Environment Agency

using science to create a better place

Landspreading on agricultural land: nature and impact of paper wastes applied in England & Wales

Science Report SC030181/SR

ea/br/e/sci/v1

SCHO0805BJNJ-E-P

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 1844324885

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing enquiries@environment-agency.gov.uk or by telephoning 08708 506506.

Author(s):
Dr Paul Gibbs, Ian Muir, Selwyn Richardson, Gordon Hickman an
Chambers

Dissemination Status:
Publicly available

Keywords:
landspreading | paper waste| agriculture| soil| paper mill sludge| paper pulp| paper sludge

Research Contractor:
Dr Paul Gibbs, Ian Muir, Selwyn Richardson, Gordon Hickman and Prof Brian Chambers
ADAS Gleadthorpe Research Centre, Meden Vale, Mansfield, Notts NG20 9PF

Environment Agency's Project Manager:
Caroline Hawkins,
Environment Agency, Ty Cambria, 29 Newport Rd, Cardiff CF32 0TP

Science Project reference:
Science Report SC030181/SR

Product Code:
SCHO0805BJNJ-E-P

Science at the Environment Agency

Science underpins the work of the Environment Agency, by providing an up to date understanding of the world about us, and helping us to develop monitoring tools and techniques to manage our environment as efficiently as possible.

The work of the Science Group is a key ingredient in the partnership between research, policy and operations that enables the Agency to protect and restore our environment.

The Environment Agency's Science Group focuses on five main areas of activity:

- **Setting the agenda**: To identify the strategic science needs of the Agency to inform its advisory and regulatory roles.
- **Sponsoring science**: To fund people and projects in response to the needs identified by the agenda setting.
- **Managing science**: To ensure that each project we fund is fit for purpose and that it is executed according to international scientific standards.
- **Carrying out science**: To undertake the research itself, by those best placed to do it - either by in-house Agency scientists, or by contracting it out to universities, research institutes or consultancies.
- **Providing advice**: To ensure that the knowledge, tools and techniques generated by the science programme are taken up by relevant decision-makers, policy makers and operational staff.

Professor Mike Depledge Head of Science

Executive summary

This technical report provides up to date information on the extent, nature and environmental implications of spreading paper waste on agricultural land in England and Wales. It uses information gathered from four main sources: (i) the Environment Agency – collating information held about landspreading activities under the Waste Management Licensing Regulations; (ii) paper mills in England and Wales – detailing the types and amounts of paper wastes produced; (iii) spreading contractors employed by the paper mills – detailing standard practices employed in the field; (iv) the scientific literature – compiling a comprehensive review which quantifies the impacts of spreading paper waste on soil properties and functions. The report presents a series of conclusions and recommendations and identifies key gaps in existing knowledge.

Central to the concept of sustainable waste management is the move away from disposing of waste through landfill or incineration, and towards reduction and recovery/re-use. As part of the UK Government's aims to reduce waste, certain exemptions from waste management licensing have been made for some recovery operations in order to encourage their use. These exemptions include the use of waste for "agricultural benefit or ecological improvement" (HMSO, 1994). Since a robust knowledge base is necessary in order to provide effective guidance to enterprises applying for such exemptions, this study collates current information on key practices and scientific knowledge which relate specifically to the recovery of wastes from paper mills through landspreading on agricultural land.

Main findings

In 2003 the quantity of paper waste materials spread on agricultural land in England and Wales was an estimated 712,000 tonnes fresh weight (FW) – or 280,000 tonnes expressed on a dry solids basis. These paper wastes, which were applied to around 10,500 hectares of land, had a mean dry solids content of 39% compared with 'typical' data from the 1990's of 21% dry solids. This suggests that the paper industry has gradually moved, over the last decade, towards applying drier 'cake' materials, which are cheaper to transport and can lead to significant improvements in handling. The majority of wastes were stored for a short period prior to land spreading (78% for less than two months) and were applied in the late summer/early autumn period (61% of total) before winter-sown combinable crops. Expectations from the paper mills are that the quantity of paper waste spread on agricultural land will most likely decrease to around 600,000 tonnes FW over the next five years, largely as a result of paper wastes being diverted into other waste recovery processes, such as energy recovery or use in land restoration.

Using a broad classification based on nutrient and heavy metal concentrations, the paper wastes produced in England and Wales can be split into two

categories: (i) paper wastes with a biological element in the treatment processes and (ii) paper wastes containing no, or only a small, biological element in the treatment process. Spreading contractors reported that they took these differences into account when calculating application rates, with biologically treated paper wastes typically applied to tillage land at a rate of *c.*40 t/ha FW, and non-biologically treated paper wastes at a rate of *c.*75 t/ha FW. This distinction was also taken into account when considering whether to apply extra inorganic fertiliser nitrogen to compensate for nitrogen 'lock-up'. In general, no extra nitrogen (N) was applied following spreading of biologically treated paper wastes, while an average of 0.8 kg fertiliser N/tonne FW of paper waste was applied following spreading of non-biologically treated materials.

Paper mills and spreading contractors identified a number of benefits relating to applying paper wastes to agricultural land – liming value, nutrient supply and soil conditioning properties, each of which was confirmed by experimental data in the scientific literature.

The literature reveals that liming values of paper wastes generally range between 0.1 and 0.7 pH units (increase) per 100 t/ha FW applied, depending on the neutralising value of the paper waste. The literature also shows that the total nutrients supplied depend on the type of waste (ie biologically or non-biologically treated). However, there were only limited data on the availability of these additional nutrients to plants, particularly for phosphorus, potassium and sulphur. One common finding was a decrease in nitrate losses through leaching during the winter following the paper waste application, apparently due to N immobilisation in the soil matrix. However, in the longer-term some of the immobilised N may subsequently be remineralised and leached. Finally, the literature also reports potential benefits to soil conditions as a result of the organic matter applied in paper wastes, such as porosity, moisture retention, structural stability and bulk density, as well as increased soil biological activity and microbial and faunal (eg earthworm) populations.

In terms of the negative impacts of applying paper wastes to agricultural land – including heavy metal load, organic contamination and odour generation – the scientific literature reports levels similar to, or lower than, those arising from other commonly applied organic materials. In addition, it appears that many of the disadvantages previously encountered by the spreading contractors (such as N 'lock-up' and soil compaction) have now largely been overcome through changes in management practice.

Conclusions and recommendations

Information from the surveys of the paper mills and spreading contractors, combined with data emerging from the literature review, reveal a number of key findings from which we can draw a number of important conclusions relating to the types of waste generated by the mills, the benefits and disbenefits of paper waste spreading, and the information gaps that currently exist.

Contents

List of tables

List of figures

Introduction

1.1 Moving away from landfill

Sustainable development lies at the core of the Environment Agency's goals and practices. In terms of sustainable waste management and the 'waste management hierarchy', the key goal is to move away from disposal (through landfill or incineration) and towards reduction and recovery. In line with this thinking, the UK Government has set out its aims for reducing waste sent to landfill in its *Waste Strategy 2000* (Defra, 2000). The strategy includes tough targets for reducing levels of industrial and commercial waste that are going to landfill; targets which will be met by increasing landfill tax, tightening regulation of landfill operations and implementing action programmes. In contrast, certain exemptions from waste management licensing have been made for some recovery operations in order to encourage their use. These exemptions include the use of waste for "agricultural benefit or ecological improvement" (HMSO, 1994).

1.2 Legislation: implications for landspreading

While recovery and re-use are generally encouraged, the EU's Waste Framework Directive does outline certain restrictions on the recovery or disposal of wastes, stating that:

"Member States shall take the necessary measures to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular:

- without risk to water, air, soil, plants and animals;
- without causing a nuisance through noise or odours; and
- without adversely affecting the countryside or places of special interest."

In addition, a waste recovery activity only qualifies for exemption from a waste management licence subject to certain conditions as laid out in the regulations. For example, Schedule 3, paragraph 7 of the *Waste Management Licensing Regulations* (HMSO, 1994) prescribes the specific conditions and limitations of the exemption that allows the use of paper wastes. Of particular significance is the requirement for the activity to result in "benefit to agriculture or ecological improvement".

A number of the current exemptions (including paragraph 7) have recently been reviewed and Defra (Department for Environment, Food and Rural Affairs) has undertaken the relevant consultation exercise. As a result, while there have not yet been any amendments to the regulations, it is likely that any revisions will reflect a tightening of control over waste recovery involving landspreading, especially as far as the need to prove agricultural benefit is concerned. Since such changes will almost certainly lead to an increased need for clear guidelines for practitioners, an improved understanding of the agricultural impact of landspreading is now urgently needed.

1.3 The need for scientific evaluation

Environment Agency officers are regularly asked to register exemptions for the spreading of paper wastes for agricultural benefit. And, given the anticipated tightening of the measures to discourage landfilling, it seems likely that the frequency of such registration applications will increase.

In light of these changes it is the Environment Agency's responsibility to determine best practice with respect to the recovery of paper waste materials, balancing the concerns of different stakeholders while weighing up the potential benefits and disbenefits of landspreading. At present, whilst wishing to encourage the practice of genuine recovery, more comprehensive background information is needed in order to remove the potential for sham recovery or environmental pollution. The intention of this study is therefore to provide an up to date analysis of the science and practice of landspreading recovery, in order to inform policy development and determine best practice.

1.4 Scope and objectives of this study

The aim of this project was to deliver a technical report that provides regulators and practitioners with clear, consistent and up to date information on the extent, nature and environmental implications of spreading paper wastes on agricultural land in England and Wales. The report has reviewed and summarised current information (from 2003) from the Environment Agency's own information on landspreading practices, along with new information supplied by both paper mills in England and Wales and their landspreading contractors. Information relating to agricultural benefits for each type of paper waste spread has been supplemented using data and information from the scientific literature. Meanwhile, information on the quantities of paper wastes spread and land application practices has been summarised.

The study pursued three main objectives:

- **to survey the extent and variability of paper waste production in England and Wales by assessing:**
    - types of paper waste produced, reasons for differences in types of waste and the paper- manufacturing processes from which different wastes arise;
    - quantities of paper wastes produced, imported and exported, and the quantity of land-spread in England and Wales in 2003;

- general properties of the paper waste types, including: nutrient content; moisture content; organic matter content; actual and potential chemical contaminants; actual and potential biological contaminants; odour potential.

- **to investigate the extent and effect of controls on landspreading, and to identify good and bad practice by examining:**
  - management practices and techniques, including: pre-treatment; field storage; land application; soil incorporation; addition of nitrogen; timings of applications;
  - existing auditing or accreditation schemes that are currently used, including an assessment of their effectiveness;
  - any gaps in knowledge/information that require additional research.

- **to undertake a comprehensive review of the literature to identify:**
  - the benefits and disbenefits associated with each type of paper waste;
  - areas where additional research is required to fill gaps in understanding.

2. Paper waste: production and types

2.1 Producing waste

Paper waste arising at paper mills results from two principal routes of effluent treatment – the primary and secondary treatment processes. While primary treatment is basically physical, secondary treatment may be chemical/physical or biological.

Primary treatment involves initial screening of the mill effluent to increase the fibre content of the paper waste by, for example, settlement. Secondary chemical/physical treatment reduces the biological/chemical oxygen demand and clarifies the effluent using a range of methods, such as adding chemical coagulants or polymer flocculants, or dissolved air flotation. It also increases the dry solids content of the paper waste. Secondary biological treatment is also used to reduce the biological/chemical oxygen demand of the effluent and to increase the dry solids content of the paper waste, but uses methods such as the surplus activated sludge process. Tertiary treatment is used to reduce the solids and ammonia content of effluent being discharged from mills.

2.2 Quantities of paper waste produced

2.2.1 Environment Agency data: area office records

To establish the level of information held by the Environment Agency for 2003, each of the 26 area offices in England and Wales provided information on exemption registrations relating to landspreading paper waste materials on agricultural land. Each area office provided the following information:

- tonnages of paper wastes applied to agricultural land;
- whether total tonnages could be split into different types of waste;
- whether paper wastes were blended or mixed with other wastes;
- whether copies of laboratory analysis data were provided by spreading contractors;
- whether spreading contractors stated the agricultural benefit expected from the treatment;
- whether there were any issues or concerns regarding landspreading in a given region.

Information provided by all 26 area offices made it possible to identify 33 different contractor operations. However, it was not possible, on the basis of this information, to determine whether any one mill contractor was working in two or more Environment Agency areas. For the purposes of this report, each of these 33 operations is referred to as a single 'contractor operational area' (COA).

Tonnages of paper wastes applied to agricultural land

Tonnages notified to the Environment Agency were identified for only around 75% of the contractor operational areas, and amounted to approximately 326,000 tonnes FW of paper wastes for 2003[1]. Tonnages from the remaining COAs could not be assessed within the time constraints of the project.

Types of paper waste

In most cases, the material was generically documented as paper 'waste', 'pulp', 'cake', 'sludge' or 'crumble', or as a description of what was used as a feedstock at the paper mill – for example recycling newspaper. Hence it was not possible to provide a list of the types and associated quantities of different paper waste materials applied to agricultural land.

Paper waste blending or mixing with other wastes

Around 12% (4 responses) of the COAs used some form of blending/mixing of paper waste with other wastes (Table 2.1). However, blending/mixing may be more common than indicated if the 'not typically' and 'no comments provided' categories are also taken into account.

Table 2. 1 Reports of mixing or blending paper wastes with other waste materials

Paper waste blended or mixed	No. of responses
no known mixing/blending	11
not typically	5
not provided in pre-notification	2
some	2
some with farmyard manure	1
mixed at the field site (liquid)	1
no comments provided	11
Total	**33**

Provision of laboratory analysis data

[1] Note that the notified tonnage is the quantity which is *likely* to be spread, and not necessarily the actual tonnage spread.

Approximately half of the COAs provided a full set of paper waste laboratory analyses along with their notification of intention to landspread (Table 2.2).

Table 2. 2 Laboratory analysis data received by Environment Agency area offices

Laboratory information received from contractors	No. of responses
full set	17
partial information	2
none	14
Total	**33**

Where the data provided matched the analysis suite detailed in the Paper Federation of Great Britain's *Code of Practice for Landspreading Paper Mill Sludge* (1998) this was recorded as a 'full set', while information below that level of detail was recorded as 'partial information' (Table 3.1). It is likely that where the Environment Agency received no analysis data for a given exemption application, the area office already had typical waste analysis data on record for that COA.

The analysis data submitted provide the following information regarding the composition and application rates of paper wastes spread on agricultural land in 2003:

- total neutralising value (TNV): range, 1 to 21%; mean, 8% (on a dry solids basis);
- organic matter content: range, 31 to 70%; mean, 49% (on a dry solids basis);
- carbon: nitrogen (C:N) ratio: range, 14:1 to >150:1; mean, 70:1;
- application rates: range, 40 t/ha to 200 t/ha; mean, 75 t/ha fresh weight (FW).

Statements on agricultural benefits

One third (12) of the 33 COAs included an agricultural benefit statement with their notification of intention to landspread. Benefit statements came in various forms: some were simply the chemical analysis of the paper waste; others were either the site risk assessment/recommendation report or a technical report on the composition of the paper waste. Three main benefits were reported:

- soil conditioning due to organic matter
- soil pH increases due to liming value
- addition of major plant nutrients

Issues or concerns

Approximately 60% (20) of the COAs raised some issues or concerns to the area offices; 20% (6) had no issues or concerns; the remaining 20% made no comment.

The main issues or concerns raised by the COAs were:

- whether paper waste is beneficial to agricultural land:
  - small or no benefit in some cases
  - was there a benefit if extra fertiliser N had to be applied
  - would like to see more detail on statement of benefit
  - organic matter and liming value thought not to be of benefit in some cases
  - long-term storage may reduce the benefit of nutrients in the material
- odour from storage and landspreading activities
- leaching/run-off from long-term stockpiles
- short or late notification period
- presence of potentially toxic elements
- stockpiles are visual
- not incorporated quickly
- application with other wastes
- uncertainty over some consultants' suitability to provide properly qualified advice
- frequency of waste analysis
- over-application
- more guidance needed on the benefits of consecutive applications

However, since no area offices provided details on how they dealt with these concerns, it is not possible to attribute any significance or otherwise to the comments.

2.2.2 Paper mills data: responses to questionnaires

The 56 paper mills in England and Wales were asked a series of questions regarding the types, quantities and nature of paper wastes that they produce and apply to agricultural land (Appendix A). Their responses indicate that there were seven main routes of paper waste re-use/recovery in 2003 (Table 2.3).

Table 2. 3 Paper waste re-use/recovery routes in England and Wales, 2003

Re-use/recovery route	No. of mills	Waste quantity (000 tonnes FW)
agricultural landspreading	28	699
composted	4	13 (3 mills*)
effluent discharge to sewer	6	-
landfill	5	50 (4 mills*)
energy recovery	4	147
land restoration	6	85 (5 mills*)
export	1	-

*Number of mills upon which estimated quantity is based

The most common form of paper waste recovery was landspreading on agricultural land, with 50% of the mills employing this route. The quantity of paper waste reportedly applied (699,000 tonnes FW) was greater than the notifications recorded by the Environment Agency (only 326,000 tonnes FW), although there was reasonable agreement between the two data sources in terms of the number of operations undertaking landspreading activities (28 and 33 from the paper mills and Environment Agency data, respectively). Differences between the two data sets most probably result from multiple paper waste applications made *per* exemption; Environment Agency records show only the quantities anticipated at the exemption stage.

Six mills reported that they used multiple re-use/recovery routes. Four used landspreading as one method of recovery alongside either energy recovery (2 mills) or land restoration (2 mills). One used energy recovery alongside land restoration, and one used composting alongside energy recovery. Two mills reported that they produced no form of waste material from their operation.

Four other mills reported that all or part of their paper waste production was used to produce compost, a proportion of which may subsequently have been spread on agricultural land. However, the amount of material managed in this way was relatively small (around 1% of the total).

The paper mills anticipate that the amount of paper waste spread on agricultural land will show a small decrease over the next 3-5 years to around 611,000 tonnes FW. This anticipated decrease (70,000 tonnes FW) is largely linked to one mill, which has decided to divert all of its future paper waste into energy recovery (specifically power generation from incineration). Several other mills indicated that as part of large multi-national companies decisions on their future paper waste recovery policies would largely be governed by global economics and legislation.

2.2.3 Contractor data: responses to questionnaires

Compared to data from paper mills (699,000 tonnes FW), spreading contractors reported around 725,000 tonnes FW of paper waste applied to agricultural land in 2003. The small difference between these two figures is not considered significant, most likely resulting from some mills moving to or from landspreading as part of their paper waste management strategy. In addition, the storage of material prior to landspreading could have contributed to differences between mill and contractor estimates.

The 28 paper mills recovering paper waste to agricultural land employed 16 contracting companies, of which five were managing around 88% of total landspread each year (Table 2.4).

Table 2. 4 Paper waste tonnages spread by contractors, 2003

Contractor	No. of mills	Waste quantity (000 t/a FW)
Contractor 1	1	194
Contractor 2	3	166
Contractor 3	6	127
Contractor 4	3	88
Contractor 5	2	63
Contractor 6	1	23
Contractor 7	1	18
Contractor 8	1	16
Contractor 9	3	11
Contractor 10	1	7
Contractor 11	1	4
Contractors 12-16	5	8

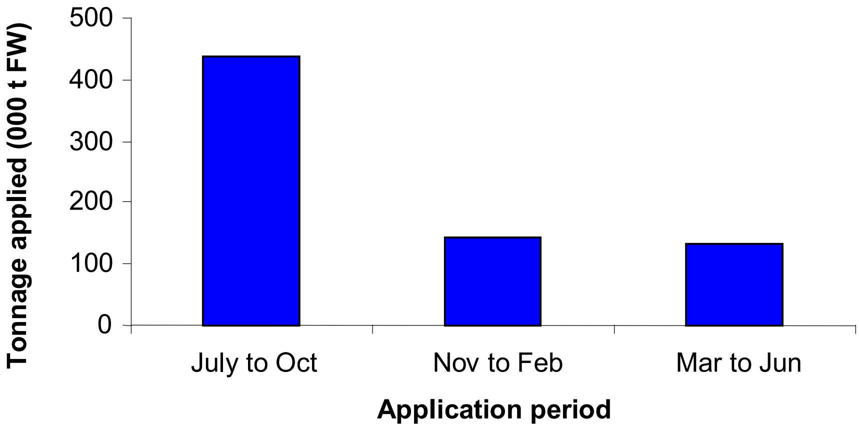
Of these 16 contractors 14 provided responses to the questionnaire (Appendix B), representing 99% of the total paper waste applied to agricultural land in 2003. Contractors provided information on a number of aspects of their landspreading practices, including the storage of paper waste prior to spreading, the soil types used, and any additional nutrient additions. These issues are discussed in the following sections.

Storage of paper waste prior to landspreading

For the majority of mills storage of paper waste materials at the mill is neither practical nor feasible, although three mills could store material for up to two months. For the larger mills, paper wastes were either stored in field heaps on or adjacent to the designated field for spreading, or in some cases (mainly in high rainfall areas) were stored on 'hard standings' to ease access. The length of the storage period varied considerably, depending mainly on cropping and field conditions, but in the majority of cases, storage was relatively short-term, with 78% stored for less than 2 months. Of the remainder (148,000 tonnes), the majority (21%) was stored for between 6 to 8 months.

For materials stored over the short term, land cropped in autumn and spring was most widely used for spreading. However, in places where factors such as cropping patterns, climate or soil type made it difficult to access suitable sites within feasible haulage distances, longer storage periods were often employed. These extended storage periods were used to ensure that the material was applied when field conditions were favourable, to avoid causing compaction damage to fields. Following extended storage (6-8 months), the majority of paper waste materials were spread in late summer/early autumn (Figure 2.1).

Figure 2. 1 Timing of paper waste applications, 2003

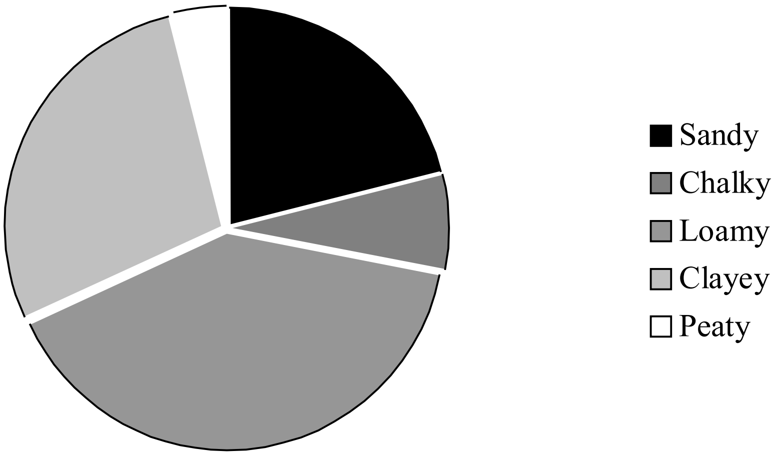


Biological and chemical activity taking place during storage could potentially give rise to changes in paper waste composition and quality that might influence the properties of the material. Potential effects of storage include changes in chemical composition, pathogen content and biological activity, while potential environmental impacts include leachate quality and volumes, and gaseous emissions, both during storage and following landspreading. Although the exact nature and levels of these effects are currently unclear, a pilot study simulating the stockpiling of deinked newspaper sludge prior to land application showed that heavy metal concentrations in leachate samples were below, or comparable to, permitted drinking water levels (Tucker *et al*., 2001). However, anecdotal evidence based on contractor observations do indicate that short-term odour generation is worse when breaking into heaps following storage, particularly for biologically treated materials.

Soil types used for landspreading

Paper wastes were applied to a range of soil types, with the majority applied to loamy (40%), sandy and clayey soils (Figure 2.2).

Figure 2. 2 Paper waste applications onto different soil types, 2003



Land bank used for paper waste spreading

It is estimated that during 2003 around 725,000 tonnes FW of paper wastes were applied to around 10,500 hectares of agricultural land – that is a mean application rate of 69 tonnes/ha (with a range of 10-250 t/ha FW). Table 2.5 shows how different application rates were used depending on the cropping situation and paper waste composition. The highest rates were applied in grass re-seed situations, where the re-seeding operation offered the opportunity to apply large amounts of organic matter and address any build up of soil acidity during the previous phase of agricultural rotation. The lowest application rates were made to the surface of permanent grassland (presumably because of concerns about smothering).

Table 2. 5 Paper waste application rates, 2003

Agricultural situation	Minimum (t/ha FW)	Maximum (t/ha FW)	Mean (t/ha FW)
tillage land (non-biologically treated)	30	200	76
tillage land (biologically treated)	25	65	41
permanent grassland (surface)	10	30	26
grass re-seed	100	250	145

On tillage land, differences in paper waste composition were clearly taken into account, the higher nutrient content biologically treated paper wastes being applied at much lower mean rates (around 50%) than non-biologically treated paper wastes.

Cropping

Winter-sown combinable crop land was widely used for spreading paper wastes, with 55% of the annual applications preceding these crops (Table 2.6). Many contractors also targeted land where winter oilseed rape was grown immediately before application, as this provided the widest possible application window before winter-sown cereals. Contractors appeared to favour winter-sown crops for two reasons: first, the summer/early autumn months provide by far the best ground conditions for application; second, the winter-sown crops are generally less sensitive to nitrogen deficiencies than spring-sown crops following paper waste application.

Table 2. 6 Cropping regime following paper waste applications

Crop type	Quantity of paper waste (% total spread)
combinable crops (winter-sown)	55
combinable crops and maize (spring-sown)	22
permanent grassland (surface)	11
grassland re-seed (winter-sown)	6
grassland re-seed (spring-sown)	5
roots	<0.5
others	<0.5

Spring-sown combinable crops and maize constituted the second largest cropping group (22%), commonly used as a means of extending the spreading window.

Where livestock were a predominant feature in the local farming system, the mill contractors applied surface treatments (11%) to permanent grassland (undisturbed). Whilst this practice extended the spreading window, paper wastes were applied only at low rates (10 to 30 t/ha FW), and in some cases, paper waste materials with a biological content were considered unsuitable for surface applications on account of their potential for odour. However, where grassland was being re-seeded (ploughed and sown with new grass seed) the mill contractors used this opportunity to apply a further 11% of the total landspread paper wastes. Grass re-seeds usually provide good ground conditions for application, as well as the potential to use higher application rates compared to surface applications to permanent grassland.

Six of the contractors reported that legume (nitrogen-fixing) crops performed particularly well following paper waste applications. These applications are permitted in Nitrate Vulnerable Zones (NVZs) before legume crops, on account of their low levels of readily available nitrogen (Defra, 2002). However, three contractors indicated that they avoided using certain paper waste materials – particularly biologically treated materials – before legume crops, since any nitrogen benefit gained would be lost on the crop.

This issue of N availability is a recurring theme within landspreading practice. Applications of some paper wastes – predominantly non-biologically treated wastes – can result in N 'lock-up' which leads to nitrogen deficiency in some crops (with spring barley particularly sensitive). Such applications are permitted in NVZs and legume crops can benefit as outlined above. However, other wastes, and especially biologically-treated wastes, tend to have higher levels of available N and have rather different effects in terms of N load (see Section 4.2.1).

Ten contractors indicated that they specifically avoid applying paper wastes to high value crops, particularly potatoes, stating that the risks of actual – or even perceived – cropping problems were too great. Having said that, one farmer/contractor was successfully using paper waste on sugar beet land. Several other contractors also reported avoiding spring-sown malting barley (which is nitrogen sensitive), oilseed rape and maize crops, due to their subsequent 'poor performance'.

Following the application of paper wastes to tillage land, almost all cultivation was by deep discing or ploughing (Table 2.7). However, to avoid potential odours, a shallow cultivation was often used to achieve rapid soil incorporation prior to deep cultivation. This was a particularly common practice where biologically treated paper wastes were applied.

Table 2. 7 Paper waste incorporation methods

Incorporation method	Quantity of paper waste (% of total spread)
deep (discing or ploughing)	88
shallow	0.5
none (spread on grassland surface)	11.5

Extra fertiliser nitrogen addition

The short-term 'lock-up' of soil nitrogen resulting from some wastes, leads many contractors to add extra inorganic fertiliser nitrogen (N) to counteract the effect. Levels of N added vary between contractors, with a mean application rate of 48 kg N/ha and a range of 0-280 kg N/ha. Reassuringly, all contractors applying additional N reported that these additions were adjusted to take account of the chemical composition and application rate of the paper waste, and that they were based on experience. One contractor reported that their N application rates were based on previous scientific trials.

Five contractors reported that they had never applied additional fertiliser N – usually cases where biologically treated paper wastes were applied. In general, there was a trend towards applying lower rates of fertiliser N following applications of biologically treated paper wastes (higher available N content), and higher rates following chemically/physically treated materials (lower available N content). On average, where extra fertiliser N was applied to compensate for N 'lock-up', this was at a rate of around 0.8 kg N/tonne FW of paper waste applied (equivalent to 2.0 kg N/tonne dry solids applied).

Additional organic materials

Contractors also reported applications of additional organic materials to around 11% of the land area used for paper waste spreading (Table 2.8). In most cases these additional materials were taken into account when providing field recommendations.

Table 2. 8 Land area receiving additional organic materials in the same year as paper waste application, 2003

Organic material	Land area (% of total land-spread area)
farmyard manure/slurry	7.5
poultry manure	1.5
sewage sludge	1.8

Benefits and disbenefits to agriculture

Almost all spreading contractors recognised the soil conditioning properties of applying paper waste. Nearly three quarters of them also reported the liming capacity and/or nutrient content of the wastes as a major benefit to agriculture.

In terms of agricultural disbenefits, the most commonly reported was nitrogen deficiency in subsequent crops, although soil compaction through applying paper waste in unsuitable weather conditions was also identified as a problem. However, a third of contractors reported no disbenefits arising recently from the application of paper waste, noting that where they had previously identified problems, these had now been more or less overcome through changes in management practice.

Problems arising from mismanaging an operation

Table 2.9 summarises potential problems that can arise through mismanaging a paper waste landspreading operation. These range from soil compaction and pollution to nutrient supply and public relations.

Table 2. 9 Problems arising through the mismanagement of landspreading

Potential problem	No. of comments
soil compaction	10
application to unsuitable fields, including over-liming	8
nitrogen 'lock-up'	7
pollution risk	5
over-supply of nutrients	4
colour	2
blowing in the wind	1
adverse public relations	1

Other comments

A number of contractors made additional comments regarding the recovery of paper wastes to agricultural land. Some of the more common responses included that:

- landspreading is environmentally friendly and avoids landfilling;
- paper waste materials are (hugely) beneficial to agriculture;
- paper waste materials are in demand from farmers;
- the Environment Agency needs to develop consistent guidelines on waste applications;
- industry would welcome greater acknowledgement from regulatory bodies for all the hard work put in on this waste stream;
- regulatory bodies and the public tend to be precautionary about potential disbenefits and not positive enough about the real benefits of the land recovery route;
- 'cake' has historically been given a bad name because of the contractor, not because of the product; contracting must be undertaken to an acceptable standard.

2.3 Paper waste materials

The survey of paper mills revealed that the majority of paper waste materials could be classified into one of three broad categories based on the waste type and treatment process: (i) primary; (ii) secondary – with biological treatment; (iii) secondary – with chemical/physical treatment (Table 2.10).

Table 2. 10 Types of paper waste produced in England and Wales, 2003

Waste type	No. of mills	Quantity (000 t/a FW)
primary (fibre concentration only) (100%)	4	57
primary > 75% (5-25% with secondary biological treatment)	4	165
secondary (100% biological treatment)	3	23
secondary (100% chemical/physical treatment)	6	48
secondary (mixture of biological and chemical / physical treatment)	5	309
not disclosed	6	97

Clearly, the majority of paper wastes spread on agricultural land in England and Wales have either undergone secondary treatment or else contain an element of secondary treated material. This waste amounts to a total 545,000 tonnes FW, of which 380,000 tonnes all received secondary treatment and 165,000 tonnes contained between 5-25% of secondary biologically treated material. Davis and Rudd (1998) previously described the composition of all paper waste materials under the single banner of 'paper sludge'. However, chemical composition data for these paper waste materials reveal clear differences in type relating to the treatment method employed (Tables 2.11-2.13).

In terms of dry solids, total nutrient (N, P_2O_5, K_2O, SO_3) and heavy metal (Cu, Cd, Ni, Pb and Cr) contents, there are clear distinctions between secondary biologically treated paper wastes and primary or secondary chemically/physically treated paper wastes. The biologically treated wastes show a dry solids content of around 10% lower, and nutrient and heavy metal contents which are consistently higher that chemical/physical wastes. These differences are most likely a result of using biologically active materials to drive the biological treatment process.

Table 2. 11 Chemical composition of primary treated paper waste

Analysis	Units	No. of samples	Minimum	Maximum	Mean
total solids	(%)	37	28.2	60.4	42.6
pH	(%)	29	5.8	11.3	7.7
TNV*	(% CaO)	23	2.3	17.8	6.2
N	(kg/t FW)	37	0.6	11.1	2.5
C	(kg/t FW)	37	8.6	295	136
NH_4-N	(kg/t FW)	22	0.01	0.95	0.31
P_2O_5	(kg/t FW)	29	0.2	3.06	0.59
K_2O	(kg/t FW)	29	< 0.1	0.87	0.19
MgO	(kg/t FW)	29	0.1	3.78	1.58
SO_3	(kg/t FW)	28	0.2	2.75	0.62
Zn	(mg/kg FW)	29	5.2	79.3	21.9
Cu	(mg/kg FW)	29	4.6	35.1	16.5
Cd	(mg/kg FW)	29	< 0.1	0.4	< 0.1
Ni	(mg/kg FW)	29	< 0.1	7.2	1.2
Pb	(mg/kg FW)	29	0.9	20.0	3.6
Hg	(mg/kg FW)	29	< 0.1	< 0.1	< 0.1
Cr	(mg/kg FW)	29	0.5	10.2	2.1

* Total neutralising value

Table 2. 12 Chemical composition of secondary biologically treated paper waste

Analysis	Units	No. of samples	Minimum	Maximum	Mean
total solids	(%)	4	19.6	33.2	27.5
pH	(%)	4	6.7	7.0	6.8
TNV*	(%Ca0)	4	2.3	7.4	3.4
N	(kg/t FW)	4	5.7	10.5	7.5
C	(kg/t FW)	3	83.7	103	93.3
NH_4-N	(kg/t FW)	1	-	-	0.81
P_2O_5	(kg/t FW)	4	2.1	7.6	3.8
K_2O	(kg/t FW)	4	0.39	0.53	0.44
MgO	(kg/t FW)	4	0.55	1.12	0.97
SO_3	(kg/t FW)	3	1.95	2.93	2.35
Zn	(mg/kg FW)	4	26.3	62.3	38.1
Cu	(mg/kg FW)	4	25.5	34.0	30.3
Cd	(mg/kg FW)	4	0.1	0.3	0.2
Ni	(mg/kg FW)	4	0.7	9.2	2.9
Pb	(mg/kg FW)	4	6.4	10.0	8.0
Hg	(mg/kg FW)	4	< 0.1	< 0.1	< 0.1
Cr	(mg/kg FW)	4	2.2	11.4	5.0

* Total neutralising value

Table 2. 13 Chemical composition of secondary chemically/physically treated paper waste

Analysis	Units	No. of samples	Minimum	Maximum	Mean
total solids	(%)	59	23.9	85.7	39.8
pH	(%)	64	5.3	11.6	7.3
TNV*	(%CaO)	62	< 0.1	12.5	3.8
N	(kg/t FW)	62	0.6	4.1	1.8
C	(kg/t FW)	37	83.2	394	171
NH_4-N	(kg/t FW)	29	0.01	0.35	0.08
P_2O_5	(kg/t FW)	62	0.15	1.37	0.37
K_2O	(kg/t FW)	62	< 0.1	1.95	0.18
MgO	(kg/t FW)	57	0.1	2.87	1.16
SO_3	(kg/t FW)	28	0.3	3.06	1.10
Zn	(mg/kg FW)	55	2.6	174	45.9
Cu	(mg/kg FW)	55	2.3	117	22.9
Cd	(mg/kg FW)	55	< 0.1	< 0.1	< 0.1
Ni	(mg/kg FW)	55	< 0.1	3.0	1.3
Pb	(mg/kg FW)	55	< 0.1	15.5	3.1
Hg	(mg/kg FW)	55	< 0.1	< 0.1	< 0.1
Cr	(mg/kg FW)	55	0.1	6.2	2.7

* Total neutralising value

In terms of their application rates and potential for nutrient/heavy metal additions, we have identified two classes of paper wastes: (i) those containing a substantial element of biologically treated material and (ii) those with no, or only a small, biologically treated component. However, since the analysis for biologically treated paper wastes was based only on four samples (compared to more than 80 samples for the primary and secondary chemically/physically treated paper wastes) this interpretation should be treated with caution until more data on biologically treated paper wastes are available.

Either way, each of these paper waste classifications, when applied at the current maximum rate – an N loading of 250 kg/ha total N in NVZs (Defra, 2002) – showed nutrient and heavy metal loadings similar to, or lower than, those for other organic materials commonly spread on agricultural land (Table 2.14).

Table 2. 14 Nutrient and heavy metal loads from paper waste applications at 250 kg / ha total N

Organic material	Rate (t/ha FW)	P_2O_5	K_2O	MgO	SO_3	Zn	Cu	Cd	Ni	Pb	Cr
		(kg/ha/a)									
paper waste (non-bio*)	123	54	23	160	106	4.6	2.6	< 0.1	0.2	0.4	0.3
paper waste (bio**)	33	125	15	32	78	1.3	1.0	< 0.1	0.1	0.3	0.2
cattle FYM[a]	42	146	333	29	75	0.7	0.2	< 0.1	< 0.1	< 0.1	< 0.1
biosolids[a]	6[b]	300	trace	200	43	4.6	3.2	< 0.1	0.3	1.3	0.9

*Primary or secondary chemical/physical treatment; ** Biological treatment; [a] Data from Nicholson *et al.* (2003); [b] Application rate in dry solids.

3. Paper waste: spreading and operational practice

3.1 Code of practice

Paper mills have been spreading paper wastes on agricultural land for around 30 years, during which time the paper industry has been able to identify best management practices for the landspreading of these wastes. This experience has been collated by the Paper Federation of Great Britain to produce a *Code of Practice for Landspreading Paper Mill Sludge* (Paper Federation of Great Britain, 1998) with a view to defining best practices for landspreading, and to outlining the key legislative requirements with which the industry needs to comply. In order to support this objective, and to meet the exemption criteria in the Waste Management Licensing Regulations (HMSO, 1994), the code identifies a number of practices which should ensure that the application of paper waste:

- provides either agricultural benefit or ecological improvement;
- does not impair the nutrient needs of plants or soil quality;
- does not cause pollution to either surface or ground water;
- is non-injurious to human, animal or plant;
- does not adversely affect the countryside or places of special interest;
- does not cause public nuisance (eg through visual impairment or odour).

Whilst the code of practice focuses on landspreading as a recovery option, it also recognises that the principal aim should be to achieve the objectives of the waste management hierarchy: first minimise waste, then re-use/recover. Any route chosen for re-use/recovery must then be based on the principle of the best practicable environmental option (BPEO). The code also promotes regular evaluation of other recovery options, such as energy recovery and other end uses, including composting and animal bedding. It also points out that consideration should be given to the distance required to transport waste when making an overall environmental impact assessment.

The scope of the code of practice covers all paper wastes produced during the papermaking operation and thus includes deinked, primary and secondary treated wastes, each of which is likely to have different characteristics at different mills.

Section 5 of the code of practice advises that properly qualified advice (PQA) should be sought when assessing either the suitability of a landspreading site or the paper waste properties for landspreading. Of the 28 mills currently using landspreading to agriculture as a recovery route, 22 (79%) reported that they used PQA. These 22 mills accounted for 655,000 tonnes FW of paper wastes (94% of the total) recovered to agricultural land in 2003. It is therefore reasonable to assume that, provided contractors follow the PQA, the majority of paper waste spread on agricultural land in England and Wales has a low risk of incurring negative environmental impacts.

The code of practice also recommends that any analysis of soils and paper wastes intended for landspreading should follow industry best practice. The recommended waste analyses are summarised in Table 3.1, together with the analysis suites used by the four laboratories analysing paper wastes for the paper mills and contractors in 2003.

Table 3. 1 Recommended testing suite for paper wastes compared to analytical data provided to paper mills and spreading contractors

Parameter	COP[a]	Lab 1	Lab 2	Lab 3	Lab 4
dry solids	✓	✓	✓	✓	✓
pH	✓	✓	✓	✓	✓
TNV*	✓	✓	✓		✓
C	✓	✓	✓	✓	✓
N	✓	✓	✓		✓
NH_4-N		✓			✓
P_2O_5	✓	✓	✓		✓
K_2O	✓	✓	✓		✓
MgO		✓	✓		✓
SO_3			✓		✓
Zn	✓	✓	✓	✓	✓
Cu	✓	✓	✓	✓	✓
Cd	✓	✓	✓	✓	✓
Ni	✓	✓	✓	✓	✓
Pb	✓	✓	✓	✓	✓
Hg	✓	✓	✓	✓	✓
Cr		✓	✓	✓	✓

[a] Paper Federation of Great Britain *Code of Practice*; * Total neutralising value.

With the exception of one laboratory (Lab 3) whose analysis simply covered dry solids, pH, organic carbon and heavy metal contents, all of the labs provided an analysis programme which was more complete than the recommended suite. We suggest that it would make sense to update the code of practice to include an additional three paramaters – ammonium-N (NH_4-N), magnesium (MgO) and sulphur (SO_3) – such that spreading contractors are provided with data on these potentially available plant nutrients. Given that the majority of the mills are already using a service that provides these analyses, there would be no need to change 'normal' practice for most.

3.2 Auditing

Of the 28 mills in England and Wales using landspreading as their recovery route for paper waste materials, 24 conducted some form of auditing of their landspreading operations. Of these18 either conformed with, or were working towards, ISO14001 accreditation, while the other six were working within the recommendations of the Paper Federation's code of practice. The remaining four mills, which appeared to have no auditing in place, accounted for only 9,000 tonnes FW – equivalent to around 1% of the total amount of paper wastes spread on agricultural land in 2003. The majority of mills (79%) were using PQA.

Of the spreading contractors servicing these mills, almost half used Defra's *Codes of Good Agricultural Practice* for the protection of water, soil and air (MAFF, 1998a; b; c) as the main guidance documents for their landspreading operations. A further third used an ISO compliant scheme, the remainder using either a mill-specific code, the Paper Federation of Great Britain's code, or no guidance documentation.

Around 70% of contractors obtained paper waste application and fertiliser advice from FACTS-qualified individuals (Fertiliser Advisers Certification & Training Scheme). The remaining contractors used 'experienced' staff.

4. Landspreading of paper wastes: scientific evaluation

A detailed literature survey supports many of the observations and practices reported by the mills and spreading contractors – particularly in relation to agricultural benefits and environmental impacts. Details of these are discussed in this chapter, while areas requiring further study are highlighted in Section 6.

4.1 Application practices

4.1.1 Solids *versus* liquids

The contractors indicated that all the paper waste materials applied to agricultural land were in a 'cake' form (ie stackable solid materials), as opposed to liquids. This was further confirmed by the laboratory data, which revealed dry solids contents ranging from 20 – 86% (mean = 39%). The landspreading of 'cake' rather than liquid materials is probably related to the costs of transportation (less water means less mass) and to the ease of handling, soil incorporation and subsequent cultivation. These data contrast with paper sludge analysis data collated by Davis and Rudd (1998), which showed a mean dry solids content of only 21%. This suggests that the paper industry has gradually moved, over the last decade, towards applying drier 'cake' materials, which can lead to improvements in handling as reported by Aspitarte *et al*. (1973). These workers found that paper waste with a dry solids content of less than 20% was difficult to handle or evenly incorporate into the soil, while pressing the paper waste to 38% dry solids produced a material which was much easier to handle, apply and incorporate into soil. Meanwhile, Vagstad *et al*. (2001) found that the physical structure of biologically treated paper waste could sometimes cause handling problems and that pre-treatment to address the instability of the waste was beneficial. However, in grassland situations it can be beneficial to apply liquid materials (around 4% dry solids) where injection below the soil surface is a practical option.

4.1.2 Incorporation into topsoil

Our contractor survey clearly reveals that cultivation following paper waste applications to 'tillage' land (ie excluding permanent grassland) was virtually all by deep discing or ploughing (Table 2.6). However, it was also noted that where odour nuisance was likely – for example, where paper wastes with a biologically treated component were applied – a shallow cultivation was often used prior to deep cultivation to eliminate the problem.

One study in Scotland (Vinten *et al*., 1998) has revealed that the best cultivation technique for reducing nitrate leaching losses following landspread is conventional mouldboard plough cultivation. This technique allows incorporation of wastes to a depth of 150 mm – compared with deep mouldboard ploughing (350 mm depth) or reduced cultivation with a power harrow (50 mm depth) –

and the benefit is most likely due to better mixing of the paper waste within the topsoil. Similarly, cultivation into the topsoil using a conventional mouldboard plough (150 mm depth) was also found to be the best technique for reducing nitrous oxide emissions following the application of paper mill sludge (Baggs *et al.,* 2002).

Reports on surface applications differ significantly. Hughes and Girdlestone (2001) have reported adverse effects on crop growth immediately after broadcast applications of paper mill sludge. These they attribute to a lack of crop available N and high soil water content, leading to anaerobic conditions within the topsoil and discouraging root penetration. They conclude that the application method was the main cause of the problem, the surface application compacting into a single layer and resulting in high temperatures and anaerobic conditions, whereas immediate incorporation into topsoil encouraged sludge decomposition within the soil matrix. In contrast, Chantigny *et al.* (2000a) reported that the presence of sludge on (or near) the surface could have distinct advantages in terms of soil water holding capacity and reductions in water loss through evaporation. To help alleviate the potentially negative effects of paper sludge application (anaerobic conditions, N immobilisation, soil capping and smothering) and to allow time for the decomposition process to commence, Chantigny *et al*. (2000a) recommend delaying planting after sludge application. Similarly, Simpson *et al*. (1983) suggest delays of two and four weeks following the application of secondary and primary sludge applications, respectively.

4.2 Soil quality and sustainability

4.2.1 Nutrient supply and turnover

Paper wastes are primarily applied to agricultural soils to act as organic conditioning amendments and liming materials, and are often combined with additional inorganic fertilisers which supply crop nutrient needs. Nevertheless, the nutrients in paper wastes themselves can also make an important contribution in terms of nutrient supply and microbial activity. For comparison, the nutrient compositions of paper wastes produced within EU member states (prior to expansion) are shown in Table 4.1. On the whole, these nutrient data (for nitrogen, ammonium-N, phosphate and potash) show good agreement with comparable data provided by the mills in England and Wales (Tables 2.11 to 2.13). However, the mill data from England and Wales did show lower levels for sulphur (4 kg SO_3/tonne dry solids) and magnesium (3 kg MgO/tonne dry solids) than the EU means.

Table 4. 1 Nutrient concentrations in paper wastes from the EU15

Nutrient	Minimum	Maximum	Mean
	(kg/tonne dry solids)		
total N	4	50	13
NH_4-N	0	3	0.2
P_2O_5	2	80	7
K_2O	0.6	8	2
SO_3	-	-	13
MgO	0.2	60	10

Source: Gendebien *et al.*, 2001

Variation in the composition of paper wastes is primarily dependent on the treatment process at the mill. Primary sludges consist of organic matter, mainly in the form of cellulosic paper or wood fibre, and have a low N content of typically 0.1 – 0.25% on a dry solids basis (Bellamy *et al.,* 1995). Since nitrogen and phosphorus are essential to biological processes, these are added to secondary (biological) treatment processes and typically result in higher nitrogen (2–4% dry solids) and phosphate (0.1–0.3% dry solids) contents in resulting wastes. In practice, because of they are easier to handle, the paper wastes applied to agricultural land are commonly a mixture of primary and secondary treated materials.

Effects on crop growth and yields

Aitken (1997) has concluded that paper waste sludge, waste paper and deinked paper pulp would all be of 'unlikely' or 'low' benefit in supplying N, P and K for crop uptake. However, experiments with crops such as oats *(Avena sativa* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), ryegrass (*Lolium perenne* L.), maize (*Zea mays* L.), cucumber (*Cucumis sativus* L.), tomato (*Lycopersicon esculentum* L.), peppers (*Capsicum annuum* L.), potato (*Solanum tuberosum* L.), linseed (*Linum spp.* L.) and sugar cane (*Saccharum officinarum* L) have all shown improvements in crop growth at low to moderate paper waste application rates (up to around 100 t/ha FW), and reductions in crop growth at higher rates (Dolar *et al.*, 1972; Cabral and Vasconcelos, 1993; Vasconcelos and Cabral, 1993; Zhang *et al.*, 1993; Bellamy *et al.*, 1995; Trépanier *et al.,* 1998; Voundi Nkana *et al.*¸1998a;b; Demeyer and Verloo, 1999; Hughes and Girdlestone, 2001; Vagstad *et al.*, 2001; O'Brien *et al.,* 2002; Douglas *et al.*, 2003). In these reports, growth characteristics were assessed on the basis of plant height, foliar surface area, length of leafstalk and/or dry matter production.

Measured improvements to crop yields have been highlighted by Vagstad *et al.* (2001), who reported that applying raw paper sludge at 160 t/ha FW (18 tonnes of organic carbon (C) per ha) resulted in significant (P < 0.001) increases in grain yields of spring barley. Occurring in the season following sludge application this increase – of around 0.6 t/ha – was equivalent to an inorganic fertiliser N application of around 40 kg/ha. In the three subsequent years, the residual effects of the paper sludge produced grain yield increases of around 2 t/ha higher than those of the untreated control. In contrast, however, other workers have found either no significant ($P > 0.05$) effects on crop yields (Vinten *et al.,* 1998), or only small improvements two to three years after application (Aitken *et al.*, 1998). The consensus view is that observed yield increases were not related to nutrient levels, but were rather a result of improvements in soil physical (eg water holding capacity) and chemical (eg cation exchange capacity) properties. The yield decreases at higher paper waste application rates were largely attributed to decreased nutrient availability, mainly of nitrogen, as outlined in the following section.

Nitrogen limitation

In 1987 Zibilske reported N immobilisation following the application of a paper sludge, with net N immobilisation proportional to the rate of sludge applied. The data indicated that over a 250 day period, decomposition of the sludge (which had a C:N ratio of 478:1 and was applied at rates from 0 to 670 t/ha FW) could create an N deficiency equivalent to around 1.5 kg N/ha per tonne FW applied. Similarly, Aitken *et al.* (1998), in a study in Wales, reported decreases in soil nitrate-N concentrations during the first year after deinked paper sludge application. Reported decreases were around 0.4 kg N/t FW of paper waste applied.

It is clear from these and other studies that applications of paper waste can decrease crop available N through the assimilation (immobilisation) of inorganic N in the soil biomass (Zibilske, 1987; Aitken *et al*., 1995; Aitken *et al.,* 1998). Voundi Nkana *et al*. (2000) reported reduced soil nitrate concentrations following paper pulp applications of 15-70 t/ha FW. They concluded that the reduced soluble nitrate concentrations could limit losses due to leaching but could also result in reduced N availability, the remaining N being bound instead to soil. Similarly, reduced nitrate leaching losses was also observed by Vinten *et al.* (1998), in a study in Scotland, who found that over-winter nitrate leaching losses were reduced from 177 to 94 kg N/ha following the application of 127 t/ha FW of paper mill waste (11 tonnes C/ha). These workers concluded that applying paper waste was an effective means of reducing nitrate leaching losses in the first winter following application. Supporting these findings are a number of investigations into the effects of applying paper waste alongside 'high' N materials such as biosolids and inorganic fertilisers. Dolar *et al.* (1972) have reported improved groundwater quality following co-applications of paper waste at a rate of around 60 t/ha FW. They conclude that this is most likely the result of N immobilisation by the paper waste. This is supported by a similar study in England which found substantial reductions in net N mineralisation following the co-application of paper waste (100 t/ha FW) and vegetable residues (Rahn *et al.*, 2003).

Carbon content and nitrogen availability

It is the readily available C compounds contained in paper wastes that lead to the observed decreases in the soil inorganic N pool, and which thus reduce levels of N potentially available for leaching. These same C compounds can also exacerbate N loss due to denitrification, particular under warm and wet conditions (Baggs *et al.,* 2002). This loss of N through denitrification is, in turn, likely to increase nitrous oxide emissions (a powerful greenhouse gas), unless complete reduction to di-nitrogen occurs – which is unlikely. However, N losses due to denitrification do have advantages for groundwater protection, in that N is lost to the air rather than to groundwater. It could be argued therefore, that where minimising nitrate losses to ground or surface waters is the priority (as in Nitrate Vulnerable Zones), then water protection should take priority. Moreover, there would be the added benefit that, by reducing nitrate leaching losses to groundwater, any indirect nitrous oxide emissions from nitrates in surface water systems would also be reduced.

The benefits of N immobilisation

Reducing N losses via leaching, through N immobilisation in the soil biomass, has the potential advantage of conserving N in the soil for later crop use. However, careful management is required if the N subsequently released from organic fractions is to be exploited effectively. For example, on applying paper waste at a rate of 43 t/ha FW (or 2.9 tonnes C/ha), Motavalli and Discekici (2000) noted that the remineralisation of N, over a 400 day period, took place at very low rates.

Various authors have cautioned that care should be taken in simply using the C:N ratio of paper waste as an accurate guide to its potential for N mineralisation/immobilisation. The N content of paper waste is strongly influenced by the secondary treatment process used (biological or chemical/physical), the N content of polyacrylamide flocculants used in the waste treatment process, and the composition of dyestuffs and surfactants used in the manufacturing process (Vinten *et al.,* 1998). Polyacrylamide flocculants are used as soil conditioners (Vinten *et al*., 1998) and are known to be resistant to attack by micro-organisms (Quastel, 1954; Fuller and Gairaud, 1954).

In addition to reduced available nitrogen levels following paper waste application, the nutrient analysis of crops has in most cases revealed reduced concentrations of N, P and K, particularly at higher amendment rates (ie those exceeding 100 t/ha FW) (Dolar *et al.*, 1972; Vasconcelos and Cabral, 1993; Zhang *et al*., 1993; Bellamy *et al.*, 1995; Aitken *et al.*, 1998; Voundi Nkana *et al.*¸1998; Demeyer and Verloo, 1999; O'Brien *et al.,* 2002). However, it is difficult to say whether these decreases are due to reduced nutrient availability *per se* or are only apparent decreases due to crop growth dilution.

As a result of the relatively high C:N ratio of paper waste materials, and the observed decreases in available nutrient supply (primarily of N) which follow landspreading, a number of workers have found that sustained crop productivity requires supplemental applications of inorganic fertilisers alongside any paper waste applications. Studies by Aitken *et al*. (1998) in Wales have shown that, in order to compensate for nitrogen immobilisation, 40 kg/ha of inorganic fertiliser N were needed for each 100 t/ha FW of deinked paper mill sludge applied. Meanwhile, using data from 10 years of field trials Bellamy *et al*. (1995) concluded that, for a large range of crops, paper pulp and sludge provided a beneficial organic amendment to potting media and field soils as long as sufficient inorganic fertiliser N was also applied.

4.2.2 Soil organic carbon

As a result of its carbon (organic matter) content, paper sludge is primarily considered as an organic soil conditioning amendment (Vasconcelos and Cabral, 1993; Bellamy *et al.,* 1995). Hence, the application of paper waste to agricultural land is largely seen as a method of improving soil fertility through the application of large amounts of organic matter (Chantigny *et al.,* 1999). It is therefore not surprising that studies which have measured soil organic carbon (C) levels following landspreading with paper wastes, have found a positive relationship between paper waste application rates and soil organic C content (Zibilske, 1987; Vasconcelos and Cabral, 1993; O'Brien *et al.,* 2002). Applying papermill sludge at rates of 0 to 400 t/ha FW, Zibilske (1987) observed a 0.58% increase in soil organic C/100 tonnes FW of sludge applied. Similarly, Vasconcelos and Cabral (1993) measured a soil carbon build-up of 0.15% per 100 t/ha FW applied. However, at lower rates of application – around 15-70 t/ha FW – Voundi Nkana *et al*. (1998) were unable to measure any differences in soil organic C content between treatments.

4.2.3 Liming value

Aitken (1997) has concluded that paper waste sludge, waste paper and deinked paper pulp will confer liming benefits ranging from 'unlikely' up to 'moderate' levels, depending on the production process and the raw material used. A number of studies have identified positive trends between paper sludge application rate and soil pH increases (Cabral and Vasconcelos, 1993; Vasconcelos and Cabral, 1993; Demeyer and Verloo, 1999; Calace *et al.,* 2000), and hence liming capacity. These relationships were attributed to the lime content of paper sludge, which typically has one-fifth of the liming capacity of ground limestone on a dry solids basis (Davis and Rudd, 1998).

Using a soil at near neutral pH (6.93), Demeyer and Verloo (1999) measured a soil pH increase of 0.44 units following the application of 350 t/ha FW of paper waste. Similarly, Calace *et al*. (2000) measured an increase in soil pH of 0.9 units (6.6 to 7.5) during a laboratory experiment where paper sludge was applied at a rate equivalent to 360 t/ha FW. In a UK study, on a field that had received 200 t/ha FW of paper sludge, Piearce and Boone (1998) measured a rise in soil pH of 0.4 units (from 5.77 to 6.17). They also measured pH rises of between 0.5 and 0.7 pH units per 100 t/ha FW, for an acidic pasture soil (pH 3.9), the variations observed relating to the sludge type used. Meanwhile, Vasconcelos and Cabral (1993) reported that the addition of 30-50 t/ha FW of paper sludge to a soil of pH 5.7, increased soil pH by between 1 and 1.5 units. In contrast, however, Douglas *et al*. (2003) found that applications of 385 t/ha FW of paper waste had only a small effect on soil pH (a 0.2 unit increase), while Vagstad *et al.* (2001) measured only small pH increases for sludge treatments of 160 t/ha FW, compared to untreated controls.

In general, soil pH increases arising from paper waste applications appear to range between 0.1 and 0.7 units per 100 t/ha FW of paper sludge applied, the range reflecting differences in the lime content of the paper wastes used. Given the overall range of these increases – 0.1 to 1.5 units, some care should be taken when managing paper waste applications to ensure that soils are not over-limed as this can result in trace element deficiencies in crops and livestock (Anon, 2000).

4.2.4 Texture and structure

Aitken (1997) has concluded that paper waste sludge, waste paper and deinked paper pulp will provide soil conditioning benefits ranging from 'low' to 'moderate'. As a mixture rich in clay, calcium carbonate and cellulose fibre materials, paper waste has the potential to improve soil texture and structure, thereby improving characteristics such as soil drainage, aeration and ease of root penetration.

Given its high carbon content, paper waste is primarily considered as an organic amendment (Section 4.2.2) and is likely to have a major influence on soil physical properties. Indeed, Zhang *et al.* (1993) found that applying a mixture of primary and secondary sludge (ratio 3:1), at a rate of 246 t/ha FW, reduced soil bulk density and increased porosity, improved moisture retention and soil structure, and, as a result, enhanced the root zone growing environment. Other workers have also concluded that applying paper wastes can improve soil structural stability, particularly on clay soils (Phillips *et al.,* 1997; Trepanier *et al*., 1998). Chantigny *et al*. (1999) found that the proportion of water-stable aggregates (> 1 mm) present in a clay soil one year after paper sludge application was two to six times greater in the amended soil (190 t/ha FW) than in the untreated control. This effect was still significant ($P < 0.05$) three years after application.

In one study in North America, Bellamy *et al.* (1995) found that the application of paper sludge to soil increased the clay content – something which would be of particular benefit on light-textured droughty soils. However, elevated sodium (Na) contents (> 2,500 mg/kg) in some paper sludges were shown to defloculate soil clay particles (Bellamy *et al*., 1995), resulting in a deterioration of soil structure. Cabral and Vasconcelos (1993), in a study in Southern Europe, found that the application of a combined primary and secondary paper sludge, with a sodium concentration of 2,500 mg/kg, resulted in elevated exchangeable sodium percentages where more than 160 t/ha FW were applied. They concluded that successive applications of paper sludge with elevated sodium levels may result in a deterioration of soil structure. Moreover, sodium can also accumulate in the root zone, affecting plant physiology and reducing water availability (Trépanier *et al.,* 1998).

Since no analytical data on the sodium content of paper waste materials applied to agricultural land in England and Wales were available, it has not been possible to assess the significance of these findings to the structural stability of soils in England and Wales.

4.2.5 Water holding capacity

In theory, the water holding capacity of a soil should be improved following paper waste application as a result of both improved soil structure and the water holding capacity of the waste itself (Diehn and Zuercher, 1990). This hypothesis was confirmed by Zhang *et al*. (1993) who found that a mixture of primary and secondary sludge (ratio 3:1) applied at a rate of 246 t/ha FW increased the water holding capacity of a soil by between 20 and 74% around 3 months after application. However, there is little data available on the time period over which these benefits last. Phillips *et al.* (1997), in a study in England, found that applying paper mill sludge at 125 and 250 t/ha FW to a clay soil for three years significantly improved the volume of total available water, although little improvement was measured for a sandy loam soil receiving the same treatment. Meanwhile, Chantigny *et al*. (2000a) showed that 190 t/ha FW of deinked paper sludge increased soil water content by up to 35%, this increase being attributed to both the addition of paper sludge to the soil, and the presence of sludge on the soil surface (particularly at the 190 t/ha rate) acting as a soil mulch which inhibited evaporation. In this case, the differences in soil water content between the sludge amended treatment and the untreated control decreased with time, highlighting the benefit of regular and repeated applications.

4.2.6 Biological activity

The organic components in paper waste provide a potential source of readily available carbon and nutrients for soil biota, such that the application of paper waste to agricultural land often leads to increased soil biological activity and microbial populations. These increases have been confirmed by a number of studies.

For example, Baggs *et al*. (2002), in a study in Scotland, measured significant (P < 0.05) increases in biomass C (68 to 185 mg/kg soil) in early spring, following the autumn application of paper sludge at 127 t/ha FW. Similarly, Chantigny *et al.* (2000a) measured a 2-fold increase in soil microbial biomass C, following the application of 190 t/ha FW of paper sludge. The increase was statistically significant (P < 0.001) and proportional to the rate of paper waste applied for a period of two and a half years after application. These increases are most likely to be due either to the growth of microbes in response to the enhanced C supply (Anderson and Domsch, 1989), and/or to the introduction of micro-organisms present in the waste material (Perucci, 1992).

In one study, in England, involving the co-application of paper waste mineral fibres (100 t/ha FW) with brussel sprout residues, Rahn *et al*. (2003) measured significant (P < 0.05) increases in soil biomass N (40 mg N/kg soil) during the first 14 days after application. In contrast, Vinten *et al.* (1998), in a study in Scotland, measured only small (5 mg/kg soil) and not significant (P > 0.05) increases in soil biomass N where paper sludge was applied at 127 t/ha FW. Meanwhile, Chantigny *et al*. (2000b) found that microbial activity (as measured by enzyme activity) levelled off at elevated (>190 t/ha FW) sludge application rates. This could be due to changes in the microbial community structure resulting from anaerobic soil conditions or nutrient deficiency (eg of nitrogen where there are high rates of carbon addition).

In addition to increasing overall levels of microbial populations, paper sludge applications have also been shown to support greater numbers of higher organisms. In one UK study, Piearce and Boone (1998) found that a sandy arable soil treated with paper sludge (200 t/ha FW) supported a greater abundance of lumbricid earthworms than an adjacent untreated soil, the response being the same whether the sludge had received primary or secondary treatment. Similarly, Thiel *et al*. (1989) measured an increase in earthworm population size following paper sludge application.

These increases in earthworm numbers could be attributable to greater water retention within the soil profile thereby reducing summer mortality rates – and certainly Piearce and Boone's data (1998) were collected after an exceptionally dry summer. Alternatively, the liming benefits of paper wastes on acid soils (pH < 5.0) could also greatly enhance worm abundance and species diversity (Robinson *et al.*, 1992). In contrast, a scarcity of earthworms has been reported below and adjacent to paper sludge storage areas (Piearce and Boone, 1998), though this may be a result of heavy compaction of the soil surface (Piearce, 1984) rather than any effect of the paper sludge *per se*.

4.2.7 Potentially toxic elements (PTEs)

Potentially toxic element (heavy metal) additions in paper waste applications vary with the type of paper waste and treatment process used. For example, the concentrations of heavy metals in paper wastes produced within certain EU member states (France, UK, Finland and Benelux) are shown in Table 4.2.

Table 4. 2 Heavy metal concentrations in paper wastes from certain EU member states

	Minimum	Maximum	Mean
		(mg/kg dry solids)	
Zn	1.3	330	135
Cu	2	349	61
Cd	0	4.0	1
Ni	< 1	32	12
Pb	< 1	83	13
Hg	< 0.01	1.4	0.2
Cr	< 1	44	34

Source: Gendebien *et al.*, 2001

Given the rather limited geographical scope for these data, Table 4.3 summarises heavy metal concentrations in paper waste materials collated from 21 scientific papers from around the world, covering a range of treatment processes. In general, these were in good agreement with the data provided by Gendebien *et al*. (2001).

Table 4. 3 Heavy metal concentrations in paper wastes applied to agricultural soils (global data)

	Minimum (mg/kg dry solids)	Maximum	Mean
Zn	< 15	262	98
Cu	5.0	227	66
Cd	< 0.1	9.0	1.2
Ni	0.4	75	15
Pb	1.7	110	33
Cr	0.4	39	13

The heavy metal concentrations in paper waste materials are generally below those found in municipal biosolids (Gendebien *et al*., 1999), and similar to those typically present in livestock manures (Nicholson *et al*., 1999) or other organic 'waste' materials (Gendebien *et al.,* 2001) (Table 4.4). Based on data reported by Gendebien *et al*. (2001), Nicholson *et al*. (2003) calculated that at a typical application rate of 100 t/ha FW, heavy metal inputs from paper wastes were considerably lower than the maximum permissible average annual rate of metal additions for sewage sludge in the UK (DoE, 1996).

Table 4. 4 Heavy metal concentrations in organic materials applied to agricultural soils

Source	**Zn (mg/kg dry solids)**	**Cu**	**Cd**	**Ni**	**Pb**	**Cr**
municipal biosolids	802	565	3.4	59	221	163
cattle slurry	170	45	0.3	6.0	7.0	6.0
pig slurry	650	470	0.4	14	8.0	7.0
cattle FYM	68	16	0.2	2.8	2.4	2.0
pig FYM	240	168	0.2	5.2	3.2	2.4
layer manure	583	90	1.3	10	9.0	5.7
broiler litter	217	32	0.6	4.0	3.3	2.0
food industry waste	110	26	< 6	0.1	< 22	< 22
textile waste	276	253	< 7	3.2	13	8
compost[a]	75	25	0.7	10	65	50

Source: Adapted from Nicholson *et al.* (2003) and [a] Anon. (1998).

Heavy metals in soils

Aitken (1997) has concluded that paper waste sludge, waste paper and deinked paper pulp additions have a 'moderate' risk of having adverse effects due to their heavy metal content if spread on agricultural land. However, in short-term field trials, in Wales, with deinked paper sludge, Aitken *et al.* (1998) found no significant increases in Zn, Cu or Pb concentrations in soil treated with paper sludge applied at rates up to 300 t/ha FW compared with an untreated control. Similarly, Trépanier *et al*. (1998) monitored soil heavy metals after two years of paper sludge application at 60 t/ha FW and found no significant differences between the sludge treatments and the untreated control.

In fact, the literature suggests that applying paper sludge can be beneficial in terms of reducing heavy metal bioavailability. In a laboratory study where paper sludge was applied at a rate of 360 t/ha FW, Calace *et al*. (2000) found that concentrations of soluble Zn, Cu and Pb decreased, while unavailable forms bound to organic matter, (humic acids and manganese oxide) increased. Decreases in extractable Mn and Zn concentrations were also reported by Voundi Nkana *et al.* (1998) in soils treated with paper pulp at a rate of 70 t/ha FW.

Heavy metals in crops

In addition to decreased concentrations of extractable metals in soils, several workers have also reported decreased concentrations of metals in crops. Calace *et al.* (2000) reported decreased concentrations of Zn, Cu and Pb in the stems and roots of *Hordeum disticham* (barley); Vasconcelos and Cabral (1993) decreased concentrations of Cu, Fe, Mn and Zn in the leaves of yellow lupin; Aitken *et al.* (1998) decreased concentrations of Cu, Mn and Zn in the leaves of barley; and Voundi Nkana *et al.* (1998) decreased concentrations in ryegrass.

These decreases in both metal solubility and crop metal uptake have been attributed to increases in soil pH associated with increasing rates of sludge application (Vasconcelos and Cabral, 1993; Aitken *et al.,* 1998; Voundi Nkana *et al.,* 1998; Calace *et al.,* 2000). In addition, in the case of Mn, decreased uptake may be related to poorer soil-root contact, as a result of decreased soil bulk density following paper waste application (see Section 4.2.4).

4.2.8 Pathogens

Davis and Rudd (1998) made an assertive conclusion that paper wastes can be regarded as pathogen- and parasite-free, and that they present no microbiological risks to the health of humans, animals or plants. However, no scientific data were presented to support this conclusion and we have found no data in the scientific literature to either confirm or refute this conclusion. Nevertheless, data from our survey of paper mills did reveal evidence of *E. coli* levels ranging from ‘not detectable’ to up to 20,000 colony forming units/gram dry solids. This was for paper wastes that had undergone secondary biological treatment, such as an activated sludge process. It is highly unlikely, however, that pathogens (as indicated by *E.coli* presence) would be present in primary or secondary physically/chemically treated materials.

4.2.9 Organic contaminants

The production and use of organic chemicals has risen rapidly over recent decades, and the widespread application of these compounds (for example, agricultural pesticides, dyes, detergents and industrial solvents) has caused concern about their potential impacts on the environment, and in particular on human health (Rogers, 1987). In contrast with these perceived concerns, the general scientific consensus is that organic contaminants applied to agricultural soils are unlikely to cause significant environmental problems (Wild and Jones, 1991; Sweetman *et al*., 1994).

Since plant uptake and translocation of trace organic compounds from soils occur only to a limited extent or not at all (Dean and Suess, 1985; O'Connor *et al*., 1991), this route poses very little risk to animals or humans. This means that the principal route of any bioaccumulation of trace organics in the food chain is through the ingestion, by grazing stock, of soil contaminated with organic compounds (Jones and Wild, 1991; Stark and Hall, 1992). However, Stark and Hall (1992) have concluded that for the application of sewage sludge to agricultural land, the risk of adverse effects of sludge-borne organic contaminants on animal or human health is low at agronomic rates of application. Similarly, in their report to the UK's Department of Environment (now Defra) Sweetman *et al*. (1994) conclude there is no evidence of any significant problems arising from organic contaminants in sewage sludge applied to agricultural land.

Organic contaminants in paper wastes

In 1996, Webber reported on the organic contaminants present in various types of paper pulp and paper sludge, including an analysis of eight deinked primary pulp and paper sludges from Quebec (Canada). The study found that total dioxin and furan (PCDD/Fs) concentrations were low, and that 2,3,7,8-tetrachlorodibenzo-p-dioxin toxicity equivalents (TEQ) ranged from 1.3-13.6 ng/kg dry solids. The concentrations of PCDD/Fs in combined primary and secondary sludges from a paper mill in Canada were $\leq$ 12 ng TEQ/kg dry solids when chlorine was used in the process, compared to < 3.5 ng TEQ/kg dry solids when chlorine was not used. Other paper waste analysis data from Canadian mills using chlorine bleaching found that PCDD/Fs concentrations were generally < 14 ng TEQ/kg dry solids.

In the US, the maximum allowable concentration of PCDD/Fs in landspread paper sludge is 250 ng TEQ/kg dry solids, while the maximum soil concentration is 27 ng TEQ/kg dry solids (Keenan *et al.,* 1990). In the Canadian province of Ontario, the maximum allowable PCDD/Fs concentration is 100 ng TEQ/kg dry solids for organic residues applied to land, and the maximum soil concentration is 10 ng TEQ/kg dry solids. These values are clearly much higher than those detected in Canadian sludges, suggesting that the wastes are suitable for landspreading..

Bellamy *et al.* (1995) have reviewed the organic chemical content of paper mill sludges from Canada. Their analyses included phenolics, polychlorinated biphenyls, xylene, phthalate-esters, chlorodioxin/furans and volatile compounds. They concluded that the concentrations were very low – well within acceptable Canadian limits – and that they would therefore not constrain the use of paper mill wastes in agriculture. Similarly, Trépanier *et al*. (1998) analysed deinked paper sludges for a range of organic compounds (aromatic hydrocarbons, phenols, polychlorinated biphenyls and polynuclear aromatic hydrocarbons), finding no compounds that were above contamination limits for soils in the province of Québec (Canada).

Environmental impact of PCDD/Fs in paper wastes

To date the scientific literature reveals little upon which to establish the potential environmental impact of organic contaminants present in paper wastes spread on agricultural land. Thiel *et al*. (1989) have reported that applying paper mill sludge (no application rate given) containing up to 80 ng TEQ/kg dry solids to a forest soil presented little risk to wildlife. Clutch size, hatching rates and fledgling rates of several species of bird, together with age distributions of mouse populations, indicated normal reproduction. Indeed earthworm, mouse and insectivorous bird populations were generally higher in the sludge treated areas. In addition, litter invertebrate diversity and density were unaffected by sludge application. And, although soil invertebrate diversity and density were reduced, this was deemed likely to be a result of increased soil moisture content and the smothering effects of the applied sludge. The study concluded that the risk of harm to wildlife appeared to be low.

Using the woodcock as a sensitive species to assess PCDD/Fs exposure in the environment, Keenan *et al.* (1990) found no potential human or wildlife risks from the landspreading of paper sludge, where the upper soil concentration was 50 ng TEQ/kg dry solids. Meanwhile, in the US, Rabert and Zeeman (1992) predicted 'best estimate' risks from paper sludge applications incorporated to a depth of 15 cm. They estimated risks to be 'low' or 'unlikely' from paper sludge with a PCDD/Fs concentration of 34 ng TEQ/kg dry solids, giving a soil concentration of 0.2 ng TEQ/kg dry solids. However, they did predict 'likely possible' risks to terrestrial wildlife, for paper sludge with a PCDD/Fs concentration of 681 ng TEQ/kg dry solids, giving a soil concentration of 14 ng TEQ/kg dry solids.

Rabert and Zeeman (1992) also assessed any risks to fish resulting from runoff into aquatic areas as 'low or unlikely'. However, they did predict possible risks for predatory wildlife in locations where poor management practices (with respect to runoff from an application site) were employed.

In an inventory of potential PCDD/Fs emission sources in the UK, the paper production process was not included (Eduljee and Dyke, 1996), presumably because it was thought to only make a negligible contribution.

Environmental impact of other organic contaminants

Welker and Schmitt (1997) have reported that levels of absorbable organic halogens (AOX) in paper sludges can reach or exceed 500 mg/kg dry solids. The main sources of these compounds in paper wastes arise from chlorinated wood polymers (lignin, polyphenols and cellulose) and printing inks (particularly yellow pigments). In general AOX compounds are insoluble in water, and these workers anticipate that in this respect the environmental impacts of landsrpreading are likely to be insignificant. Nevertheless, they do recommend that AOX levels in paper sludge should be reduced by phasing out the traditional bleaching process using chlorine. In this context, it is important to note that the use of elemental and total chlorine has now been phased out in the UK paper industry (D. Gillett, Confederation of Paper Industries, pers. comm.).

Meanwhile, in the current study, reports from the paper mills indicate that organic contaminants do not appear to be a problem in paper waste materials spread on agricultural land in England and Wales. Of the 28 mills using landspreading as a recovery route for their paper wastes, 15 had undertaken analyses for the presence of organic contaminants, and in each case the levels of organic contaminants in the paper wastes were below laboratory detection limits.

Based on the available scientific literature and our own data, we believe that there are reasonable grounds to expect a very low risk to the environment from organic contaminants in paper waste materials spread on agricultural land in the UK.

4.3 Air quality

Storage of paper waste and landspreading operations can cause odour nuisance. The odour detected around landspreading operations is most probably related to gaseous emissions of, for example, sulphurous compounds (such as hydrogen sulphide), phenols and ammonia. However, the scientific literature reveals no studies measuring odour emissions following the storage and landspreading of paper wastes, although a number of studies do examine nitrous oxide (N_2O) emissions following landspreading.

Since the start of the industrial revolution, concentrations of N_2O in the atmosphere have increased at a rate of 0.2-0.3% per annum (Beauchamp, 1997), a trend which is a cause for concern given nitrous oxide's role as a greenhouse gas (Houghton *et al*., 1996). Soils are an important source of N_2O, with agricultural soils thought to account for 25% of all global emissions (Mosier *et al*., 1998). These emissions result from the microbially mediated processes of nitrification and denitrification, which are commonly stimulated by fertiliser nitrogen applications and the landspreading of organic materials (Chang *et al*., 1998).

Vinten *et al.* (1998), in a study in Scotland, have reported that where paper sludge was incorporated into soils at a rate of 127 t/ha FW (or 15.5 tonnes C/ha) N_2O emissions were higher (up to 2.64 kg N_2O-N/ha) over a seven week period compared with the untreated control. However, these differences could not be confirmed statistically ($P > 0.05$). In a related study, Baggs *et al*. (2002) also measured increased N_2O emissions following soil incorporation of paper mill sludge. In this case the treated area emitted up to 1.3 kg N_2O-N/ha more than the untreated control (0.1 kg N_2O-N/ha) over the first three weeks.

This same study also found that cultivation method had an impact on N_2O emissions. Over a 79 day period following the application of paper mill sludge, N_2O emissions, although higher than controls, were lower (0.6 kg N_2O-N/ha) following conventional mouldboard ploughing (150 mm depth of incorporation) compared to both deep mouldboard ploughing to 350 mm (1.2 kg N_2O-N/ha) and reduced cultivation to 50 mm (1.4 kg N_2O-N/ha). Overall, the increased

N_2O emission rates were attributed to the readily available C inputs fuelling the denitrification process.

Even so, when compared with other organic materials that are recovered to agricultural land, the application of paper waste imposes only a similar, if not lower burden on the atmosphere per unit mass of material applied. For example, Baggs *et al*. (2000), in a related study in Scotland, measured N_2O emissions of up to 1.6 kg N_2O-N/ha following the application of 1.6 tonnes dry matter/ha of lettuce leaves – that is around 50-fold greater than emissions per tonne of paper waste dry solids applied). Similarly, following the application of a green manure at a rate of 5-6 tonnes dry matter/ha, Sarkodie-Addo *et al*. (2003) measured N_2O emission rates of up to 0.5 kg N_2O-N/ha (around 5-fold higher than per unit mass of paper waste dry solids). Finally, Scott *et al.* (2000) measured N_2O emission rates of 15 kg N_2O-N/ha following the application of 185 tonnes/ha dry solids (digested sewage sludge) – that is around a 2-fold higher emission rate than per unit mass of paper waste dry solids applied.

4.4 Water quality

To reduce the risks of water pollution from landspreading organic materials on agricultural land, *The Water Code* (MAFF, 1998c), advises that "materials should not be spread within 10 metres of any water course". In addition, to reduce the risks of groundwater pollution, the landspreading of organic materials should "not be made within 50 metres of any spring, well or borehole supplying water for human consumption". The code also advises that factors such as field slope, the presence of field drains and soil conditions should also be taken into account when applying organic materials to agricultural land. Provided this guidance, which is also contained in the *Code of Practice for Landspreading Paper Mill Sludge* (Paper Federation of Great Britain, 1998), is followed, the risks of a detrimental impact on water quality are likely to be minimal. Indeed, a number of workers have shown that surface and groundwater quality can be improved following paper waste spreading on agricultural land, on account of reduced levels of nitrate leaching (Dolar *et al.,* 1972; Vinten *et al*., 1998; Voundi *et al*., 2000; and see Section 4.2.1).

4.5 Human and animal health

In theory, applying organic materials to agricultural land could give rise to risks to both human and animal health, due to the potential transfer of pathogens (eg *Salmonella*), the application of organic pollutants and/or the build-up of heavy metals in the topsoil.

Pathogens

Although the risks of pathogens are low (see Section 4.2.8) there does appear to be a small potential risk of pathogen transfer to crops and livestock where paper wastes have undergone secondary biological treatment. These risks are likely to be greatest where ready-to-eat crops (ie crops that are unlikely to be cooked before they are eaten) are grown, or where livestock graze soon after applications of secondary biologically treated waste. In reality, however, it is highly unlikely that paper wastes would be applied prior to ready-to-eat crops (see Section 2.1.3). And while pathogens such as *E.coli* O157 can survive for up to 4-6 months in soil (Nicholson *et al*., 2000; Fenlon *et al*., 2000), in practice most of the die-off occurs in the first month (Nicholson *et al.,* 2005). Hence, where paper waste has been biologically treated, and there is a possibility of pathogen presence, the risks of pathogen transfer to grazing livestock can be reduced by ensuring that a 'no-grazing' period of around 3-4 weeks between the paper waste application and the re-introduction of grazing livestock. This is in line with advice in the *Code of Practice for Agricultural Use of Sewage Sludge* (DoE, 1996) and the *Safe Sludge Matrix* (ADAS, 2001).

Organic pollutants

The potential risks to human health, through consuming or inhaling organic compounds contained in paper wastes, are likely to be negligible. Research findings from North America have shown that concentrations of organic compounds in paper wastes were very low and well within acceptable limits, and would not constrain the use of paper wastes in agriculture (Bellamy *et al.,* 1995; Webber, 1996). Keenan *et al*. (1990) also predicted no potential human or wildlife risks from the land spreading of paper wastes (see Section 4.2.9).

Heavy metals

Finally, the concentrations of heavy metals in paper waste materials were generally below those found in municipal biosolids (Gendebien *et al*., 1999), and were similar to, or lower than, concentrations found in livestock manures (Nicholson *et al*., 1999) or other organic wastes (Gendebien *et al.,* 2001) spread an agricultural land (Section 4.2.7). At typical application rates, heavy metal inputs from paper wastes were considerably lower than the maximum permissible average annual rates of addition where sewage sludge is applied to agricultural land in the UK (DoE, 1996). The impacts of heavy metal additions on human and animal health can be considered very low in the short term, and similar to, or lower than, other organic materials applied to agricultural land in the long term.

4.6 Biodiversity

There is some evidence suggesting that soil invertebrate diversity and density can be reduced by paper waste applications (Thiel *et al*., 1989), most probably due to increased soil moisture contents and smothering effects. However, increased soil organic matter contents following the application of paper waste materials can lead to increased soil microbial biomass and activity (Chantigny *et al*., 2000; Baggs *et al.,* 2002), and, in the longer term, to greater earthworm numbers (Piearce and Boone, 1998).

5. Key findings and conclusions

Information from the surveys of the paper mills and spreading contractors, combined with data emerging from the literature review, reveal a number of key findings from which we can draw a number of important conclusions:

1. **Quantities of landspread wastes:** It is estimated that around 712,000 tonnes fresh weight (FW) of paper wastes (or 280,000 tonnes of dry solids) were recovered to around 10,500 ha of agricultural land in 2003. Future expectations from the paper mills were that this quantity would most likely decrease to nearer 600,000 tonnes FW over the next 5 years, largely as a result of diverting paper wastes into other waste recovery processes, such as energy recovery or use in land restoration.
2. **Two distinct types of waste:** The paper wastes produced in England and Wales can be split into two broad categories based on their nutrient and heavy metal concentrations: (i) paper wastes with a biological element in the treatment process and (ii) paper wastes containing no, or only a small, biological element in the treatment process, with the latter having lower nutrient and heavy metal concentrations. Spreading contractors reported taking these differences into account when calculating application rates.
3. **Auditing waste:** Most mills reported using the Paper Federation of Great Britain's *Code of Practice for Landspreading Paper Mill Sludge*. Almost all of the paper wastes spread on agricultural land (99% of total) were audited in some way and most of the mills (79%) were using PQA. Moreover, around 70% of paper waste materials were managed by staff with a FACTS qualification.
4. **Cultivation methods:** The majority of paper wastes spread on agricultural land (89% of total) were applied to tillage land (arable land or reseeded grassland) and were incorporated into the soil by deep cultivation (ie ploughing or deep discing). Wastes were most commonly applied in the summer/early autumn (61% of total) when ground conditions were most favourable, while preceding crops, such as winter cereals, that were not sensitive to N 'lock-up'.
5. **Application rates:** Mean paper waste application rates ranged from 26–145 t/ha FW depending on the cropping situation and the composition of the paper waste. The mean application rate on tillage land was 76 t/ha FW for non-biologically treated paper wastes and 41 t/ha FW for biologically treated paper wastes. Mean application rates to the surface of permanent grassland were 26 t/ha FW and to re-seeded grassland 145 t/ha FW.
6. **Additional N fertiliser:** All of the spreading contractors who managed paper wastes containing no biologically treated material (primary and secondary physically/chemically treated materials) applied extra inorganic fertiliser N to overcome the problems of N 'lock-up'. The mean rate of application was 0.8 kg fertiliser N/tonne FW (2 kg fertiliser N/tonne dry solids) of paper waste applied.

7. **Agricultural benefits:** The main benefits of applying paper wastes to agricultural land, as identified by the paper mills and spreading contractors, were liming capacity, nutrient supply and soil conditioning properties. All three of these identified benefits were confirmed by experimental data in the scientific literature.

    a. **Liming:** The scientific literature report liming values for paper waste materials of between 0.1 and 0.7 pH units rise per 100 t/ha FW applied, depending on the neutralising value of the paper waste. However, care must be taken not to over-lime soils and exacerbate trace element deficiencies.

    b. **Nutrient supply:** While the total amount of nutrients supplied was dependent on the paper waste type (ie biological *versus* non-biological treatment), there are currently only limited data on the availability of the applied nutrients to plants – particularly for phosphorus, potassium and sulphur.

    c. **Soil conditions:** Soil condition is improved as a result of the organic matter applied in paper waste additions, particularly in relation to porosity, moisture retention, structural stability and bulk density.

8. **Soil biological activity:** Microbial and faunal (eg earthworm) population sizes increased following the application of paper waste materials.

9. **Heavy metal loading:** At commonly used application rates (around 75 t/ha FW), heavy metal loading rates from paper wastes were generally below those from biosolids, and either similar to, or lower than, those from farm manures and other organic materials that are commonly applied to agricultural land.

10. **Organic contaminants:** There is no evidence to indicate any significant risks to the environment from organic contaminants potentially present in paper waste materials. Indeed, no organic contaminants were detected in paper wastes analysed from the UK paper mills.

11. **Nitrogen availability:** Spreading paper wastes in autumn was reported to reduce nitrate leaching losses in the following over-winter drainage period, although in the longer term some of the immobilised N may subsequently be re-mineralised and leached.

12. **Odour nuisance:** During the break-out of field heaps and following landspreading, odour nuisance can be a problem for some landspreading operations, particularly where biologically treated paper wastes are applied.

13. **Knowledge gaps:** There are a number of clear gaps in the scientific knowledge which need to be addressed in order to improve the UK knowledge base on these issues and to provide clear guidance to industry. These gaps are summarised in Section 6.

6. Knowledge gaps

1. **Longer-term studies:** The experimental data reported in the scientific literature are largely focused on the effects of paper waste applications in the short-term (commonly one year up to five years following spreading). There is a need to for *longer-term studies* on the effects of repeated paper waste applications on soil physio-chemical and biological properties, nutrient cycling, crop quality and yields. These studies should also include an assessment of the potential effects of sodium present in paper waste materials on soil structural stability.
2. **Two distinct types of waste:** While there appeared to be clear differences in the nutrient and heavy metal contents of biologically treated paper wastes compared to wastes that had undergone secondary physical/chemical treatment, the biologically treated paper waste data set was very small (only 4 samples). There is a need to obtain more analytical data on the *nutrient and heavy metal contents* of biologically treated paper wastes.
3. **Plant available nutrient supply:** Since nutrient availability to plants cannot be inferred from total element analysis, there is a need to quantify *plant available nutrient supply* (particularly phosphorus, potassium and sulphur) following paper waste applications to agricultural land. Almost all studies to date have concentrated on N supply and cycling.
4. **Microbial quality of biologically treated materials:** It may be worthwhile to obtain further data on the *microbiological quality* of biologically treated materials, to ensure adequate understanding of any potential risks to food safety and animal health.
5. **Odour generation:** The processes and factors affecting *odour generation* following the treatment, storage and landspreading of paper wastes have been largely overlooked, and require considerably more attention.
6. **Storage:** The effects of paper waste *storage* on material quality and potential environmental impacts – for example leachate, biological and chemical oxygen demand levels, ammonium-N and suspended solid concentrations – may merit further investigation.
7. **Nitrogen ‘lock-up’:** Given the significance of this phenomenon, it would be useful to gain an improved scientific understanding of the factors controlling *N ‘lock-up’* (immobilisation) and N release (mineralisation) following the landspreading of paper wastes. This will allow more robust guidance to the industry on any need for additional inorganic fertiliser N requirements following landspreading.

7. Recommendations

Nutrient testing: to enhance the Paper Federation of Great Britain's recommended testing suite to include the ammonium-N, sulphur and magnesium content of paper waste materials

8. Acknowledgements

The ADAS project team would like to acknowledge the invaluable assistance of Caroline Hawkins (Environment Agency Project Manager), Dave Gillett (Confederation of Paper Industries) and Stewart Begg (SCA Hygiene Products) in the delivery of this contract.

9. Abbreviations

AOX	absorbable organic halogens
BPEO	best practicable environmental option
C	organic carbon
COA	contractor operational area
Defra	Department for Environment, Food and Rural Affairs
FACTS	Fertiliser Advisers Certification & Training Scheme
FYM	farmyard manure
N	nitrogen (organic and mineral)
NVZ	nitrate vulnerable zone
PCDD/Fs	dioxins and furans
PQA	properly qualified advice
PTE	potential toxic elements
TEQ	toxicity equivalents
TNV	total neutralising value

10. Bibliography

ADAS. (2001) *The Safe Sludge Matrix*. 3rd edition, April 2001. http://www.adas.co.uk/matrix

Aitken, MN (1997) Use of non-agricultural wastes on farmland. *SAC Technical Note T459.* SAC, Edinburgh.

Aitken, MN, Lewis, JG and Evans, B (1995) Effects on soil fertility from applying paper mill sludge to agricultural land. *Soil Use and Management* **11,** 152-153.

Aitken, MN, Evans, B and Lewis, JG (1998) Effect of applying paper mill sludge to arable land on soil fertility and crop yields. *Soil Use and Management* **14,** 215-222.

Anderson, JPE and Domsch, KH (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology and Biochemistry* **21,** 471-479.

Anon. (1998) *Compost Quality: The UK Standard*. CON9801. Henry Doubleday Research Association Publications. Ryton, Coventry.

Anon. (2000) *Fertiliser Recommendations for Agricultural and Horticultural Crops*. Defra Reference Book 209, 7th edition. The Stationery Office, Norwich (ISBN 0 11 2430589)

Aspitarte, TR, Rosenfeld, AS, Smale, BC and Amberg, HR (1973) Pulp and paper mill sludge disposal and crop production. *TAPPI Journal* **56,** 140-144.

Baggs, EM, Rees, RM, Smith, KA and Vinten, AJA (2000) Nitrous oxide emission from soils after incorporating crop residues. *Soil Use and Management* **16,** 82-87.

Baggs, EM, Rees, RM, Castle, K, Scott, A, Smith, KA and Vinten, AJA (2002) Nitrous oxide release from soils receiving N-rich crop residues and paper mill sludge in eastern Scotland. *Agriculture, Ecosystems and Environment* **90,** 109-123.

Beauchamp, EG (1997) Nitrous oxide emission from agricultural soils. *Canadian Journal of Soil Science* **77,** 113-123.

Bellamy, KL, Chong, C and Cline, RA (1995) Paper sludge utilization in agriculture and container nursery culture. *Journal of Environmental Quality* **24,** 1074-1082.

Cabral, F and Vasconcelos, E (1993) Agricultural use of combined primary/secondary pulpmill sludge. *Agrochimica* **37,** 407-417.

Calace, N, Petronio, BM, Picciolo, M, Pietrantonio, M and Pietroletti, M (2000) Changes in copper, lead and zinc concentration in plants from paper mill sludge-treated soils. *Annali di Chimica* **90,** 655-663.

Chang, C, Cho, CM and Janzen, HH (1998) Nitrous oxide emission from long-term manured soils. *Soil Science Society of America Journal* **62,** 677-682.

Chantigny, MH, Angers, DA and Beauchamp, CJ (1999) Aggregation and organic matter decomposition in soils amended with de-inking paper sludge. *Soil Science Society of America Journal* **63,** 1214-1221.

Chantigny, MH, Angers, DA and Beauchamp, CJ (2000a) Active carbon pools and enzyme activities in soils amended with de-inking paper sludge. *Canadian Journal of Soil Science* **80,** 99-105.

Chantigny, MH, Angers, DA and Beauchamp, CJ (2000b) Decomposition of de-inking paper sludge in agricultural soils as characterised by carbohydrate analysis. *Soil Biology and Biochemistry* **32,** 1561-1570.

Davis, RD and Rudd, C (1998) Investigation of the criteria for, and guidance on, the landspreading of industrial wastes. Final Report to the Department of the Environment, Transport and the Regions, the Environment Agency and the Ministry of Agriculture, Fisheries and Food. Ref. No: EPG 1/7/63.

Dean, RB and Suess, MJ (1985) The risk to health of chemicals in sewage sludge applied to land. *Waste Management and Research* **3,** 251-278.

Defra. (2000). *The Government Waste Strategy (Waste Strategy 2000)* http://www.defra.gov.uk/environment/waste/strategy/cm4693/index.htm

Defra. (2002). *Guidelines for Farmers in NVZs – England*. Department for Environment, Food and Rural Affairs, London (PB5505).

Demeyer, A and Verloo, M (1999) Evaluation of paper sludge as organic fertiliser for growth of ryegrass on a Belgian clay soil. *Agrochimica* 43, 243-250.

Control Federation **59,** 32-38.

Diehn, K and Zuercher, B (1990) An integrated waste management program for paper mill sludge high in ash. *TAPPI Journal* **73,** 81-86.

DoE. (1996) *Code of Practice for Agricultural Use of Sewage Sludge.* Department of Environment, Publications, London.

Dolar, SG, Boyle, JR and Keeney, DR (1972) Paper mill sludge disposal on soils: effects on the yield and mineral nutrition of Oats (*Avena sativa* L.). *Journal of Environmental Quality* **1,** 405-409.

Douglas, JT, Aitken, MN and Smith, CA (2003) Effects of five non-agricultural organic wastes on soil composition, and on the yield and nitrogen recovery of Italian ryegrass. *Soil Use and Management* **19,** 135-138.

Eduljee, GH and Dyke, P (1996) An updated inventory of potential PCDD and PCDF emission sources in the UK. *Science of the Total Environment* **177,** 303-321.

Fenlon, DR, Ogden, ID, Vinten, A and Svoboda, I (2000). The fate of Escherichia coli and E. coli O157 in cattle slurry after application to land. *Journal of Applied Microbiology,* **88,** 149S-156S.

Fuller, WH and Gairud, C (1954) The influence of soil aggregate stabilisers on the biological activity of soils. *Soil Science Society of America Proceedings* **18,** 35-40.

Gendebien, A, Carlton-Smith, C, Izzo, M and Hall, JE (1999) *UK Sewage Sludge Survey: National Presentation.* Environment Agency Final Technical Report P165. WRc Publications, Swindon.

Gendebien, A, Ferguson, R, Horth, H, Sullivan, M, Davis, R, Brunet, H, Dalimier, F, Landrea, B, Krack, D, Perot, J and Orsi, C (2001) Survey of Wastes spread to Land. Final Report of DG Environment Study Contract B4-3040/99/110194/MAR /E3. Available from: http://europa.eu.int/comm/environment/waste/studies/compost/landspreading.pdf

HMSO. (1994) *Waste Management Licensing Regulations.* SI 1994, No 1056, HMSO, London.

Houghton, JT, Meira Filho, LG, Callander, BA, Harris, N, Kattenberg, A and Maskell, K (1996) *Climate Change 1995: The Science of Climate Change,* The Cambridge University Press, Cambridge.

Hughes, JC and Girdlestone, SJA (2001) Use of solid waste bagasse from a paper mill as an organic amendment and its effect on some soil properties: a case study. *South African Journal of Plant and Soil* **18,** 128-134.

Jones, KC and Wild, SR (1991) *Organic Chemicals Entering Agricultural Soils in Sewage Sludges: Screening for the Potential to Transfer to Crop Plants and Livestock.* Report No. FR 0169. Foundation for Water Research, Marlow, UK.

Keenan, RE, Knight, JW, Rand, ER and Sauer, MM (1990) Assessing potential risks to wildlife and sportsmen from exposure to dioxin in pulp and paper mill sludge spread on managed woodlands. *Chemosphere* **20,** 1763-1769.

King, LD (1984) Availability of nitrogen in municipal, industrial and animal wastes. *Journal of Environmental Quality* **13,** 609-612.

Kirchmann, H and Berstrőm, L (2003) Use of paper mill wastes on agricultural soils: is this a way to reduce nitrate leaching? *Acta Agriculture Scandinavia Section B, Soil and Plant Science* **53,** 56-63.

MAFF/WOAD. (1998a) *The Air Code – Code of Good Agricultural Practice for the Protection of Air.* PB0618, MAFF, London.

MAFF/WOAD. (1998b) *The Soil Code – Code of Good Agricultural Practice for the Protection of Soil.* PB0617, MAFF, London.

MAFF/WOAD. (1998c) *The Water Code – Code of Good Agricultural Practice for the Protection of Water.* PB0587, MAFF, London.

Mosier, AR, Duxbury, JM, Freney, JR, Heinemeyer, O and Minami, K (1998) Assessing and mitigating N_2O emissions from agricultural soils. *Climatic Change* **40,** 7-38.

Motavalli, PP and Discekici, H (2000) Utilization of waste office paper to reduce nitrate leaching into the Northern Guam aquifer. *Biology and Fertility of Soils* **31,** 478-483.

Nicholson, FA, Chambers, BJ, Williams, JR and Unwin, RJ (1999) Heavy metal contents of livestock feeds and animal manures in Engaland and Wales. *Bioresource Technology* **70,** 23-31.

Nicholson, FA, Hutchison, MA, Smith, KA, Keevil, CW, Chambers, BJ and Moore, A. (2000). *A Study of Farm Manure Applications to Agricultural Land and an Assessment of the Risks of Pathogen Transfer into the Food Chain*. Final contract report to MAFF Joint Food and Safety Standards Group, Project FS2526.

Nicholson, FA, Smith, SR, Alloway, BJ, Carlton-Smith, C and Chambers, BJ (2003) An inventory of heavy metals inputs to agricultural soils in England and Wales. *The Science of the Total Environment* **311,** 205-219.

Nicholson, FA, Groves, SJ and Chambers, BJ (2005) Pathogen survival during livestock manure storage and following land application. *Bioresource Technology,* **96,** 135-143.

O'Brien, TA, Herbert, SJ and Barker, AV (2002) Growth of corn in varying mixtures of paper mill sludge and soil. *Communications in Soil Science and Plant Analysis* **33,** 635-646.

O'Connor, GA, Chaney, RL and Ryan,, JA (1991) Bioavailability to plants of sludge-borne toxic organics. *Reviews of Environmental Contamination and Toxicology* **121,** 129-155.

Paper Federation of Great Britain (1998) *Code of Practice for Landspreading Paper Mill Sludge*. Paper Federation of Great Britain, Swindon.

Perucci, P (1992) Enzyme activity and microbial biomass in a field soil amended with municipal refuse. *Biology and Fertility of Soils* **14,** 54-60.

Phillips, VR, Kirkpatrick, N, Scotford, IM, White, RP and Burton, RGO (1997) The use of paper-mill sludges on agricultural land. *Bioresource Technology* **60,** 73-80.

Piearce, TG (1984) Earthworm populations in soils disturbed by trampling. *Biology and Conservation* **29,** 241-252.

Piearce, TG and Boone, GC (1998) Responses of invertebrates to paper sludge application to soil. *Applied Soil Ecology* **9,** 393-397.

Quastel, JH (1954) Soil Conditioners. *Annual Review of Plant Physiology* **5,** 75-92.

Rabert, W and Zeeman, M (1992) Dioxins/Furans: U.S. EPA ecological risk assessment for land application and disposal methods for paper pulp sludge. *Chemosphere* **25,** 1499-1504.

Rahn, CR, Bending, GD, Turner, MK and Lilywhite, RD (2003) Management of N mineralization from crop residues of high N content using amendment materials of varying quality. *Soil Use and Management* **19,** 193-200

Robinson, CH, Piearce, TG, Ineson, P, Dickson, D and Nys, C (1992) Earthworm communities of coniferous soils: field observations and implications for forest management. *Forest Ecology and Management* **55,** 117-134.

Rogers, HR (1987) *Organic Contaminants in Sewage Sludge (EC9322 SLD): Occurrence and Fate of Synthetic Organic Compounds in Sewage Sludge – A Review.* WRc Report No. PRD 1539-M. WRc Medmenham, UK.

Sarkodie-Addo, J, Lee, HC and Baggs, EM (2003) Nitrous oxide emissions after application of inorganic fertilizer and incorporation of green manure residues. *Soil Use and Management* **19,** 331-339.

Scott, A, Ball, BC, Crichton, IJ and Aitken, MN (2000) Nitrous oxide and carbon dioxide emissions from grassland amended with sewage sludge. *Soil Use and Management* **16,** 36-41.

Simpson, GG, King, LD, Carlile, BL and Blickensdefer, PS (1983) Paper mill sludges, coal fly ash and surplus lime mud as soil amendments in crop production. *TAPPI Journal* **66,** 71-74.

Stark, BA and Hall, JE (1992) Implications of sewage sludge application to pasture on the intake of contaminants by grazing animals. In: Hall J.E., Sauerbeck D.R. and L'Hermite P. (eds), *Effects of Organic Contaminants in Sewage Sludge on Soil Fertility, Plants and Animals.* Commission of the European Communities, Luxembourg, pp. 134-157.

Sweetman, A, Rogers HR, Watts, CD, Alco, R and Jones, KC (1994) *Organic Contaminants in Sewage Sludge: Phase III (Env 9031)*. Final Report to the Department of the Environment. WRc Report No. DoE 3625/1. WRc Medmenham, UK.

Thiel, DA, Martin, SG, Duncan, JW and Lance, WR (1989) The effects of a sludge containing dioxin on wildlife in pine plantations. *Tappi Journal* Jan 1989, 94-99.

Trépanier, L, Gallichand, J, Caron, J and Thériault, G (1998) Environmental effects of deinking sludge application on soil and soil water quality. *Transactions of the American Society of Agricultural Engineers* **41,** 1279-1287.

Tucker, P, Fletcher, S.I., Hursthouse, A.S., Bialkowski, M., Swiderski, K. (2001). Metal release rates from a simulated paper-mill sludge stockpile. *Paper Technology*, May 2001.

Vagstad, N, Broch-Due, A and Lyngstad, I (2001) Direct and residual effects of pulp and paper mill sludge on crop yield and soil mineral N. *Soil Use and Management* **17,** 173-178.

Vasconcelos, E and Cabral, F (1993) Use and environmental implications of pulp-mill sludge as an organic fertilizer. *Environmental Pollution* **80,** 159-162.

Vinten, AJA, Davies, R, Castle, K and Baggs, EM (1998) Control of nitrate leaching from a Nitrate Vulnerable Zone using paper mill waste. *Soil Use and Management* **14,** 44-51.

Voundi Nkana, JC, Tack, FMG and Verloo, MG (1998a) Paper pulp as an amendment to a tropical acid soil: effects on growth of ryegrass. *Communications in Soil Science and Plant Analysis* **29,** 1329-1340.

Voundi Nkana, JC, Tack, FMG and Verloo, MG (1998b) Comparing the effects of paper pulp and lime additions to tropical soils using batch experiments. *Journal of Plant Nutrition and Soil Science* **162,** 207-213.

Waste Framework Directive:
http://europa.eu.int/eur-lex/en/consleg/pdf/1975/en_1975L0442_do_001.pdf

Webber, MD (1996) *Compilation, Review and Evaluation of Organic Contaminants in Compost and Compost Feedstock Materials*. Report no. 1996-RRS-2 for the Canadian Council of Ministers of the Environment. Water Technology International Corporation, Burlington, Ontario, Canada.

Welker, A and Schmitt, TG (1997) A basic investigation of AOX-substances in paper sludges. *Water Research* **31,** 805-815.

Wild, SR and Jones, KC (1991) Organic contaminants in wastewaters and sewage sludges: Transfer to the environment following disposal. In: Jones K.C. (ed), *Organic Contaminants in the Environment*. Elsevier Science Publishers Ltd, Barking, UK, pp. 133-158.

Zhang, X, Campbell, AG and Mahler, RL (1993) Newsprint pulp and paper sludge as a soil additive/amendment for Alfalfa and bluegrass: greenhouse study. *Communications in Soil Science and Plant Analysis* **24,** 1371-1388.

Zibilske, LM (1987) Dynamics of nitrogen and carbon in soil during papermill sludge decomposition. *Soil Science* **143,** 26-33.

Zibilske, LM, Clapman, WM and Rourke, RV (2000) Multiple applications of paper mill sludge in an agricultural system: soil effects. *Journal of Environmental Quality* **29,** 1975-1981.

APPENDIX 1: QUESTIONNAIRE TO COLLECT BACKGROUND DATA FROM PAPER MILLS

1. Quantity of paper wastes produced in the 2003 calendar year

Description of waste stream and feedstock		**Please insert tonnages (wet weight) of each type of sludge (If data is not available please enter total tonnage in end column and indicate which types of sludge make up this total**						Disposal/re-use routes	
Paper Waste Description	**Type of Feedstock** e.g. Virgin pulp, recycled paper, de-inked paper, newsprint, cardboard etc.	Primary Sludge e.g. settlement or drying beds	**Secondary Sludge- (Chemical / physical treatment)** e.g. DAF)	**Secondary Sludge- (Biological)** e.g. SAS	**Tertiary Treatment Sludge** e.g. final settlement lagoon sludge	**Total Annual Production** (tonnes wet weight)	**Approx. Dry Matter** (%)	**Proportion of waste stream recycled to agriculture**	**Other disposal or reuse routes** (please detail)
Example 1 De-Ink Sludge	*Recycled newsprint & recycled de-ink paper*	-	✓	-	✓	*3,000 t (wet)*	*21%*	*100%*	-
Example 2 Carbonless Paper	*Virgin pulp*	-	*10,000 t (wet)*	*3,000 t (wet)*	*1,000 t (wet)*	*14,000 t (wet)*	*27%*	*30%*	*Land restoration 20% Incineration 50%*
1.									
2.									
3.									

Appendix 1

2. Laboratory Analysis Results

We need to establish the chemical composition and variability of paper wastes being applied to agricultural land. We would be grateful if you could append copies or summaries of any laboratory analysis results you have for the past 12 months. Please label them clearly if your mill produces more than one type of waste product. (In particular we seek information on pH, organic matter, neutralising value, beneficial crop nutrients and potentially toxic elements).

3. Organic contaminants

Have you or do you analyse for any potential organic contaminants?

If 'Yes' please append details and analysis results

Please tick (✓)

YES	NO

1.1.1.1.1.1 Comments

4. Microbiological quality

Have you or do you analyse for microbiological quality?

If 'Yes' please append details and analysis results

Please tick (✓)

YES	NO

1.1.1.1.1.2 Comments

5. In the future, do you expect the quantity recycled to agriculture to change?

We expect the quantity of paper wastes Recycled to agriculture within the next 3-5 years to

	tick (✓)	+/- % Change
Increase		
Stay the same		
Decrease		

6. Monitoring and auditing of the landspreading operation

Please tick (✓)

	YES	NO
Do you have a system of monitoring or auditing of the landspreading operation?		
Do you specify that properly qualified advice (PQA) must be used.		

If 'Yes' please give details below and refer to any third party auditing.
Please indicate whether you or your contractors operate to have ISO 14001 or similar accreditation

7. Name of spreading contractor

Please insert the name of the spreading contractor(s) you use to apply paper wastes to **agricultural land**.

	Contractor 1	Contractor 2	Contractor 3
Name(s):	______	______	______
Contact Person(s)	______	______	______
Contact Tel No(s).	______	______	______

Please tick (✓)

YES	NO

The project team would like to contact contractors to discuss operational details, crops to which paper wastes are applied, timings etc. May we contact the above spreading contractor(s) and refer to your name ?

Please note that the project team will approach a range of spreading contractors known to be involved in landspreading of wastes, in any case, but will not refer to any paper mill or company unless expressly authorised.

8. Basis of operation

Please indicate how you manage and operate the recycling of paper wastes to agricultural land and the basis of the contract with your spreading contractor(s)

	Please tick (✓)
The mill retains full operational responsibility and employs the spreading contractor(s) direct	
The mill employs an agent / third party to manage the spreading operation but paper wastes are still recycled on behalf of the company	
The mill pays for the wastes to be removed and has no direct involvement in the spreading operation	
Other please specify……………	

9. Other comments

Please add any other comments or information that you feel may be helpful.

10. Your details

Name: ______________________________

Company name: ______________________________

Mill Name: ______________________________

Telephone no. _______________________

Email: ________________________________

Please send, fax or email completed questionnaire to:

Paul Gibbs, ADAS Project Manager

Tel: 01623 844331 Fax: 01623 844472

Email: paul.gibbs@adas.co.uk

Address: ADAS Gleadthorpe Research, Meden Vale, Mansfield, Nottingham, NG20 9PF

Thank you for your assistance

Appendix 2: questions to contractors
Spreading paper waste to agricultural land

1. **Name, address and telephone number of <u>contractor</u>:**

2. **Name of <u>Mill</u> to which these questions/answers relate:**

3. ***Which Paper Sludge material(s) have been used in <u>agriculture</u> over the last year from this Mill?***

	Type of Paper Sludge*	Liquid or cake	Quantity per year (Tonnes fresh weight)	Area used per year (Hectares)
1				
2				
3				

****Are any of these mixed/blended sludges – please give details***

4. **Which counties have the Paper Sludge been spread in?**

5. **Is the spreading activity "audited" by the contractor/Mill or by a third party? Is it carried-out under an environmental accreditation scheme and/or in compliance with a particular code or guide? Please provide details.**

6. **Is the person providing the field site application/fertiliser recommendations FACTS qualified?**

7. ***What application/incorporation methods are used (by % area)?***

			Surface spread, followed by……			
	Surface spread only	Injection	Chain harrowing	Ploughing	Deep discing	Shallow discing/tines
1						
2						
3						

8. **What is the typical cropping <u>following</u> Paper Sludge application (by % area)?**

	Grass			Combinable									
	Un-disturbed	Re-seed Winter Spring		Cereal Winter Spring		OSR Winter Spring		Peas/Beans Winter Spring		Linseed Winter Spring		Other Winter Spring	
1													
2													
3													

9. **Which crops are typically 'targeted' to follow Paper Sludge application? Please provide a reason where appropriate.**

1.

2.

3.

10. **Which crops do NOT normally follow Paper Sludge application? Please provide a reason where appropriate.**

1.

2.

3.

11. **What soil types (by % area) are typically used for Paper Sludge spreading?**

	Sandy	Chalk	Medium & silty	Clays	Peaty	% Calcareous Soil (i.e. pH>7.3)
1						
2						
3						

12. **Rate of Paper Sludge application details:**

	Max (t/ha)	Min (t/ha)	Typical (t/ha)	Comments (where max, min, etc)
1				
2				
3				

13. **Storage on farm and application details:**

	Storage type & location on farm	Storage period (months)		Application period (by % area)		
		Max	Typical	Jul to Oct	Nov to Feb	Mar to Jun
1						
2						
3						

14. ***Is*** **ADDITIONAL nitrogen fertiliser recommended to combat N lock up? Please provide details:**

	Kg/ha Extra Nitrogen			
	Max	Min	Typical	Comments (autumn & spring, rates)
1				
2				
3				

15. **Do the recipient farmers combine Paper Sludge with any other "wastes", such as poultry manure, sewage sludge, FYM, etc.? If so, for what % of the total Paper Sludge? Please also state types of other wastes.**

1.

2.

3.

16. **What, in your view, are the benefits to agriculture from landspreading this/these Paper Sludge material(s)?**

1.

2.

3.

17. **In your experience, have any disbenefits to agriculture from landspreading this/these Paper Sludge material(s) been encountered? If yes, please provide details.**

1.

2.

3.

18. **What, in your view, are the potential disbenefits to agriculture from mismanaging the landspreading of this/these Paper Sludge material(s)?**

1.

2.

3.

19. **If there are any other issues relating to the spreading of Paper Sludge in general that you wish to draw attention to, please provide detail**s: