EQual Paper sludge field trials

Summary report

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Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH
Email EQual@environment-agency.gov.uk
www.environment-agency.gov.uk

Introduction

Background

In the United Kingdom millions of tonnes of biodegradable organic materials are landfilled every year. By diverting organic materials away from landfill, they are available to be beneficially recycled to land. This has the potential to provide benefits in terms of the sustainable use of plant nutrients, reducing the need for manufactured fertilisers and quarried lime, and adding organic matter to improve soil structure. However it is essential that the application of organic wastes to land is truly beneficial and is not harmful to the environment or human health.

The EQual LIFE+ programme aims to promote the re-use and recycling of waste materials whilst protecting human health and the environment. Deriving value from waste materials by turning them into safe, high quality products is an essential element in the move towards a more circular economy. Offering both economic and environmental benefits, if supported and regulated appropriately, waste-derived products improve business resource efficiency and competitiveness, reduce reliance on landfill, and help to conserve virgin raw materials.

The Environment Agency led the programme with six partners: Rijkswaterstaat (the Netherlands' Ministry of Infrastructure and the Environment), The Chartered Institution of Wastes management, Organics Recycling Group Environmental Services Association, Northern Ireland Environment Agency and Energy UK.

As part of the EQual programme field trials for four waste derived materials were undertaken to improve understanding of the behaviour of these materials in the environment. The evidence base obtained from the trials will support the appropriate use of these materials in place of non-waste materials.

Two of the field trials focused on the construction industry (pulverised fuel ash and incinerator bottom ash aggregate), and two on agricultural use (poultry litter ash and paper sludge). This document reports the paper sludge field trials.

Over the period 2005-2010 an average of c.800,000 tonnes (fresh weight) of paper sludge (PS) was applied to agricultural land, equivalent to c.60% of the total produced (EA, 2012). Whilst there has been some work assessing agricultural benefit, limited work has been carried out on the impact of applications to the wider environment (i.e. water, crop and soil quality) and human health.

Aims

Field trials were carried out to further understanding of the environmental (soil, terrestrial organisms and controlled waters) and human health risks of land application of PS to agricultural soils.

The aims of the field trials were to:

1. assess the environmental impacts of the application of PS to agricultural soils;
2. provide data to inform future generic Quantitative Risk Assessment (QRA); and
3. improve understanding of the magnitude of agricultural benefits derived from PS compared to non-waste-derived alternatives.

Aims 1 and 2 were the primary aims.

Methodology

The field trials were carried out by ADAS UK Ltd and Harper Adams University College at two existing experimental sites at ADAS Gleadthorpe (loamy sand textured soil) and Harper Adams University (sandy loam textured soil) (

a) Harper Adams; spring barley June 2014 b) Gleadthorpe – spring barley; June 2013

Figure 1).

b) Harper Adams; spring barley June 2014 b) Gleadthorpe – spring barley; June 2013

Figure 1. Field trials sites

The field trials comprised three sets of study plots:

- Control plots (normal agricultural practice including manufactured fertiliser applied following the recommendations in the “Fertiliser Manual (RB209)” (Defra, 2010) and FACTS qualified advice);
- Plots with PS applied during the EQual Paper sludge field trials (These plots are termed the ‘fresh PS’ treatment plots in this report); and
- Plots which had previously received repeated applications of PS as part of the Defra SOIL-QC experimental programme[1]. These plots are termed the 'historic PS' treatment plots in this report.

Topsoil samples were taken in January 2013 to determine the baseline against which to assess results. The samples were analysed for:

(a) Total Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, P, K, Se, Ag, Na, Sr, Tl, Sn, Ti, V and Zn
(b) Hexavalent Cr (CrVI)
(c) pH
(d) Olsen extractable P
(e) Ammonium nitrate extractable K & Mg
(f) Organic C, total N and C:N ratio
(g) Organic matter
(h) Mineral N (ammonium-N & nitrate-N)
(i) Electrical conductivity
(j) E-coli[1]
(k) Microbial biomass C and N
(l) Aggregate stability

The original intention was to apply fresh PS to the historic PS treatment plots, to continue extending the record of results of repeated PS additions. However, baseline sampling showed that the pH of the historic PS plots was above the level at which PS application was agronomically justifiable. New 'fresh PS' treatment plots were therefore established in Autumn 2013, as it was too late to establish the new plots for the 2013 crop harvest. However, the baseline sampling enabled comparison with data from the historic study, to evaluate the impact of PS application over a longer timescale.

To minimise potential confounding interactions, all plots other than the ‘historic PS’ plots, had manufactured fertilisers applied (based on “Fertiliser Manual (RB209)” recommendations) to ensure no major nutrient limited plant growth, as far as was practically possible.

[1] DEFRA, 2011. Organic manure and crop organic carbon returns- effects on soil quality: SOIL-QC. Final report to Defra Project SP0530.

Figure 2. Field trials 'fresh PS' plot following PS application

The PS was applied by hand, and then incorporated by ploughing at Gleadthorpe and by disc at Harper Adams. Material was stored and used in accordance with the CPI Code of Good Practice for Landspreading of Paper Mill Sludges (CPI, 2011). A Regulatory Position Statement was obtained from the EA for the use of the PS materials.

Samples of the PS applied at each site were taken to provide a cross-check to the compositional data provided with the materials, to enable material variability to be taken into account.

Topsoil samples were taken from the control and fresh PS treatment plots in April 2014, *c*.6 months after treatment application, and analysed as for the baseline samples.

Crop yields were determined in August 2014 at both sites, with samples of the grain analysed for the substances listed in (a) above.

Storage study

An additional study was carried out to evaluate the effect of unprotected PS storage on the environment and the beneficial properties of PS. Three field heaps of fresh PS material (as used in the field trials) were constructed in a series of hydrologically isolated, sloping concrete bunkers. Leachate from each heap was collected, and sampled on a monthly basis and analysed for total N, ammonium-N, nitrate-N, Total P, orthophosphate-P, BOD, pH, e-coli, Total Al, Active Al, Sb, As, Ba, Be, Cd, Cr, CrVI, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Ag, Te, Tl, Sn, Ti, U, V and Zn.

During construction of the heaps triplicate samples were taken for analysis and four 'litter' bags, each containing *c.*2kg of the PS material, were buried at known separate locations within each heap. These were retrieved after 1, 3, 6 and 12 months for analysis. Measurements of the quantity of leachate from each storage heap were taken and related to rainfall volumes.

Figure 3. Paper sludge heaps at the start (a) and end (b) of the storage period

Results

Statistical analysis was carried out on the field trials and storage study results, to answer the following research questions:

How do physical and chemical properties of soil in the plots change over time?

There was very little change in soil properties between the baseline sampling of the control and fresh PS treatment in September 2014 and in April 2014, *c*.6 months after application of PS. Differences in topsoil extractable magnesium at Gleadthorpe and extractable potassium concentrations at Harper Adams measured at the outset of the field trial, prior to fresh PS additions, were still apparent and can be attributed to background soil variability.

How do physical and chemical properties of soil in plots with application of paper sludge compare to control plots?

There was a small (*c.*0.3-0.6 pH units), but not statistically significant increase in topsoil pH *c.*6 months in 'fresh PS' plots, relative to the control. However, overall the single application of PS had no significant effect on topsoil chemical properties, microbial biomass and aggregate stability.

Comparison of baseline sampling of the historic PS treatment plots in January 2013 with data from the Defra SOIL-QC study[1] provided valuable information on the longer-term effects of repeated PS additions, although only a limited number of analyses were common to the sampling undertaken in 2006/07 (notably pH, total C and microbial biomass). Six to nine years of annual applications demonstrated the value of PS as a liming material as well as a soil conditioner, increasing pH by *c.*2 pH units, relative to the untreated control. The carbon inputs associated with the PS additions up to 2006/07 resulted in *c.*6-8 t/ha additional carbon in the topsoil, associated with an increase in soil microbial biomass.

There was very little effect of the repeated PS additions on topsoil metal concentrations. Only topsoil strontium concentrations increased relative to the untreated control, although concentrations were low and well within the range of reported values for typical agricultural soils[2].

To what extent are potential substances of concern taken up by crops grown with application of paper sludge, and how does this compare to uptake by crops grown in control plots?

There was no significant effect of a single fresh PS application on the uptake of potential substances of concern by winter wheat or spring barley.

How does the total soil microbial biomass change over time in soils with application of paper sludge, and how does this compare with total soil microbial biomass in control plots??

At Gleadthorpe, microbial biomass carbon was lower in both the control and 'fresh PS' treatments in April 2014 than in prior to PS application. This is thought most likely to be due seasonal variation in soil moisture and temperature. The microbial biomass is very dynamic in soil and responds to weather, carbon input and season. The size of the microbial biomass is therefore subject to soil moisture and temperature conditions at the time of sampling as well as plant dynamics[3].

At Harper Adams, microbial biomass carbon remained relatively constant over this time period. However data from the historic PS applications does show that repeated applications of PS over 6-9 years results in an increase the total soil microbial biomass[4,5].

There was no significant effect of a single application of fresh PS on topsoil microbial biomass, relative to the untreated control. However, where PS had been applied annually for 6-9 years (on the historic PS treatment) topsoil microbial biomass increased *c.*2 fold at Gleadthorpe and *c.*1.5 fold at Harper Adams.

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2 RAWLINS, B.G., McGRATH, S.P., SCHEIB, A.J., BREWARD, N., CAVE, M., LISTER, T.R., INGHAM, M., GOWING, C. AND CARTER, S. 2012. The advanced soil geochemical atlas of England and Wales. British Geological Survey, Keyworth. www.bgs.ac.uk/gbase/advsoilatlasEW.html.

3 RICE, C.W., MOORMAN, T.B., BEARE, M. 1996. Role of Microbial Biomass Carbon and Nitrogen in Soil Quality. In: Methods for Assessing Soil Quality. Eds. J.W. Doran & A.J. Jones. SSSA Special Publication 49. pp.203-215. Madison, USA.

4 BHOGAL, A., NICHOLSON, F.A. AND CHAMBERS, B.J. (2009). Organic carbon additions: effects on soil biophysical and physico-chemical properties. European Journal of Soil Science, 60, 276-286.

5 BHOGAL, A., NICHOLSON, F.A., YOUNG, I., WHITMORE, A.P. AND CHAMBERS, B.J. 2011. Effects of recent and accumulated livestock manure carbon additions on soil fertility and quality. European Journal of Soil Science. 62, 174-181

Measurements of soil microbial biomass size i.e. carbon and nitrogen contents, provide an indication of a soil's ability to store and recycle nutrients and energy, such that a higher soil microbial biomass generally indicates a 'better' soil quality[6]. The results at both sites, therefore, suggest that repeated PS applications can result in an improvement in soil biological functioning and quality.

How do storage durations affect key properties of the paper sludge (e.g. nutrient content, pH, pathogens)?

The storage study showed a decrease in total carbon and organic matter content and total sulphur, and an increase in total manganese and strontium in the paper sludge over the 12 month study.

E.coli was present at the start of the storage period, possibly due to the presence of some biologically treated material within the batch of PS, but after just 1 month of storage these had died off.

Over the storage period the PS heaps generated leachate containing elevated concentrations of multiple pollutants (e.g. nitrate-N, ammonium-N, total-P and orthophosphate-P, with BOD and E-coli elevated in the first month of storage), which could cause detrimental effects if they reached surface water bodies in an undiluted form. Total loadings were low and less than a tenth of those measured from solid manure heaps. In practice pollutants in leachates infiltrating soil underneath a field heap of PS or in runoff from the heap are likely to either be retained in the soil or will be diluted with runoff from the rest of the field.

The results highlight the need to follow good agricultural practice for the storage of PS in temporary field heaps[7,8], and in particular, the Confederation of Paper Industries Code of Practice[8].

How do the yields of crops grown with application of paper sludge compare with those grown in control plots?

There was no significant difference in winter wheat and spring barley grain yields from paper sludge plots compared to the controls.

Conclusions

The PS field trials demonstrated the agricultural benefit of PS as a valuable liming material and soil conditioner. An increase in topsoil organic matter and soil biological function was observed following PS application, suggesting that repeated PS applications can result in an improvement in soil biological functioning and quality.

However, it is important that adequate manufactured fertiliser is applied in order to account for potential nitrogen immobilisation following PS application. This ensures that crops do not become N-limited and yields are not impaired.

The PS field trials demonstrated no significant impact on the environment in the short-term. Further work over longer time periods and higher application rates are required in order to fully understand any potential risks.

The storage study demonstrated a reduction in the beneficial properties of PS in exposed field heaps; and the generation of potentially harmful leachates which could cause detrimental effects if

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[6] DICK, 1992. A review: long-term effects of agricultural systems on soil biochemical and microbial parameters. Agriculture, Ecosystems and Environment, 40, 25-36.

[7] ANON, 2009. Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers. Crown Copyright, 2009. TSO, Norwich.

[8] CPI, 2011. Code of Practice For Landspreading Paper Mill Sludges.

they reached surface water bodies in an undiluted form. This highlighted the need to follow good agricultural practice[9,8], in particular, the Confederation of Paper Industries Code of Practice[10].

[9] ANON, 2009. Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers. Crown Copyright, 2009. TSO, Norwich.
[10] CPI, 2011. Code of Practice For Landspreading Paper Mill Sludges.