SEPA
Scottish Environment Protection Agency

Soil quality:

Investigating the impact of applying sewage sludge and exempt waste to agricultural land

Introduction

SEPA aims to provide an efficient and integrated environmental protection system for Scotland. *SEPA's Corporate Plan 2005–2008* has six environmental outcomes, one of which is good land quality. The principal soil quality targets associated with this are:

- to develop soil quality indicators best suited to measuring existing conditions and potential changes in Scottish soils;
- to implement a soil monitoring strategy which will use soil quality indicators to assess impacts on soils when land is treated with waste.

SEPA's soil compliance monitoring strategy

A risk-based compliance monitoring strategy has been developed for SEPA-regulated activities[1] that impact on soil. The soil quality indicators developed for use in this programme were: pH; soil organic carbon (C_{org}); total nitrogen (N); extractable phosphorus (P), potassium (K) and magnesium (Mg); total cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and mercury (Hg); potentially mineralisable nitrogen; microbial biomass carbon (C_{mic}); earthworms and bulk density.

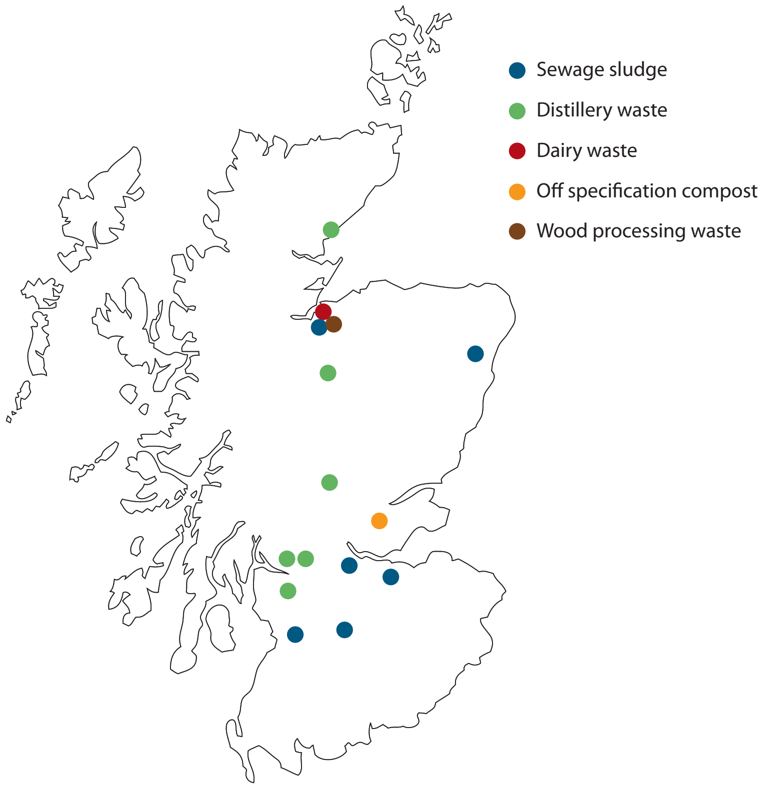
In 2007, soil sampling was carried out in fields to which exempt organic waste or sewage sludge had been applied for agricultural benefit. Where possible, sampling was also carried out in adjacent reference fields that had the same agricultural management but with no waste applied.

Methods

Soil samples were taken from 60 fields at 15 farms in 2007. The locations of farms sampled and the type of materials applied are shown in Figure 1.

Soils were sampled according to the SEPA soil sampling protocol. A representative soil sample was obtained from each field by taking 25 core samples to a depth of 20cm on a 'W' pattern across the field and then mixing them together. Samples were analysed for the soil quality indicators outlined above (except earthworms and bulk density), using the in-house methods at the Scottish Agricultural College (SAC) and Macaulay Institute's analytical labs. Earthworms were sampled and analysed for a subset of fields, according to SEPA sampling and analysis protocol for earthworms. Bulk density was not measured in 2007.

Figure 1 Locations of farms sampled in 2007 and the types of material applied.



[1]SEPA regulated activities that impact on soil include the spreading of sewage sludge to agricultural land under the Sludge (Use in Agriculture) Regulations 1989 (as amended) and the spreading of exempt waste to agricultural land under the Waste Management Licensing Regulations 1994 (as amended).

Results

Tables 1 and 2 show the mean and median values for each parameter determined, along with the maximum and minimum values measured and number of samples analysed. The range of values found for each parameter highlights the variability of soil. It will take several years of sampling before statistically robust means can be calculated.

Table 1 Mean, median and ranges for selected soil quality indicators.

Parameter	Unit	Mean	Median	Minimum	Maximum	No. of samples
pH		5.9	5.8	5.1	7.5	60
P*	mg l^{-1}	9.3	7.1	0.8	42.6	60
K*	mg l^{-1}	120	104	35.8	459	60
Mg*	mg l^{-1}	177	149	40.6	435	60
C_{org}§	%	4.5	4.4	1.4	9.7	60
N†	%	0.35	0.33	0.17	0.80	60
C:N		13	13	7	19	60
Cd†	mg kg^{-1}	0.20	0.17	0.05	0.69	60
Cr†	mg kg^{-1}	32.3	33.6	4.1	76.8	60
Cu†	mg kg^{-1}	14.6	13.5	2.0	46.9	60
Hg†	mg kg^{-1}	0.15	0.12	0.04	0.49	60
Ni†	mg kg^{-1}	21.1	21.7	1.7	65.5	60
Pb†	mg kg^{-1}	35.5	28.2	5.8	154.8	60
Zn†	mg kg^{-1}	63.2	62.1	13.4	190.9	60
C_{mic}~	µg g^{-1}	673	529	72	1615	39
C_{mic} as a % of C_{org}		1.4	1.4	0.2	2.9	39

*extractable, §organic carbon, †total, ~microbial biomass carbon

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

Parameter	Unit	Mean	Median	Minimum	Maximum	No. of samples
No. of species		4.7	4.5	2	7	17
Total abundance	Ind m^{-2}	332	314	87	776	17
Total biomass	g m^{-2}	117	120	21	225	17

Effects of waste application

The data was analysed according to the type of material applied (sewage sludge, distillery waste and reference sites, ie none) in order to determine any effects of waste application across the country. The overlapping values in Figures 2, 3 and 4 show that it is very difficult to detect any impact of sewage sludge or distillery waste application on soil quality on a country-wide scale. This is due to the natural variation between soils, which masks any effects of the application of waste. Since soils form on many different parent materials and under a variety of climate types, topographies and land uses, this would be expected.

Figure 2 a) Extractable phosphorus (P) and b) microbial biomass carbon (C_{mic}) in soils to which sewage sludge and distillery waste have been applied. The symbol on each bar is the mean value. The bar shows the range of values measured.

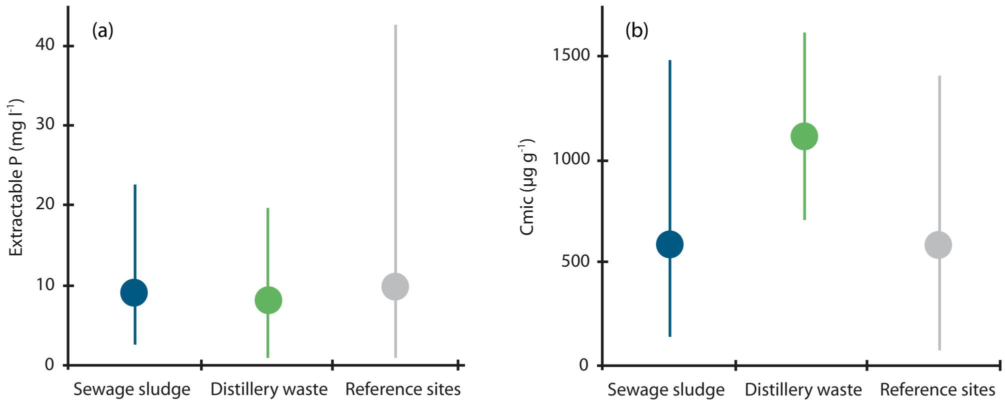


Figure 3 Potentially toxic element concentrations in soils to which sewage sludge has been applied, compared to the reference sites. The symbol on each bar is the mean value. The bar shows the range of values measured.

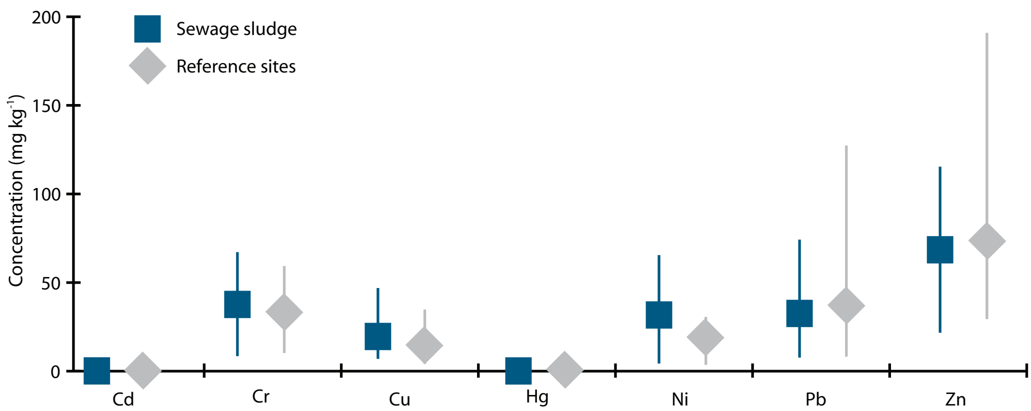
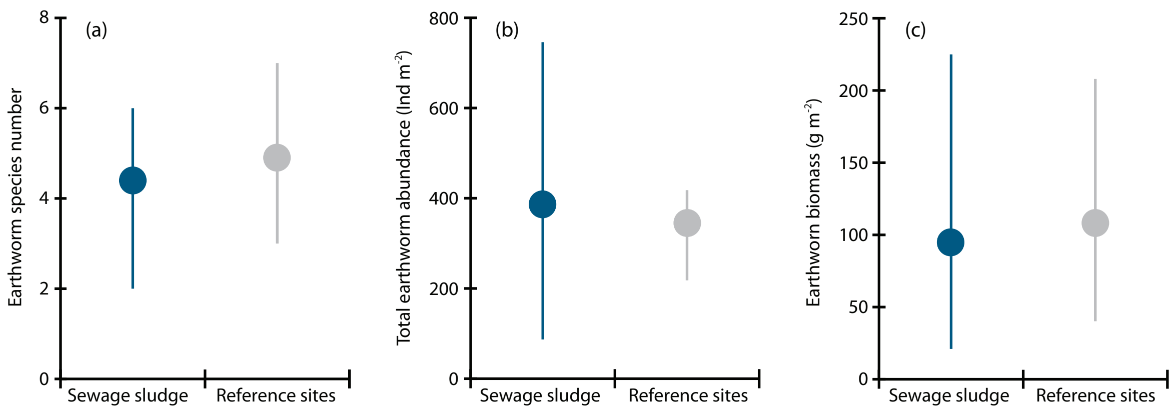


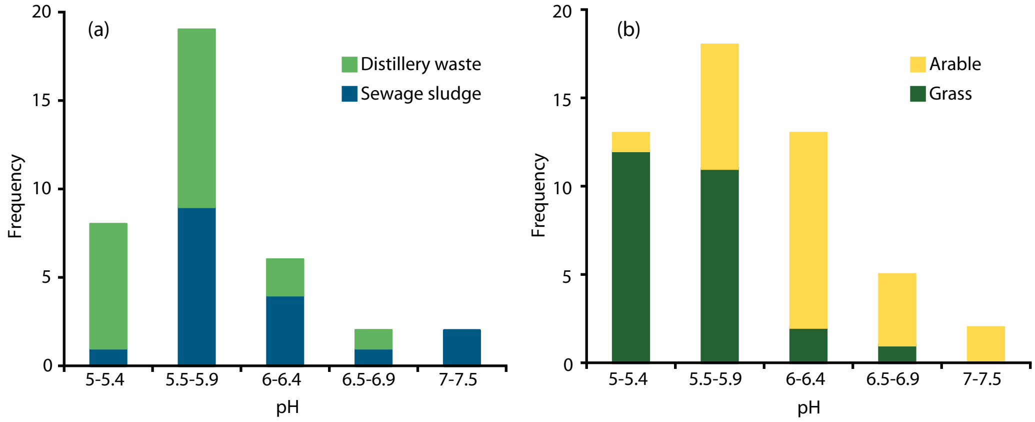
Figure 4 a) Earthworm species number, b) total abundance and c) total biomass measured in soils to which sewage sludge has been applied, compared to the reference sites. The symbol on each bar is the mean value. The bar shows the range of values measured.



Effects of land use

Land use has an overriding influence on soil properties. Initial results suggest that soils to which distillery waste is applied have a lower pH (Figure 5a) and a higher soil organic carbon concentration than soils to which sewage sludge is applied. However, this is more likely to be a reflection of the land use rather than the type of material applied. Arable land to which sewage sludge was more commonly applied is maintained at a higher pH than grassland and this is confirmed in Figure 5b. Meanwhile, grassland soils, to which distillery waste was more commonly applied, tend to have higher soil organic carbon and microbial biomass carbon concentrations.

Figure 5 Frequency of pH values measured as a function of a) waste type and b) land use.

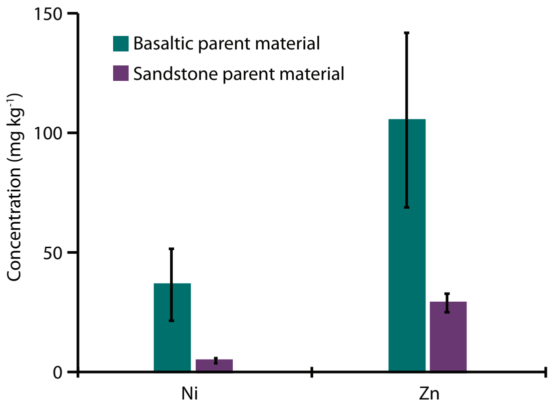


Earthworms are also affected by land use, with more species present in grassland and non inversion tillage arable fields than in conventionally ploughed arable fields. Total earthworm biomass was also noticeably higher in grassland than in arable soils.

Effects of parent material

The soil parent material has a strong influence on soil potentially toxic element (PTE) concentrations. This was particularly evident when comparing the soils to which distillery waste was applied in different parts of Scotland. Some of the soils sampled in south west Scotland are formed from basaltic parent materials and naturally have much higher PTE concentrations (eg nickel and zinc) than the soils sampled in north east Scotland formed from sandstone parent materials (Figure 6).

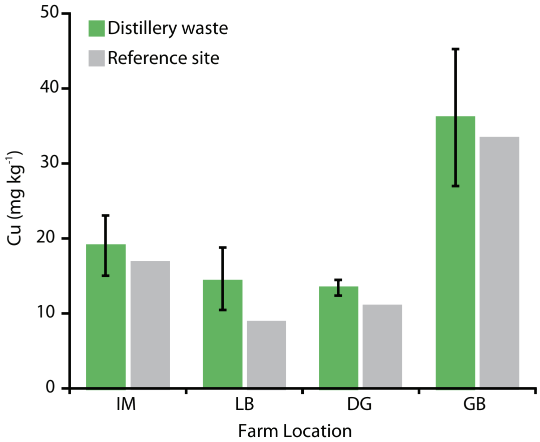
Figure 6 Comparison of nickel (Ni) and zinc (Zn) concentrations in soils formed from basaltic parent materials in south west Scotland with those formed from sandstone parent materials in north east Scotland (mean ± standard deviation).



Farm scale effects

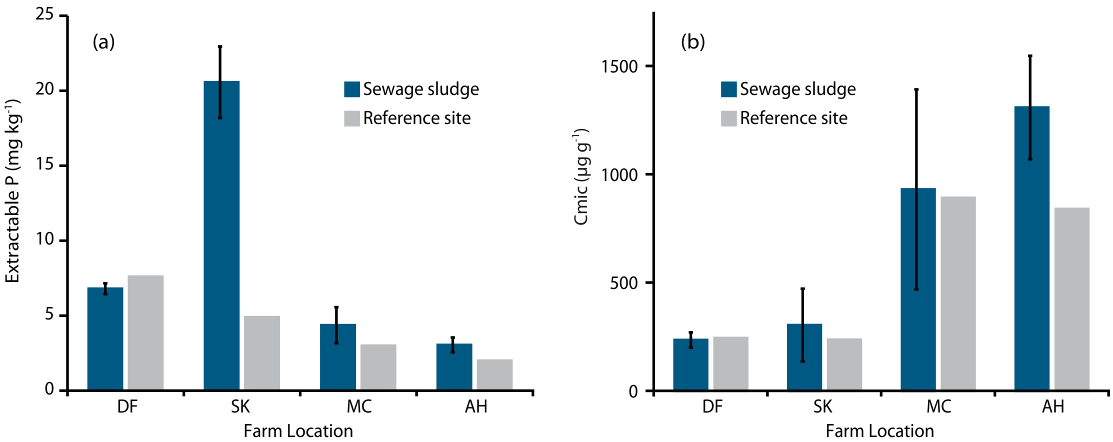
While it is difficult at this stage to draw country-wide conclusions, it is possible to determine the effects of sewage sludge or exempt waste application on soil quality on a farm by farm basis, where a suitable reference site is available. For example, at four farms in central Scotland where distillery waste had been applied, it was found that copper concentrations were higher in soils to which waste had been applied than in the reference fields (Figure 7).

Figure 7 Copper (Cu) concentrations in fields to which distillery waste has been applied (mean ± standard deviation) compared to the reference site.



There were also four farms in central Scotland, with suitable reference sites, where sewage sludge had been applied. Soil pH, extractable phosphorus concentration, total nitrogen, soil organic carbon and microbial biomass carbon were all found to be higher in three out of the four farms sampled (Figure 8).

Figure 8 a) Extractable phosphorus (P) and b) microbial biomass carbon (C_{mic}) in soils to which sewage sludge has been applied (mean ± standard deviation) compared to their reference sites.



Compliance with regulations

Of the 60 fields sampled, 97% were found to be compliant with the Sludge (Use in Agriculture) Regulations 1989 (as amended). One farm to which sewage sludge had been applied had two fields with soil nickel concentrations very slightly above the limit for soil at the pH measured (nickel concentration > 60 mg kg^{-1}, pH < 6). However, these fields overlie basaltic rocks, so there is a strong possibility that the reason for the non compliance is geochemical rather than a result of sludge application. This highlights the importance of considering parent material when interpreting soil PTE concentrations.

Conclusions

The principal premise of applying organic material to land is that it will provide agricultural benefit, such as the supply of nutrients to improve crop growth. However, it is important to ensure that nutrients are not allowed to build up to levels at which they can become damaging, not just to the soil, but also to the water and air environments. Care should also be taken to ensure that PTEs, while beneficial in trace amounts in the case of copper and zinc, do not accumulate and become toxic to plants, soil organisms and, ultimately, to humans via the food chain.

Initial results from SEPA's soil compliance monitoring programme illustrate the natural variability of soil parameters. They also highlight the fact that it will take many years of sampling to build up a picture of the effects that applying exempt waste or sewage sludge has on soil quality in Scotland. However, in the meantime, effects can be seen on a farm by farm basis and the compliance of soils with the Sludge (Use in Agriculture) Regulations 1989 (as amended) can be monitored.

Acknowledgements

SEPA would like to acknowledge the farmers who gave permission to take soil samples and the waste operating companies who supplied waste spreading information.

Further details

Email: soil@sepa.org.uk