Guide to the Use of Wastewater Biosolids in Agriculture

TIM EVANS ENVIRONMENT

Principal author Tim Evans, TIM EVANS ENVIRONMENT Stonecroft, Park Lane, Ashtead, KT21 1EU England
tim@timevansenvironment.com

Advisory team
Peter Balmér, Gryaab, Karl IX:s väg, 1834 Göteborg, Sweden
peter.balmer@telia.com
Hubert Brunet, SEDE, 5 rue Frederic Degeorge, B.P. 175 - 62003, ARRAS CEDEX, France
h.brunet@sede.fr
Jeremy Hall, Bryn Cottage, Highwood Bottom, Speen, Princes Risborough, HP27 0PY. England
sludge.hall@virgin.net
Susanne Klages, KTBL, Bartingstraees 49, D-64289 Darmstadt, Germany
s.klages@ktbl.de
Piotr Kowalik, Gdansk University of Technology, Poland
pkow@pg.gda.pl
Katia Lasaridi, Harokopio University, 70 El. Venizelou, 176 71 Kallithea, 176 71 Athens, Greece
klasaridi@hua.gr
Alexander Maddan, Agrivert Ltd., The Stables, Radford, Chipping Norton, OX7 4EB England
AMaddan@agrivert.co.uk
Horst Müller, Müller Abfallprojekte GmbH, Hauptstr.34, A-4675 Weibern, Austria horst.mueller@tb-mueller.at
Lluís Sala, Consorci de la Costa Brava, Plaça Josep Pla 4, 3er 1a, E-17001 Girona, Spain
lsala@ccbgi.org

ACKNOWLEDGEMENTS

The author and members of the advisory team are very grateful to the European Commission for funding the preparation of this document and to all those who have contributed comments, information, case studies, quotations and pictures for use in this Guide to the use of sludge in agriculture.

January 2006

GUIDE TO USE OF WASTEWATER BIOSOLIDS IN AGRICULTURE

CONTENTS

Preamble

This guide is intended to provide advice and information for farmers, land owners, the food industry, consumer associations, members of the general public and local authorities responsible for waste management. The aim of the European Commission and the authors is that it will encourage and enable an informed choice about the use of sludge on agricultural land and will explain the agronomic potential of sludges (in particular sewage sludge) suitable for recycling on agricultural land, the benefits to society of such practise and how to minimise potential drawbacks. The document has been prepared in the context of the European Community Waste Management Policy and with reference to the "Directive on the Protection of the Environment, and in Particular of the Soil, when Sewage Sludge is Used in Agriculture" (86/278/EEC), the sludge directive; it does not reflect a Commission position.

The Community Strategy for Waste Management COM(96) 399 calls for the avoidance and diminution of waste and, where this is not possible, for reuse and recycling; disposal is considered the last resort when there is no preferable alternative. Some 7 million tonnes of sewage sludge (on a dry matter basis) are produced every year in the European Union. During the period 1995-2000 about 40% of all the sewage sludge produced in the EU was spread on agricultural land as a total or partial substitute for mineral fertilisers and to improve the soils by increasing their organic matter content. In addition sludge was also used for land reclamation and other non-agricultural uses. This is about 1% of all the organic resources (manure, compost, food factory waste, etc.) used on land. The extent of beneficial use varies from one Member State to another.

Introduction

Research carried out in the past thirty years or so continues to demonstrate that responsible and well-monitored use of sludge - in compliance with the requirements of the sludge directive (86/278/EEC) - causes neither environmental damage nor endangers the food chain (see page 8 for a description of the directive). This directive was the first to deal specifically with protecting soil. The EU has framework directives to protect air and water; it is now working on a general strategy for protecting the other major element, i.e. soil.

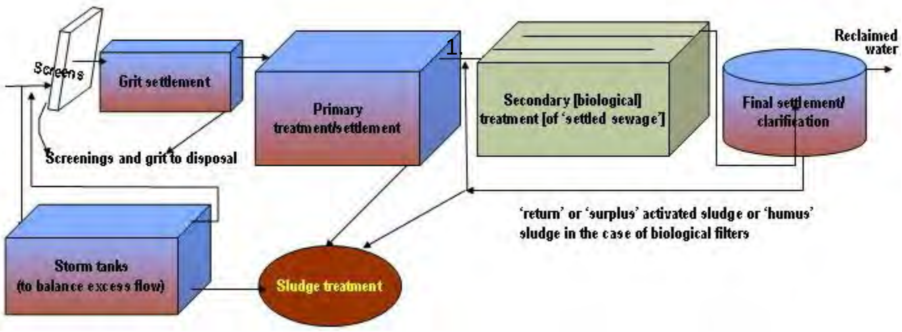
Using biosolids in agriculture makes an important contribution to stewarding the planet's phosphate. P is essential for all cells, it is the least abundant of the major plant nutrients, at the current rate of extraction it might be exhausted in 300 years.

"...life can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent.... We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation - but for phosphorus there is neither substitute nor replacement." 'Asimov on Chemistry' (1974) Doubleday, NY.

Adults excrete 98% of the P they consume because they are turning cells over rather than laying down new ones. A large proportion can be captured in biosolids.

It has been recognised that soil is under threat from erosion, sealing (by roads, development, etc.), contamination, compaction, loss of organisms living in the soil (reduced biodiversity), salinisation (damage by salt accumulation), and desertification. The last is becoming a real concern in parts of Southern Europe exacerbated by climate change and increased likelihood of low rainfall in summer. Organic matter is a key factor in all of these, except for sealing (obviously) which is a matter of planning where and how we constructs roads and other developments.

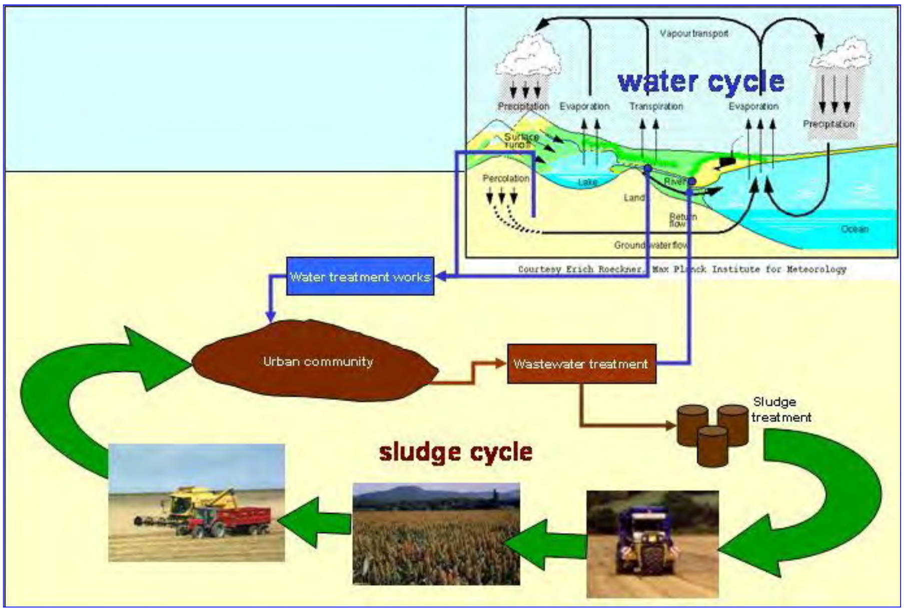
Soil is not only important for growing crops and other plants on which our food and landscape depend, it is also a filter for rainwater soaking into the ground, as the water cycle shows, and by soaking up water (instead of it running off) it prevents flooding. Organic matter makes soil friable, crumbly and able to let water in. It is easier for plant roots to grow in friable soil. Organic matter also provides reserves of plant nutrients and water. Incorporating organic matter into soil also helps to lessen climate change by reducing greenhouse gas emission. Maintaining soil organic matter has been recognised as a key part of soil protection.



Cologne Porz-Wahn wastewater treatment works (above) and schematic (right) (photo Prof. Pinnekamp, schematic Tim Evans)

This is a conventional works treating a mix of domestic and industrial inputs equivalent to the domestic sewage from 250,000 people

1 screens
2 grit settlement
3 primary settlement
4 secondary treatment
5 final settlement
6 storm tanks
7 anaerobic digester
8 biogas holder



Background

1.1 Farming and fertility

The use of sludge in agriculture feeds the soil by returning organic matter and completes the cycle of nutrients. This guide discusses the origins of sludge, the science about its impacts and the controls that have been developed.

Farms produce food that is taken to villages, towns and cities. Fertile soil contains organic matter, which stabilises the structure making soil friable and easy to cultivate and easy for roots to grow in. Organic matter is a store for carbon and a reserve of nutrients, rather like a 'deposit account' in the bank; plants absorb nutrients (food) from the available pool (like a bank 'current account') which soil microorganisms replenish from the reserves in the organic matter. Organic matter is also important for holding plant-available water in the soil. Soil organic matter gradually decays and is replenished by crop residues (leaves, stalks and roots), dung from animals and additions of organic materials such as sludge, manure or compost.

The earliest farmers cleared patches of land and grew their crops on them until the fertility (organic matter) had run down and then they moved on to a new area leaving the old one to regenerate and recover.

There has been settled farming in Europe for more than 4000 years. Farmers learnt that the only way to keep farming the same piece of land was by returning fertility to the soil by crop rotation, dung, manure and any other amendments. Even so, yields were only 10-20% of those achievable today; the crops were taking less out of the soil and they only needed to feed a smaller population of humans and animals.

Mineral fertilisers, pesticides and improvements to crop varieties have all contributed to substantial increases in yields so that we can produce enough food to feed our massively expanded population. However we still need to feed the soils with organic matter so that they are healthy for roots, they are not prone to erosion and they filter rainwater on the way into the ground. The heavier crop yields are taking more out of the soil and it is therefore important that organic matter and nutrients are recycled.

1.2 Water and wastewater

Most people in urban areas don't think very much about tap-water and even less about wastewater. Both are taken for granted but they are what keep us healthy. We expect wholesome water to come out of the taps and the wastewater from our kitchens, lavatories, bathrooms etc. to disappear. People who have septic tanks (because their homes are not served by sewers) think a bit more about wastewater because they have to get a tanker to empty the tank occasionally.

Most people don't realise that it was the collection and removal of wastewater that enabled healthy cities to develop – it could be said to have been a key factor enabling the industrial revolution and high density urban living. It keeps town dwellers and their rivers healthy. To this extent water and wastewater treatment are the real health services whereas the medical services could be called the sickness services – they treat people when they are sick.

1.2.1 Wastewater Collection

Wastewater (or sewage) is taken from homes, offices, factories, shops, schools, hospitals and conveyed through sewers (the sewerage system) to treatment works, where it goes through a number of processes designed to separate water from solid material. Especially in the older areas the sewerage system also conveys rainwater. Human waste products form a relatively small proportion of the total volume of sewage. During very wet weather sewers can get very full, to the point of overflowing, so there are generally some relief points so that overflow happens where it is less problematic. It is important that people do not put things down the drain that could block the sewers.

1.2.2 Wastewater treatment

Wastewater treatment works can be thought of as the kidneys of our society; kidneys clean blood, wastewater treatment works clean water. When we treat wastewater so as to recover water that is fit to be released back into streams, rivers, lakes and seas we also recover 'sludge'. This is a slurry containing the organic matter, soil, nutrients and trace elements and compounds from the wastewater together with the surplus microbial biomass that grows on the nutrients and organic matter in order to purify the wastewater. Some of the trace elements are nutrients but others have no beneficial qualities and might be dangerous in excess. Wastewater treatment and control of contaminants are described in the section on the origin of sludge.

The more we treat the wastewater the more sludge we get. The transformation from the muddy-looking sewage entering the works to the crystal clear effluent that leaves is really quite magical to see, and it is all done by natural processes that are controlled and enhanced to give optimum

Comparison of screened sewage and reclaimed water against the background of a treatment works—final clarifiers in the foreground, activated sludge behind (Tim Evans)

History

There was wastewater collection in ancient times but there was no wastewater treatment. City dwellers in the Indus Valley (2500 BC) had excellent sanitary sewer systems made of burnt brick. At about the same time there were copper sewer systems in Egypt. The Minoans on Crete (2000-1400 BC) had highly developed sanitary systems flushed with water. The Romans built bath houses, aqueducts, public toilets (water-flushed) and sewers (mainly for surface water but also for sanitary purposes) throughout the empire (500 BC to 455 AD).

All of these systems merely conveyed the wastewater away from where people lived to the river or to the sea. For example the exit of the Cloaca Maxima (sewer) can still be seen in the bank of the River Tiber in Rome. These engineering works fell into disuse and disrepair following invasions and falls of civilisations. There was no sewerage for more than 1000 years.

Before wastewater collection the size of communities was frequently limited by water-borne disease. City populations would grow and when there were too many people living close together, an epidemic would cut them back. Many cities in Europe have memorials to deliverance from epidemics.

During the 1830s only half of the babies born in Europe lived to the age of 5; the other half died of diarrhoea, dysentery, typhoid and cholera because sewage contaminated their drinking water. The sanitary drainage from houses was either thrown into the streets or collected in cesspools. The cesspools were supposed to be emptied regularly. People had to pay to have septage and "night-soil" removed. It was then sold to farmers along with dung from the animals in the towns. It was called "town manure". In those days many horses (for transport) and cows (to provide fresh milk) were kept in towns and fed with crops brought in from the country. Cesspools were often allowed to overflow (to reduce the cost of emptying them). Because of the density of housing they were often not far from the nearest well so wells got infected.

In the 1840s farmers typically paid €0.20 per load for town manure, but by 1847 guano (bird droppings imported from South America) became available as a cheaper alternative. This increased the cost of night-soil removal because the "rakers" were not paid as much for town manure. People became even more reluctant to pay as the cost of night-soil removal increased, and so illegal connections were made to the urban rivers and streams (the drains) which were supposed to be for surface water only (i.e. rainfall). The problem was compounded by the introduction of water closets in about 1810 because of the water for flushing. As the popularity of water closets increased, the volume of wastewater discharged almost doubled.

City-dwellers in Europe were ordered to discharge wastes into the drains so as to avoid contaminating the groundwater and the wells. These drains discharged to the main rivers. The slogan in Paris was *tout-a-l'égout* (everything to the sewers). In 1850 engineer Eugène Belgrand designed the present Parisian sewer network as subterranean well-ventilated multipurpose conduits. Dual water-supply pipes (one potable and one non-potable), telegraph, pneumatic pipes for postal services and now other services are hung from the roof of the sewers. The main sewers have walkways above normal water level for ease of inspecting these additional services and for maintenance. Tours of the sewers started during the Paris Exposition of 1867 and continued until 1975. Tourists were taken through the sewers in wagons or boats attended by sewermen in clean white overalls. Larousse reported in 1870 "no foreigner of distinction wants to leave the city without making this singular trip". There is still an interesting museum in one section.

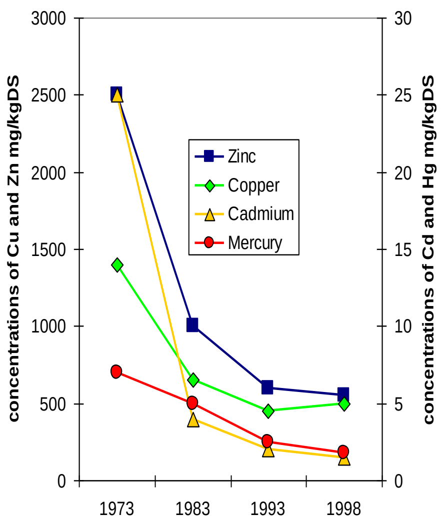
In 1854 Dr John Snow traced the cause of a cholera epidemic in London to the Broad Street [drinking water] pump, which he believed was contaminated from local cesspools. Other health professionals disagreed; they thought it was in the air. He proved his point by removing the pump handle and the disease subsided.

Transferring wastewater to the river solved one problem but created another. London was one of the earliest to experience this problem for two reasons: its population was the largest (3 million by the 1860s) and the river was tidal so that which was discharged on a low tide was brought back by the next high tide.

Parliamentarians were eventually forced to accept that something needed to be done in July 1858 because of the "great stink". In about ten years Joseph Bazalgette completed massive engineering works to intercept the drains and divert them into pipes that carried away the water to be treated and discharged at a safe distance downstream of the city. This became the pattern for other cities in Europe and elsewhere. Some of today's sewerage infrastructure dates from the 19th century and is a tribute to the construction and engineering skills of those who built them.

Initially the standards of wastewater treatment were fairly rudimentary. They improved over the years because of better understanding of the effects of pollution and by technological development. Continuing with the example of the River Thames, in the 19th century no salmon were caught after 1833. As a result of Bazalgette's drainage work, and considerable investment in wastewater treatment over the years, the river was clean enough to successfully reintroduce salmon in 1985. This success has been replicated in other European rivers.

Use of farmland for wastewater treatment continued from the second half of 19th century for more than 100 years. By 1900 Berlin devoted 6900 ha to sewage farming and Paris 5000 ha. The Parisian sewage farms had declined to 4487 ha by 1948 but still accounted for 10% of the vegetables sold at the central market of Les Halles; the vegetables were prized by the best hotels (Reid, 1991).



Changes in metals in sludge from Stockholm's Henriksdal and Bromma waste water treatment plants with time.
(Lars Ulmgren, Stockholm Water Co.)

performance.

The European Union has ensured that the cleanup of rivers and prevention of pollution is an obligation for all Member States. The Urban Wastewater Treatment Directive (91/271/EEC) required a programme of installing and upgrading wastewater treatment. The Water Framework Directive (2000/60/EC) requires protection of waters and reversal of degradation.

Sludge

1.3 The origin of sludge

Wastewater flows through the sewer pipes swiftly so that it carries the solids with it. The solids consist mostly of faecal matter from the toilet, soil from vegetable preparation and washing and runoff from roofs, paths and roads. This wastewater contains nutrients, contaminants and organic matter. If it were to get into rivers and lakes directly it would feed plants and microorganisms. This nutrient enrichment is called eutrophication. The increased microbiological growth would remove oxygen from the water which may even kill fish if they were unable to respire. Wastewater is treated using biological processes to prevent this; in principle the processes are the same as nature's own but intensified by giving them the optimum conditions in which to operate.

Rain collects dust etc. from the air, and most sewer networks collect surface water (run-off from roofs, roads and other hard surfaces) in some areas. Many years of air quality legislation such as the Air Quality Framework Directive (96/62/EC) have reduced the pollutants in the air but road run-off especially still contributes metals and organic pollutants to the urban drainage. Removal of lead from petrol has greatly decreased lead in run-off, but there are other potential pollutants such as zinc and cadmium from tyres and PAHs (polyaromatic hydrocarbons) from exhausts.

A very important step in environmental protection happens outside the wastewater treatment works. It takes place at factories and other non-domestic premises. This is the control of potential pollutants at source before they get into the sewer. For example garages (petrol stations) are required to have interceptor traps to prevent oil, etc. from getting into the sewer. The contents of these interceptors must be disposed to separate facilities. In order to prevent pollution, people who do their own car maintenance at home should dispose of waste oil at municipal facilities; they should not put it down the drain. Dentists have traps on their drains too so that the mercury from tooth fillings doesn't get into the sewage. Electroplating factories etc. are required to remove metals from their wastewater before they discharge it.

Wastewater operators analyse sludge regularly and if they find an increase in concentration of a potential pollutant they actively seek out the sources. They also have programmes of inspections to ensure that identified sources are operating satisfactorily and keeping to their agreements. In the case of substances that are particularly hazardous governments have simply banned them. For example Europe introduced restrictions on the marketing and use of PCBs (see the box on organic micropollutants) in 1976 (76/769/EEC) and strengthened these in 1985 (85/467/EEC) and again in 1996 (96/59/EC); their manufacture is banned and products containing them must be destroyed in a controlled manner.

When the water gets to the wastewater treatment works it is screened to remove plastic and other debris. It is amazing what people put down the drain – out of sight out of mind. These should be disposed in the refuse bin rather than the drain.

The next two stages are essentially physical and involve letting suspended particles settle out of suspension. This is done by reducing the velocity. Grit and sand are settled first; the flow is still quite fast, but not fast enough for sand and grit to remain in suspension. The next tanks are much wider and the flow is so slow that even fine particles settle out; this sediment is called primary sludge (see the figures on page 2).

The water from the primary sludge settlement step still contains very fine and dissolved organic matter and nutrients; these are removed by biological treatment. It uses the same sort of aerobic (air breathing) organisms that would be found in rivers, but in conditions ideal for a much larger population. With more organisms than there would be in a river the 'food' is eaten more quickly. Optimising the living conditions for the microorganisms means for example adding oxygen (or air) to the water.

Aerobic treatment is very similar to composting. The sludge from this stage is a product of the microorganisms, more correctly it is the surplus organisms (called biomass).

By carefully adjusting conditions the microorganisms can also remove nitrogen and phosphate from the water. These are the two main nutrients that encourage plant growth in rivers and lakes. Phosphate can also be removed by adding iron, aluminium or organic binders to form the same sort of compounds that hold phosphate in soil.

The quality of sludge depends on the quality of wastewater, just as the quality of compost depends on the quality of organic waste or manure that you put in.

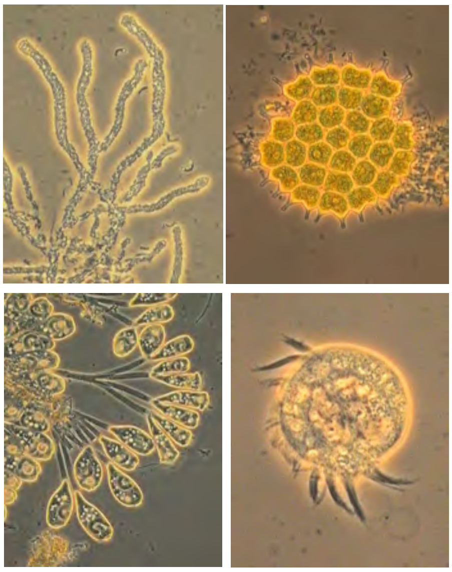
Before releasing the treated water (into the river, etc.) the microorganisms are settled out in the final clarifier (settlement) tanks. Some of the sludge from the tanks must be returned to maintain the microbial population (just as some yeast is recycled in a brewery) the excess is combined with the primary sludge and goes forward to the sludge treatment processes.

Sludge treatment is defined by the sludge directive as "significantly reducing the fermentability and health risks when sludge is used on land" this means it reduces the number of pathogens (disease causing organisms) and reduces the risk of smell; it does not affect the content of chemical contaminants. The different sludge treatment processes are described below.

In some treatment works (generally the smaller ones) there is no primary settlement and the screened sewage is aerated for an extended period of time in order to reduce the biological oxygen demand and the solids content. This type of treatment is more compact and can have lower capital cost, than primary settlement followed by secondary treatment, it produces good effluent but in general it uses more energy and the eventual sludge is more difficult to treat and to dewater.

The biological treatment steps in wastewater treatment can also be considered as a biological monitor of the quality of the wastewater. If there were a spill of some toxic substance somewhere in the catchment its effect would be seen first in these steps and it would be isolated before it could affect the river, lake or sea into which the treated water is discharged; and if the sludge were contaminated it too would be isolated and not taken to land.

There are other sources of sludges such as the food, drink and paper industries. The total quantity is about twice

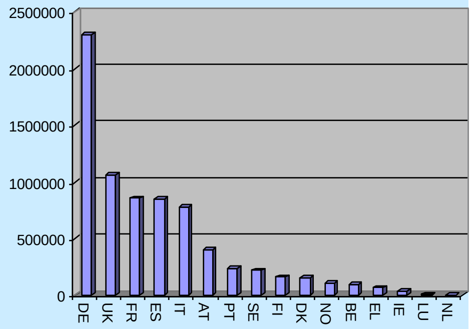


Aerobic wastewater treatment organisms (Werner Maier, iat Stuttgart)

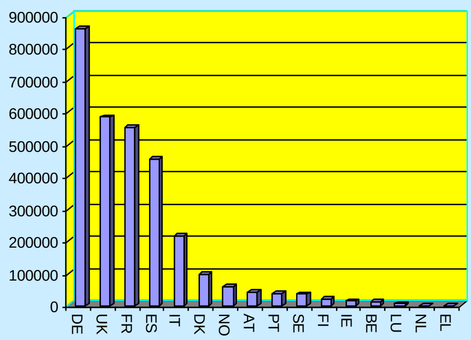
How much sludge do we make?

The amount of sludge produced is related to the population connected to the wastewater collection system and also to the extent of treatment, so if we divide the total quantity produced by a country by the total population of the country to get the production per person we find it differs from one country to another but approximately each of us produces about 25 kgDS/year.

The graphs below show the total quantity produced by each country expressed as tonnes dry solids (i.e. if all the water had been evaporated) per year (tDS/year) in 2000 [top] the quantity used on agricultural land (tDS/year) [middle] and the percentage of the total that was used on agricultural land [bottom].

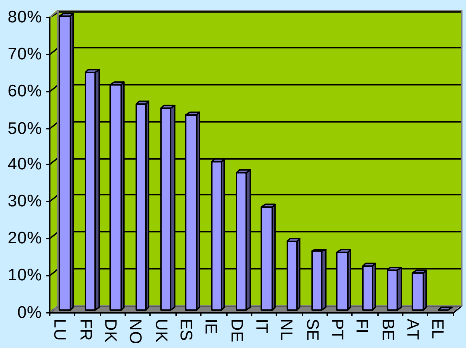


Germany with the largest population in Europe produces the most sludge and also recycles the largest quantity to agriculture. Luxembourg has the highest percentage recycling but its production is small.



The data are those reported by member states of the EU to the European Commission [COMM(2003)250] for 1998 to 2000 plus Norway.

The order in which the countries appears differs between the graphs reflecting their different performances.



the quantity of sewage sludge. The total quantity of slurry and manure from livestock farming is about 50 times that of sewage sludge. These comparisons are all on a dry matter basis. These are all potentially valuable organic resources that can be recycled to complete nutrient cycles and conserve organic matter as part of sustainable development. They share the same benefits and hazards as sewage sludge although the sizes of the effects differ one from another.

1.4 Chemical, biological and physical characteristics of sludge

The chemical, physical and biological characteristics of sludge from a particular wastewater treatment works are to some extent influenced by the nature of the catchment from which the wastewater is collected. The following examples illustrate the point:

- if there is a factory making meat pies or several restaurants there might be a lot of fat in the sewage. This is wonderful for biogas production at a treatment works where there is anaerobic digestion, but fat can clog sewers;
- wastewater from a wool processor might contain fibres and lanolin; the fibre makes the sludge easy to dewater and the lanolin has a high biogas yield. In the past lanolin was recovered for cosmetics;
- an electronics factory making printed circuit boards might discharge copper and other metals;
- an abattoir might discharge blood and manure.

If the drinking water supply is 'hard' there will be more calcium in the sewage than in a soft-water area. Hard water is the sort that results in lime scale in kettles, etc. The calcium is useful to people and to most plants.

If the sewer system is 'combined' (i.e. carries surface water as well as sanitary sewage) the flows will fluctuate more widely than if it is sanitary sewage only, and also it will carry road grit and soil and any pollutants that happen to fall on the roads, roofs, etc. for example from vehicles or from atmospheric deposition, as discussed above, this has decreased because of decades of air quality legislation.

Some premises produce wastewater that could harm the fabric of the sewers (and in extreme circumstances injure people working in them), damage the wastewater treatment process or pollute the sludge. In order to prevent this, industries are required to pre-treat their wastewater so that the wastewater they discharge is within acceptable quality limits (Urban waste water treatment Directive, 91/271/EEC). There have been many examples that demonstrate the success of this co-operation between industry and wastewater operators. People often think that industrial effluents are very contaminated with 'heavy metals', but the reality is that concentrations have decreased dramatically over the years. This subject will be discussed further under Hazards and Risks.

The chemical, physical and biological characteristics of the final sludge are influenced by both the wastewater treatment processes and the sludge treatment processes. For a particular treatment works the final sludge is normally remarkably consistent through time so that users of the sludge appreciate that it can be a reliable and predictable input to farming.

Some methods of sludge treatment reduce microbiological risk to ambient levels; i.e. the sludge does not increase the risk of disease transmission compared with normal crop production situations. Other treatment methods produce sludge that is microbiologically more like manure and these types of treatment need to be complemented by restricting the types of farming/cropping, and/or intervals to harvest (i.e. a second barrier to transmission). The Sludge Directive requires a dual barrier approach: treatment or injection and restriction on cropping and on harvest intervals.

1.5 Sludge use in agriculture directive 86/278/EEC

Trace element loading limits kg/ha/yr*

Parameter	Limit values (mg/kgDS)
Cadmium	0.15
Copper	12
Nickel	3
Lead	15
Zinc	30
Mercury	0.1

* based on a 10-year average

On 12th June 1986 the EU Council of Ministers adopted the Directive 'on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture' (86/278/EEC). This was the first directive to deal with soil protection. It has been a success in that there have been no cases of adverse effect where sludge has been used in accordance with its requirements.

Sludge trace element limit values*

Parameter	Limit values (mg/kgDS)
Cadmium	20 to 40
Copper	1000 to 1750
Nickel	300 to 400
Lead	750 to 1200
Zinc	2500 to 4000
Mercury	16 to 25

* extracted by ‘strong acid digestion’

Soil trace element limit values* for pH 6-7†

Parameter	Limit values (mg/kgDS)
Cadmium	1 to 3
Copper	50 to 140
Nickel	30 to 75
Lead	50 to 300
Zinc	150 to 300
Mercury	1 to 1.5

* extracted by ‘strong acid digestion’
† for soils with pH<6 MS must consider the possibility of increased availability
for soils with pH>7 the limit values can be increased by up to 50%

The directive recognises that sludge can have valuable agronomic properties and encourages its use. It states its purpose is 'to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man, thereby encouraging the correct use of such sewage sludge.'

Member States (MS) are required to implement the directive into national legislation that is no less stringent than the directive. They are also required to report sludge recycling activities to the Commission every three years. MS regulations can either control contaminant addition by setting sludge concentration limits and sludge application rate limits or by limits on the rate of contaminant addition per hectare.

Sludge recyclers are required to analyse the sludge for the regulated parameters and for dry matter, organic matter, pH, nitrogen and phosphorus. Sludge shall be analysed at least every 6 months or more frequently if the analytical results are variable. For assessing agronomic value it is often useful to analyse for ammonium as well as total-N and in the case of lime-stabilised sludge to measure neutralising value.

Sludge recyclers are required to take representative samples of the soil to which sludge is to be applied by combining 25 sub-samples from areas not exceeding 5 ha. Soil must be analysed for pH and the regulated parameters before sludge treatment starts and then at a frequency appropriate for the expected rate of contaminant addition. They shall ensure that concentrations of cadmium, copper, nickel, lead, zinc and mercury do not exceed the prescribed limit values. They must also take account of the change in plant-availability of contaminants with changing soil pH, thus, less is permitted at lower soil pH values. With modern sludges the rate of accumulation of trace elements is so slow that it would more than 10 applications before any change in soil analysis was even measurable against the natural variation of soil within a field.

Recyclers must record the analytical data together with details of the methods of sludge treatment and how much sludge was supplied, when and where. The data are to be available for inspection by the competent environmental protection authority at any reasonable time.

Sludge must be 'treated' before it is applied or it must be injected or worked into the soil as quickly as possible. Treatment is defined as 'biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards resulting from its use'.

Grass and forage crops shall not be grazed or harvested within three weeks of treatment. There shall be a ten-month interval between treating soil and harvesting fruit or vegetable cops that are normally in contact with the soil and are eaten raw. This is the 'second barrier' concept discussed later.

The directive requires that account is taken of the agronomic needs of plants and the nutrient supply of the sludge. In this context recyclers must provide users with analysis of the sludge they have received.

MS have set their own regulations to suit their local conditions, methods of chemical analysis and methods of using sludge.

1.6 Methods of sludge treatment

1.6.1 Purpose

The purposes of sludge treatment are to:

- reduce sludge volume to minimise handling and transport costs,
- reduce the number of pathogens (disease-causing organisms) in the sludge
- prevent it smelling objectionable.

Biological treatments reduce the content of unstable reactive organic compounds. Human pathogens are disease-causing microorganisms that have evolved to live in our bodies, and so cannot grow when excreted but could infect another human if they were consumed. Sludge treatments accelerate the natural die-off of pathogens for example by depriving them of food, exposing them to antagonists, lethal temperature or chemical conditions.

1.6.2 Dewatering

One of the purposes of sludge treatment is to reduce the volume of material, which reduces off-site transport requirements. Untreated sludge from the primary and final clarifiers is typically 98% water and after gravity thickening it contains about 95% water. Sludge treatment often reduces the volume of sludge by removing some of the water. To **dewater sludge** (i.e. to reduce the moisture content from 95% to 80% or less) a conditioning chemical is added. This attracts the individual sludge particles into 'flocs', which makes it easier to separate the water and solids by filtration or centrifugation. Dewatered sludge usually contains about 20-35% dry matter (80-65% moisture) depending on the type of sludge and method of dewatering. It looks quite solid and can be stacked in a heap. Dewatering is a key pre-treatment to many subsequent processes.

The effectiveness of sludge dewatering is critical to the efficiency of subsequent processes. The costs of haulage and spreading when cake is recycled are directly related to the effectiveness of dewatering. This is also true of the cost of thermal drying because dewatering affects the amount of water that has to be evaporated. The better the dewatering, the better the cake will stack, the easier it is to compost or to sanitise with lime and the smaller the energy requirement for drying.

Dewatering

The three principle methods of dewatering are plate and frame press (top), filter-belt press (middle) and decanter centrifuge (bottom). These are merely examples; there are several variants for each type.

In each case a conditioner is added to the sludge so that the particles 'flocculate' and the water is free to be removed. Organic polyelectrolytes are the most commonly used conditioners. It is essential to select the correct conditioner for the particular sludge and to use it at the optimum dosing rate. The surface chemistry of the sludge changes with time, which means that the optimum dose changes, because of this there is work to develop automatic in-line dose optimisers in order to get the desired cake dryness at the lowest conditioner dose.

(Bucher-Guyer AG)

The plate and frame press filters the water through cloths supported on frames. The water is forced out of the cake by the pressure created by the sludge pumps that fill the press; in some presses the pumps are assisted by air-bags on alternating plates that squeeze the cakes. Pressures of 5-10 bars are typical. Very few are installed nowadays because although they can produce the driest cakes they occupy a large footprint and require attendance when they are discharged, i.e. 4-hourly.

Another press that uses supported filter cloths (shown right above) has been used very successfully of extracting fruit juice and might have the benefits of high dewatering capability of the plate and frame press but combined with continuous unattended operation.

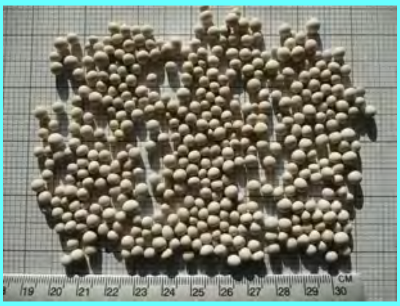
The filter-belt press comprises two continuous moving belts; conditioned sludge is fed onto a horizontal section of belt and water drains by gravity. The wet cake is then sandwiched by the second belt and the sandwich moves on a zig-zag path through a sequence of rollers that increase the pressure up to about 1.5 bars.

The decanter centrifuge spins on a horizontal axis subjecting the conditioned sludge to about 2000-times the force of gravity. This sediments the solids rapidly.

Centrifuges occupy the smallest footprint, use the most electricity, can run continuously unmanned and achieve drier cake than belt presses. When sludge enters a centrifuge it undergoes high shearing forces, which can result in more odorous cake than with a filter-belt if sludge has not been very well stabilised.

There is no universal answer for dewatering; each works needs to find the best solution for its particular sludge and circumstances and then ensure it is operated optimally. (Photos Tim Evans)

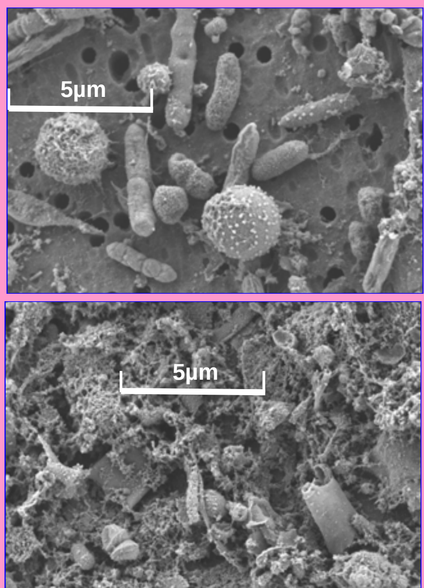
Filtrate or centrate (the water separated by dewatering machines) can be a large load on a treatment works; alternatively it is an opportunity to recover ammonia solution and phosphate. These physico-chemical recovery processes are financially competitive with merely returning the liquor to the WwTW and have smaller global warming potentials. Magnesium ammonium phosphate (struvite) is a good fertiliser. Ammonia solutuion has industrial uses in addition to its fertiliser use.



Different designs of digesters and biogas holders

Low aspect-ratio [lower and wider] older digesters with floating roof gas holders (top)
Modern high aspect-ratio cylindrical digesters with spherical fabric gas holders (middle)
Egg-shaped digesters with cladding (bottom) (photos Tim Evans, Monsal, Thames Water, Wiesbaden, Hessen)

Combined heat & power (CHP) engine running on biogas (Tim Evans)



Waste activated sludge: untreated (above) and after disintegration (below)

These electron microscope pictures show how disintegration of sludge prior to digestion releases the cell contents for conversion to biogas by smashing the cells and it also improves dewatering. (MicroSludge)

Thermal hydrolysis prior to digestion

It sterilises the sludge and disintegrates it, which increases the biogas yield and improves dewatering. (Tim Evans)

1.6.3 Biological treatments

The most widely practised type of sludge treatment is '**anaerobic digestion**'. It stabilises the sludge, reduces pathogen numbers and produces biogas. They are often called biogas plants. Liquid sludge is treated in heated tanks from which air is excluded; bacteria that can live without air (anaerobes) feed on the organic matter and make methane -rich biogas. This can be burnt in engines that turn generators to make electricity and heat. It is a clean and renewable alternative to fossil fuel.

Digested sludge has a tarry ammoniacal smell and more of the nutrients are in forms available to plants. It is a nitrogen:phosphate:sulphur (N:P:S) fertiliser with organic matter. It also contains trace elements and maintenance quantities of potassium (K) and magnesium (Mg) (see Features and Benefits).

Anaerobic digestion with combined heat and power generation (CHP) became popular in the 1930s. It is still the most widely practised form of sludge treatment, indeed there has been renewed interest to maximise its efficiency because of its capacity to make renewable energy whilst at the same time conserving all of the plant nutrients and reducing the quantity of sludge produced.

Innovations have focussed on increasing the amount of sludge that can be treated, improving mixing in digesters and making the sludge more digestible (increasing biogas yield and solids destruction). Examples of techniques to increase digestibility are breaking open cells using ultrasound, microwaves or a homogeniser or by hydrolysing them enzymatically or by pressure cooking. These pre-treatments can also improve the later dewatering and sanitisation of the sludge and the odour of the digestate.

Sometimes other organic wastes are co-digested with the sludge. Denmark, Germany and the Netherlands have made biogas from anaerobic digestion of biomaterials (organic fraction of municipal solid waste, sludge, manure and organic wastes from industry) part of their national energy strategies.

Composting is another type of sludge treatment. It has of course been used for centuries and all gardeners know the value of compost for improving the fertility and workability of soil. Composting is another natural biological process (like biogas

Retail packs of composted sludge in a garden centre (Tim Evans)

production) but this time it is aerobic. Dewatered sludge is too dense for air to move through it so straw, woodchips, sawdust, greenwaste or some other material is added to open up the structure. This 'bulking agent' also provides extra carbon to feed the composting bacteria and balance the nitrogen content of the sludge. Aerobic bacteria feed on this mixture and give off heat which raises the temperature of the compost.

Composting kills pathogens because they cannot tolerate the high temperatures and other conditions in the composting material. The product of composting is crumbly, nutrient-rich brown soil improver.

Experience from the city of Helsinki in Finland shows that gardeners love sludge if

Bio-Vegetal's compost turner (top) and windrows (bottom) with the bagging line shown right. (Tim Evans)

Reedbed (built 1996) treating the sludge from an extended-aeration works serving 42,000 people. Note the proximity of the house. There are no odour complaints (Tim Evans)

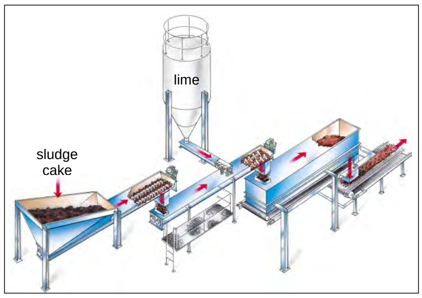
it is available. The Viikinmäki plant (serving 800,000 people) was constructed in underground rock caverns to protect it from Helsinki's cold winter weather. All the sludge is anaerobically digested (with the biogas used for CHP) and then dewatered. The cake (58,000 tonnes/year) is composted with bark and peat. In Finland peat is growing faster than it is extracted.

Composting started in 1982. Each cubic metre of compost is blended with 0.8 kg sand, 15 kg crushed biotite stone (which acts as potassium source) and 15 kg crushed limestone to produce Metsäpirtin Bio-Soil.

Helsinki's gardeners and landscapers buy all the Metsäpirtin Bio-Soil the plant can produce (100,000 m^3/year) for about €17 / m^3. It accounts for 25% of the market for soil improvers in the Helsinki area. Long experience has shown them that they can trust Metsäpirtin Bio-Soil and that it is good for their plants and their soils.

At the opposite (north-south) extremity of Europe, Bio-Vegetal in Bari, Italy composts sludges from wastewater treatment and from food processing with other organic residuals and then granulates it and dries it. The product is sold as granular organic fertiliser that is exported to countries around the Mediterranean and also to Northern Europe where it is valued in glasshouse crop production.

Reedbed treatment of sludge started in the 1980s and has been steadily gaining acceptance. The beds are sealed; they



Schematic of lime stabilisation (RDP)

contain drains set in a bed of aggregate on which reeds are planted. Sludge is applied to the beds in shallow layers in sequence. Odour is contained within the reed canopy, even in winter. The reeds excrete oxygen from their roots which maintains the root zone aerobic. Bacteria initially, and later earthworms, mineralise the sludge and sanitise it. The mineralised sludge builds up in the beds (at about 40%DS). After about 10-15 years the cycle of digging out the beds in rotation is started. This is especially useful for sludge from extended aeration treatment, but it is also suitable for other types of wastewater treatment. Energy and chemical use are very low.

1.6.4 Chemical treatment

Lime stabilisation is practised widely in Europe and other countries. It entails mixing dewatered sludge with quicklime or some quicklime containing additive.

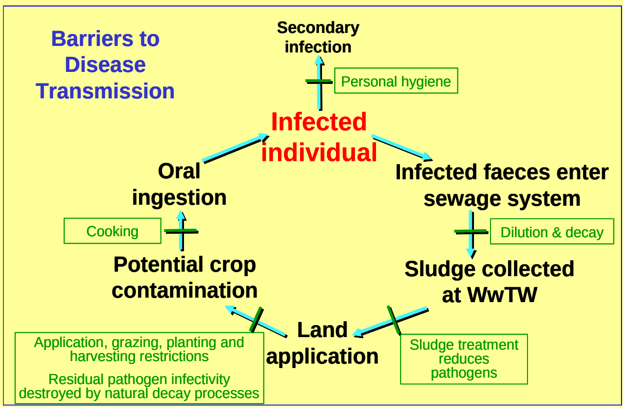
Quicklime has been used to disinfect

Gas-fired rotary sludge dryer (Baker Rullman)

Multiple barriers to transmission of infection from an infected individual

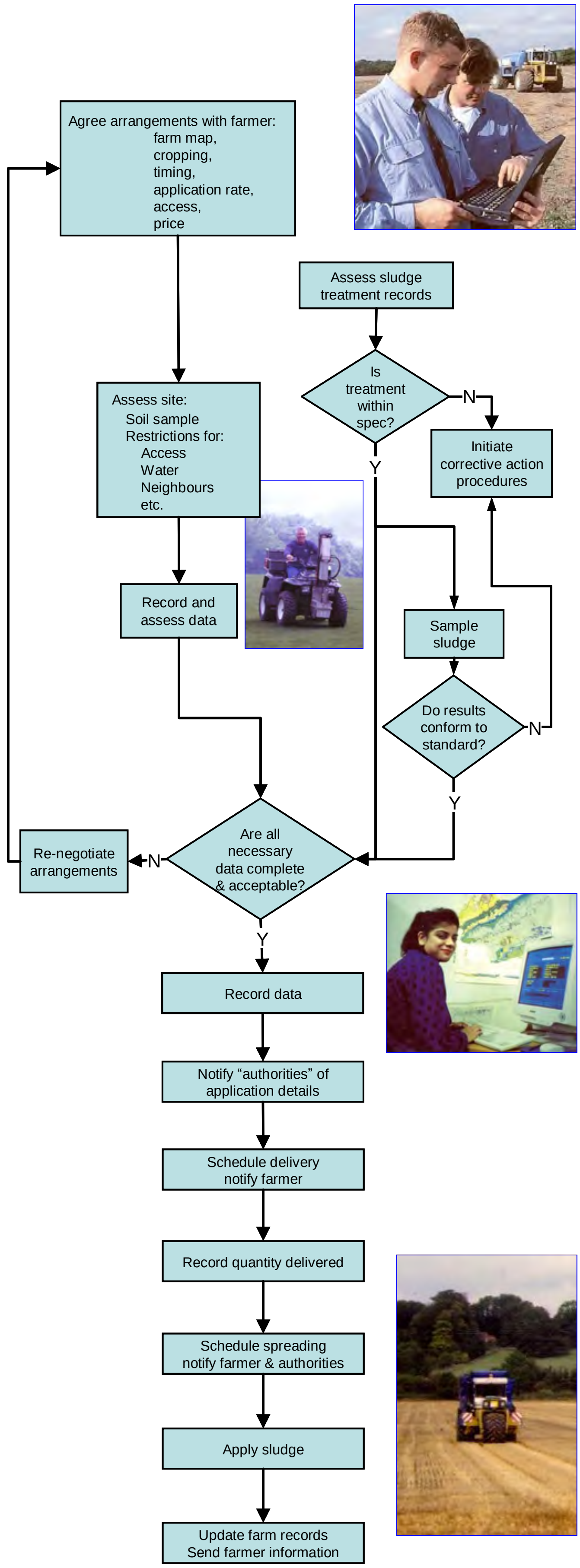
The diagram shows the barriers that prevent disease transmission via sludge use in agriculture. Firstly pathogens die en route to the treatment works and during the treatment process. They are further reduced during sludge treatment. Some types of treatment virtually eliminate pathogens or reduce their numbers to the same as in soil. The sludge directive imposes a further barrier by restricting the types of cropping and the interval between sludge application and harvest or grazing. If sludge is not treated it must be injected or ploughed into the soil as soon as possible. There is further die off between sludge application and harvesting and then there is the sanitising effect of food preparation.

A comprehensive risk assessment (UKWIR, 2003) estimated the worst-case risk when treated (conventional anaerobically digested) sludge is used on farmland with the controls on cropping and harvest intervals. It assumed that because of some error in the process 2% of the sludge by-passed sludge treatment entirely. The worst risk would be one additional infection in a population of 58 million people in 45 years. This was for cryptosporidium; for the other pathogens the risk was less than one additional infection every 10 million years. Personal hygiene (especially hand washing) has been recognised as one of the most important and effective barriers to preventing transfer of infection.



Sludge recycler's decision tree (an example of good practice)

(photos Tim Evans)



materials for centuries. It is limestone that has been burnt in a kiln, which makes it very reactive with water. When quicklime is added to moist dewatered sludge heat is generated and the pH rises (the mixture becomes alkaline), ammonia is liberated these three effects kill pathogens and prevent production of bad-smelling compounds. The high pH prevents reinfection and fermentation. Some of the nitrogen in the sludge is lost during the process. The product is valuable on land as a liming material that also contains phosphorus and other nutrients.

Lime is very useful for agriculture where soils are acid. On neutral soils it should be used with caution to avoid inducing trace element deficiencies. On limestone and chalk soils the lime in the sludge has no benefit, but since the soils are lime-saturated already it is not detrimental either.

Automated solar drying using random path robots to turn the batches of sludge inside the greenhouses.
(Thermo-System GmbH)

1.6.5 Drying

Drying is essentially the evaporation of water (or most of it) from dewatered sludge. In many cases the sludge is digested first and the biogas is used to heat the dryer. Of course, evaporating water requires a lot of energy; this is offset to some extent by reduced haulage costs and has to be evaluated in comparison with all of the other options.

Sludge can be dried by natural evaporation in the open air. This was widely practised in the past and is still appropriate where drying conditions are predictable and land is not too expensive.

Computer controlled greenhouse drying requires a smaller area of land, it is independent of rain or snow and air from the greenhouses can be treated so that there are no odour problems. The greenhouse method uses only 1% of the energy needed for thermal drying.

Desiccation (drying out) and high temperatures kill pathogens. Dried sludge is often granulated (small round particles) or pelleted (small cylinders). This makes it an attractive and clean material that is easy to spread by hand or with fertiliser spreaders. In some places it is available to gardeners. It can also be used as fuel (e.g. electricity generators and cement kilns).

1.6.6 Summary

The amount of sewage sludge produced is related to the quantity of wastewater treated, the extent of the treatment to remove constituents from the wastewater and the type of sludge treatment.

Treated sludge is very different from the untreated starting material. As can be seen from the discussion about wastewater treatment and the origins of sludge, some of it (often as much as

40%) is surplus biomass that grew when micro-organisms fed on the organic matter and nutrients in the wastewater as part of the treatment process.

Treated sludge differs from untreated sludge in colour, odour, chemical characteristics and agronomic behaviour. It can be liquid, semi-solid or dry. To differentiate the treated product from the untreated in the minds of people involved in recycling it, the term 'wastewater biosolids' was coined in 1990 to describe the treated material. Although many have found it helpful to use this term, this guide uses the expression sewage sludge because that is the one used in European legislation.

1.7 Operational aspects of using sludge

The use of sewage sludge on farmland has been the subject of extensive research into both the benefits and the hazards. In the mid-1970s, as knowledge increased, countries introduced controls on how sludge is used. In 1986 the Council of Ministers adopted the **sludge directive** (described earlier).

The directive sets limits for the concentrations of certain trace elements in soil. It requires controls on these regulated elements and on application rates and requires that sludge treatment should reduce health risks and stabilise the sludge. The directive restricts the types of crops that can be grown on sludge treated land in order to provide an additional barrier to manage the risk of disease transmission (this was shown diagramatically earlier).

The directive also permits the use of untreated sludge on land provided it is injected or worked into the soil as quickly as possible.

There are requirements for data recording and for providing data to people whose land is treated with sludge in order that they can make best use of the nutrients and grow appropriate crops.

It is important to be aware of the relevant **national provisions** because they might impose different restrictions and obligations on sludge treatment and application within the framework of the sludge directive.

From the above it can be seen that there are many aspects involved with operating sludge use in agriculture. There is a significant amount of information and data gathering, checking, recording and reporting. For compliance with the directive all of these aspects have to be considered when designing, planning and operating sludge recycling.

Farming is becoming increasingly precise in its use and application of inputs. Recyclers need to be aware of these changes and adapt their practices appropriately. This is partly to make the most cost-effective use of inputs and partly to avoid adverse environmental impacts. There is also the ‘cross compliance’ requirement of the reformed Common Agricultural Policy (CAP) that makes compliance with environmental legislation a condition of eligibility for farm payments (Regulation 1782/2003).

One farming innovation is monitoring the health and condition of crops by satellite imaging to assess when, where and how much fertiliser, pesticide or irrigation is needed.

Farm equipment can be located precisely using signals from global positioning satellites. Harvesters can monitor yields continuously. Thus maps of crop inputs and crop response can be produced. Digital maps of requirements for pesticides and fertilisers can be loaded into the application equipment so that there is precise and spatially appropriate application.

The number of people actively engaged in farming has been decreasing for many years and this is continuing because of low world prices for agricultural commodities. It is therefore more important than ever for sludge recyclers to provide information to their farmer customers about the fertiliser (and lime) replacement value and to ensure that this information is in a format that their customers can understand.

Planning sludge recycling requires a significant amount of information. Recyclers need to know:

- the analytical information about the chemical composition of the soil and the sludge,
- the crops the farmer intends to grow (not forgetting grass, which is a crop too, and set-aside) and hence the type of sludge that will be compatible with this type of farming,
- whether there are any wells or surface water near the application site or ground-water protection zones,
- whether there are gradients or probability of flooding that indicate run-off or surface-water pollution is a risk,
- whether there are footpaths or rights of way crossing the land,
- whether the land is drained with land-drains,
- information about the road access that will be used for delivering the sludge and whether there are any restrictions about its use such as weight limits or social factors such as school traffic.

Quality Assurance (QA) and HACCP

Quality Assurance (QA) revolutionised manufacturing industry and the reliability of its products by formalising procedures in order to ensure that operations were performed correctly every time.

QA was first applied to sludge recycling operations in 1989 by the largest sludge recycler in the UK. The result was 100% auditable compliance with legislation and codes of good practice. Subsequently many others have adopted QA. For example:

- in Germany there is a co-operative QA scheme involving 35,000 farmers and the use of 250,000 t sludge;
- operators in France launched SYPREA in 2002 as a national QA scheme;
- there is an independently accredited QA system in Sweden and
- the National Biosolids Partnership offers EMS with third-party audit in America.

EMS (Environmental Management System) is a type of QA that includes a focus on environmental outcomes. Continual review and continuous improvement are core features of QA. There are international standards for QA (ISO 9000 and ISO 14000); BS 8555 provides a stepwise approach to achieving them.

One of the criticisms of QA is that it makes sure that you do the same thing every time but that if the process has not been designed properly the outcome will be wrong every time. This is not really an entirely fair criticism of QA but a process design paradigm from the food industry provides an ideal complement to QA because it is a structured approach to analysing the hazards that could affect the product. It is called Hazard Analysis and Critical Control Point (HACCP).

HACCP was developed for the USA's manned space programme in the 1960s by the Pillsbury Company. It has subsequently been adopted by the World Health Organisation (WHO), which maintains it, and by most national governments. It is the basis of EU food safety legislation. HACCP is being adopted for drinking water treatment.

The National Aeronautic and Space Administration (NASA) was concerned that with its system of "end-of-pipe" testing it only knew about the safety of the samples of food that it had tested, but this was not the food that was going into space with the astronauts. The HACCP process produced by Pillsbury involves "Critical Control Points" (CCP), through which all of the production passes, that reduce the risk from specific hazards to levels that are acceptable. In the case of food, a CCP to prevent food poisoning might be the cooking step, if all of the food is cooked for a particular time and temperature then biological risk will be controlled provided the food cannot be recontaminated after cooking. By monitoring the cooking time and temperature and ensuring that it does not deviate from the prescribed tolerances (called the Critical Limits) one can be sure that risk in all of the food will have been controlled. The records of the operating conditions of the CCPs provide auditable records that risk has been controlled.

HACCP also requires that "Corrective Action" procedures are designed in advance to cope with occasions when something goes wrong, such as equipment breakdown. When a HACCP plan is first implemented it is validated to ensure that it is effective. End-of-pipe testing becomes mere verification that the CCPs are operating correctly instead of the sole means of control.

HACCP does not mean that every kitchen has to cook food at the same temperature, it allows innovation and solutions that are appropriate to the particular circumstance. The main thing is that it does not matter whether it is established technology, or a unique new approach, it has to be verifiably effective and traceable and plans have to have been made for the inevitable occasion when something does not go right.

Sludge application techniques

(Kreisstadt der Landkreises Waldeck-Frankenberg)

Liquid sludge can be applied using conventional tractor liquid-manure tanker equipment. Delivering sludge to the application tractor by flexible pipe is efficient and means that it does not have to return to fill up. Sub-surface injection puts the sludge below the surface which means that any odours and all the nutrients are captured. By using a mobile field-storage tank into which road tankers deliver maintains their efficiency.

(B.P.McKeefry)

(Schwalm-Eder-Kreis machinery ring)

(Ag-Chem self-propelled injector with GPS nutrient management mapping)

Application booms with drop hoses place the liquid sludge on the ground, reducing ammonia and odour losses.

Dewatered, composted and limed sludges are spread with manure-type equipment. Flotation tyres reduce soil compaction. On-board weighing can indicate application rates accurately.

(Agrivert)

Containing a stockpile with an air-beam roller stockpile cover keeps out rain, prevents loss of structure, runoff and odour.

(Tim Evans)

Failure to account for these could jeopardise a farmer's payment under the CAP.

The best way to cope with all of this information is by using a computer database, preferably with a mapping system so that everybody has access to the most up to date information. It is also advisable to have some sort of system to assure that all of the requirements are undertaken.

Quality Assurance (QA) is a management system that was developed to improve the reliability of manufactured products. A motto of QA is 'right first time, every time' and this really encapsulates the essence of QA. Processes in the manufacturing chain are analysed and then described and documented so that each person performs the task in the same way and does not forget any particular element. It also ensures that there is a record to demonstrate that the work has been performed. It is traceable and auditable. This is very important, especially in today's 'culture of suspicion'.

One of the outcomes of discussing sludge recycling with the food industry in the UK was that operators adopted **HACCP** (Hazard Analysis and Critical Control Point) voluntarily. HACCP is maintained by a committee of the World Health Organisation; it is the basis on food legislation in most developed countries. It can be applied to the whole sludge process from the control of pollution at source right through to the treatment of land and growth of crops. Use of HACCP means that sludge recyclers are talking the same language as the food industry. If farmers are required to apply HACCP (as seems likely) it will be easier for them to use sludge if it is from a recycler operating under HACCP. There are international moves to make HACCP the basis for drinking water treatment.

Application rates are commonly set according to a crop's needs for nutrients. The control of inputs of pollutants to sludge has been so successful that these rarely, if ever, limit application. When the application rate is set according to nitrogen it would be the needs of the next crop (i.e. the one following application). When the application rate is set according to phosphate it is normal agricultural practice to supply two, three or even five years' requirements in a single application. This is provided the sludge application rate is within other restrictions, which vary between countries.

Several countries have closed periods during the year when organic resources cannot be applied to land. These restrictions are aimed primarily at minimising the risk of nitrate leaching (and also phosphate in some countries) over the autumn and winter. They are related to the local soil, climate and water-protection issues.

As has been described under Methods of Treatment sludge can be treated so that it does not smell unacceptable. Nearly everything smells of something but if sludge has a smell that is clinging, persistent and obnoxious it is very likely to generate complaints. Provided the odour is tolerable surveys have found most people consider sludge recycling is part of sustainable development and better than most of the alternatives. Experience shows that if there is opposition to sludge recycling the root cause is almost invariably **odour**. It is difficult to regulate odour legally but it is easy to judge whether or not it is acceptable by keeping records of complaints.

Other industries have found that although compliance with legal obligations is essential, it is not enough. Other steps in the journey to sustainability are public trust followed by resource recovery, use of renewable resources, improved stewardship, clean technology and inherently safer products and processes. They have also found that going beyond legal compliance like this makes good business sense. Building public trust requires openness and sharing information using leaflets, the web, open days, etc.

When **liquid sludges** are to be applied to land they are usually delivered by road tankers to a transportable holding tank from which the application equipment works. If the viscosity of the sludge is low enough that it can be pumped long distances (typically about 1 km) the most efficient method of application is for the tractor to be supplied continuously by a hose (called an umbilical) from the holding tank. However if the sludge is viscous a tanker applicator is required. This means more travelling across the field which could result in damage to soil structure but this can be avoided by stopping work when soil is excessively wet and by using low ground-pressure tyres.

Dewatered, lime-stabilised and composted sludges are generally delivered as bulk materials and stacked on the farm before application. Sometimes they are delivered and spread without stacking. It is important that these stacks are sited carefully so that they are not at risk of being flooded or of moving and causing pollution. Many people consider it is good practice to use an excavator to shape stockpiles so that they are tidy and occupy the minimum area.

Many countries have a legal requirement that when sludge is stored on a farmer's field, awaiting application, it is secure and contained such that it cannot escape and members of the public do not have access to it.

If necessary there should be warning signs at delivery sites, out of consideration for the safety of other road-users, warning them of possible obstructions from turning or parked vehicles. There should also be facilities for removing mud and for cleaning up any spillage of sludge. People engaged in the work should have access to washing facilities in case of accidental contact with sludge and for use prior to work breaks, etc. This is good practice to avoid excessive occupational exposure.

1.8 Features and Benefits

Sludge contains organic matter and plant nutrients. Victor Hugo was eloquent about the wisdom of using this resource (see box). Organic matter is literally the vital ingredient of fertile soil because it provides a reserve of nutrients and water for plants; vital because it feeds the life in the soil. There are more species of organisms in soil (more biodiversity) than there are on the surface.

The European Commission has recognised the importance of soil organic matter in COM(2002)179 'Towards a Thematic Strategy for Soil Protection'. Preventing and reversing loss of soil organic matter is one of the main themes.

Organic matter is the glue that sticks tiny soil particles together into larger crumbs, which makes soil friable and crumbly. A friable, well-structured soil is also less prone to erosion by wind or water. It is easier for plant roots to grow through friable soil. A plant with a restricted root system will be more prone to drought in dry weather and to nutrient deficiency because it has access to a smaller volume of soil.

Rainfall soaks into friable soil easier and the excess water drains away easier as well. If soil is compacted it is more difficult for water to drain and for roots to penetrate. If there is a gradient and rainwater cannot soak into soil it runs across the surface, and erodes it, carrying soil with it.

Good soil structure in the farmland is also important to the downstream urban communities because it lessens the speed and quantity of water discharged to surface waters and thus the risk of flooding.

Soil organic matter is therefore incredibly important to the health of soil. It is also very important to watercourses because it stops soil erosion. Eroded soil is very harmful to the health of watercourses because the nutrients from eroded soil cause eutrophication and the mud upsets ecosystems including damaging spawning grounds for fish.

Sludge recycling is a way of returning organic matter to soil. Increasing soil organic matter results in 'carbon-sequestration', which is a component of reducing greenhouse gas emissions and climate change.

Farmer Nigel Lawrence in South Oxfordshire, England discovered just how important it is to maintain soil organic matter when he took on land that had been farmed with continuous cereals for many years with negligible inputs. He said, after it had been treated with lagoon-thickened liquid digested sludge, "The soil is now more alive and earthworm populations have quadrupled."

"Before we treated this land, few seagulls

Nigel Lawrence showing the improvement in his soil (Tim Evans)

Comparison of spring wheat top-dressed with sludge (left) and 'conventionally grown (right). The ears on the right are smaller (lower yield) and they also have dark sooty fungus. (Tim Evans)

Farmer Nigel Lawrence's inputs and yields using sludge growing Kira winter barley

		Without sludge	With sludge
Inputs			
Seedbed fertiliser	€/ha	22.23	0.00
N-topdressing	€/ha	64.98	14.70
Herbicide	€/ha	30.48	30.48
Fungicide	€/ha	29.64	21.23
Total	€/ha	147.33	66.41
Saving	€/ha		80.92
Grain yield	t/ha	5.00	5.40

From Les Miserables by Victor Hugo - 1862*

Science, after having long groped about, now knows that the most fecundating and the most efficacious of fertilisers is human manure. The Chinese, let us confess it to our shame, knew it before us. Not a Chinese peasant goes to town without bringing back with him, at the two extremities of his bamboo pole, two full buckets of what we designate as filth. Thanks to human dung, the earth in China is still as young as in the days of Abraham. Chinese wheat yields a hundred fold of the seed. There is no guano comparable in fertility with the detritus of a capital. A great city is the most mighty of dung-makers. Certain success would attend the experiment of employing the city to manure the plain. If our gold is manure, our manure, on the other hand, is gold.

What is done with this golden manure? It is swept into the abyss.

Fleets of vessels are despatched, at great expense, to collect the dung of petrels and penguins at the South Pole, and the incalculable element of opulence which we have on hand, we send to the sea. All the human and animal manure which the world wastes, restored to the land instead of being cast into the water, would suffice to nourish the world.

Those heaps of filth at the gate-posts, those tumbrils of mud which jolt through the street by night, those terrible casks of the street department, those fetid drippings of subterranean mire, which the pavements hide from you,--do you know what they are? They are the meadow in flower, the green grass, wild thyme, thyme and sage, they are game, they are cattle, they are the satisfied bellows of great oxen in the evening, they are perfumed hay, they are golden wheat, they are the bread on your table, they are the warm blood in your veins, they are health, they are joy, they are life. This is the will of that mysterious creation which is transformation on earth and transfiguration in heaven.

Restore this to the great crucible; your abundance will flow forth from it. The nutrition of the plains furnishes the nourishment of men.

* from:
Book Second. The Intestine Of The Leviathan.
Chapter I The Land Impoverished By The Sea.
trans. Isabel F. Hapgood, May, 1994 [Etext #135]
http://www.ibiblio.org/gutenberg/etext94/lesms10.txt
The Project Gutenberg

or rooks bothered to follow the plough. Now there are so many it is sometimes difficult to see the work from the tractor seat. The increased fertility has allowed us to alter our cropping programme. Now, instead of growing spring cereals and harvesting less than 2½ tonnes/hectare, we can combine up to 8 t/ha of winter corn."

He also said "Where we have treated [with sludge] we have harvested some amazing crops that have stood up well without growth regulators, have been disease free, and have yielded as well as, if not better than, those given 175 kg/ha of nitrogen top-dressing."

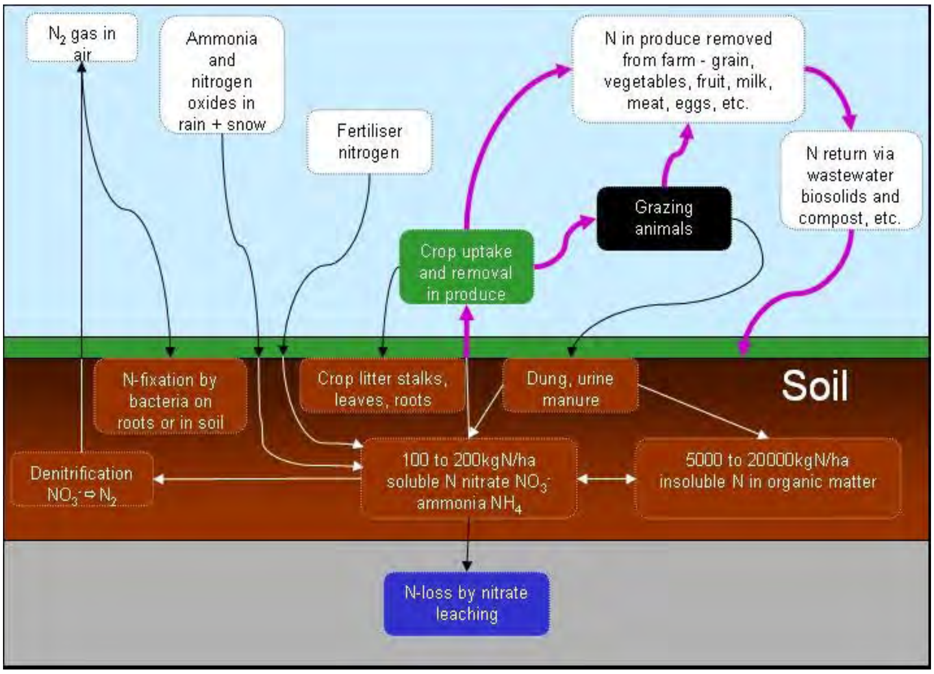
Discussing a typical field growing Kira winter barley he said "The treated crop had no seedbed fertiliser, the cost of top-dressing was cut to just €14.70 /ha and it required one less fungicide application ... the margin increased by almost 22%."

1.8.1

1.8.2 Plant nutrients, the basics

Plants need many chemical elements and water, sunlight and carbon dioxide. They can only absorb the chemical nutrients from soil if they are dissolved in water, they cannot eat solid soil or manure.

Justus von Leibig showed (see box) that plant growth is determined by many factors and their overall performance is restricted to that which is allowed by the most limiting factor. In terms of nutrients, they require nitrogen N, phosphorus P, potassium K (these are called the major nutrients) sulphur S, calcium Ca, magnesium Mg (these are called the secondary nutrients) and iron Fe, boron B, manganese Mn, copper Cu, molybdenum Mo, chlorine Cl and zinc Zn (micronutrients). In addition to these, animals also need chromium Cr, sodium Na, selenium Se, arsenic As. Some plants need silicon Si to increase the rigidity of their stems and leaves. In addition some plants and animals need other trace elements. Plants also need adequate light, temperature, water, oxygen at the roots and carbon dioxide at the leaves and support from the soil so that they do not fall over.



The nitrogen cycle

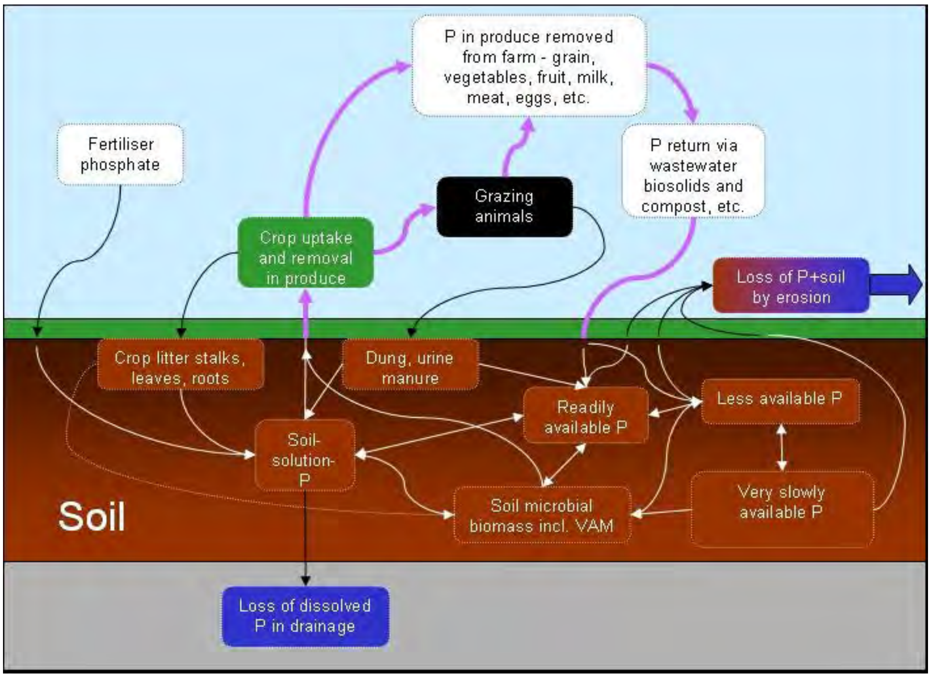
The pH of the soil has a strong influence on the availability of the different elements to plants, for example increasing the pH of soil could induce iron deficiency but correct magnesium deficiency. It is especially important to recognise this agronomic aspect when using lime stabilised sludge because trace element deficiencies or toxicities to plants or animals can be induced by changing the balance of trace elements. Copper (Cu) and molybdenum (Mo) are a well known case; if the pH of a soil with a large concentration of Mo and small concentration of Cu is raised, the Cu:Mo ratio in herbage could cause 'molybdenosis' (scouring and loss of condition) in grazing animals. The soils where trace element issues are likely are generally well known to agronomists because liming is a well established agricultural practice and if in doubt their advice should be sought.

Plant nutrients undergo many transformations in soil as can be seen from the nitrogen and phosphate cycles.

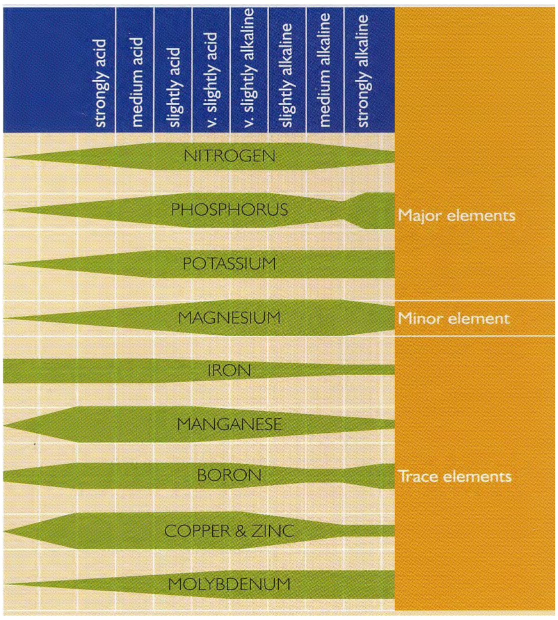
Soil microbial activity is critically important in affecting the transformation from one form of nitrogen to another. Plants need nitrogen to make protein, which is one of the building blocks of life, but they can only use certain forms of nitrogen. Air contains about 80% nitrogen but plants cannot use it. They can only absorb nitrogen as nitrate, or less commonly ammonium; they cannot differentiate where this nitrate or ammonia came from originally (fertiliser, manure, sludge, etc.). Some soil bacteria can fix nitrogen from the air and convert it to nitrate, which plants can use, some mineralise organic-N to ammonia and others nitrify ammonia to nitrate. If there are zones in soil from which air is excluded (anaerobic soil) bacteria convert nitrate to nitrogen gas, which is lost.

Nitrate is much more prone to leach (percolation down through the soil and loss in drainage) than phosphate which is more prone to be lost by erosion attached to soil particles. Clearly it is important that the microbial life in soil is healthy. As Nigel Lawrence and other farmers have found, sludges feed the life in soil.

The diagram of the nitrogen cycle shows a 'pool' of soluble nitrogen (100-200 kg/ha) this is fed from mineralization of organic nitrogen (5,000-20,000 kg/ha), from soluble fertiliser and from ammonia



The phosphate cycle



Generalised representation of the influence of soil pH on the availability of different nutrients to plants

and nitrate in rain. Plants absorb N from this soluble pool, but it can also be lost by leaching or denitrification.

Decaying plant remains (leaf fall, roots and stems after harvest, etc.) add to the organic matter. Nitrogen is mineralised in the warm soil after harvest and will be lost in the winter rains unless it is 'captured' by an autumn-sown crop.

When the pool of soluble-N is boosted with mineral fertiliser plants respond quickly (the crop colour changes to a rich green). This new growth is soft and easily attacked by plant diseases. By contrast the gradual release of soluble-N from sludge feeds plants continuously; the surfaces of the leaves etc. are tougher and less susceptible to infection.

The phosphate cycle shows why it can be difficult to raise the phosphate status of deficient soils with fertiliser because the soluble-P moves through to the 'very slowly available' pool. Sludge is very effective at raising the P-status of soil, presumably because the P is protected from rapid transfer to the very slowly available pool.

The phosphate cycle diagram shows 'VAM', this refers to thread-like fungi (vesicular arbuscular mycorrhizal fungi) that infect plant roots. VAM and plants have a mutually beneficial relationship. The plant supplies the VAM with food and the VAM scavenges P from the soil and transports it to plants' roots. VAM can also be important in supplying water. Sugar beet is one of the few crops for which a mycorrhizal association has not been found. VAM acts like an extension of a plant's roots.

Response of oilseed rape to sulphur fertiliser (left) (Rothamsted Research)

It should be clear from the examples of the nitrogen and phosphate cycles that plants are only able to use a part of the total content of either of these nutrients. The same is true of the other nutrients but some of the reserves and transformations are different.

Sulphur (S) became a limiting factor for agricultural crops towards the end of the 20th century as a result of reducing sulphur emissions from power stations and other combustion processes. This was first observed in countries such as Ireland and Norway whose prevailing airflow from the Atlantic was least enriched with S. In addition the S-concentration of fertilisers has reduced and S-deficiency became widespread.

Sulphur (S) has become a nutrient of great interest to farmers in many areas of Europe. It is an essential constituent of proteins. Sulphur supply from organic resources is inversely related to the carbon:sulphur ratio and, since digestion reduces this ratio, digested sludge is a good source of S. The S-cycle is similar to the N-cycle, except that there is little or no loss to atmosphere. Plants absorb S as sulphate, which is leachable like nitrate but to a slightly lesser extent. The most reliable method for assessing S-supply is plant-tissue analysis. Special S-containing fertilisers have been formulated.

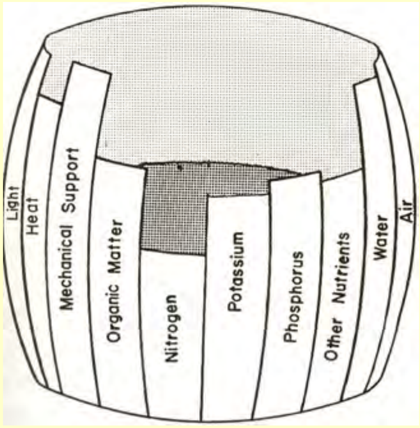
1.8.3 Plant nutrition applied to sludge recycling

It is important that sludge recyclers understand the basics of fertiliser advice and the fertiliser replacement value of their particular sludge(s). Then they can advise

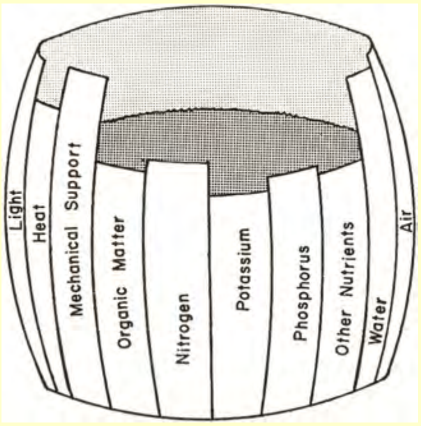
Leibig's principle

In the nineteenth century the famous German chemist Justus von Leibig (1803-1873) propounded the concept of limiting principles. This is that the amount of biomass that can grow is determined by whichever of the essential requirements for life is most limiting.

The concept can be illustrated by a barrel with staves of unequal length, each representing a principle requirement of growth. The amount of water in the barrel represents the biomass yield.



In the upper barrel nitrogen is the limiting principle i.e. water overflows this stave; this is the maximum amount of biomass that can be grown with this combination of conditions. The limiting element could have been another nutrient (including a trace element) or water, or light, etc.



By adding fertiliser-N the height if the N-stave is raised and then the capacity becomes limited by the height of the potassium stave (lower barrel).

From this it should be apparent that all of the principles for growth need to be adequate in order to maximise growth up to the genetic potential of the crop. In fact, on sludge treated land, if there is a limiting element it is almost invariably potassium because sludge contains everything else except potassium because potassium is so soluble that it stays in the water rather than the sludge.

Comparison of amounts of nutrients removed by different corps

	DM	N	P_2O_5	K_2O	CaO	MgO	SO_3	Fe	Mn	Cu	B	Zn	Mo
		kg/tonne dry matter						g/tonne dry matter					
Cereal-grain	85%	20.0	9.2	6.7	0.8	2.5	3.8	47	29	5	1	29	0.4
Cereal-straw	85%	7.1	0.8	8.0	4.9	0.9	1.1	47	71	3	7	18	0.4
Sugar beet - roots	22%	39	1.4	8.2	3.8	0.9	1.8	91	32	5	14	18	0.5
Sugar beet - tops	16%	20	3.1	30	12	5.0	3.8	190	50	6	38	19	0.6
Potato - tubers	22%	14	1.8	22	1.3	0.9	1.3	18	18	9	3	18	0.2
Oilseed rape	92%	36	7.6	9.8	5.6	2.5	9.8						
Grass-silage	20%	32	3.0	20	8.4	1.5	1.5	150	100	10	10	50	1.5
Grass - hay	85%	17	3.1	7.6	5.6	1.2	1.2	140	150	7	8	47	2.4
Kale	15%	24	3.3	28	30	2.0	6.0	33	67	7	33	33	1.3
Average		19.6	3.7	16.7	7.9	1.9	3.4	89	65	6	14	29	0.9
Minimum		7.1	0.8	6.7	0.8	0.9	1.1	18	18	3	1	18	0.2
Maximum		35.9	9.2	30.0	30.0	25.0	9.8	190	150	10	38	50	2.4
Dewatered digested sludge	25%	50	60	3.6	39	7.7	2.8	14000	400	400	85	500	2

The table (left) shows the approximate amounts of nutrients removed in crops per tonne of dry matter.

The yields of these crops are very different, for example the yield of oilseed rape might be 2.5 tDM/ha, cereal grain 8 tDM/ha and potatoes 12 tDM/ha. At these yields and if the straw were incorporated back into the soil, oilseed rape would remove 25 kgP2O5/ha, cereal 74 kgP2O5/ha and potatoes 22 kgP2O5/ ha.

The table also shows indicative analyses of dewatered digested sludge but these are totals, the proportion available to plants will depend on the time of year of application, the type of soil and the climate.

It should be clear from this table that no single fertiliser can supply all of the nutrients for every crop. Sludge, manure, etc. can provide a base that should be supplemented with the right amount of mineral fertiliser

their customers how to make the best use of the nutrients that are being applied to their land; with good advice, their farmer customers will be confident about the amount of complementary mineral fertiliser to use to provide optimum nutrition for their crops. This is good for the customers and good for the environment.

In most countries in Europe fertiliser nutrients are expressed as oxides (e.g. P_2O_5, K_2O), in others they are expressed as elements (e.g. P, K) even though neither is their real chemical form. The reason is historic. To avoid confusion it is important to use the format that farmers understand locally.

The easiest way to estimate the nitrogen-fertiliser (N) replacement value of sludge is to consider it as a combination of inorganic-N and proportion of the organic-N. In the cooler soils of northern Europe about 10-20% of the organic nitrogen is mineralised in the first year, but more is mineralised in southern Europe (about 60% in Costa Brave, Spain) because of the higher soil temperatures. In most sludges the inorganic-N is ammonia, this is 100%

Aerial view of field trials:

Different application times on grass/ clover (left) an arable rotation of winter wheat, spring barley and break (centre) and a long term trial to test the validity of the limits for trace elements (right). Soil microbiology was studied on all treatments. (Tim Evans)

available to plants when it is applied, but some might be lost into the air if it is surface applied. Compost is the only form of sludge likely to contain nitrate. Ammonia is attracted to soil minerals and therefore does not leach easily.

As the nitrogen cycle shows, soil bacteria 'mineralise' the organic-N to ammonia and other bacteria 'nitrify' ammonia to nitrate (when the temperature is above about 4ºC). These conversions are faster at warmer temperatures (in fact there is a nice time-temperature relationship). Gradual release sludge-nitrogen has agronomic advantages.

In the first year after sludge application a proportion of the organic-N becomes available to plants, depending on the type of sludge and the climate. N-mineralisation and plant growth both respond to temperature so as soil warms up the plants start to grow and bacteria mineralise organic-N. It is often forgotten that topsoil contains 5,000-20,000 kgN_{org}/ha in the ‘stable’ organic matter.

People sometimes think that sludge-N is less predictable than fertiliser-N but they forget that a) fertiliser-N is just as prone to loss by leaching if there is heavy rain following application and b) that the fertiliser recommendations that we use are averages from many years of field experiments for the very reason that field experiments have a spread of results due to variations of weather and soil.

One difference between fertiliser-N and sludge is that fertiliser-N can be applied in split dressings according to the growth stage of the crop but there is still the risk of rain washing out nitrate. There is a surge of soft growth after fertiliser-N is applied; this soft growth is more susceptible to attack by pests and diseases.

Several years of field experiments have shown that sludge-N is reliable and predictable. Recyclers need to do field trials for their own sludge(s) in their own climatic area in order to benchmark the results into established fertiliser recommendations.

The precision farming innovations of using chlorophyll-sensors (greenness) and leaf-area index (density of crop) to gauge N requirements are equally applicable for mineral fertiliser and sludge. It is a more precise alternative to using the average from a succession of field trials.

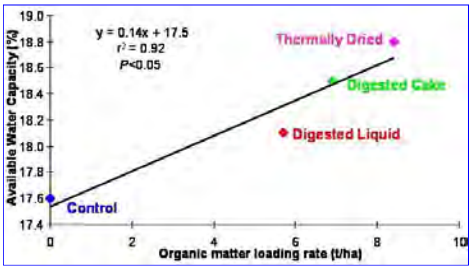
Of the different types, anaerobically digested sludge generally has the most N-fertiliser replacement value followed by thermally dried sludge. It seems that the high temperature during drying increases the availability of some of the organic N. In hot climates the mineralization rate of aerobic sludges can make them good sources on N as well. Lime-stabilised and composted sludges have relatively low N-fertiliser replacement values.

Sludges have a proportionately high content of phosphate (P) compared with crop offtake (see box comparing the amounts of nutrients removed by different crops), but it is not all available. Approximately 35% of the P in digested, composted and lime-stabilised sludge is available in the first year but thermal drying seems to convert P into forms that are only very slowly available.

The phosphate industry estimates that at the current rate of exploitation, the life of the economic reserves of P is only 100 years. P is essential for life; it is part of DNA and there is no substitute for this function. Conservation of primary resources is a key part of sustainable development; this is especially urgent in the case of P and is an additional reason for recycling sludge and manure.

Since the late 1990s there has been a trend for sludge to contain more P because of requirements for works to remove P from the treated water (and concentrate it in the sludge) and also because in some areas P is added to drinking water supplies to reduce 'plumbosolvency' (dissolution of lead) from old supply pipes in customers' premises.

Potassium (K) is the major nutrient that is least abundant in most sludges. This is because it is so soluble that it remains in



Soil structure improvement—increase in AWC with increasing sludge applied (ADAS Gleadthorpe)

the water all the way through treatment. Farm animal manure and slurry are rich in K because they are the total combined dung and urine and they have not been 'washed' with water. The most common exceptions are composted sludge if K comes from the bulking agent and some types of lime-stabilised sludge if they are made using alkaline additive containing K such as kiln dust from cement works or wood ash. However, even digested sludge provides enough K to maintain soils that already have a moderate K-status.

K is the least expensive of the major nutrients but it is essential that the K-status is not neglected when sludge is used otherwise it could become the limiting factor. Soil tests are good predictors of K-status but for some reason it is the neglected nutrient. It makes sense to keep an eye on K inputs and outputs and to do soil tests for P, K, Mg and pH every 4 years or thereabouts (for example cutting grass for silage, etc. removes a lot of K).

Sludge provides enough magnesium (Mg) to maintain the Mg-status of soil and even to gradually increase it. Sludge also takes care of the sulphur requirements of crops.

Since part of sludge is derived from plant and other food material, it is not surprising that it contains all of the trace elements needed by plants, animals and humans. Sometimes the crop response from sludge is remarkable and this is probably because it has provided a trace element that was a limiting factor unbeknown to the farmer. Plants, like humans, need the correct balance of nutrients. Some of these nutrient elements are also potential pollutants if they are available in excessive quantities.

Correcting a previously undiagnosed micronutrient deficiency (as well as response to the major nutrients, etc.) was probably the case that caused farmer Eric Mew to say “We've never grown such good maize at Hall Barn Estate before.” The two pictures (below) were taken on the same day and in the same field but only the end of the field shown right had been treated with liquid digested sludge, the end on the left was the same maize variety but grown with the conventional fertiliser. The soil was gravelly and the maize on the left was very likely to have been limited by a restricted supply of zinc.

Lime-stabilised sludge is an excellent alternative to agricultural lime because it also supplies seedbed fertiliser requirements. It can be considered to be a fortified lime, or lime-plus, which is the name that some people give to this type of sludge.

Organic matter is good for soil. As farmer David Harvey (550 ha arable and grass near Stansted Airport in England) says “There's no doubt that our soils are getting better [through using sludge]. In the end it's the fertility of the soil that is the key to profitable farming. ... We have discovered that [sludge] allows us to manipulate the second wheat so it will yield about the same as a first wheat but at much lower cost of mineral fertiliser”. When wheat is grown directly after wheat the yield of the second wheat is normally lower because its roots are attacked by a soil borne fungus called Take-All. Sludge applied after harvesting the first wheat

Dramatic response of maize (right) to lagooned liquid digested biosolids at Hall Barn Estate (Keith Panter)

Trace elements—essential minor nutrient and potentially toxic element

Copper (Cu) is a good example of an essential micronutrient that is also a potentially toxic trace element. About 95 million hectares of Europe's soils are types that are potentially low in available copper. Copper-enriched mineral fertilisers, or copper containing trace element sprays are used routinely to correct this mineral deficiency in crops and copper supplements are provided to farm animals. Thus it is important to recognise the potential benefits of trace elements and balance them with the possible negative effects—seeking ever lower concentrations of copper in sludge is not necessarily worthwhile.

Relative susceptibility of selected crops to copper deficiency

Highly susceptible crops				
Carrot	Citrus	Lettuce	Lucerne	Oats
Onion	Table beet	Spinach	Rice	Wheat
Moderately susceptible crops				
Apples	Barley	Broccoli	Cabbage	Celery
Clover	Grapes	Maize	Pears	Radish
Turnip	Sugar beet	Tomato	Triticale	Stone fruit
Least susceptible crops				
Beans	Asparagus	Lupin	Grass	Peas
Rape	Soybean	Rye		

The soils at risk of copper deficiency are sandy soils where there is little copper in the parent material and calcareous soils and organic soils where the copper is bound in the soil in forms that are unavailable to plants.

Soil analysis is an unreliable guide to copper supply for crops because there is a seasonal/climatic interaction. Plant-tissue analysis is the only reliable guide. By the time that visible symptoms are seen it might be too late to take corrective action. Therefore it is really a matter of knowing the soil and the crops.

Although grass is listed with the crops that are least susceptible to copper deficiency, the requirement of animals consuming the grass should also be considered. The copper concentration in grass might be deficient for the diet of animals even if it is not limiting the growth of the grass. In addition there is an interaction between Cu and molybdenum (Mo) in animal nutrition; animals need more Cu where there is excess Mo.

Case study – Historic application of sludge and its effects

In the area where London's Heathrow Airport now stands there used to be farms producing fruit, salads and vegetables for the London market. In 1935 a sludge treatment site was built that received digested sludge by pipeline from Mogden treatment works 11 km closer to London. It thickened the digested sludge by long-term lagooning and dried it on drying beds. Mogden served 1½ million people and industry. When the area was farms, the sludge treatment site was in the middle of its customers. For 40 years farmers considered this a very important source of fertility.

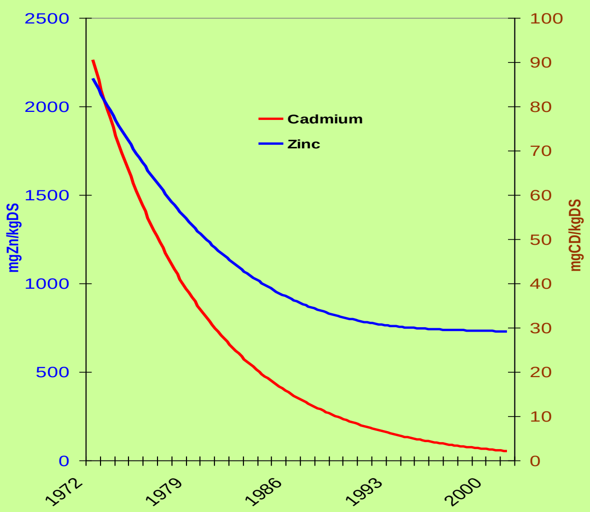
By the 1970s analytical techniques enabled measurement of trace quantities of metals in soils and discussion of acceptable concentrations. The use of sludge on this land stopped in 1976 because the concentrations of some elements in the soil were found to exceed these 'acceptable' concentrations, sometimes by 10-times.

The extent of source control had been limited (as shown by the graph) and application rates were very high (as the pictures show). The farmers ate the produce they grew; they were therefore the most exposed individuals. The government undertook a detailed study of the farmers and their families but did not find any adverse effects that could be attributed to the prolonged use of "contaminated" sludge and soil concentrations considerably in excess of those now in the EU directive (86/278/EEC).

(Tim Evans)

The sludge composition and the application technique would not be allowed now but the inability to measure adverse health effects does demonstrate the wide safety margin that there is in today's rules protecting human health from excessive intake of chemicals via fruit, salads and vegetables.

If we calculate the number of applications of sludge at today's chemical composition and typical application rate, it would take about more than 4,000 applications to bring about the change in soil composition seen on these fields. At an average use of one year in five this would take 20,000 years of today's sludge.



improved the soil and led to much better root development and less Take-All.

A long-term trial with sludge was established in 1994 at nine sites in England, Scotland and Wales to give a range of climates and soil types; it is continuing. The purpose was mainly to look at hazards and risks but the opportunity was taken to test for effects on soil structure at the same time. One measurable effect has been a significant increase in water infiltration. This means there is less risk of flooding, runoff or soil erosion and soil warms up more quickly in the spring. An increase in soil shear-strength was also measured at these sites, which denotes improved soil structure. This improvement in soil structure is the reason for the improved water infiltration rate and for a measured improvement in available water capacity (AWC). An extra 0.5% AWC would yield an extra 0.75 t/ha potatoes (worth €95) or 0.4 t/ha carrots (worth €55) or 0.02 t/ha cereals (worth €3).

Charles Darwin (1881) described earthworms as 'nature's ploughmen', he estimated that the annual production of worm casts in an English pasture was equivalent to a soil layer 5 mm deep being deposited annually. When it is considered that deep burrowing species commonly go down to 1 m deep and can penetrate as deep as 2.5 m it is clear that they are very important in cycling and distributing materials around the soil profile.

Sludge increases the number and size of earthworms. Sludge has been measured to create conditions favourable for deep burrowing species where previously there was only a small population of surface working worms. In addition to cycling material, earthworms create channels for water, air and for roots to grow through.

Henry du Val de Beaulieu farms 650 ha of arable crops near Andover in England with only one employee. They use minimal cultivation. Speed and efficiency are of the essence. "We would never revert to the plough. The soil structure has improved incredibly with minimal tillage, aided immensely by addition of organic matter from sludge ... which has improved the water holding capacity and soil structure." "The autumn nitrogen and increased microbial activity from sludge cake assists with rapid breakdown and incorporation of stubble straw. Spring barley consistently achieved ultra-low nitrogen needed for malting and in many instances the quality was better with brighter, bolder grains."

1.9 Hazards and Risks

1.9.1 Introduction

Essentially there are three different bases on which regulation can be set:

i) Risk Assessment

ii) The best that can be achieved

iii) No net accumulation

It is a political choice which of these is used.

Risk assessment is the most intellectually challenging; it means constructing 'source-pathway-receptor' models and if necessary undertaking research to fill gaps in knowledge.

The difficulty with 'the best that can be achieved' is that it changes with time. If regulators keep changing limits it might suggest that they were wrong the first time, which does not give the public confidence.

No net accumulation is just a matter of arithmetic. In the case of soil protection it means not adding more than crops will remove, but this ignores the immobilisation reactions in soil.

1.9.2 Inorganic hazards

Inorganic potential pollutants (metals e.g. zinc, copper, nickel, cadmium, lead and mercury) have a longer residence in soil than organic micropollutants or pathogens, because they do not degrade or die and they only move very slowly down through soil in drainage water (geological rather than human time). The reason that leaching is so slow is because these inorganic trace elements are sorbed (bound) by soil. This sorption also means that only a small proportion of the total amount of a trace element is available to plants. When trace elements are added to soil in sludge they are bound to the organic matter in the sludge; later they gradually equilibrate with the minerals and organic matter present in soil. Even the non-organic fraction of soil is dynamic and on a microscopic scale parts of some minerals dissolve and other minerals and gels form. Trace elements become occluded [deeply buried] within these gels and growing minerals.

There is now good evidence to refute the old simplistic idea that metals might become more available to plants when the organic fraction of sludge decays. Metals tend to become less available to plants over time because of the dynamic nature of soil chemistry.

One of the consequences of this dynamic inorganic chemistry with its complex reactions and transformations is that the sorption capacity of soil is finite at any particular time. It is rather slow by human time but very rapid by geological time. When undertaking field experiments into the risks of long term accumulation of potential pollutants they are generally added in quantities that exceed those permitted by the sludge directive (86/278/EEC). Because of 'swamping' the sorption chemistry, the outcome might not be representative of the situation where loading rates are controlled according to the sludge directive. It is at best a worst case. The latest field experiments (even though loadings exceeded 86/278/EEC) confirm the safety of the soil concentration limits in the sludge directive.

The agencies that manage the wastewater collection systems have achieved great reductions in the concentrations of inorganic potential pollutants by working with industries to prevent discharges to the sewers.

1.9.3 Organic hazards

Fewer than 200 of the total 150,000 potential organic micropollutants are likely to be found in sludge and there is little or no scientific evidence that any needs to be regulated to protect human, plant, animal or soil health when sludge is used in agriculture according to the sludge directive (86/278/EEC).

The key question is not whether substances can be found but whether they are present in sufficient concentration and have a pathway from source to receptor that could deliver a dose that would be a risk to the receptor.

No controls were considered necessary to be included in the EU's 1986 sludge directive or in the USA's 1993 sludge regulation.

Some Member States of the EU have set limits for some organic micropollutants but there is no consensus as to which should be regulated. Some of these organic chemicals used by the general public with intimate personal contact, e.g. surfactants used in washing-up liquid, shampoos, etc.

Many organic micropollutants are actually collections of compounds (congeners) within families. The different congeners have different toxicities. Regulations are not consistent in their selection of the individual congeners to include in the family-suites.

Studies that have tracked the concentrations of organic micropollutants in sludges have found that concentrations are now far below the values of concern (because of general declining emissions) and concluded there is no justification for continuing with the high cost of monitoring.

The Swedish EPA, the Environment Agency of England and Wales and the USEPA have all concluded they can find no reason to regulate organics in sludge but that research and surveillance should continue.

To put organic micropollutants into some sort of perspective, the total amount of in a typical sludge application is a similar order of magnitude as the amount of active ingredient in a single application of [approved] agricultural pesticide; a field might receive several pesticide applications during a year. However by definition pesticides are highly bioactive (otherwise they would not do their jobs) whereas organic contaminants in sludge have low bioavailability because they are strongly sorbed by organic matter and soil. The approval regime for pesticides in the EU is very strict in order to prevent harm.

1.9.4 Soil ecology

The next question is the potential impact on soil biological activity, including fauna (earthworms, beetles, etc.) and soil microbes (bacteria, fungi, etc.). There are more species living in soil than on top of it. Soil microbiological biodiversity and population dynamics are not yet fully understood. Populations are affected by such things as seasonal changes (e.g. temperature and moisture), addition of organic matter (crop residues, manure, sludge, etc.) and addition of mineral fertilisers and pesticides. Soil has many functions and it is important that these are not compromised in the long term.

Rothamsted Experimental Station is the oldest agricultural research station in the world; it maintains some classic long term field experiments on its farm that are a unique resource. Between 1942 and 1961 sludge was used on the classical 'Woburn Market Garden' experiment to assess its fertiliser value. This was the same sludge that was used in the

Risk, hazard and perception

The terms 'hazard' and 'risk' are often used incorrectly as synonyms but they are not the same. The International Standard definition of 'hazard' is a potential source of harm; 'harm' is physical injury or damage to the health of people or damage to property or the environment. 'Risk' is the combination of the probability of occurrence of harm and the severity of that harm. Thus risk can be assessed quantitatively; it is the basis on which insurance premiums, and tolerable daily allowances (for food safety) are set. There is an additional factor and that is the perception of risk; for example people perceived lower risk of injury in a car accident than actuaries calculate, consequently it was difficult to persuade them to wear seat belts.

Classically the 'perceived-risk' of voluntary activities (e.g. driving, sunbathing and smoking) is less than the quantitative risk and the reverse is true of involuntary or imposed activities and events. Perception is reality for the perceivers. 'Risk communication' has been developed by social scientists to bring risk and perceived-risk more into line. Factors that contribute to perception such as voluntariness, familiarity, benefits, understanding, delayed effects, etc. have been called 'outrage factors' and perceived-risk as the sum of risk plus outrage. It is a useful concept to bear in mind in connection with sludge use on land.

It is self-evident that in order for there to be a risk there has to be a source, a pathway and a receptor. Quite obviously there is no risk if there is no source, and neither can there be risk if there is no pathway of transmission to the receptor. It is equally true that risk is related to dose.

About 500 years ago Paracelsus (1493-1541) wrote: "*Dosis facit venenum*." ("The dose makes the poison."). The relationship between dose and response (effect) is one of the most fundamental concepts of toxicology (the science of poisons), but when we discuss environmental alarms and chemical health risks it is sometimes forgotten.

The potential receptors are humans, animals, plants, fish (if there is transfer to water) and soil fauna and microorganisms. The potential pathways are uptake from soil by direct ingestion of soil or via plants, or from water or respiration of contaminated dust or aerosols.

The position of the European Commission is that policies should be proportionate to risk, but that if there is insufficient information about a hazard to assess the risk, the Precautionary Principle should be applied in a way that is proportionate, time-limited and non-discriminatory, and that at the same time as applying it, measures should be put in hand to fill the knowledge gaps in order that a risk-based policy can be made. This was published by the European Commission in 2000 as a COM(2000) 1 'Communication on application of the Precautionary Principle'.

Research carried out in the past thirty years or so continues to demonstrate that a responsible and well-monitored use of sludge - in compliance with the requirements of Directive 86/278/EEC – does not cause environmental damage or endanger the food chain.

Control of potential pollutants at source, i.e. by working with industry so that industry reduces the amounts discharged in wastewaters has been very effective at reducing the concentrations in sludges. Sludge use in agriculture has been a particular motivation for source control.

The pollutant content of sludges decreased enormously during the last third of the 20th century, but it is worth remembering that these sludges were being used on land even whilst these reductions were being affected (and before). These sludges had concentrations of substances that we would now consider unacceptable. There is remarkably little evidence that this had any adverse effects (see box on historic sludge). Whilst not condoning historic practice, this experience should give confidence that there is a good margin of safety in today's controls.

Organic micropollutants commonly considered in environmental research

Several families of organic compounds have been the subject of environmental research. Some European countries have regulated some of them in sludges used in agriculture.

Dioxins (PCCD), furans (PCCF) and polychlorinated biphenyls (PCB) are all families of chlorinated organic compounds. There are 75 dioxins, 135 furans and 207 PCBs. Their half-lives (the time it takes for the concentration to decay to half the original) differ but they are of the order of years rather than months. The toxicities of the individuals differ; there are tables of weighting factors to calculate the 'toxic equivalence' (TEQ) of each congener by multiplying its concentration by its wieghting factor. The TEQs of all the congeners can then be totalled (ΣTEQ). These compounds cause skin irritation, affect liver, spleen, kidney and the respiratory and nervous systems, and might be carcinogenic.

Dioxins and furans (PCCD/F) were contaminants in the manufacture of other chemicals; they are also produced by imperfect combustion, including natural fires. Releases from industry (including incinerators, etc.) have been controlled to such an extent that garden bonfires, natural fires and fireworks are now the major sources. The global environmental burden has decreased and as a consequence the wash-off into sludge has also decreased; this is shown clearly by analyses of samples archived from the Woburn trial show below.

PCBs were used as insulators, they are no longer manufactured intentionally and global burden is decreasing also. In 1985 the EU adopted a directive (85/467/EEC) to limit the production and marketing of PCBs, this was strengthened in 1996 by a directive (96/59/EC) that prohibits production of PCB and requires destruction of stocks, including products containing these compounds.

PCCD/F and PCB are all strongly sorbed by organic matter; there is minimal root uptake and translocation within plants is minimal. The only significant transmission pathways are aerial deposition onto plants (but emissions to air have been greatly reduced as discussed) and direct ingestion of contaminated soil.

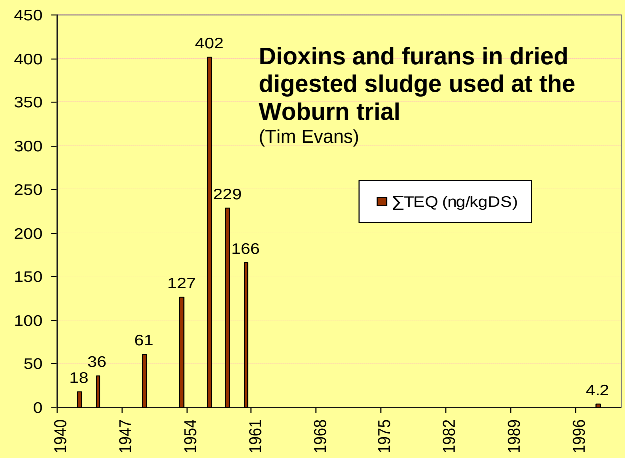
AOX (Adsorbable Organo-Halogens) is an analytical technique to measure the total of all of the halides (fluoride, chloride, bromide and iodide) that is in organic compounds in the test sample. Some countries have used AOX as an inexpensive indicator and analyses have decreased over the years, reflecting controls on halogenated organic compounds. AOX takes no account of the toxicities of the constituent organo-halogen compounds.

LAS (Linear Alkylbenzene Sulphonate) is a surfactant and widely used in many washing products, shampoos, etc. It degrades very rapidly (half-life about 2 weeks) in aerobic soil. At high concentrations it temporarily inhibits nitrification (the conversion of ammonium to nitrate) but agronomically it is quite desirable to delay nitrification and products are actually sold for that purpose. Nitrification resumes when the LAS degrades. Plant uptake is minimal. It is not toxic to humans.

PAHs (Poly Aromatic Hydrocarbons) comprise another family of compounds that is a product of combustion, including the charring of meat on a grill or barbecue. They are rapidly metabolised in animals and do not accumulate. They are strongly sorbed to organic matter and degrade slowly. Their mode of toxicity is carcinogenicity. Plant uptake is minimal.

NPE, NP (Nonylphenol Ethoxylates and Nonylphenol) and DEHP (Di-(2-ethylhexyl) phthalate) all degrade rapidly in soil. Root uptake and translocation within plants are minimal.

The brominated flame retardants (BFR) are one of the latest organic micropollutants of environmental concern. They are endocrine disrupters, i.e. they affect hormone systems. The plastic casings of televisions and CRT computer displays are one of the main sources. The heat from the screens causes the BFRs to volatilise into the air. Their introduction reduced deaths from fire and inhalation of toxic smoke by thousands per year; alternatives are being sought. They have spread around the Earth in the air and are precipitated in rain. Now they are ubiquitous and have even been found in polar bears. They have low solubility in water and are sorbed on solids. Inevitably a small part of these volatilised BFRs washes into the wastewater system and can be measured in sludges but the question is not whether they can be measured but whether there is likely to be transmission of a toxic dose to a receptor. These compounds are not taken up by plants and the main source of transmission is inhalation by humans with high exposure and, for grazing animals, direct ingestion of soil. Sludge is not a significant source.



London, Heathrow area (see historic case study box). The 'Woburn Market Garden' soil is sand and therefore the sorption capacity is small. In the 1980s rhizobia (the useful bacteria that infect legume roots, form nodules and fix nitrogen from air, which they supply to the plants) from the sludge-treated plots were found to be ineffective at N-fixation. The phenomenon was attributed to excessive metal concentrations in the soil. However when operationally-treated farm fields, which had a range of soil trace element concentrations as a result of sludge use, were surveyed, the N-fixing abilities of the rhizobia were not correlated with the trace element content of the soil. Whatever the reason for the loss of effectiveness by the Woburn rhizobia, it does not appear to be a general phenomenon. This survey also showed that farmers would be well advised to inoculate their legume seed with efficient rhizobia because the indigenous rhizobia had such a wide range of effectiveness (unrelated to soil metal content). Inoculation is inexpensive and would increase yields. For some reason this is routine in some countries but not in others.

There are other important soil microbial functions and it was to examine these that the 9-site field trials (referred to above) were established in England, Scotland and Wales. Even though trace element concentrations were built up to 150% of the maximum limit values permitted under the sludge directive (86/278/EEC) in only 4 years, no adverse effects on any soil microbial functions have been measured. The trial is probably the most extensive and intensive long-term trial to be established anywhere in the world since 1980 at least. The trial is continuing. The evidence to date is that the controls in 86/278/EEC are adequately protective of all of the soil-fertility and crop uptake end-points that can be measured.

A 5-year field trial (autumn 1993 to harvest 1998) tested the effect of sludge on soil microbial respiration quotient (MRQ) and crop yield. MRQ is a measure of how hard the soil microorganisms have to work to stay alive. It is a direct readout of stress and probably the most sensitive test that could be studied. It is not necessary to know which chemicals to test for. MRQ is a more sensitive test of adverse effects than the effect on crops. The sludges were from a domestic-industrial catchment with combined sewerage. They were applied annually at operational rates compliant with 86/278/EEC. There was no evidence of stress following application of sludge. Transient stress was measured from the soil drying out in summer and from application of a selective herbicide, but it was the same for all the plots (including the controls).

1.9.5 Biological hazards

Pathogens are disease causing organisms; inevitably they occur in wastewater. The pathogen content in wastewater reflects the general health of

Bioaerosol sampling (top to bottom) near liquid sludge application, cake application and an array of six samplers. (Ian Pepper)

the population. Before there was centralised collection of wastewater, drinking water was frequently contaminated with sewage and a continual cycle of infection resulting in a hygiene and disease status in the population much worse than today's.

Every step of the wastewater process reduces the numbers of pathogens.

In addition to human and animal pathogens we need to consider plant pathogens. Some animal pathogens can infect humans (and vice versa), but plant pathogens do not. However it would be very undesirable to farmers to have their land treated with sludge if there were a risk that their crops would be infected with a plant disease.

The risk of disease transmission from using sludge on farmland is managed in three ways. One is to treat the sludge in such a way that the pathogens are eliminated or at least reduced to similar concentrations to those found in normal soil and therefore the risk is not changed by the use of this type of treated sludge and a second barrier is unnecessary. Another is to manage the time between application and harvest (or planting) so that the number of pathogens (if they were present) would have died to less than an infective dose (see multiple barrier diagram earlier). The third is to prohibit the planting or harvesting of certain crops (such as those that are eaten raw and grow in contact with soil) after certain types of sludges from which pathogens have not been eliminated.

Numerous reviews have concluded that when sludges are used in compliance with regulations there is no evidence of adverse health effects.

Biological hazards comprise bacteria, parasites, fungi and viruses. There are also beneficial micro-organisms and biological factors that promote growth and/ or suppress disease.

It is difficult to conduct experiments using pathogenic organisms so there has been much work to identify non-pathogenic organisms that can be used as indicators because they display similar die-off characteristics to pathogenic organisms. Indicator organisms have been used for many years for testing drinking water.

An alternative to using indicators is to use pathogenic organisms contained within 'microcosms' so that they cannot escape into the wider environment. The difficulties with microcosm work are ensuring that all of the conditions outside the microcosm are mimicked inside it and that the passage of the microcosm through the process mimics the bulk of the unconfined material.

Naturally occurring non-pathogenic strains of a bacterial species called *Escherichia coli* have been found to display similar susceptibility to its pathogenic strains and also to *Salmonella* and other pathogenic bacteria. *E. coli* is a normal resident of the intestinal tract of many animal species including humans so there are millions in every gram of faeces from healthy as well as sick individuals. This is the reason that *E. coli* (or faecal coliforms which is an analytically similar parameter) has been widely used as an indicator of faecal contamination in water and food for many years.

E. coli came to notoriety towards the end of the twentieth century because of the emergence the O157:H7 strain, which is highly infectious to humans and potentially lethal. Many farm animals are infected with this strain (approx. 10% of cattle) but display no symptoms. The potential that their infected dung contaminates meat or produce grown in fields treated with their manure is significant. The food industry is working to reduce incidence. It is rare in municipal wastewater (and hence sludge) because incidents of human infection are fortunately very uncommon. Non-pathogenic *E. coli* is ubiquitous and it appears that there is a standing population in normal soils.

Human infection with *Staphylococcus aureus* has been [erroneously] attributed to sludge. Staphylococci exist in air, dust, sewage, water, milk, and food or on food equipment, environmental surfaces, humans, and animals. However despite intensive investigation *S. aureus* has not been detected in sludge or downwind of sludge application, even in the air at application sites when the air samplers were located only 1 metre from the applicator. This research was conducted in all the climatic zones found in Europe. It included "positive" control treatments comprising water seeded with the organisms and tested for airborne viruses as well as bacteria. It found that risk from airborne infection was transient (1 or 2 minutes) as the applicator passed the receptor and that there was no residual release from the treated land.

1.9.6 Nutrients

Leakage of nutrients from soil to water is a pollution hazard if the application of nutrients in sludge, or indeed any other nutrient-rich amendment is excessive or inappropriate.

Diffuse pollution of water resources from agriculture has become a greater concern since the control of point-sources of pollution (factories, wastewater treatment works, etc.) has been so successful in reducing water pollution.

The nutrients of concern are mostly nitrogen and phosphorus; they have already been discussed under Features and Benefits. When sludges are used according to good agronomic practice the risk of this hazard should be negligible. The EU's Nitrate Directive (91/676/EEC) protects water from nitrate pollution from agricultural land by restricting nutrient addition in vulnerable areas.

1.9.7 Odour

Odour is probably the most serious risk to the sustainability of a sludge recycling programme because of the number of people that could be affected. Sludge treatment should be designed and operated so that odour from sludge application sites is tolerable to the neighbours. If sludge is injected below the soil surface as a liquid there will be no odour risk but otherwise it is inevitable that there will be sludge on the surface of the soil [until it becomes incorporated] and therefore it could emit some odour.

Sludge can be treated so that its odour is not offensive. It is difficult to set numerical limits for odour because instruments have difficulty matching the discriminatory powers of the human nose and because odour dispersion depends on climatic conditions. It is obvious when there is unacceptable odour because there are complaints.

Regulators say that of the limited number of complaints they receive about use of sludge on land, complaints about odour are far and away the most common. Complaints about use of sludge on land are very infrequent in relation to the total areas of land treated with sludge. This demonstrates that sludge treatment can be operated to produce sludge whose odour is tolerable.

Although odour control is not a direct requirement of the sludge directive (86/278/EEC) it is a sensible precaution for operators to be aware of this aspect and to take all reasonable efforts to ensure that their activities are inoffensive to the neighbours in this regard.

1.9.8 Perception

Adverse perception is a threat to the continuation of sludge recycling. There have been instances where a food or drink company has said it will not buy produce from land that has been treated with sludge because of concerns within the company that its customers might be worried about the quality of the product. Such concerns usually originate from the marketing departments rather than technical departments.

There have been few quantitative assessments of public attitudes into the use of sludge in agriculture. Those that have been undertaken have found that a majority considers it is the best alternative. The proportion in favour increases when the benefits, risks and controls (including regulations) have been explained. Members of the public appreciate that the use of sludge to complete nutrient cycles and conserve organic matter is part of sustainable development. This research highlights the importance of informing the public about sludge recycling.

Furthermore if products based on sludge are available to them, members of the public are eager to use them in their gardens. These are positive demonstrations that the public is not averse to using sludge on land, especially their own gardens if it is available.

Companies that take a policy not to buy produce from sludge-treated land are taking a decision that is contrary to sustainable development.

In order to maintain positive perception it is important that sludge recyclers have integrity and a pride in their work. Operations should be clean and professional, with due regard for communication with customers and respect for third parties. These are attributes that are useful for any activity that is to be successful.

Tree section showing accelerated growth following sludge application (NBMA)

1.10 Alternative Means of Recycling

There are many uses of land other than agriculture where the sludge can be used beneficially to complete nutrient cycles and conserve organic matter. The following section lists the more significant of these.

There are many successful programmes where sludge is used as soil improver or fertiliser for landscaping, amenity and other horticultural purposes. In some cases it is sold through retail outlets to gardeners. It is essential that sludge is treated so that it is inherently safe if it is going to be sold in this way.

There are many examples where sludge has been the key to successful restoration of disturbed and derelict land to agriculture, forestry and green areas. Even when the original soil from such sites has been stripped and stockpiled prior to quarrying or mineral extraction, it is normally biologically dead and infertile by the time that it is returned. Many times there really is no soil.

Experimental studies have shown that self-sustaining topsoil can be created when sludge is added at a rate that supplies about 50-200 tonnes organic dry matter per hectare; provided the site drainage is designed properly and the soil chemistry is acceptable. This large application (usually as a single dose) provides the organic matter to stabilise soil structure and kick-start biological activity in the soil. It also provides a reservoir of plant nutrients. A useful guide is that topsoil should contain at least 2,000 $kgN_{organic}$/ha. When this foundation of fertility has been created the soil becomes self-sustaining through nutrient cycling via plant residues.

On areas where mineral fertiliser alone was used, the fertility dropped to very low levels when the mineral fertiliser ceased to be applied; in other words the soil was not self-sustaining and restoration failed.

The use of sludge for land restoration differs in some respects from using sludge in farming. The rate of application is much greater (about 50 times greater) but with modern sludge quality this is not a problem. One factor that must be considered is the history of the site to be resorted and of the soil-forming material that is available. Another factor is the intended use of the site after it has been restored.

The conditions on 'brownfield' sites (i.e. former industrial or other development land) might be very different from former quarries that may have been landfilled and capped with clay and then soil, and these conditions might also differ from colliery or other mining waste.

There is a wide range of variation amongst mining spoils; the pH could be anywhere in the range from very acid to very alkaline. There might be 'potential acidity' in the form of sulphide minerals that, upon exposure to air, could oxidise to form sulphuric acid. The texture could be fine clay through to coarse sand and very stony. Addition of organic matter can ameliorate many of these problems.

Organic matter can improve the structure of structureless clays and silts, increase the moisture holding capacity of excessively drained sands and prevent the release of potential acidity. Composted sludge has a neutral to alkaline pH and will therefore raise the pH of acid materials and buffer them against re-acidification. Lime-stabilised sludge is even more effective for correcting acidity, but probably not as useful for supplying organic matter because (depending on the stabilisation process and the soil's lime requirement) it might add too much lime.

The use of sludge in forestry can increase the growth of trees in the same way that it does agricultural crops. There is a longer history of this type of recycling in the America. Research in the EU is confirming that the results are applicable here too. In the south-eastern USA the time to harvest pine trees for boards was halved when liquid digested sludge was applied over young trees at about 5 years of age. Sludge can be applied before planting but the grower should be aware that it will stimulate the growth of weeds as well as the growth of the commercial trees. For this reason some have found that the optimum time to apply sludge is when the young trees are 1-2m high so that they are tall enough to shade out or grow above weed competition. Trees that have been top-dressed look unsightly and it is probably not acceptable where members of the public have access, but in plantations that can be closed it can improve profits significantly.

In the Pacific Northwest of the USA forest soils are rocky and contain relatively few nutrients; productivity is limited by lack of nutrients or water. Douglas-fir grows up to 75% faster following sludge. Accelerated growth reduces wood density by 15% but this is only to the density typical of timber grown on highly productive land or with mineral fertilisers; the strength is well within the range required for structural timber.

One would not normally think of using sludge in natural forests, but it can be very useful for stabilising soil, establishing vegetation and re-forestation after forest fires and other devastation, as has been done successfully in the South of France, for example.

Sludge is also used to increase yields of biomass crops that are harvested as sources of non-fossil fuel. High yielding perennial members of the grass family of plants (such as Miscanthus) or trees such as willow and poplar that will re-grow after they have been cut to the ground are harvested, dried and burnt as fuel. The nutrient requirements are similar to any other crops producing large amounts of biomass.

Landfilling of dewatered sludge with municipal waste (Tim Evans)

Fluidised bed sludge incinerator for 2.2 million p.e. including plate and frame press dewatering (Tim Evans)

Sludge can provide these nutrients, which would otherwise be supplied by mineral fertiliser or manure if comparable yields were to be obtained.

1.11 Alternatives to Recycling

Everything has to go somewhere. Sludge is an inevitable product of wastewater treatment and, generally, the more we treat wastewater, the more sludge we are going to generate. If is not used on land, some means must be found to dispose of it.

Landfilling of biodegradable materials such as sludge is becoming increasingly restricted in the EU; this is because of the Landfill Directive and because we are running out of landfill capacity. Therefore if materials can be used it is undesirable to dump them in landfills and take up precious space that could be used for materials for which there is no practicable use.

Landfilling sludge also loses the opportunity to recycle the phosphate and other beneficial constituents it contains.

One of the purposes of the Landfill Directive (1999/31/EC) is to minimise adverse environmental impact from methane -rich landfill-gas leaking from landfills (i.e. global warming and explosion risk). The processes when there is biodegradable waste in a landfill are similar to those in an anaerobic sludge digester with the landfill-gas being burnt in CHP (combined heat and power) engines and of generating electricity from non-fossil sources.

Disposal of sludge at sea ended at the end of 1998 in the EU. Since then **incineration** (or some other thermal process) is really the major alternative to using sludge on land.

Dewatering is one of the keys to successful incineration. Water does not burn, it is therefore necessary to reduce the moisture content so that there is sufficient heat from burning the dry matter to evaporate the remaining water. This is called autothermal combustion, i.e. no external heat source is required except for starting up the incinerator. Water vapour adds to the volume of gas for emission clean -up. Flue-gas clean-up is a very significant part of the cost of incineration. A few incineration systems dry the sludge first to eliminate water vapour and reduce the volume of exhaust gas that has to be cleaned, which reduces the capital and operating costs significantly.

Incineration results in ash, which is normally disposed in landfills. Although the ash contains the phosphate from the sludge it is in chemical forms that are unavailable to plants (and therefore it has no direct use as a fertiliser) and it is so hard to extract the phosphate from ash that it costs at least 6-times as much as extracting P from rock-phosphate.

Work to find uses for incinerator ash has not yet been very successful.

A variation to incineration has been developed in Japan, it is called melting furnace; ash is heated to such a high temperature that it melts and forms a glass; this is even more expensive than conventional incineration.

In some areas there are large numbers of people and also intensive livestock production and consequently there is insufficient land to use all of this organic resource. In such circumstances incineration might be the most practicable alternative to recycling.

The EU's Incineration Directive (2000/76/EEC) ensures that when wastes (including sludges) are burnt, the risks from emissions to air are within acceptable limits. Modern fluidised bed incinerators are able to meet these exacting standards consistently.

Some treatment works dry their sludge and then supply it as fuel for use in cement kilns and other energy intensive processes. Whilst this is a substitution for fossil fuel, care is needed that the phosphate content of the cement is not raised excessively.

In energy terms the energy used to evaporate the water to dry the sludge should be deducted from the fuel value of the dried sludge.

Some coal-fired electricity generators have been converted to be able to burn a small proportion of either dried or dewatered sludge together with coal. However, quite rightly, burning wastes in these facilities brings them into the purview of the Incineration Directive (2000/76/EEC), which some operators consider an unwelcome additional responsibility.

There has been at least 20 years' work to try to convert sludge into ash and oil or gas by **gasification** or **pyrolysis**. In essence the sludge is dried and then burnt in a restricted amount of air such that there is enough combustion to heat the rest of the sludge and convert the carbonaceous matter to oil or gas. Either of these fuels has the advantage (over electricity) that it can be stored until it is required, or transported to a place where it can be used. However, despite considerable investment in research and development, only one operational sludge facility was built in 20th century. This was the oil from sludge plant at Subiaco, Perth, Australia; it closed about 1999.

Gasification and pyrolysis have not achieved operational status for sludge, despite much interest. They are operating with other materials. Whether this apparent inability to apply the technology to sludge means that it is inapplicable for sludge or not, the experience appears to indicate that it is at the best difficult.

Sludge can be mixed with clay to make **ceramic building materials**; there are very few examples of this anywhere in the world but it is an interesting application. Naturally occurring organic-rich clays are valued for brick manufacture because as the bricks are fired the organic matter in the clay burns contributing energy to the process and at the same time results in bricks of lower density that are easier to transport and to handle. Sludge can be mixed with clay that contains little or no organic matter to produce similar effects.

One consequence of all of these alternatives to sludge use on land is that phosphate is lost, or at least it is concentrated in the ash or char from which it is too expensive to recover. The concern is that the phosphate industry estimates the life of the known reserves of phosphate rock to be only 100-200 years at the current rate of exploitation. As discussed above, phosphate is essential for life. Cadmium is present, to a greater or lesser extent, in all phosphate rocks. The lower-cadmium sources are only about 15% of the known reserves. Mining will be forced into higher-cadmium sources as the global reserves run down. A consequence of not recycling sludge will be that 'new' cadmium will be brought into the anthropogenic cycle more quickly than if sludge were recycled.

Rock-phosphate (of the higher cadmium variety) has been used for fertiliser for more than 150 years. No adverse effects have

Phosphate mining—the scale of the operation is evident from the size of the machines (Tim Evans)

Quotations about the use of sludge in agriculture

In the course of compiling this guide the subject has been discussed with a range of stakeholders. The following have generously offered these statements about their attitudes to the use of sludge in agriculture and other sludge recycling.

COPA, the European Farmers' Organisation

COPA (Comité des organisations professionnelles agricoles) the Committee of Agricultural Organisations comprises 73 member organisations and associates from across the EU. COPA considers that in order to achieve a more sustainable agriculture it is necessary to recycle nutrients and organic matter, firstly from within agriculture and then from other sources such as sludges. All of this should be done in accordance with good agronomic practice. It is essential that materials are fit for purpose and that quality is maintained at appropriate levels.

COPA recognises that the ability to use sludges on farmland is important for civil society and is also concerned that this should be seen from the positive perspective of being an essential part of sustainable development, rather than attracting any negative perception to the treated land or produce grown on it, because farmers depend on customers' perceptions.

Society demands increasingly safe, high quality food and farm products and improved environmental protection. Farmers are prepared to recycle nutrients and organic matter provided the processors and authorities are committed to producing sludges that have received the necessary treatments so as to make them safe and sufficiently homogenous for use in agriculture, are prepared to give all the necessary guarantees in terms of quality and accept liability if there were any adverse effect and provided such recycling is of positive benefit for the ecosystem and meets the crop and soil requirements in agronomic terms.

Peter Gæmelke, President of COPA
(COPA)

ELO, the European Landowners' Organisation

The European Landowners Organisation exists to ensure that the policies of the European Union promote a prosperous and attractive countryside, and that private landownership can continue to make a positive contribution to the economy and environmental management of rural areas.

Landowners stand at the centre of the rural world. They are involved in farming and forestry, they generate employment for local people; and are responsible for the management of the majority of Europe's landscape. Landowners regard themselves as the "temporary custodians" of land that has been in their families for generations, and therefore they are committed to the future of the countryside. The ELO is thus well-placed to speak for Europe's rural areas.

Margot Wallstom with Thierry de l'Escaille Secretary General of ELO

The ELO has national constituent organisations in all the Member States of the EU and thus represents millions of landowners throughout Europe.

The ELO regards the use of sludge and other organic resources on land as part of sustainable development. It should be said that because of the long-term relationship landowners have with their land, that the ELO regards the matter of quality and fitness for purpose as fundamental considerations and requirements. ELO is confident that modern good practice standards in sludge recycling satisfy this requirement sufficiently for individual land managers to make their own decisions on the use of sludge. Many land managers have personal experience of the value of sludges for feeding soils and crops.

Lisemore Castle, Ireland (ELO)

Food retailers

Richard Ali, Director of Food Policy at the British Retail Consortium (BRC) described the supermarkets' attitudes to the use of sludge in agriculture. Food safety is the over-riding priority for Britain's food retailers, who are committed to working with other partners in the food chain to identify and manage appropriate issues with a view to achieving more sustainable outcomes. The largest also have significant operations in other European countries and buy globally. In recent years the BRC has been involved in the development of assurance schemes, which include integrated crop management programmes that have positive effects on biodiversity and the minimisation of pesticide and chemical use.

The BRC has also been instrumental in the development and promotion of initiatives such as the 'Safe Sludge Matrix,' which was developed in conjunction with the water and farming industries and government to find environmental and ecologically sustainable ways to re-cycle biosolids. Richard Ali says, 'The Safe Sludge Matrix both places food safety considerations at its heart, and addresses the needs of farmers and growers to have access to a valuable and cost effective source of nutrients and organic matter. It is underpinned by comprehensive scientific research.

Richard Ali (BRC)

Under the Matrix's rigorous controls, untreated sludge is not allowed on agricultural land. Only enhanced treated sludge or biosolids can be applied to land used to grow ready to eat crops such as fruit or salad crops and then there has to be a 10 month interval between application and harvest. Enhanced treated biosolids are highly processed and tested prior to application to ensure that Salmonella is not present. Conventionally treated biosolids used in accordance with the Matrix are perfectly acceptable for combinable (cereals) and animal feed crops and for grassland as long it is deep injected into the soil and there is no grazing or harvesting within 3 weeks of application.'

Agricultural Extension Services

Dr Dave McGrath of Teagasc (Tim Evans)

Teagasc—Ireland's Agriculture and Food Development authority

David McGrath from the Irish national agricultural advisory service **Teagasc** says "Agriculture is very important for Ireland for the rural economy and for its export earnings, which are underpinned by its clean environmental image. The science underpinning sludge is pretty good. Controlling rates of application [according to EU and national legislation] has in practice eliminated the heavy metal problem. There's no evidence of disease transmission. For society as a whole, the use of sludge in agriculture is of tremendous value."

Washington State University Extension Service

Jim Kropf, "The use of biosolids substantially **reduces wind and water erosion** of agricultural soils by adding organic matter, promoting root growth and improving crop canopy to protect the soil. Dryland crops grown with biosolids are bigger, greener and have equal or greater yields than crops from commercially treated fields."

Organic farming

Patrick Holden, Director of the Soil Association, which is the leading certifier of organic farming in the UK, considers that the use of sludge in agriculture would be consistent with its principles of sustainability because it completes nutrient cycles and feeds the soil. However it is specifically excluded from the permitted inputs by the EU's organic farming regulation so no Member States are allowed to use it at present.

Patrick reported in the association's magazine 'Living Earth' "In the past, Soil Association Organic Standards approved the use of sewage products under certain restrictions and in the right circumstances. … the Soil Association Council approved a motion on the use of sewage products; 'Council agrees that the use of sewage products in organic agriculture is acceptable in principle, provided that adequate safeguards are put in place to ensure protection of the soil from contamination and livestock and consumers from health risks'."

Patrick Holden, Director of the Soil Association (Soil Association)

Friends of the Earth

Prof. Dr Hubert Weiger (BUND)

Prof. Dr Hubert Weiger of the German branch of Friends of the Earth, Bund für Umwelt und Naturschutz Deutschland (BUND) says that the premise behind supplying sludge to agriculture is minimising pollution and that incineration is not the solution. BUND believes that using sludge in agriculture is useful for regional ecosystems and that it is imperative for the conservation of resources.

Case studies of the use of sludge in agriculture and alternative uses on land

This section contains examples of uses of sludge in agriculture and of other uses of sludge on land to feed soil and crops. The case studies cover most of the climate types experienced in the EU. Some examples are from outside the EU but the experience illustrated is no less applicable within Europe provided they are consistent with the national and local regulations. Some might give inspiration for innovation, for example if predictions for desertification as a consequence of climate change materialise. It is important that people who are using sludges have enough information to enable them to make best use of the benefits and avoid the risks.

Mixed Farming

Mixed farming at high elevation in Austria

Bernhard and Andrea Ebner farm south of the small market town of Dimbach in Upper Austria. They have been using lime-stabilised dewatered sludge every year since 1994. Their 30 ha farm is 50 km east of Linz; it is a typical of the Bohemian massif area. They raise cattle for **milk** and **beef**. The farm is half grass and half arable. The arable crops are **maize, triticale, spring barley, oats** and **clover**. By using limed sludge every year in combination with the manure from their cattle the soil phosphate content has increased from level A (deficient) to B-C (average to good). **Soil pH** has increasing from 5.1–6.2 (which would be too low for optimum crop yield) up to 5.5–6.7. Potassium and magnesium are now in the optimal range. The crop yields are significantly above the average for the area. The soil-structure is better than 9 years ago so it is easier to cultivate and less likely to erode. These soil improvements mean that the Ebners are able to grow maize without problems even though they are situated 650 m above sea-level and the annual rainfall is 800-900 mm.

Bernhard and Andrea Ebner's farm where sludge enables them to grow maize even at 650 m above sea level (Horst Müller)

Irrigated low-rainfall, Mediterranean farming in Egypt

Mohamed Said farms 10 ha of reclaimed desert land near Alexandria in Egypt. He has been using composted sludge from Alexandria for three years for which he pays the equivalent of €6/m^3.

His soil, which is calcareous loam, has a very low organic matter content. The annual rainfall is only 200 mm and it is seasonal so all crops are irrigated. He grows two arable crops per year, predominantly **wheat** and **berseem** (a forage legume) in the winter and **maize** in the summer.

Since Mohamed has used sludge his yield increases have been spectacular, which he reckons is due to the organic matter and **trace element** additions as much as the nitrogen and phosphorus in the sludge. He also grows **apples** and **pears** which used`to suffer from chronic trace element deficiency requiring expensive supplementary fertilisers, but since using sludge, the deficiency symptoms are much reduced with substantial increases in yields. Although he pays for the sludge, he says that not only is sludge better than using fertiliser, it is also much cheaper with longer -lasting effects. He has also been able to diversify his cropping, growing more valuable crops particularly cotton. He was not able to grow these crops previously,

Control maize—grown conventionally
(Jeremy Hall)

Maize grown with 20 m^3/ha sludge compost (Jeremy Hall)

Arable farming in Germany

hanseWasser is the largest wastewater treatment company in the north western part of Germany. It is located in Bremen.

Each year hanseWasser treats 62.8 million m^3 of wastewater from the city-state of Bremen as well as neighbouring communities. The company says that one of the decisive factors for its success is its knowledge and expertise in the use of sludge.

Its combined production of sludge is 16,000 tonnes dry solids per year (tDS/y). Of this total amount 5,400 tDS/y are recycled to farms in the local area; the demand from farmers is increasing. The sludge is anaerobically digested and dewatered using centrifuges that have been upgraded so the cake has increased from 20 %DS to 25 %DS.

Sludge from Bremen is well known as a high quality fertiliser because it is rich in nitrogen and phosphate and low in potentially toxic constituents.

hanseWasser's four full-time sludge consultants work hand-in-hand with farmers to maximise the effectiveness of sludge use. They also provide soil analysis free of charge to every interested farmer. Transportation and spreading of the material is also free. All of hanseWasser's partners including hanseWasser itself are certified recycling enterprises and in total approximately 200 farmers are supplied with sludge.

Farmer Henry Grimm has been using sludge for 15 years
(Gabi Kaiser, hanseWasser GmbH)

Family farm finds sludge saves fertiliser and improves soil moisture

Henry Grimm has a 180 ha family farm at Worpswede near Bremen. He grows **maize**, **oilseed rape**, **wheat** and **sugar beet**. "The land I farm has been owned by my family since 1756. For the last 15 years we have been using biosolids on approximately 100 ha. We save money using biosolids on our sandy soil instead of chemical fertiliser and at the same time we increase sustainable productivity." Henry Grimm says his farm, which is a family enterprise, benefits greatly from the use of sludge; applying it to land improves soil properties and plant productivity, enhances moisture retention and reduces dependence on chemical fertilisers. Regular soil analysis and advice on application rates make sure that in the future his now 16-year old son can take over the farm.

Farmer and adviser predicts more farmers will use sludge

Dr. Joachim Wendt, has a 105 ha farm at Oberboyen in Lower-Saxony and he is also one of hanseWasser's four consultants to other farmers. Like Henry Grimm, he grows maize, oilseed rape, wheat and sugar beet and uses sludge on about 70 ha of the farm. "Lower-Saxony is very much an agricultural state – we have lots of farms here. I, myself, have used biosolids on my farm for the last 10 years and I am very convinced by the product. The biosolid material that the farmers in the area receive is high in nutrients and low in toxic agents. That was reason enough for me to also work part time as a consultant. For Lower-Saxony my prognosis is an increase in the use of biosolids – there already has been a dramatic increase over the last 5 years. Farmers understand that there is no other fertilising material that is as regularly analysed as biosolids – **it is the ideal soil enhancement**."

Lower-Saxony farmer and sludge consultant Dr. Joachim Wendt
(Gabi Kaiser, hanseWasser GmbH)

Sugar beet in Ireland

Mick Fitzpatrick farms in County Laois, Ireland. He has a mixed farm and his crops include **sugar beet**. He said that following having his land treated with a mix of sludges from brewery and food industries his margins have improved. "**Sludge saved me €170-190/ha**. I cut my sugar beet fertiliser from 1250 kg/ha to 875 kg/ha. The sugar content of the beets was better as well so the **factory paid a better price**."

Cereal growers in Norway

Ola Breivik farms 200 ha of **cereal grains and oil seeds** (including 100 ha of rented land) and 150 ha of **silviculture** at Nummestad farm, Hobøl.

He is one of several cereal grain-producing farmers using sludge from VEAS, which is the wastewater treatment plant for Oslo (http://www.veas.nu), and other treatment plants and has no doubts about the high quality of the product and its good fertilising values.

Ola Breivik says "Biosolids are a challenge for society, and we are all responsible for finding solutions to this challenge. Meaning that we must all respect each other; farmers, water industry and authorities. I don't think there is a lack of will among the cereal grain producers, but probably some are sceptical. Therefore certification for the use of the biosolids is necessary as a matter of priority, otherwise scepticism may increase. It is also important that research in this field is maintained".

Farmer and businessman Ola Breivik
(Arne Haarr)

"Norwegian biosolids are amongst the best in the world regarding quality and hygiene; they also have high fertilising values that are long lasting. Research results show that the nitrogen from biosolids is released throughout the growing season, and that organically bound nitrogen is released over several years. Undoubtedly, this is a positive factor and it even increases enzymatic activity in soils. However, one should be aware of the risk of over-fertilising, because that can lead to lodging."

There are still some uncertainties about the fate of phosphorus recycled through sludge and its availability for plants; knowing the type of soil and soil pH is important for giving the right assessment.

Traditional heavy industry in urban areas has decreased in the last 30 years and at the same time process-technology has improved greatly. These have been major reasons for the reduction of heavy metals in sludge. Ola Breivik says "VEAS has done a very good job in focusing on quality and on providing information about the beneficial use of biosolids. This has helped us all … farmers should be seen as major stakeholders in the chain of players, and should be rewarded for the job they do for society".

Melby Machine Station spreader
(Melby)

Contractors often spread sludge because many grain producers lack adequate machinery to do this job. Ola Breivik says "We use contractors for several operations in spring and autumn, it gives me the possibility to do other things, and at the same time makes sure work is done on time. But much equipment is very large and heavy, including the spreading equipment. For soils rich in clay and with poor porosity and draining capacity it is essential to pick the right time so as to avoid compaction. The best time for spreading is autumn, and with weather like we had the last couple of years, there have been no problems, but this is for the farmer himself to decide; he knows his land".

Ola Breivik is a very busy person; he is a member of the board of a nationwide cereal grain company, chair of another local grain company, and chairs the local forestry association. "We farmers need to make money from our businesses; otherwise there will be no future. All potential sources of income from the farm should be examined."

Asbjørn Melby of Melby Machine Station at Rakkestad is one of the contractors spreading manure and sludge, "We use 13.5 m^3 and 17.5 m^3 wagons and spread in both spring and autumn but not when conditions are wet. VEAS biosolids also contains lime, which is probably another reason for its popularity. There is a growing interest in the use of biosolids among cereal grain producers, but some still say 'no'. Conditions should be as dry as possible, but the farmer decides. We do not spread without his permission, and there is also a restriction to spread in 10-year intervals. Therefore, the spreading of manure is a more important challenge for the soil's structure."

Mixed farming in Spain—wet maritime Galicia and drier Mediterranean Costa Brava

CBWA's sludge application (Lluís Sala)

Agroamb recycles sludges to land in **Galicia**, NW Spain. The sludges include sewage sludge and organic residuals from food industries, mainly dairies, slaughterhouses, and canneries. It works with the University of Santiago de Compostela to optimise the value of these materials for the Galician soils and environment.

Galicia has a maritime climate with plenty of rain (1000-2000 mm/year) – they say "Galicia - Green Spain". The geology is mainly granite. The topography is mountainous. Soils on slopes tend to be shallow and acid; a soil pH of 4.5 is typical. There are deeper soils in the valleys and

A farmer's field of sorghum growing on sludge treated soil. (Lluís Sala)

crops grow well in the mild climate. Farmers value sludge not only because of the nutrients but also because it reduces aluminium availability in acid soils (and hence aluminium toxicity), **raises soil pH**, improves soil structure and stops soil pH falling as quickly in the future. The trace element content of soils can be high

One of the winter wheat field trials at Fundació Mas Badia (Lluís Sala)

(especially nickel) because of the geology; sometimes it is above the sludge directive limits. If the sludge smells a bit the farmers find that it has an added benefit – it **deters wild boar** which can do a lot of damage in crops, especially maize fields. Use of sludge to increase tree growth and for reclaiming quarries is also of interest in Galicia.

Costa Brava Water Agency in NE Spain has a long experience of planned sludge recycling for agriculture. The agency has 18 biological WwTP and the combined sludge production is 26,000 t/year. In summer the population increases 8-fold—from 150,000 to more than 1-million.

Since 1996, 80% of the sludge has been recycled to agriculture; mainly to cereal crops which are mostly **wheat** in winter and **maize** in summer, there is also with some spreading on **ryegrass**. Sludge is stored during the growing seasons when there is no land to treat. Fields are treated at agricultural rates and with a total satisfaction of users. Soil analyses are performed prior to calculating the application rates and farmers are informed of the nutrient contributions they can expect from the sludge. Analysis, transportation and spreading are free to farmers (these costs are part of the wastewater treatment costs), which also includes controlling the fate of the sludge.

To get a better understanding of the agronomic value of its sludge, CBWA has been working with the prestigious agricultural experimental station, Fundació Mas Badia, since 1996. It has been running field experiments and assessing sludge fertilisation on wheat and maize, in order to gather information on optimum application rates and how they should be varied over time. They have also studied the quality of the crops and the changes in the soils.

The conclusions after eight consecutive years are very promising. There has been no statistically significant increase in the heavy metal content of the soils. The quality of the crops is similar to the plots where conventional fertilisation was used, but at much reduced fertiliser inputs. The field experiments have shown that 60% of the organic nitrogen is mineralised to plant-available N. The plant-available P-status of the sludge-treated plots is better than those of the plots that received mineral fertiliser.

Sludge improves fertility and reduces wind erosion on an arable farm in UK

Chris Ashley, who farms in Shropshire, England, said "When I came to this farm in 1958 there were terrible problems with **wind erosion and blowing soil**, it regularly blocked the roads and even the railway. Nobody else would take it on but I was keen to farm. We used to have livestock and the manure helped the soil but have had none since the foot and mouth of 1967. Wind blow was so bad I often had to drill sugar beet twice because the soil and seed were blown away the first time.

"I began using liquid digested biosolids more than 20 years ago. Recently we changed to dewatered digested cake. Normally we apply biosolids before **cereals** and **sugar beet**. Soon after we started we were able to grow wheat for the first time."

The soil is free-flowing sand. "Since using biosolids, the blowing problems have stopped, the soil has become less droughty and has taken on a darker colour and is

Chris Ashley proudly shows visitors his sugar beet (top) and the sand soil he farms. (Tim Evans) generally more fertile. There has been no blowing for 15 years. Sometimes the water company would top-dress newly sown soil with liquid biosolids for me if it got very windy and this stopped blowing. We never need phosphate fertiliser because the soil levels are good and just use 50 kgN/ha, 130 kgK_2O/ha and 1.7 litres/ha of manganese because the soil is manganese deficient. The amino-N of my sugar beet is always good, unlike my brother who uses chicken manure – his are very high." [Amino-N is a quality measure, it is related to the nitrogen fertilisation, if it is high if makes sugar processing more difficult.] When asked about public reaction to his use of sludge, Chris replied "Sometimes people in the village ask why I use biosolids but then they come from miles around to buy my potatoes. We are very pleased with the results!"

Scientifically trained family farmer in UK used sludge when he was sure it was risk-free

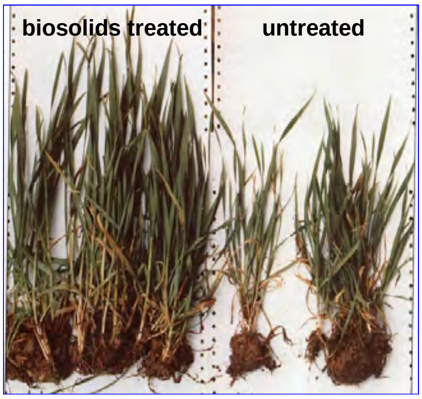
David Parker has a 400 ha **mixed farm** near Oxford in England and estimates using sludge has trimmed €8000 off his annual fertiliser bill without compromising yields. "I have been able to cut back sharply on the amount of bagged nitrogen top-dressing applied to **grass**, **cereals** and **oilseed rape** [canola] and have not had to buy any triple superphosphate."

A third of the farm is greensand and the rest is clay. There is a dairy herd, beef fattening and arable.

David, whose opinion is highly respected by his fellow farmers, said "I first used biosolids after seeing other farmers successfully using it. I am a chemist by training and knew of the potential risks from heavy metals and did not want to kill soil that my family has farmed for over 200 years. It was only when I was convinced it was risk-free that it was applied here." "The effect of biosolids on **winter barley was dramatic**. There were twice as many strong tillers by Christmas ... there was nothing wrong with the non-biosolids crop [treated with farmyard manure, FYM] but when grown alongside ... it was made to look second rate ... [sludge] yielded 0.5 t/ha more than the FYM-treated crop."

David Parker shows the clear line at the edge of sludge application in a ryegrass, clover mixture field
(TERRA ECO·SYSTEMS)

Sludge increases profits on 1100 ha arable enterprise in UK



Winter wheat from treated and untreated plots showing the improved growth and tillering.
(Peter King)

Peter King runs the 1,100 ha **arable** side of a mixed farming estate in Berkshire, England that includes two dairy herds and three pig units. He has used dewatered digested sludge for many years on the chalk hills with clay caps that he farms. He says "it is a valuable source of nitrogen, phosphate and trace elements so provides enormous scope for cost-cutting". Peter found more tillering (shoots per plant) of **wheat** on treated land and therefore cuts back seed rate by 20% so that each plant can reach its full potential. Savings amount to €37-45 /ha for N, €30-37 /ha for P_2O_5 and €15-19 /ha for seed – a **total saving of €91 /ha**. Against this was a small increase in use of slug pellets and of growth regulator (to keep the crop standing up).

Harvesting sludge-treated dryland wheat in eastern Washington (NBMA)

Dryland wheat in Washington

Gary Wenger says "The land I farm [in the low rainfall area of eastern Washington, USA] has been cultivated for 100 years. Many nutrients have been removed from the soil, and biosolids have provided the first opportunity I've found to replenish some of them particularly micro-nutrients."

Grazing and Forage

Sludge ensures reliable forage maize on drought-prone UK farm and increases profits

Maize silage provides essential winter food for farmer Nigel Powell's beef cattle in southern England but he farms on acid sandy soil "In a dry summer this sandy soil looks more like a desert than farmland and crops die back rapidly. But using biosolids ensures this does not happen and guarantees a worthwhile crop can be cut every year." Nigel had no hesitation about using sludge when he took over the farm because he had been a contractor and had seen what it did for other farms. "Maize on treated land emerges rapidly and grows much faster than on untreated land. It stays healthier and **no fungicide** is needed. It stays greener longer. The overall yield is a bit better than maize grown just with bagged fertiliser but it has bigger cobs so the feed value is better. We must be saving at least €40 /ha [on reduced fertiliser] then we benefit from the extra yield and the feed value. But the biggest advantage for us is knowing that we will be able to harvest a reasonable crop whatever the season. This is very important on the drought-prone land."

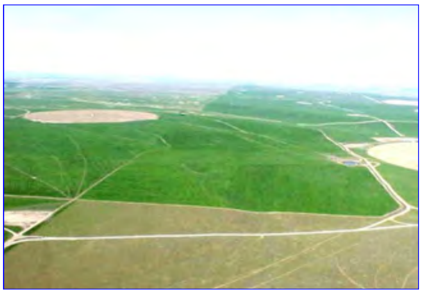
Sludge assures Nigel Powell of maize even in drought (TERRA ECO·SYSTEMS)

Ten-fold increase in beef output from Oregon ranch

K&S Ranches in Oregon was started in 1914; it is a family business and has grown to more than 8,000 ha of rangeland by good progressive farming. The current farmer, Kent Madison, started using sludge in about 1990. He has 3 full time employees sampling the soil and crops, applying the sludge, maintaining the roads, loading areas and machinery. They use about 180,000 t dewatered digested cake each year mainly from the city of Portland.

K&S' flotation-tyred, self-propelled sludge applicators (Kent Madison)

0-8 cm soil samples show that the content of major and minor nutrients has increased. There is 3.2% organic matter in the treated soil compared with 1.3% in the untreated and the cation exchange capacity has increased by 50% which means that nutrients are not lost by leaching.



Treated and untreated rangeland in Oregon seen from the air (Kent Madison)

The important thing for Kent's business is that the yield of grass has increased from 0.4 to 2.47 tDM/ha and the crude protein from 5 kg/ha to 60 kg/ha, i.e. the grass has a better food value. There is a 7:1 conversion ratio of feed to beef from the treated grass compared with 15:1 from the untreated grass, which has less young growth. This translates into 255 kg beef per day from the treated grass compared with only 20 kg/day from the untreated because there is more forage and it is of better quality.

Kent Madison says "Using biosolids is good for the farm and it's good for the environment as well; there's more wildlife on our treated rangeland, as well as all the benefits to soil and crops."

More grass of better quality means more beef (Kent Madison)

Amenity and horticulture

Composting in Finland close to the Arctic Circle

The City of Oulu is situated in Northern Finland about 200 km south of the Arctic Circle. There are about 125,000 inhabitants in Oulu; they create 15 million m^3 wastewater per year. The wastewater is treated biologically and chemically. All of the sludge is composted; this produces about 42,000 m^3 of compost per year, all of which is sold to be used in gardening, establishment of lawns and land reclamation.

After mechanical dewatering the amount of sludge is 25,000 m^3/y at about 25%DS. Immediately after being dewatered it is blended with lime and peat or bark and sand. The compost is turned once a month with a purpose-built machine that mixes the material very effectively. It takes about 2 years to compost the mixture. The finished compost is screened (sieved) before being sold. The 9 ha composting pad is paved with waterproof asphalt. All run-off water is pumped to the wastewater treatment plant.

Oulu is a fast growing city and several new residential and business areas have been established. The compost produced from sludge is called 'biosoil', it gives a good and advantageous alternative for the construction of new green areas. The quality of the 'biosoil' is monitored according to the Finnish regulations for fertilisers.

Oulu wastewater treatment works in the foreground with the biosoil production area behind (Marja Luntamo)

Bill & David Barling and their profitable golf course (Southern Water)

Farmers diversify into golf

Turf management: Bill and David Barling, farm at Rainham, Kent, England and decided to diversify by constructing an 18-hole **golf course** but grass on the first fairway always lacked vigour. "Although standard golf course fertilisers can provide a quick fix greening effect nothing has created the prolonged benefit that biosolids provided." A single application created a lush green sward that remained visibly healthier and more drought resistant for five years. David said that from this "We treated all the approaches to the greens and some of the fairways. The result has been grass swards like green velvet that have been playing extremely well. It has sustained the quality of the grass for the whole season." The resilience of the turf grass is critically linked with the commercial success of a golf course because it is the controlling factor on the number of people who can play and hence the green fees. It has helped the pay -and-play course develop its reputation as one of the busiest in Kent.

been proved linked to cadmium and the use of phosphate fertilisers.

Phosphate mining is a massive extractive process. Some of the reserves are in fragile desert ecosystems where seed reserves and soils take centuries to develop. Quarrying destroys these. Extraction of phosphate from sludge before or after incineration costs about 6-times the current market price. Even if P were recovered, the waste from the extraction process would have to be disposed because it would have no use. When we have phosphate in the anthropogenic cycle there is a sustainability obligation to recycle it whenever practicable.

Vineyards

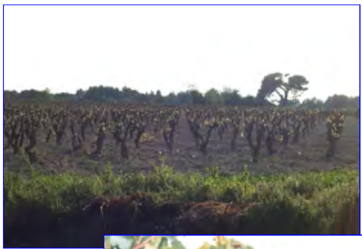
Growers in Mediterranean France find sludge improves soil and wine

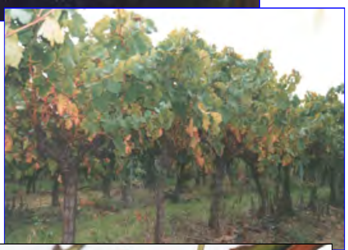
Patrick Thubert runs 63 ha of **vineyards** designated as "Côtes du Roussillon" near Perpignan. He regularly uses composted sludge that he spreads either before planting or on established vines.

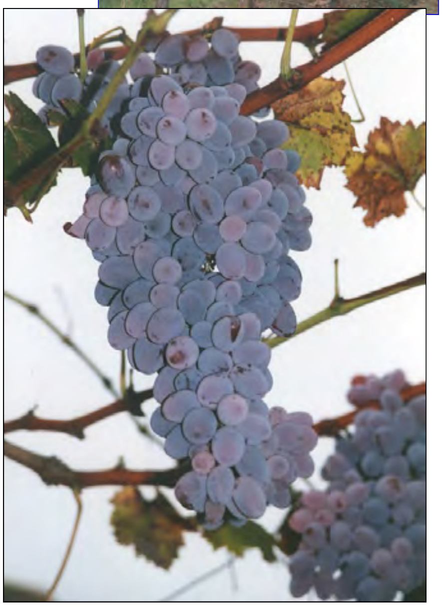
"In our area, there is a huge deficit of organic matter in the soils and some of them are near desertification" he says. "The spreading of composted sludge allows us to recreate a microbial life which has nearly disappeared because of the exclusive use of mineral fertilisers".

"The **improvement of the soil structure** has beneficial impact on the root development of the vines and limits erosion, especially during thundery episodes which are quite frequent in our region. Finally the increase of organic matter content also helps the growth of grass between the vine rows and regulates the water supply of vines better during the droughty season."

Other Mediterranean wine growers are (like Patrick Thubert) using more and more composted sludge in order to produce quality wine.







Côtes du Roussillon reflects the benefits of composted sludge (Hubert Brunet)

Land Reclamation

The following case studies describe four contrasting examples of the imaginative and successful use of sludge as part of carefully designed reclamation strategies for difficult situations.

Reversing desertification in Colorado

The untreated sand dune with a buried fence line in the foreground, there are two more fence lines below that one. (Mike Scharp)

In the 1900s irrigated wheat was grown in the southern Great Plains area of the USA using temperate farming techniques. This ended in the 1930s when severe drought lasted for several years. It resulted in the infamous "dust bowl" wind erosion.

In Southeastern Colorado there are still sand dunes from that period, they are barren and the cause of air-quality and other problems.

Various attempts have been made over the years to establish vegetation to stop the sand blowing so soil formation can happen. Old tyres (to reduce wind speed at ground level) and manure (to add nutrients) were used to try to stabilise the dunes but with very limited success.

In the 1993 dewatered digested sludge from New York City was being shipped westwards by train and it has produced the answer to vegetating and stabilising the dunes. Woodchips were applied at 25 t/ha and then the dewatered sludge at 75 t/ha, which supplied 3000 kgN/ha. The woodchips were used as a source of carbon to trap the nitrogen from the sludge in soil microbial biomass and prevent N-leaching. The 2 materials are incorporated by discing and then seed mixture comprising native and drought tolerant species was sown at just 5 kg/ha. The strategy worked, there has been no increase in nitrate in a borehole about 1 km from the site, the vegetation is healthy 10 years after application and the dunes have been stabilised.

10 years after applying the sludge/ woodchip technique, an area of dune that has been stabilised (Mike Scharp)

Sludge reclaims a waste mountain in Poland

The "White Hill" of phosphogypsum at Wislinka was visible from more than 20km (Piotr Kowalik)

The fertiliser plant at Gdansk imports rock phosphate and extracts it with acid, the waste is phosphogypsum. Phosphogypsum is acidic, and is a source of, amongst other things, toxic sodium fluorosilicate, phosphate and radionuclides. In the early 1990s the factory was producing more than ½-million tonnes/year but this has been reduced by more efficient production and because of reduced demand for phosphate fertiliser by farmers.

It is still rated as one of the 80 most environmentally-dangerous plants in Poland, mainly because of the spoil. Water draining from the heaps is a eutrophication threat to local waters; the dust is a respiratory threat to people and animals.

The Technical University of Gdansk has researched use of liquid sludge sprayed onto the heaps to develop vegetation. Seed

The succession of vegetation has started on the sludge treated surface of the White Hill of Wislinska
Piotr Kowalik)

was mixed in with the sludge. The surface layer of dried sludge stopped wind erosion and the organic matter, moisture and nutrients enabled the seedlings to grow. Their roots were then able to bind the surface and eventually other seeds colonise the stabilised area, which starts a succession of vegetation.

Sludge was the key to creating a prestige business park and golf course from a former landfill in UK

Stockley Park, west of London is a well known example of using organic amendment (in this case air-dried digested sludge) to build topsoil to a defined specification.

Alan Tate, President of the Landscape Institute, presenting the Institute's Design Award in 1995, said Stockley Park is "regarded as the doyen of British Business Parks and a rare example of an entirely man-made landscape that provides a standard for the reclamation of other polluted and derelict land".

The site is more than 100 ha; it was a gravel quarry that had been filled with refuse since the 1940s. Before reclamation work started in the 1980s it was derelict and a source of groundwater pollution.

4.6 million m^3 of fill were excavated to expose 10 ha on which to build the campus -style business park. This fill was contoured over the rest of the site to make a rolling landscape that is mainly used as an 18-hole championship golf course designed by Robert Trent Jones and also lakes, running and riding tracks. The site would have needed more than 300,000 m^3 topsoil, and there was none on site, so it was constructed *in situ* using suitably textured mineral material found during the excavations and 100,000 m^3 sludge. More than 140,000 indigenous trees and shrubs were planted "the establishment of the woodland plantations has been phenomenal and is witnessed by the truly rapid growth rates and the very small number of failures, which is less than 5%. For a landfill site that is simply extraordinary" said Bernard Ede the landscape architect. He also said "the initial scepticism about heavy metals ... proved an unnecessary precaution".

Award winning landscaped business park used sludge to make soil (Tim Evans)

Sludge compost proved the most cost effective for revegetating slopes devastated by forest fire in USA

In May 1996, fire destroyed 4806 ha of Ponderosa Pine and Douglas Fir at 2200 m elevation at Buffalo Creek, Colorado, USA.

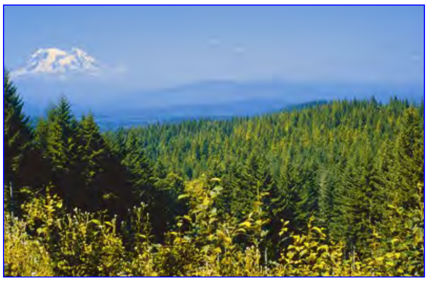
After the fire, rainwater ran off instead of soaking into the soil and streams, that in normal conditions carry <20 m^3/min, flooded with more than 50,000 m^3/min. To develop a strategy for recovering this ecological disaster 24 plots were established to compare the effects of single applications of composted sludge on plant establishment, biomass production, species diversity, chemical quality of plant and soil and runoff quantity and quality. Plots were treated at 0, 5, 10, 20, 40 and 80 t/ha. The compost was disced in and then seed mix was sown. In 2000 the untreated plots had 36% bare soil; this decreased with compost application down to 7% for the 80 t/ha plots. The conclusion was that many kilometres of watershed could be protected by revegetating using sludge but it is expensive to get sludge to Buffalo Creek so it was important to find the optimum rate. A rate of 20 t compost per hectare gave the most effect with the least amount of sludge.

The experimental plots assessing revegetation and showing the effects of increasing rates of sludge-compost application (clockwise from top left) 0, 20, 40 and 80 t/ha (Bob Brobst)

During the earth-moving stage, the business park is in the distance (Tim Evans)

The fire seen from the air (Bob Brobst)

Forestry



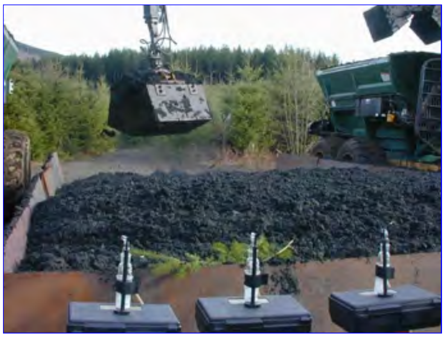
Forests in Washington State have been restored in the "Mountains to Sound" programme using sludge. (NBMA)

Long experience of sludge use in timber plantation in NW America

There has been more experience of using sludge in timber plantations in Washington and Oregon than anywhere else in the world. Others are learning from this experience. One programme is called "Mountains to Sound" (http://www.mtsgreenway.org/EnviroEd/education.htm) which has been a community activity to restore the areas despoiled by the now outdated practice of clear-felling. Sludge is used to enhance the soil to ensure trees establishment.

Dr Charles Henry, Professor of Forest Soils, University of Washington says "Biosolids recycling enhances the productivity of the entire forest ecosystem."

The application technique now favoured is to use modified side-flingers that throw dewatered cake across young trees (obviously this is only acceptable where the public are excluded).



Loading dewatered cake for forestry application (and bioaerosol samplers in the foreground) (Ian Pepper)

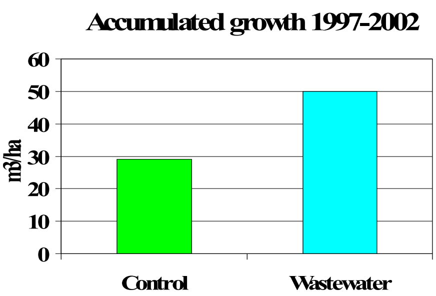
Forestry in Sweden

Professor Kenneth Sahlén at the Swedish University of Agricultural Sciences' Department of Silviculture at Umeå has found a **72% increase in growth of Scots Pine** from fertilising with wastewater at a rate corresponding to 100 kgN/ha.

The Nordic boreal and boreo-nemoral forests are dominated by Scots pine and Norway spruce; traditionally they have been managed at intermediate intensity. The rotation period is fairly long (80-120 years), during which repeated selective cuttings are made, mainly for saw timber and pulpwood. In Sweden there are 23 million ha of production forest; the annual cut is 70-80 million m^3 of wood. The forest sector is very important for the Swedish economy, accounting for an annual export surplus of about €9 billion, which is much more than any other sector. In rural areas, especially in northern Sweden, the forests are the most important raw material resources for employment and economy.

Most commonly the limiting nutrient is nitrogen; fertilisation started in the 1960s and 3.4 million ha have been treated with about 150-300 kgN/ha resulting in an average yield increase of 15-20 m^3/ha during the 10 years after fertilisation. No leaching of N has been found even at 8-times the recommended rate because it is all captured by the roots. Wood ash has also been used to recycle minerals, but the effects are much less than N.

Research testing the use of sludge started in 1996; it is co-funded by the EU's European Regional Development Fund, Finland and Sweden. One motivation for increasing production is to use wood as a renewable energy source, especially the thinnings during the earlier years of a rotation. Environmentally the heavy metal content of sludge is also lower than wood ash (e.g. Cd is only 10% of that in wood ash) and there has been no change in wild berries, fungi or mammals. The indications are that sludge can significantly increase the productivity of boreal and boreo-nemoral forest for renewable timber and fuel.



Growth increase of Scots Pine fertilised with wastewater in Sweden. The experiment started in 1997 and was harvested at the end of 2002. (Kenneth Sahlén)

Tree trunk section when Scots Pine experiment in Sweden was harvested in 2002: the 6 years of increased growth rings are clearly visible (Kenneth Sahlén)

Forestry in France

INRA's sludge application in pine plantations (Jean-Michel Carnus)

INRA, the agronomy research institute in France has set up a multi-partner network of experimental and demonstration sites led by its Director of Forest Research, Jean-Michel Carnus. The purpose is to provide reference and long-term monitoring data to evaluate the benefits and risks of sludge application in plantation forests for wood and biomass production. "This will increase our knowledge and ability to predict sludge fate and behaviour in plantation forest ecosystem and is important to refine system design and monitoring, and facilitate informed dialogue. An increased productivity of 10% per year has been measured in pine plantations growing on poor sandy soils in South-Western France, following sludge applications at low rates".

Frequently Asked Questions

What is the benefit of using sludge on land?

To some extent this depends on the way that the sewage sludge was treated. All types of sludge return organic matter (which was in the food) to the soil where it feeds soil micro-organisms, acts as a reserve of nutrients and water for plants and improves soil structure.

Soil that is better structured is less likely to erode by wind or water, which benefits farmers and the wider environment by reducing water and air pollution, reducing road blockages and flooding.

Sludge contains the whole spectrum of nutrients needed for plants (major, secondary and minor). Some sludges supply lime to correct soil acidity. The amount of other fertiliser needed to complement the nutrients supplied by sludge and bring them up to the crop's full requirements depends on the type of sludge, the crop, the climate and the soil. Nitrogen is supplied by gradual release, which means there is less risk of leaching loss.

All sewage sludges are valuable sources of phosphate and generally supply all of the following crop's phosphate requirements, and possibly subsequent crops as well.

Farmers frequently observe that crops grown on sludge-treated land are healthier and that they therefore need fewer applications of pesticides.

Lime stabilised sludge is an excellent alternative to agricultural lime because it also supplies nutrients and organic matter. It tends to provide less nitrogen than some other types of sludge.

Can I rely on the fertiliser in sludge; is it as good as chemical fertiliser?

The plant nutrient supply from sewage sludge can be just as reliable and predictable as chemical fertiliser but as with chemical fertiliser it is essential to understand the release behaviour for the particular sludge, soil and climate. With this knowledge it can be matched into the recommendations for different crops.

Nitrogen is the most difficult to understand because of the complexity of the nitrogen cycle described earlier in this Guide.

Sewage sludge should supply all of the phosphate and sulphur needs of crops.

Lime stabilised sludge can be a direct replacement for agricultural lime by using the relevant neutralising value.

Some people talk about biosolids – is this different from sludge?

In this guide we have used the term sludge (except when reporting quotations), because that is the word used in legislation. People use 'biosolids' to differentiate sludge suitable for use on land from that which is unsuitable. The word was coined in 1990. Webster's Dictionary and the Oxford English Dictionary define it as *noun* solid organic matter recovered from a sewage treatment process and used especially as fertiliser - usually used in plural.

Different countries have different limits; does that mean some are unsafe?

What to regulate and the values at which to set limits is really a political decision for individual governments. Members of the EU are obliged to set limits that are no less stringent than the sludge directive 86/278/EEC, but they can choose to be more stringent or to add parameters, which some Member States have done. All that we can say with certainty is that the risks have been very intensively researched and independent government committees have reviewed the controls repeatedly; there has been no authenticated case of adverse effect where sludges have been used in accordance with government regulations. Hundreds of thousands of hectares of farmland are treated each year in the EU and the USA and although their regulations have some differences (and also some similarities) there is no evidence that either is deficient or puts the public or environment at risk.

What about heavy metals?

It was to safeguard against past problems and the possibility of adverse effects in the future that 86/278/EEC and the national regulations were introduced.

Sludges and soils are monitored, but the real defence against pollutants has been working with industry to stop metals and other chemicals from getting into the drainage system. This has been so effective (see graphs earlier) that really fears about metals are a thing of the past provided that the cooperation with industry (which is also supported by regulation) is maintained.

Is this true of all chemicals from factories?

Factories are restricted in what they can put down the drain. Their permits to discharge are set so that they do not harm people working in the sewers, the wastewater treatment process, the water body where the effluent is discharged or the land on which the sludge is used. The European Union and national governments have banned chemicals that they considered too dangerous to the environment so they have stopped being used by industry.

Could hormones from human birth-control pills affect livestock?

The evidence from animals grazing thousands of hectares of grassland that have been treated with sludge is that there is no adverse effect on fertility. It is true that women taking contraceptive pills excrete some of the pharmaceutical. Female humans and animals also excrete the hormones they produce naturally – this includes pregnant grazing animals that excrete large quantities [relatively] onto their pastures. In addition there are naturally occurring and man-made substances that affect the endocrine (hormone) system. Legumes such as clover and soybean are quite potent producers of endocrine active substances (EAS), indeed their EAS are used in 'natural therapies'. Overall the net result is that sludge recycling has no measurable effect on endocrine systems.

Wouldn't it be better to have separate sewer systems for factories?

This might sound attractive but it would be a huge expense to build a second sewer network in our established towns and cities and it would be very disruptive to have all the streets dug up. However it is not just a matter of cost and inconvenience, we really don't want a situation where there is an industrial sewer network where 'anything goes' and a domestic network for producing useable sludge. It is much better that factories control their potential pollutants at source.

I have read that cadmium is a big problem and if the content in food doubled it would be dangerous, does this mean we should be very worried about cadmium?

If the cadmium content of the average diet were to double it could indeed be dangerous but the fallacy of the proposition is that, the way that crop uptake from soil works, it could not happen even if all the soil were at the limit concentration specified in the sludge directive 86/278/EEC.

Tobacco smokers are a special case because tobacco takes up more cadmium than other plants and when the leaf is smoked the cadmium is vaporised and then absorbed through the lungs. Smokers' kidneys contain twice the concentration of cadmium compared with non-smokers, however it is not cadmium poisoning that kills smokers.

Because of environmental concerns there is far less cadmium used by industry than in the past (alternatives are used) in addition those that do use it have been targeted to reduce their discharges. The ratio of cadmium to phosphate in sludge is now comparable to the limits being considered for fertilisers. When sludge is used on land to recycle phosphate it also recycles 'old' cadmium; if phosphate fertiliser were used instead of sludge it would bring 'new' cadmium into the anthropogenic cycle. The limits in the sludge directive protect against adverse effects of cadmium.

What about disease?

There are certainly likely to be disease causing organisms (pathogens) in untreated sewage sludge, but treatment reduces their numbers in some cases to levels that are similar to normal soil. The sludge directive (86/278/EEC) has rules about the types of crops that can be grown and the time delay between sludge application and planting, harvesting or letting grazing animals into a treated field. Of course pathogens die off naturally in the environment; otherwise we would be overrun with them. There are no authenticated cases of disease transmission (to humans, animals or plants) where sludges have been used in accordance with the sludge directive.

What about AIDS and BSE?

Thousands of samples of wastewater, faeces, urine, raw and treated sludge have been tested to try to find HIV (the virus that causes AIDS). None has ever been found. HIV has even been seeded into these samples and it has been found that it cannot survive. So the answer is that AIDS cannot be transmitted in sludge.

Prions, the abnormal protein that is the agent for transmission of BSE (mad cow disease) is not excreted by infected animals, so it is not in the dung. Prions are contained in the brain, spinal cord and other ‘specified risk material’ (SRM). Abattoirs are required to remove this SRM from carcasses and destroy it. There is a risk that, even with care, some fragments of SRM might fall on the floor and be washed out; abattoirs are required to put fine screens on their drains to ensure that no SRM could get into sewers.

The risk of BSE transfer via sludge has been controlled as part of the overall requirements of the EU Animal by-products regulation (1774/2002).

Scientists did not know about DDT, BSE, asbestos, etc. how can we be sure there isn't something in sludge they don't know about?

That's the hardest question because we can never be sure that we know everything about anything. However we have learnt from each of these major issues and as a consequence the checks and balances have got better and better.

As has been said before there have been many studies looking for negative effects but none has been proved under the conditions required by current controls on sewage sludge use on land. There are probably 50,000 references in the scientific literature, and more are being publish all the time. This guide discusses the hazards and more information can be found in the sources listed in ‘Further reading and information’. If there were something else out there it is almost certain that one or more of these researchers would have found it.

Wouldn't it be easier to incinerate all the sewage sludge?

That would be possible and it would be easier for the wastewater treatment works, but there would be significant effects of such a policy which should be considered.

We would lose the phosphate (P), which is a finite and essential resource, unless P-recovery were mandated, but the cost is 6-times the current market price for P. The economic reserves of P are predicted to have a life of only 100 years.

We would also lose the other benefits, including reduced pesticide use, reduced risk of soil erosion, sequestering carbon in soil rather than converting it to greenhouse gas and improved life in the soils. If all of the EU’s sludge production were burn it would yield about 11 million tonnes CO_2 per year.

In addition there would be more truck traffic moving sludge from the smaller wastewater treatment works to the incinerators because you cannot make small sludge incinerators that would comply with the air emissions requirements. This would contribute to congestion, traffic accidents and vehicle emissions including CO_2.

Incineration would cost twice as much as recycling, even more if there were P-recovery from the ash. This cost would be passed to the water-bill payers.

What does the food industry, supermarkets etc. think about it?

Most food companies and retailers have a strong commitment to environmental irresponsibility and sustainable development. Some have been strong supporters of environmental and animal welfare initiatives such as integrated farm management.

One or two companies in some countries have said they won't buy produce from sludge treated land. When pressed they admit this is not based on any technical reason but because of what they think their customers might think. When we look at the technical issues we see that, whatever they are, they are shared (maybe in different degrees) by farm animal manures and composts. The use of all of these organic resources is part of sustainable development and when that minority of purchasers is seen in this context it is obvious that their policies are based on narrow commercial interests and that they are contrary to sustainable development.

It is vital that in our integrated society we discuss these subjects, share information, build mutual trust and understanding and develop consensus on practices that are welcomed by all in the food chain. Farm assurance schemes have no problems with sludge used in compliance with the regulations and trade associations recommend their members to take a similar approach.

What about smell, and if it does smell does that mean it is a health risk?

Nearly everything smells of something but it should be possible to treat sewage sludge and/or apply it so that it is not a nuisance. When liquid sludge is injected there should be little or no odour. It is possible to eliminate noxious odours by sludge treatment. If dewatered sludge has noxious odour it should be incorporated into the soil as quickly as possible and it is possible to spray stabilising solutions at the same time as the dewatered sludge is applied so as to reduce odour during the interval until it is incorporated. Odour from stockpiles can be eliminated by covering.

Even if sludge does smell objectionable it does not indicate that there is any greater disease risk. The miasma theory of disease was proposed in the early-nineteenth century based on the concept that internal diseases were caused by miasmas, or noxious odours and was only replaced by the bacterial theory with difficulty. The miasma theory was the main motivation for managing sewage and garbage, but we now know that smell is not equivalent to disease.

However some odorous chemicals (odorants) can have physiological health effects if the concentrations are high enough and a few individuals are ultra-sensitive to some odorants. It is extremely unlikely that the concentrations of odorants from sludge use in agriculture would have physiological effects; nonetheless odour can be a nuisance and practices should be modified to control it.

Further reading and information

ADEME Les Boues d'Epuration Municipales et Leur Utilisation en Agriculture http://www.acta.asso.fr/prodetserv/boues1.htm http://www.ademe.fr/partenaires/boues/default.htm

Australian Water Association. Biosolids management. http://www.awa.asn.au/NSIG/bio/index.asp

CEC (2000) *Communication from The Commission On The Precautionary Principle* COM(2000) 1 final http://europa.eu.int/eur-lex/en/com/cnc/2000/com2000_0001en01.pdf Brussels, 2.2.2000

Codex (1997) *Basic Texts On Food Hygiene* Codex Alimentarius, FAO, Rome. June 1997 http://www.fao.org/DOCREP/005/Y1579E/y1579e03.htm#bm3

Commission of the European Communities (1986) Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC). *Official Journal of the European Communities*, NoL181/6-12.

Council of the European Communities (1991) Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC). *Official Journal of the European Communities*, NoL135/40-52.

European Commission websites
sewage sludge - http://europa.eu.int/comm/environment/waste/sludge/index.htm
soil policy development - http://europa.eu.int/comm/environment/soil/

European Communities (2001) Pollutants in urban waste water and sewage sludge. Prepared by ICON for DG Environment. ISBN 92-894-1735-8 http://europa.eu.int/comm/environment/waste/sludge/sludge_pollutants.pdf

Evans, T.D. (2003) *Hazard Analysis and Critical Control Point (HACCP) for Composters.* ISBN 0-9532546-6-6The Composting Association, Wellingborough, England

Foundation for Water Research—Reviews of Current Knowledge (ROCKs) http://www.fwr.org/
"Eutrophication of fresh waters. April 2000,"
"Sewage Sludge Disposal - Revised and updated December 2002"
"Endocrine Disrupters in the Environment - Revised and updated July 2002"

Halliday, S. (1999) The Great Stink of London, Sir Joseph Bazalgette and the cleansing of the Victorian metropolis. Sutton Publishing ISBN 0 7509 2580 9

Musée des Egouts de Paris (Museum of the Sewers of Paris); Pont de l'Alma (Place de la Resistance); facing 93 Quai d'Orsay, 75007 Paris; http://www.paris.org/Musees/Egouts/

National Biosolids Partnership www.biosolids.org

New England Biosolids & Residuals Association http://www.nebiosolids.org/intro.html

Northwest Biosolids Management Association http://www.nwbiosolids.org/

Orange County Sanitation District Biosolids program http://www.ocsd.com/info/biosolids/default.asp

Reid, D. (1991) Paris sewers and sewermen: realities and representations. Harvard University Press ISBN-674-65463-3 London

Smith, S. R. (2000) Are controls on organic contaminants necessary to protect the environment when sewage sludge is used in agriculture? Progress in Environmental Science **2** 129-146

Smith, S.R. (1996) Agricultural recycling of sewage sludge and the environment. CAB International, Wallingford, England.

Sustainable Organic Resources Partnership www.sorp.org

Syndicat des Professionels du Recyclage en Agriculture SYPREA http://www.syprea.org/

TERRA ECO·SYSTEMS http://www.terraecosystems.com/

The Potash Development Association. Biosolids & the need for Potash. http://www.pda.org.uk/leaflets.html

Tracking down the roots of our sanitary sewers http://www.sewerhistory.org/

UKWIR (2003) Gale, P. *Pathogens in Biosolids - Microbiological Risk Assessment*. Report ref. 03/SL/06/7. ISBN: 1 84057 294 9 UKWIR, London

Water UK (2003) Recycling of Biosolids to Land - briefing pack http://www.water.org.uk/system/markup_grab.php?id=2010


MAR 19 2003

Additional sources of information

Austria

Horst Müller, Müller Abfallprojekte GmbH, Hauptstr.34, A-4675 Weibern. email: horst.mueller@tb-mueller.at
Michael Pollak, wpa Beratende Ingenieure GmbH, Lackierergasse 1/4, A - 1090 Wien
email: michael.pollak@wpa.at
Austrian Water and Waste Management Association, email: buero@oewav.at http://www.oewav.at,
Gerhard Spatzierer, head of OEWAV sludge working group, email: Gerhard.Spatzierer@bgld.gv.at

Belgium

Raf Verlinden, OVAM, Stationsstraat 110, 2800 Mechelen email: raf.verlinden@ovam.be

Denmark

Dr Svend-Erik Jepsen, Danish EPA, Standgade 29, Copenhagen DK-104 fax: email: sej@mst.dk

Finland

Juhani Puolanne, Head of Wastes & Waste Management Unit, Pollution Prevention Division, Finnish Environment Institute, PL 140, Helsinki PB 140, Helsinki FIN-00251 email: juhani.puolanne@vyh.fi

France

Mme. Catherine Seguin, ADEME 2 square La Fayette, BP 406, 49004 Angers Cedex 01 email: catherine.segin@ademe.fr
Hubert Brunet, SEDE, 5 rue Frederic Degeorge, B.P. 175 - 62003, ARRAS CEDEX email: h.brunet@sede.fr

Germany

Susanne Klages, KTBL, Bartingstraees 49, D-64289 Darmstadt, email: s.klages@ktbl.de
Rainer Könemann, hanseWasser Bremen GmbH, Kundenbetreuung, Schiffbauerweg 2, 28237 Bremen
email: koenemann@hansewasser.de www.hanseWasser.de

Greece

Prof. Andreas Andreadakis, Department of Water Resources, Faculty of Civil Engineering, NTUA (National Technical University of Athens) 47-49 Bouboulinas, Ag. Paraskevi, Athens email: andre1@central.ntua.gr
Dr.-Ing. Constantinos Xanthopoulos, Psyttalia Wastewater Treatment Plant, Athens e-mail: xanthopoulos@psyt.gr
Dr. Katia Lasaridi, Harokopio University, 70 El. Venizelou, 176 71 Kallithea, 176 71 Athens, email: klasaridi@hua.gr

Italy

Dr. Fabio Tittarelli, Ricercatore - Sezione di Nutrizione Azotata e Microbiologia del Terreno, Istituto Sperimentale per la Nutrizione delle Piante, via della Navicella 2 - 00184 Roma email: f.tittarelli@isnp.it

Poland

Prof. Piotr Kowalik, Gdansk University of Technology, email: pkow@pg.gda.pl

Portugal

Marta Carvalho, Reciclamas, Av. Liberdade, 110, 1269-042 Lisboa email: marta.carvalho@adp.pt

Spain

Francesc Camps or Jordi Salvia, Estació Experimental Agrícola Mas Badia, E- 17134 - La Tallada d'Empordà, Catalunya email. francesc.camps@irta.es or Jordi.Salvia@irta.es
Roman Llagostera Pujol, Biosolids and Biowaste Recycling Manager, SEARSA, Bruc, 49, 1º,1ª E-08009- Barcelona email: rllagostera@searsa.com
Lluís Sala, Consorci de la Costa Brava, Plaça Josep Pla 4, 3er 1a, E-17001 Girona, email: lsala@ccbgi.org
Dr Josep Saña Vilaseca, Tècniques de Gestió Ambiental SL, c/ de la Creu 30, 08960 Sant Just Desvern, Barcelona email: tgasl@wanadoo.es

Sweden

Peter Balmér, Gryaab, Karl IX:s väg, 1834 Göteborg, email: peter.balmer@telia.com

UK

Dr Mark Aitken, SAC, Auchincruive, Ayr, KA6 5HW, Scotland email: M.Aitken@au.sac.ac.uk
Prof. Brian Chambers, ADAS, Gleadthorpe Research Centre, Meden Vale, Mansfield, Nottinghamshire, NG20 9PF email: brian.chambers@adas.co.uk
Jeremy Hall, Bryn Cottage, Highwood Bottom, Speen, Princes Risborough, HP27 0PY. email: sludge.hall@virgin.net
Dr Stephen Smith, Director, Centre for Environmental Engineering & Waste Management, Civil Engineering Department, Imperial College, London SW7 2BU email: s.r.smith@ic.ac.uk
Dr Tim Evans, TIM EVANS ENVIRONMENT, Stonecroft, Park Lane, Ashtead, KT21 1EU email: tim@timevansenvironment.com
Steve Ntifo, Water UK, 1 Queen Anne's Gate, London SW1H 9BT email: SteveN@water.org.uk

Norway

Dr Line Diana Blytt,Norwegian Agricultural Inspection Service, Box 13, As, N-143. email: line-diana.blytt@slt.dep.no

Australia

Leonie Huxedurp, Environmental & Legislative Reform Coordinator, Town Water Treatment & Recycling, NSW Department of Land & Water Conservation, L3 Macquarie Tower, 10 Valentine Ave, Parramatta NSW 2150, email lhuxedurp@dlwc.nsw.gov.au

Peter Ryan, Program Manager, Assessment and Advice, Resource Quality Branch, Hyatt Centre, Water and Rivers Commission, Western email: peter.ryan@wrc.wa.gov.au

USA

Eugene DeMichele, National Biosolids Partnership, 601 Wythe Street, Alexandria, VA 22314-1994, email: edemichele@biosolids.org www.biosolids.org

Dr Bob Bastian, Senior Environmental Scientist, Office of Wastewater Management (4204M), US EPA, Ariel Rios Bldg. -- Rm.7220B ICC Bldg. (EPA EAST), 1200 Pennsylvania Ave., NW, Washington, D.C. 20460, email bastian.robert@epamail.epa.gov

Dr Rufus Chaney, USDA, Agricultural Research Service, Room 013, 10300 Baltimore Blvd, Bldg 007 BARC-West, Beltsville, MD, 20705-2350 email: chaneyr@ba.ars.usda.gov
email: rchaney@asrr.arsusda.gov

Dr Patricia D. Millner, Sustainable Agricultural Systems Laboratory , USDA, ARS, Room 122, 10300 Baltimore Blvd, Bldg 001 BARC-West, Beltsville, MD, 20705-2350 email: millnerp@ba.ars.usda.gov

TIM EVANS
ENVIRONMENT