SEPA
Scottish Environment Protection Agency

# Soil Compliance Monitoring Annual Report 2010

## Summary


- Soil quality in Scotland is generally good.
- Scotland's soils are very diverse, which masks the effects of organic material application in the short term.
- Some outliers show potential exceedance of regulatory thresholds and more investigative work is ongoing.


## Introduction and background

In order to monitor the effects of applying organic materials on soil quality, a soil compliance monitoring strategy for SEPA regulated activities that affect soil was developed and implemented in 2007. This monitoring allows SEPA to audit compliance with the Sludge (Use in Agriculture) Regulations 1989 (Sludge Regs), and also to check soil quality at sites receiving waste under a Paragraph 7 or 8(2) exemption from the Waste Management Licensing Regulations 1994 (WML Regs), using criteria set out in Sludge Regs as guidelines. This report summarises results from soil monitoring carried out in 2010.

The Scottish Soil Framework (2009) defines soil quality as the ability of a specific kind of soil to carry out one or more of the functions below:

- providing the basis for food, forestry or other biomass production;
- controlling and regulating environmental interactions, including regulating water flow and quality;
- providing valued habitats and sustaining biodiversity;
- preserving cultural and archaeological heritage;
- providing raw material;
- providing a platform for buildings and roads.

Therefore, maintaining good soil quality is of crucial importance to the environment and economy of Scotland.

SEPA's *State of the Environment Soil Quality Report 2001,* and subsequently *The State of Scotland's Soil 2011,* recognised the importance of soil quality and soil functions. Both reports identified the main pressures on soils and recognised that, in many areas, there was a lack of data available to determine impacts on soil quality resulting from these pressures.

The amount of sewage sludge applied by Scottish Water to agricultural land increased between 2004 and 2008, although amounts dropped in 2009 and 2010 (Figure 1). Data for waste spread under exemptions is available only for 2009 and 2010. Figure 2 indicates that the amount of waste spread in 2010 was less than in 2009 for most waste types. Figure 2 also shows that more distillery by-product was spread than any other waste type, and that although no anaerobic digestate was spread to land in 2009, by 2010 it had become one of the top five waste types spread to land in Scotland, by weight.

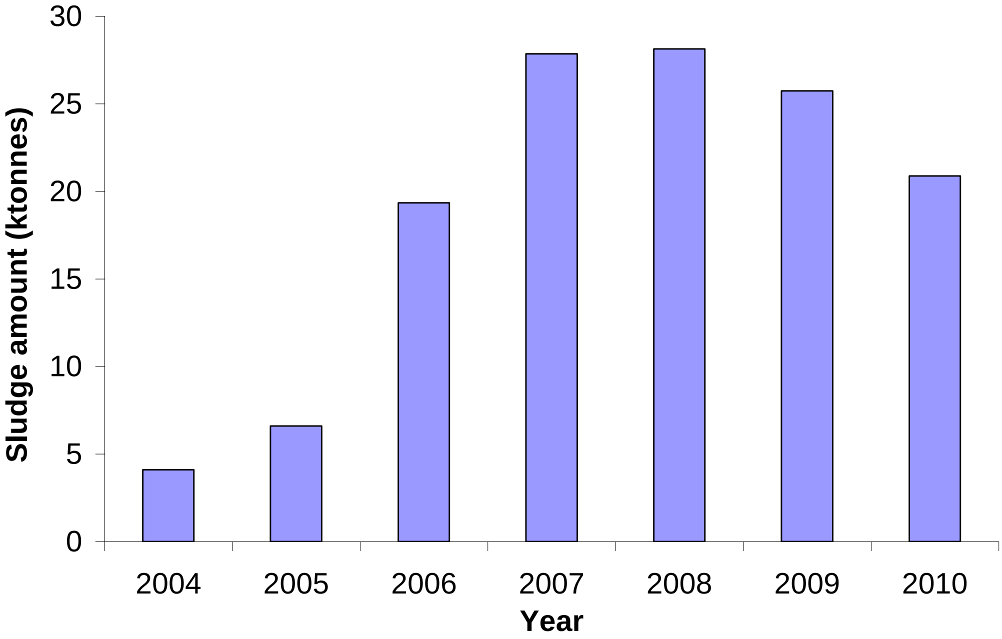



**Figure 1:** Amount of sewage sludge (in kilotonnes dry matter) spread to agricultural land by Scottish Water.

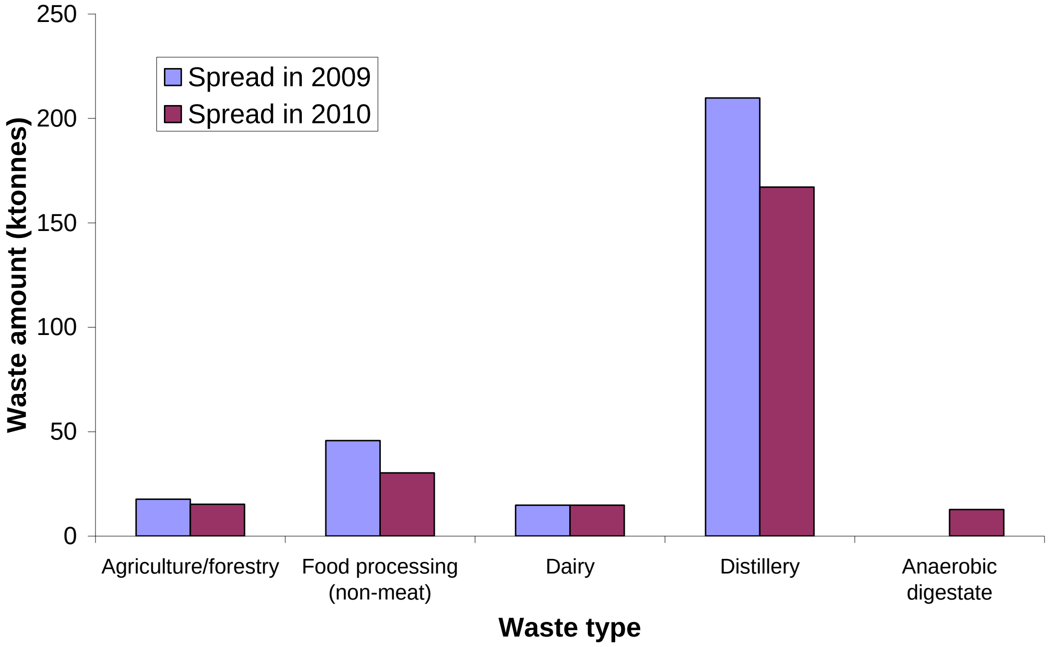



**Figure 2:** Amount of different waste types (in kilotonnes wet matter) spread to agricultural land under selected paragraph 7 Waste Management Licensing Exemption categories in 2009 and 2010.

# Methods

In 2010, SEPA staff sampled soils from 79 fields at 22 farms, which represents less than 5% of the total number of fields receiving organic material under both the WML and Sludge Regs. Samples were taken from fields across Scotland to which a variety of organic materials were applied for agricultural benefit, including sewage sludge, distillery by-products, food processing waste and off-specification compost[a] (Figure 3). Samples were analysed for the following soil quality indicators:

- pH;
- organic 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).

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

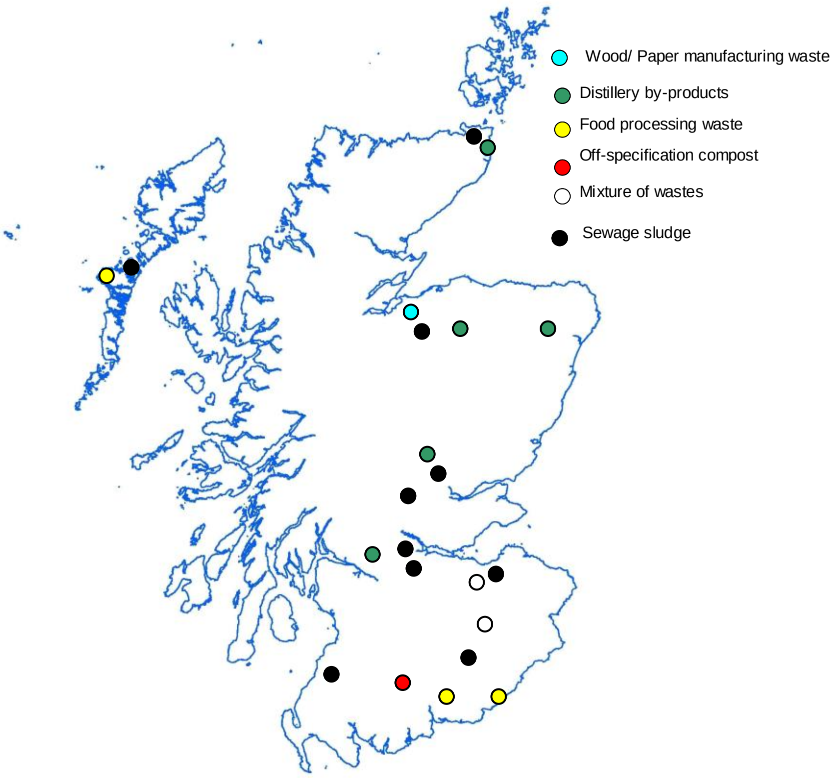



**Figure 3:** Locations of farms sampled in 2010 and organic material types applied.

[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 metal concentration was in excess of the threshold set out in the Sludge Regs and additionally four instances where concentrations may be in excess of the thresholds set out in the Sludge Regs.
In the latter cases, it is not possible to say for certain whether or not thresholds were exceeded due to inherent uncertainties in the analytical results. Thresholds for some metals vary with the soil pH and an analytical uncertainty of ±0.4 pH units could mean that two or even three different thresholds may apply. For more detailed explanation see section below, 'compliance with regulation'.

Not all exceedances of the Sludge Regs limits can be attributed to organic material application since they also occurred on reference sites, indicating that high metal concentrations in soils can be a result of geological or other factors.

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

| Parameter | Unit | Mean | Median | Minimum | Maximum | N |
|---|---|---|---|---|---|---|
| pH | | 6.1 | 5.9 | 4.9 | 8.4 | 79 |
| P* | mg/l | 9.6 | 5.1 | 0.7 | 89.6 | 79 |
| K* | mg/l | 124 | 105 | 34 | 372 | 79 |
| Mg* | mg/l | 166 | 124 | 43 | 791 | 79 |
| $C_{org}^{\$}$ | % | 4.4 | 3.8 | 1.5 | 11.9 | 79 |
| $N^{\dagger}$ | % | 0.33 | 0.31 | 0.11 | 0.71 | 79 |
| C:N | | 13.1 | 12.4 | 9.1 | 20.5 | 79 |
| $Cd^{\dagger}$ | mg/kg | 0.23 | 0.21 | 0.06 | 0.46 | 79 |
| $Cr^{\dagger}$ | mg/kg | 35.7 | 28.8 | 4.7 | 99.9 | 79 |
| $Cu^{\dagger}$ | mg/kg | 20.2 | 15.6 | 1.6 | 104.9 | 79 |
| $Hg^{\dagger}$ | mg/kg | 0.15^ | 0.08 | <0.05 | 3.02 | 79 |
| $Ni^{\dagger}$ | mg/kg | 22.5 | 21.1 | 4.0 | 78.3 | 79 |
| $Pb^{\dagger}$ | mg/kg | 37.6 | 26.0 | 1.1 | 222.0 | 79 |
| $Zn^{\dagger}$ | mg/kg | 73.6 | 68.2 | 6.7 | 268.2 | 79 |
| $C_{mic}^{\sim}$ | µg/g | 644 | 585 | 213 | 1918 | 79 |
| $C_{mic}:C_{org}$ | % | 1.6 | 1.5 | 0.4 | 5.4 | 79 |

* extractable, $ organic carbon, † 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 | 5 | 1 | 9 | 44 |
| Total abundance | Ind $m^{-2}$ | 363 | 296 | 15 | 1248 | 44 |
| Total biomass | g $m^{-2}$ | 101.4 | 94.3 | 2.8 | 478.7 | 44 |

## Effects of organic material application on soil quality

The soil quality indicator data were analysed at both a national and a local scale. Nationally, the results of all samples of the same waste type were averaged; locally the results of treated fields were compared with a reference field on the same farm.

In 2010 mean concentrations of most metals were higher in fields receiving sewage sludge than reference fields; however the differences are not significant. For example, the copper concentrations in fields that have received distillery by-products and reference fields is similar to that found in previous years with median copper concentrations in reference fields and fields receiving distillery by-products being similar.

However some fields receiving distillery by-products contained substantially higher copper concentrations than reference fields (Figure 4), which could be a result of accumulation from repeated distillery by-product application over many years in these fields, as distillery by-products typically have high copper content.

The variability of natural factors, such as geology and climate, and human influences, such as land use and the physical form of the waste (e.g. whether sewage sludge is in slurry, dry pellet, dry cake or lime-stabilised form) results in a wide spread of the results and therefore in extensive overlaps in the range of values of the soil quality indicators between fields receiving either sewage sludge or distillery by-products and reference fields. This masks the influence of the application of organic materials on soil quality. Figure 5 illustrates how extractable P varied according to land use, a pattern that has also been observed in previous years for other parameters.

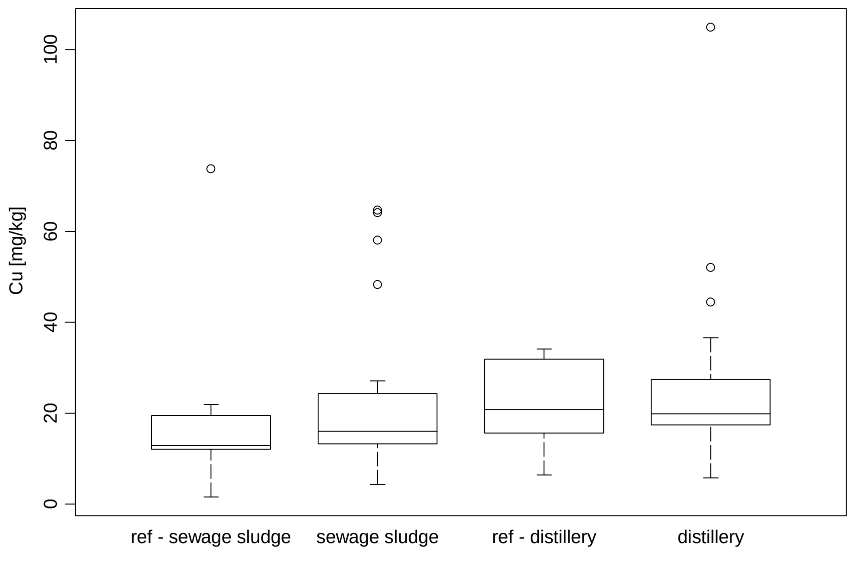



**Figure 4:** Comparison of copper concentrations in fields receiving sewage sludge, distillery by-products and reference fields. Box and whisker plot with the bottom and top of the box being the lower and upper quartile and the band near the middle of the box the median. The ends of the whiskers represent the closest points within the 1.5 interquartile range. Data not included between the whiskers are plotted as a small circle.

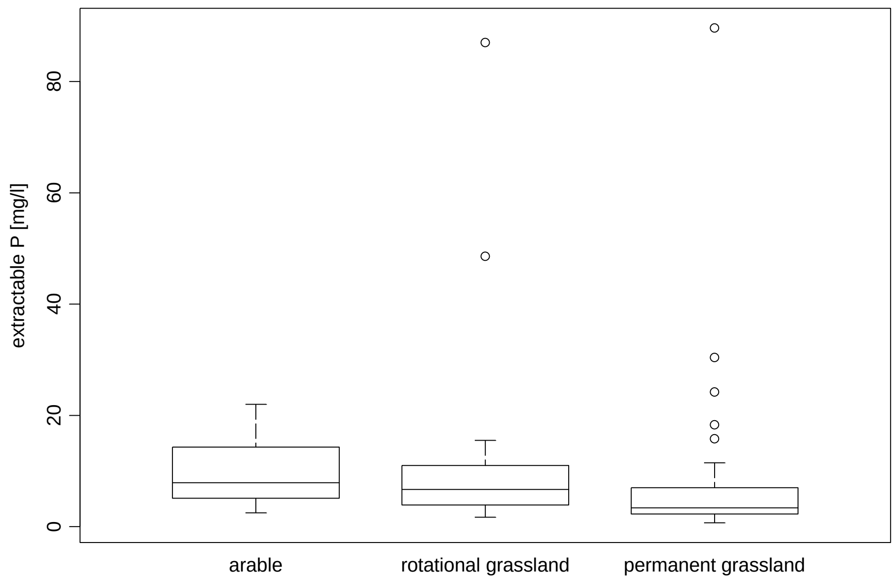



**Figure 5:** Extractable phosphorus concentration under different land use types. See Figure 4 for explanation of the box and whisker plot. (The four highest outliers represent samples taken from Machair grassland which are naturally high in plant available phosphorous.)

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 possible impacts of organic material spreading.

In 2010, there was no tendency for organic carbon concentrations to be higher in fields where sewage sludge or distillery by-product was applied than in reference fields (Figure 6). This is similar to results from 2009 for sewage sludge and from 2007 for distillery by-products.

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 by-product applications over a long time period, as copper concentrations in fields receiving distillery by-products were typically higher than in reference fields (Figure 7). This pattern of slightly higher copper concentrations in fields receiving distillery by-products compared with reference fields at the same farm has been observed in results from all years since the soil compliance monitoring strategy began in 2007. Although all concentrations shown in Figure 7 were well beneath limits set out in the Sludge Regs, copper concentrations did exceed these limits in one field receiving distillery by-product that was sampled. Data from this field are not shown on Figure 7 because there was no suitable reference field at the relevant farm to compare the result with.

High microbial biomass as well as high earthworm abundance and species numbers are related to good soil quality. Generally, application of organic material to soil increases microbial biomass and earthworm numbers since it provides food. However some organic material applications might cause a reduction in microbial biomass and/or earthworm numbers, due to adverse compounds in the material or the application practice (e.g. trafficking on wet soil leading to soil compaction). This would indicate that the organic material application has had an adverse effect on soil quality. How long the effect lasts is different for microbial biomass and earthworms, with the effect for earthworms being more prolonged than for microbial biomass.

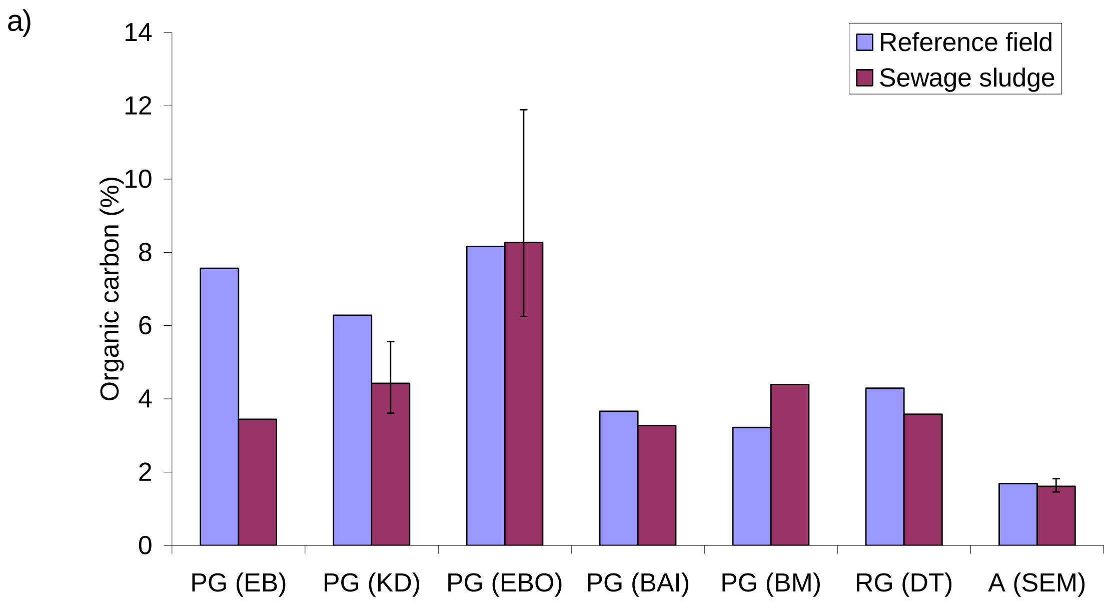
In 2010 sewage sludge application on permanent grassland sites mainly reduced microbial biomass (Figure 8) and to a lesser extent microbial biomass carbon to organic carbon ($C_{mic}/C_{org}$) ratio, the latter of which is calculated because microbial biomass is positively correlated with organic carbon content. These findings are not necessarily a general tendency, but previous years' results indicate that sewage sludge application does not increase microbial biomass or $C_{mic}/C_{org}$ ratio at permanent grassland sites. For arable land the effect of sewage sludge application seems to be relatively neutral with few differences between treated and untreated fields.

No consistent response can be seen in this year's microbial biomass results where distillery by-products have been applied to grassland. However results from previous years indicate that microbial biomass generally increased.

Earthworm abundance and biomass were higher in fields that had received sewage sludge in 2010, however impacts on species numbers vary. Effects on earthworms were mixed in previous years, with species numbers often reduced in arable fields treated with sewage sludge.

Distillery by-products also seem to be beneficial for earthworms with abundance (Figure 9), biomass, and species numbers generally being higher in fields receiving this material compared to the reference field. This generally positive effect is not entirely reflected in previous years' results, especially with regard to species number, which were considerably lower in fields receiving distillery by-products than reference fields at some farms.

**Picture 1**: Waste spreading on farmland.



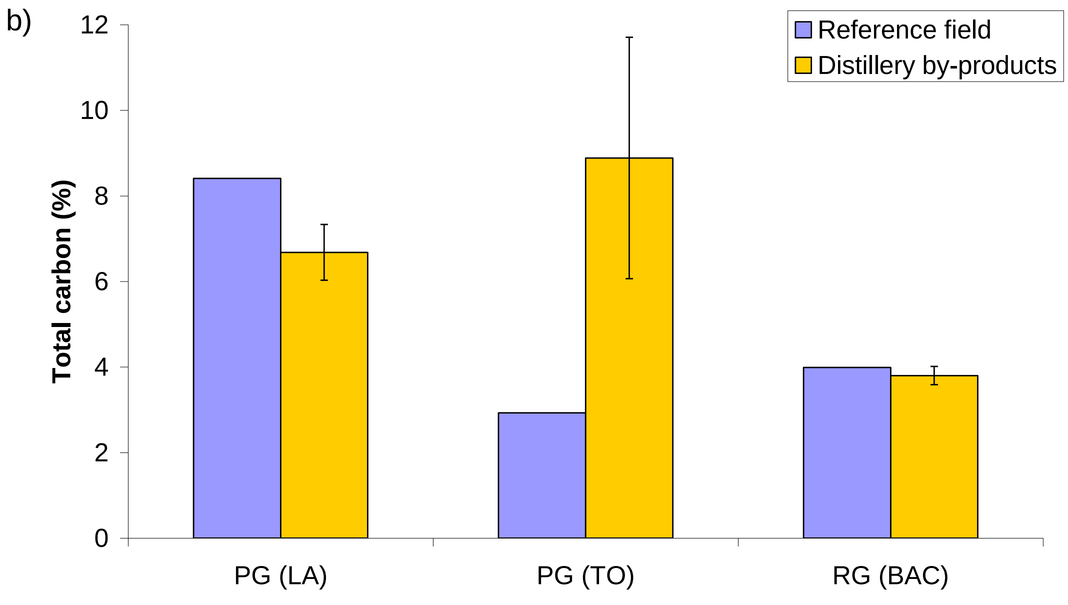




**Figure 6:** Organic carbon concentrations in fields receiving (a) sewage sludge and (b) distillery by-products in comparison with reference fields under the same land use. The main bar shows the mean concentration and the whiskers show the standard deviation. The identifiers on the x-axis of both plots represent the land use and the individual farms in brackets with PG = permanent grassland, RG = rotational grassland, A = arable.

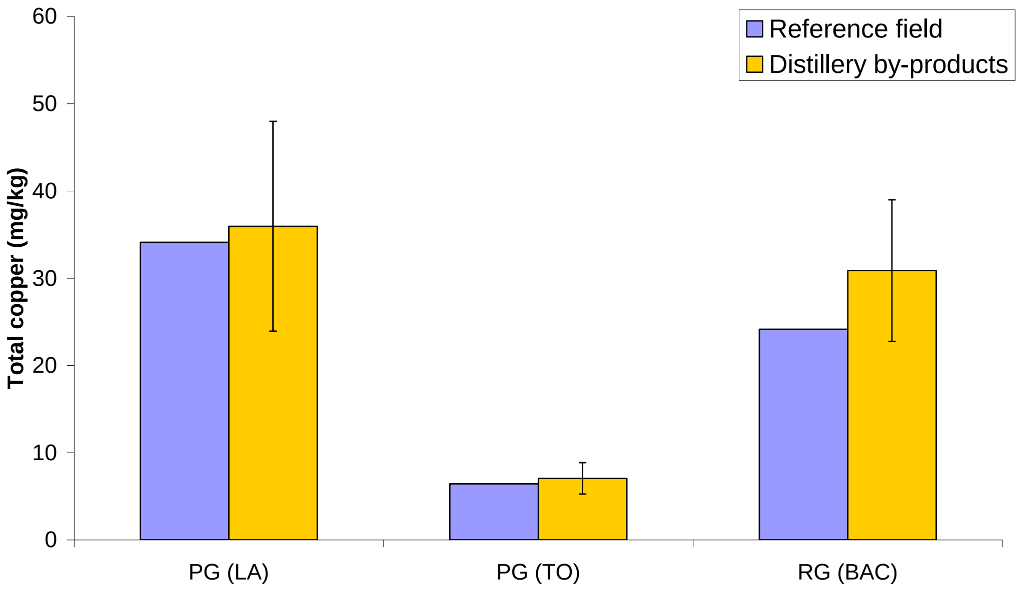



**Figure 7:** Copper concentrations in fields receiving distillery by-products in comparison with reference fields under the same land use. See Figure 6 for explanation of the plot and x-axis labels.

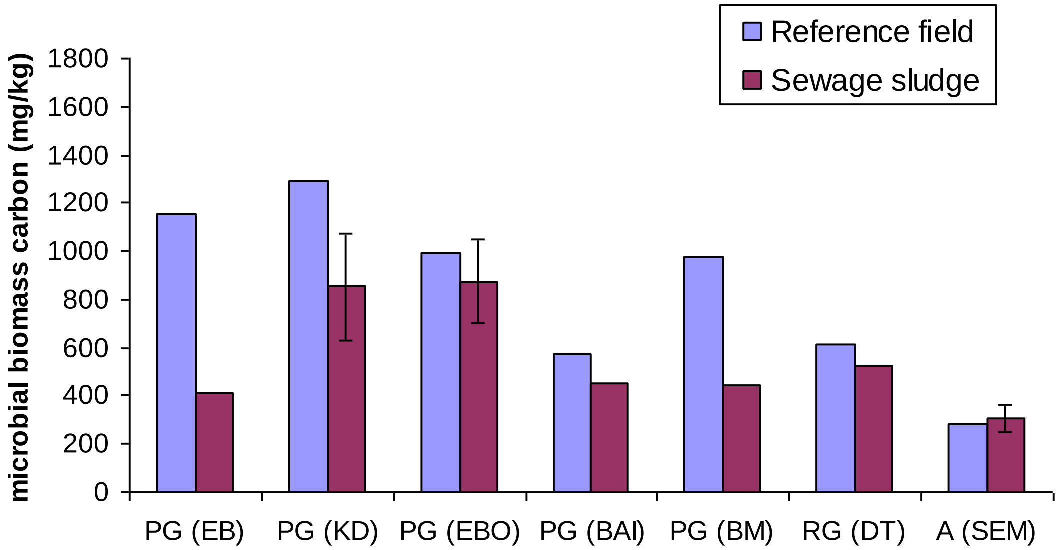



**Figure 8:** Microbial biomass carbon in fields receiving sewage sludge in comparison with reference fields under the same land use. See Figure 6 for explanation of the plot and x-axis labels.

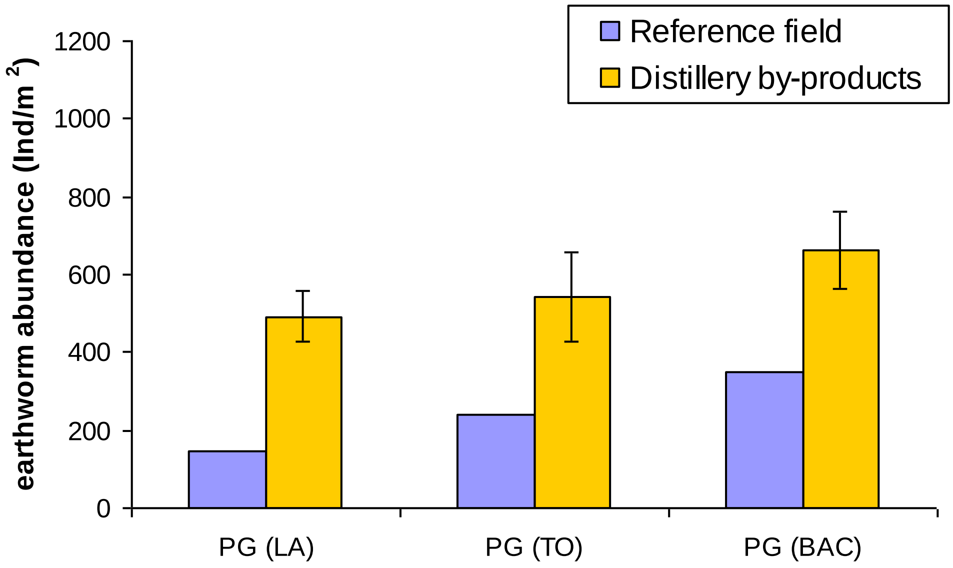



**Figure 9:** Earthworm abundance in fields receiving distillery by-products in comparison with reference fields under the same land use. See Figure 6 for explanation of the plot and x-axis labels.

## Compliance with regulations

As in previous years, results from 2010 demonstrate that the soil quality in the fields sampled was generally good.

Exceedance of the Sludge Regs metal thresholds in soils receiving organic material under WML Regs is not a breach of legislation, because the WML Regs do not set soil metal threshold concentrations. However to ensure that exempt waste spreading does not lead to excessive accumulation of metals in soils, SEPA uses the Sludge Regs limits as guidance when licensing exempt waste applications. Exceedance of thresholds is likely to lead to removal of the exemption, preventing the possibility of further material spreading on those fields.

No definite breaches of the Sludge (Use in Agriculture) Regulations 1989 were found in 2010. However, the zinc concentration of one field was possibly in excess of the regulatory limit. For soils within a pH range of 5.5 to 5.9 a maximum zinc concentration of 250 mg/kg soil is permitted, for soils with a pH of 6.0 to 7.0 the maximum zinc concentration is 300 mg/kg, whereas for pH below 5.5 the maximum zinc concentration is 200 mg/kg.

The inherent uncertainty of the analytical results (268 ± 22 mg zinc/kg, pH 5.6 ± 0.4) impedes a final conclusion. The zinc result for the sample SEPA took was much higher than from the waste operator’s own analysis, from samples taken prior to spreading sewage sludge (128 mg/kg). It may have occurred as a result of sewage sludge spreading, but such a large increase in soil zinc concentration would not be expected between the two sample dates given the amount and the zinc concentration of the sewage sludge applied in the meantime. Further investigation of this is ongoing, the results of which will be available later in 2011.

Comparisons of compliance levels for soils sampled between 2007 and 2010 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 |
| 2009 | 26 | 1* |

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.
*Further checking of potential non-compliance with the Sludge Regs is required.

## Conclusion

The natural variability of Scottish soils means that a Scotland-wide assessment of the impact on soil quality of applying organic materials to land would require a very significant and expensive survey. At the current rate of audit monitoring, such a study would take several years to complete. Through the soil compliance monitoring strategy, we will continue to gather data to allow more robust statistical analysis of the impacts of this activity. This will enable SEPA to more fully understand the extent of risks and benefits that are associated with organic material application to land and improve regulation of this activity accordingly, targeting waste spreading that poses the greatest risks to the environment more accurately. The continuation of soil compliance monitoring will also help SEPA to ensure that farmers and contractors continue to follow good practice when applying organic materials to land to ensure that safe concentrations are not exceeded and that agricultural production can be enhanced by careful use of these sources of soil nutrients.

SEPA Soil Science Working Group, August 2011