mg kg^{-1}	35.0	32.3	7.7	144	75
Cu†	mg kg^{-1}	19.9	18.9	5.0	66.3	75
Hg†	mg kg^{-1}	0.10^	0.08	<0.04	0.59	75
Ni†	mg kg^{-1}	19.6	16.2	2.9	63.5	75
Pb†	mg kg^{-1}	23.8	21.5	7.6	59.3	75
Zn†	mg kg^{-1}	54.9	56.4	16.9	105	75
Cmic~	mg g^{-1}	636	560.3	214	2088	75
Cmic:Ct	%	1.60	1.49	0.51	3.42	75

*extractable, †total, ~microbial biomass carbon, ^The mean concentration is calculated using a value of half the detection limit for all data, where measured concentration is below the detection limit.

Table 2: Mean, median and ranges for earthworm parameters measured.

Parameter	Unit	Mean	Median	Minimum	Maximum	N
Species number		5.6	5.0	2	9	42
Total abundance	Ind m^{-2}	328	316	29	949	42
Adult abundance	Ind m^{-2}	95	93	10	233	42
Total biomass	g m^{-2}	91	85	10	186	42
Adult biomass	g m^{-2}	43	42	6	91	42

Effects of organic material application on soil quality

The soil quality indicator data was analysed at both a national and a local scale. Nationally, the results were averaged on the basis of waste applied; locally they were compared with a reference field on a farm by farm basis.
Scotland-wide, extractable phosphorus concentrations were, on average, higher in soils receiving sewage sludge than in reference fields (Figure 3). In 2008, earthworm abundance was lower in fields receiving distillery waste than in reference fields, but in 2009 there was no apparent difference (Figure 4). Concentrations of most metals were similar in reference fields and fields receiving sewage sludge and distillery waste. However, although Figure 5 indicates that median copper concentrations

in reference fields and fields receiving distillery waste were similar, it also shows that some fields receiving distillery waste contained substantially higher copper concentrations than reference fields. This could be a result of accumulation over time in these fields, as distillery wastes typically have high copper content.

Figures 3, 4 and 5 also illustrate that there are extensive overlaps in the range of values of the soil quality indicators between fields receiving either sewage sludge or distillery waste and reference fields, suggesting that differences were not significant. These overlaps reflect the variability of natural factors, such as parent material, and human influences, such as land use, that mask the influence of the application of organic materials on soil quality. For example, earthworm abundance varied according to land use in the fields sampled in 2009 (Figure 6). It is also likely that the physical form of organic materials applied to land will influence its impact on soil quality indicators. Sewage sludge, for example, may be applied to land as a slurry, dried pellets, or dried cake (which may or may not be lime-stabilised). The form of the organic material, in addition to land management practise, will govern how rapidly and thoroughly it is incorporated into the soil and, therefore, the overall impact on soil quality indicators.

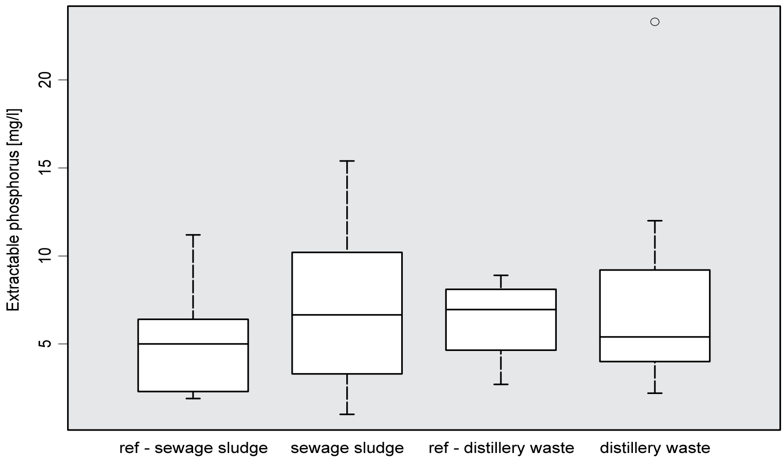


Figure 3: Extractable phosphorus for reference fields and fields where sewage sludge or distillery waste was applied. Box and whisker plot with the bottom and top of the box being the lower and upper quartile and the band near the middle of the box the median. The ends of the whiskers represent the closest points within the 1.5 interquartile range. Data not included between the whiskers are plotted as a small circle.

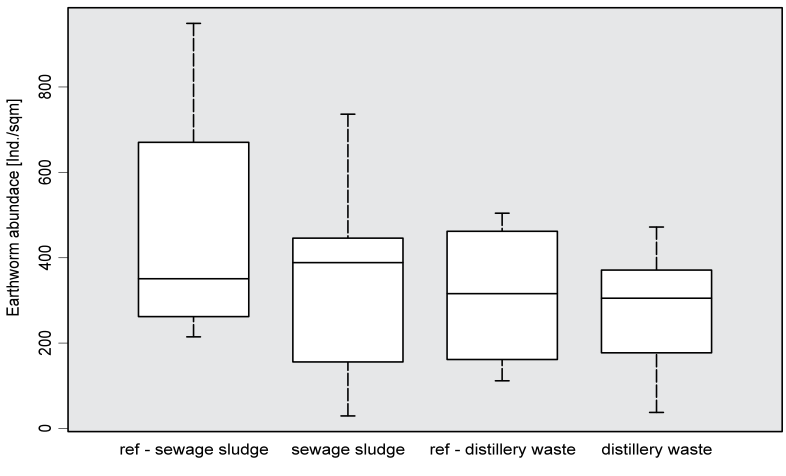


Figure 4: Earthworm abundance for reference fields and fields where sewage sludge or distillery waste was applied. See Figure 3 for explanation of the box and whisker plot.

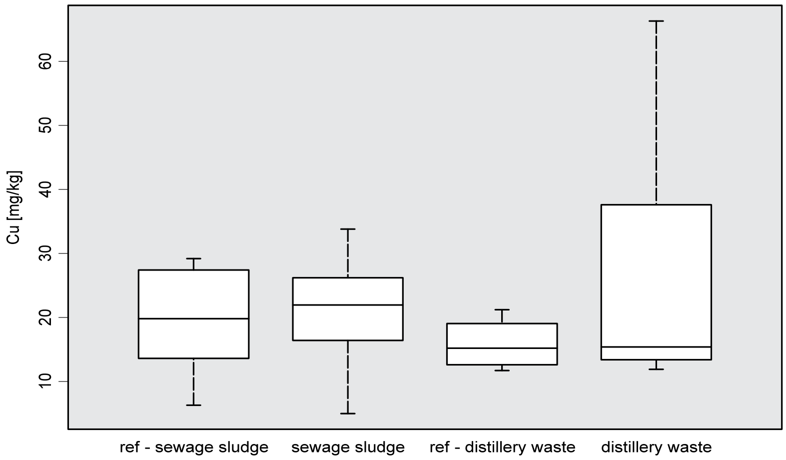


Figure 5: Comparison of copper concentrations in fields receiving sewage sludge, distillery waste and reference fields. See Figure 3 for explanation of the box and whisker plot.

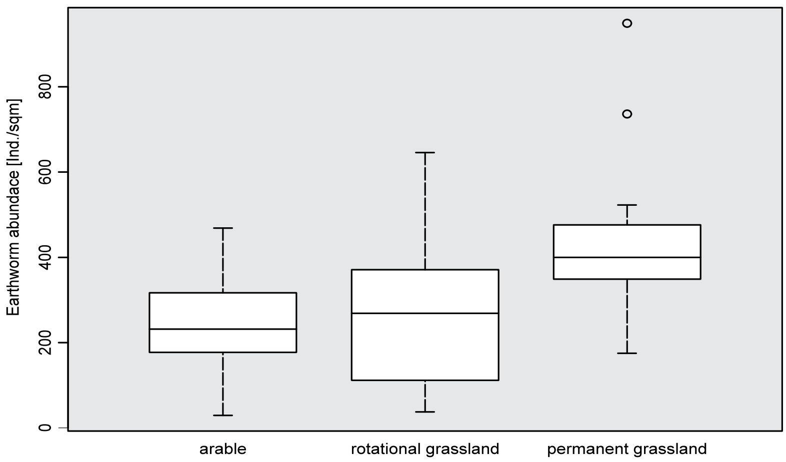


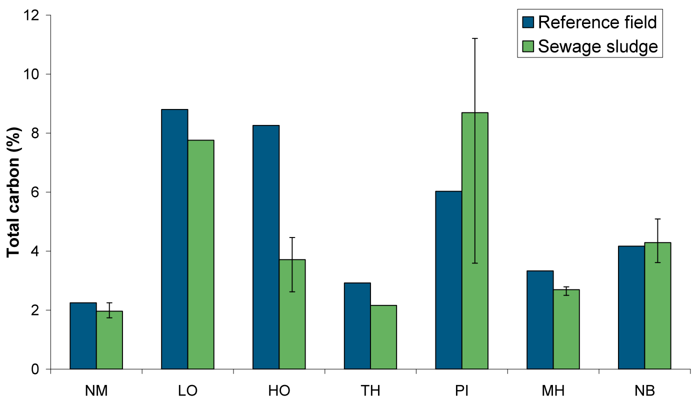
Figure 6: Earthworm abundance under different land use types. See Figure 3 for explanation of the box and whisker plot.

By comparing results from fields receiving organic materials with reference fields at individual farms, it is possible to remove some of the inherent variability and identify impacts of organic material spreading.

In contrast to results from soil sampling in 2007 and 2008, there was no tendency for total carbon concentrations to be higher in fields where sewage sludge was applied than in reference fields (Figure 7a). However, as in 2008, total carbon concentrations were generally higher in fields receiving distillery waste than reference fields (Figure 7b).

Evidence from the farm by farm analysis supports the finding at a national scale that copper concentrations may be building up in soils that have received distillery waste applications over a long time period (Figure 8), although the concentrations measured were well beneath limits set out in the Sludge (Use in Agriculture) Regulations (1989).

Figure 9 does not show any consistent evidence that, on the individual farm scale for farms sampled in 2009, earthworm abundance in fields receiving either sewage sludge or distillery waste applications differed from that in reference fields. In the case of distillery waste, this result is in contrast to that found in 2008, where there were indications that distillery waste had a negative impact on earthworm abundance at three farms. Overall, high earthworm abundance generally indicates that soil is in good condition.



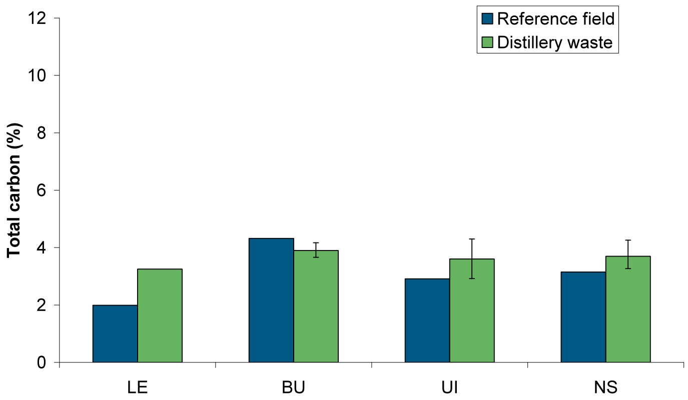


Figure 7: Total carbon concentrations in fields receiving (a) sewage sludge and (b) distillery waste in comparison with reference fields under the same land use. The main bar shows the mean concentration and the whiskers show the maximum and minimum concentrations measured. The two letter identifiers on the x-axis of both plots represent individual farms.

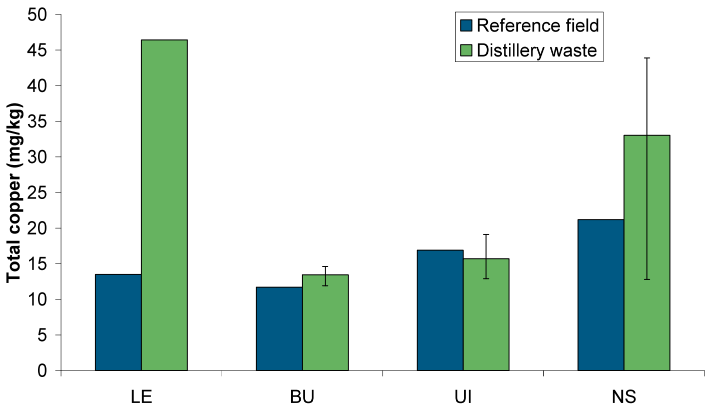


Figure 8: Copper concentrations in fields receiving distillery waste in comparison with reference fields under the same land use. See Figure 7 for explanation of the plot and x-axis labels.

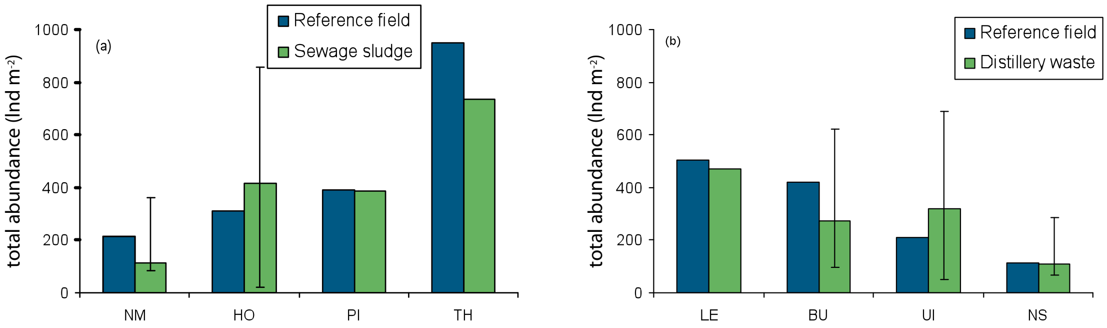


Figure 9. Earthworm abundance in fields receiving (a) sewage sludge and (b) distillery waste in comparison with reference fields under the same land use. See Figure 7 for explanation of the plot and x-axis labels.

Compliance with regulations

As in previous years, results from 2009 demonstrate that the soil quality in the fields sampled was generally good.
No definite breaches of the Sludge (Use in Agriculture) Regulations 1989 were found in 2009. However, the nickel concentration of one field was very close to the regulatory limit (63.5 ± 8.3 mg/kg nickel, pH 5.9 ± 0.4; maximum permissible at pH 5.5-5.9 = 60 mg/kg nickel). The waste operator's own analysis, from samples taken prior to spreading sewage sludge, suggested that the soil in some parts of the field contained higher nickel concentrations than permitted under the Sludge (Use in Agriculture) Regulations 1989, whereas other parts were below the limit. However, the legislation only requires compliance with the heavy metal limits on a field basis and therefore the Sludge (Use in Agriculture) Regulations 1989 were not breached. The field in question lies just downslope of a basaltic outcrop. Basalts are an important natural source of nickel in soils and therefore it is probable that the high nickel concentrations are not due to sewage sludge spreading, but instead come from the leaching of minerals from the basaltic outcrop into the soil.
Comparisons of compliance levels for soils sampled in 2007, 2008 and 2009 are shown in Table 3.

Table 3: Numbers of fields sampled to which sewage sludge was applied and number of non-compliances with the Sludge (Use in Agriculture) Regulations detected.

Year of sludge register issue	Number of fields sampled	Number of non-compliant fields
2006	17	2
2007	21	0
2008	22	0

Note: sludge registers are issued to SEPA in March each year for the previous year, and hence SEPA soil compliance sampling is based on the previous year's sludge register.

Conclusion

By analysing the 2009 results, it was possible to identify some apparent effects of sewage sludge and distillery waste spreading on soil quality parameters such as extractable phosphorus, metals, and total carbon, particularly at an individual farm level. However, the natural variability of Scottish soils means that it will take several years of sampling at the current rate to build up a Scotland-wide picture of the impact on soil quality of applying organic materials to land. Through the soil compliance monitoring strategy, we will continue to gather data to enable more robust statistical analysis of the impacts of this activity. This will enable SEPA to identify the extent of risks that are potentially associated with organic material application to land, such as build-up of heavy metals in soils. In addition, the continuation of soil compliance monitoring will help SEPA to ensure that farmers and contractors continue to follow good practise when applying organic materials to land.