MANURE MANAGEMENT AND TREATMENT: AN OVERVIEW OF THE EUROPEAN SITUATION

José Martinez*, Colin Burton

Cemagref, Livestock and Municipal Waste Management Research, CS 64427,
17 avenue de Cucillé, 35044 Rennes Cedex, France. E-mail:jose.martinez@cemagref.fr
Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, UK.
E-mail:colin.burton@bbsrc.ac.uk

Summary

Livestock agriculture in Europe has developed into an efficient industry over the latter half of the twentieth century. However, the prospects for the future are marred by an increasing number of environmental problems (e.g. water, air and soil pollution) that stem from the large quantities of manures produced within several intensively farmed regions. Existing guidelines do encourage better handling of manures treating them as *resource management* rather than a *disposal problem*. However, this approach does not always offer a complete solution, especially where the amounts of manure exceeds the local requirement. Even when there is no overall excess, optimal land spreading may not be practical and there may be still problems from odour nuisance or disease risks.

Farms tend to be highly individual; consequently, the best systems to handle the various manures produced will tend to be specific to each farm, reflecting the local situation. Likewise, no single treatment process can be put forward as a universal solution. Treatment technology has a clear role in the management of livestock manure in enabling a more flexible approach to land spreading and in dealing with some specific problems. It includes many processes often including a biological and physical step and sometimes the use of chemical additives as well. Some of these systems are already in current use on the larger farms (*e.g.* separation and composting systems, anaerobic treatments and the use of aeration to reduce nitrogen surplus and offensive odours). Other systems are very much at the research stage (*e.g.* thermal processes and the production of organo-fertilizers) but may ultimately be part of the solution.

The environmental benefits of better manure management, will only be fully realized if there is a broad uptake of such techniques in the key areas.

1. INTRODUCTION

Traditional agriculture across Europe involved close integration of livestock and arable activity in small family farms. The value of the manure was readily recognised; indeed until this century, this offered the only method of enriching the soil. The development of modern farming which has brought large improvements to the efficiency of production has also brought with it specialization. This has not only led to farms concentrating on one or two activities, but to whole regions being developed around the production of one type of foodstuff. The consequence of this has been the inevitable separation of livestock farming (and the manure it produces) from arable farming, which more often makes use of inorganic fertilizer to meet the needs of the crop being produced (Schröder, 2002; Giller et al., 2002). With relatively limited local application of livestock manures, it is perhaps not surprising that it has become increasingly seen as simply a *waste product*.

The problem of manures of increasing concern are emissions to air (eg, ammonia, nitrous oxide and methane) and water pollution through the mechanism of leaching. There is some evidence of soil pollution especially where repeated heavy doses of manure are applied (Jonbloed & Lenis, 1998). Disease risks, both to the livestock and the general public, are now also matters of concern.

In response to these manure handling problems, guidelines and regulations to encourage better farming practice have been introduced in many countries across the EU. There clearly is scope for some improvement simply by focusing attention on manure management and encouraging a more organised and better thought out approach. However; there is likely to be a limit to what can be achieved or implemented, unless there is a broader plan which looks at the whole farming system, for example, following guidelines may not be enough for a livestock farm that fundamentally lacks enough land to receive all of the manure produced. Applications amounting to manure in excess of the capacity of the environment can only end up as pollution of one sort or another. Furthermore, even if the local land has a theoretical capacity to receive the applied manure, the related pollution problems may not be eliminated; a range of other factors must be observed including timing and evenness of application. For some farms, the real solution comes down to *removing the surplus*.

It thus may be an unavoidable reality that beneficial use of all of the nutrients in the manure is not practical. The strategy in such case then shifts to one of reducing the strength of the manure by removing some or all of its nutrient content; *e.g.* the removal of some of the ammoniacal nitrogen (as di-nitrogen gas) or the organic load (as a sludge).

The purpose of this paper is to explore the subject of manure treatment and its appropriate role in livestock agriculture.

2. MANURE MANAGEMENT ACROSS EUROPE

2.1 Livestock farming systems

Total animal production (slaughter) in EU countries for the main livestock categories now accounts for 15% of the world total, with pig meat being the most important (20% of world production) (Aumaitre, 2001).

Livestock farming systems vary from country to country, and sometimes from region to region as well, due to the range of landscape, climate and cultures within Europe.

Farming systems for cattle falls into three main groups: veal, beef and milk production. The opportunities for waste management are greatest with cattle kept indoors for at least part of the year. In many European countries, liquid manure systems are dominant especially for veal and beef production. Farms systems using bedding (and producing solid manure) are more common in Scandinavia, France and many Eastern European states.

Pigs respond adversely to extreme climatic conditions: cold dramatically decreases the food conversion ratio of growing finishing animals and hot weather disturbs reproductive performance. Pigs are generally raised in indoor housing with manure collected mostly as slurry. Only in the UK, Norway and some Eastern European countries is there a significant proportion of solid manure from pig farming.

Poultry production systems, from a manure management point of view, can be broadly classified into egg production (laying hens) and meat production (*e.g.* broiler, turkey, ducks etc). Housed systems, can be divided into caged systems (*e.g.* battery for egg production) and non-caged systems (*e.g.* deep litter or aviary systems). Deep litter systems are usually ventilated and thus produce a very dry material (poultry manure).

Other farmed animals include sheep, goats, horses and a variety of specialist activities. Of these, by numbers alone, it is sheep that represents the most important animal type but there are also large numbers of goats especially in the Mediterranean lands.

For animal welfare and economic reasons, outdoor production of most types of farm animal is increasing. The UK has seen the most significant increase in outdoor units for pigs over the last few years, from less that 6% prior to 1975 to about 20% at the present time. A similar increase in popularity has also been seen in France, where outdoor production now accounts for about 10% of sows.

2.2 Manure production

Broadly, we can distinguish three waste categories :

- *Liquid manure.* (slurry) Housing system collecting all excreta in liquid form; the animal are kept on sloping solid floors that are regularly swept clear of any excreta. Some dilution can be expected from wash water;
- *Mixed manure.* Housing systems producing solid and liquid manure streams; animals are kept on bedding material, but liquids are drained from the bedding and collected elsewhere;
- *Solid manure.* Housing types producing only solid manure; animals are kept on bedding material which is collected together with all excreta as solid or farm yard manure (FYM).

When designing outside effluents stores, rain water intake must be considered in addition to the estimated slurry volumes (Table 1).

Animal	Body weight (kg)	Manure produced per animal over 6 months (m^3)	Dry matter content of manure (kg/m^3)
Dairy cow	550	9.7	100
Beef cattle >2 years	500	5.8	100
Beef cattle 1-2 years	400	4.8	100
Beef cattle 0.5-1 year	180	2.4	100
Sow plus litter	200	2.0	60
Pig (dry ration)	35-105	0.8	100
100 Laying hens	220	2.1	300
100 Broilers	220	1.1	600

Table 1. *Typical amounts of liquid manure produced by different farm animal breeds excluding water added form various sources. Design capacity of store will depend on the final concentration of effluent*

2.3 Storage of manure

Liquid manure/slurry is mostly stored in concrete tanks. Lagoons and lined ponds are especially reported from Greece, Italy, Spain, Portugal. The tanks are mostly uncovered, except in Finland, Netherlands and Switzerland. The storage capacity for liquid/manure/slurry is around 6 months in many countries, longer especially in Scandinavian countries and shorter in some Southern and East European countries. For solid manure the storage capacity varies from 2 to 12 months. Storage is also a mode of treatment, because it enhances the timeliness and convenience of disposal. In a recent review of the subject, Nicholson et al. (2002) examine the likely environmental effects of different storage methods, and provide some recommendations for the most desirable options.

2.4 Transport and land spreading of manure

Moving surplus livestock wastes away from regions with intensive livestock activity represents a seemingly simple solution to the environmental problems caused by nutrient excess. The Netherlands have developed a sophisticate system for distribution, control and accounting of manure from the southern parts of the country to the less livestock intensive northern parts. Transport of manure is also reported from countries where the organic components of the manure are in high demand as a soil improver (*e.g.* Portugal and Spain).

Slurry spreading machines (suitable for spreading material with less than 10% dry content) are schematically made up with a tank and equipment to raise stem, regulate the dosage and spread. The various design characteristics depend on the way slurry is put under pressure. In fact such an operation can be performed by letting air into the tank (slurry spreading machine with pressure tanks) or by acting directly on the slurry by means of positive displacement and centrifugal pumps. A number of improved spreading systems are available, in particular trailing hose and injection. Low level application systems allow slurry to be released directly onto the soil surface. Consequently odour emissions and losses of ammonia can be kept under control.

3. ENVIRONMENTAL IMPACTS OF LIVESTOCK MANURE

The turnover of nutrients and other materials within agricultural systems is much greater than in natural ecosystems and the potential for loss of environmentally active agents (pollutants) becomes correspondingly greater. In most instances agriculture acts as a "diffuse" source, in other words, relatively low rates of loss or emissions take place from large areas of land into waters or the atmosphere. On occasion, agriculture may also act as a "mini" point source where high rates of loss occur from relatively small areas as for example spillages or seepages from stored materials. Table 2 lists the key issues of current interest. Many of these are related to one another, and as a consequence, factors influencing the release and transfer of one constituent will almost certainly have interactions with others.

Environmental Concern/issue	Environmental and other impacts	Scale of agricultural contribution	Scale of impact
Nitrate (NO_3^-)	Water quality . Eutrophication . Health Economic . loss to farmers . cost of removal	Major source	Local: on-farm surface waters. Regional: surface waters; catchment; aquifers National/international: maritime waters
Nitrite (NO_2^-)	Water quality . fish stocks and health	Major source	Local: on-farm surface waters. Regional: surface waters and wells.
Ammonia (NH_3)	"Acid rain" . acidification of soils . eutrophication of natural systems Direct toxicity	Major source (>85%)	Local: on-farm deposition. Regional: deposition on natural ecosystems National/international : cross boundary transfer of NH_3 and deposition

Nitrous oxide (N_2O)	Greenhouse gas . global warming Ozone interactions	Substantial (likely to increase in importance as other sources decrease)	Global
Nitric oxide (NO)	Tropospheric ozone precursor	"minor" ?	Global
Phosphorus (P)	Water quality . eutrophication Health . toxins from algal bloom Economic . cost of removal	Substantial – increasing as industrial point sources decrease	Local: on-farm surface waters Regional: surface waters, catchments National/international: maritime waters (cross boundary transfer)
Methane (CH_4)	Greenhouse gas Global warming	Substantial	Global

Table 2. *Key environmental concerns derived from agriculture*
(From Numalec book, De Clercq et al. 2001).

3.1 Nitrogen efficiency in global animal production

Nitrogen plays an important role in animal production because it is essential for the production of meat, milk, eggs and wool. Livestock production has shown a steady increase world-wide as a result of an annual increase of 1.4% in developing countries and 0.9% in developed countries during the period 1960-1990. Cereals form the major feedstuff world-wide. The current global use of cereals for feed is about 57% in developed countries and 17% in developing countries. Assuming that world-wide 30% of the total trade of cereals, 21% of starchy roots, 18% of pulses and 3% of oil crops are used as animal feed, the total trade in feedstuffs thus represent 4 to 8 x 10^6 tonnes of N. Based on N contents in meat (2.5%), milk (0.5%) and eggs (2%) the global livestock production contains roughly 12 x 10^6 tonnes N. The global N excretion by animals is about 102 x 10^6 tonnes N per year. Therefore, the global N intake by animals is 114 x 10^6 tonnes N per year, yielding an efficiency of N use of only 10%. If we consider the global agricultural sector as one huge farm, the N budget shows that the quantity of animal manure N generated is much higher than the amount of fertiliser used, while that removed in products for human consumption is only 20 x 10^6 tonnes. An additional 30 x 10^6 tonnes is exported, primary as grain and animal feed (Van der Hoek, 2001). Although animal manure is recycled to cropland, up to half of the manure N may be lost to the atmosphere as NH_3 prior to its incorporation into soil.

3.2 Health issues related to manure management

Animal manure and slurries contain a variety of different pathogenic micro-organisms, e.g. bacteria, including *Salmonella spp*., *Campylobacter spp*. And *E. Coli* O157, parasitic protozoa including *Cryptosporidium parvum* and *Giardia Lamblia*, and viruses. The recycling of these wastes to agricultural land thus creates the risk of enteric pathogens contaminating the environment, entering the food chain, or infecting livestock.

Health issues from livestock waste management cover four main areas of impact: public health concerns, livestock health, farm staff health and food quality. Arguably, there is also a small risk to the wider environment especially disease in fish and water based animals but these are poorly understood due to the lack of clear data.

Evidence for public health consequences from livestock wastes is variable and, in many cases, difficult to evaluate owing to the emotions caused by the subject and the wide number of other variables that confuse the picture. The main mechanism arises from land spreading practices especially where aerosols are likely to be formed. Often the characteristic offensive odour is believed to also carry a risk to health but evidence to link the transfer of specific disease agents by this mechanism is virtually none existent.

Whilst the direct disease risk to the general public form manures is extremely small but often the subject of emotional debate, that to the stockmen is very real indeed. This arises from the close proximately with the animals themselves (including emissions within the farm building) and frequent contact with manure. A wide range of health and safety material has been produced with respect of farm staff and it is this that can achieve the best reduction of health risk. In this context, manure management is unlikely to greatly improve the situation *on farm* but good containment and the avoidance of open channels is advised.

In the future, further restrictions can be expected unless the use of manure (including treatment) is demonstrated as safe in the context of satisfying public opinion (Turner & Burton, 1997).

3.3 Environmental Legislation in Europe

Most European countries have similar regulations regarding livestock farming including (i), licensing required for housing animals, (ii), storage of manures and slurries to enable a better agronomic utilization and (iii), prohibited periods for land spreading (usually the winter months of November to February). There are however some differences between countries (and even between regions of the same country) as a consequence of the local situations. A common pollution concern is nitrate contamination of water, but in most countries there are other pollution issues as well eg, ammonia emission (in the Netherlands) and odour nuisance (in UK and Greece).

The Nitrate Directive

The most important directive concerning the loss of nutrients from agricultural sources is included under this heading, i.e. directive 91/676 concerning the protection of waters against pollution caused by nitrate from agricultural sources.

After identifying polluted waters, Member States must have designated the catchment areas draining into the polluted waters as vulnerable zones by the end of 1993. The monitoring of waters for nitrate and the review of the eutrophic state of waters must be repeated every 4 years.

Under the Nitrate Directive, Member States had to establish action programs for vulnerable zones with the purpose of meeting the objective of reducing and preventing nitrate pollution. It is the responsibility of each Member State to set limits appropriate to their vulnerable zones; there is no specific limits set in the Directive. However, the action programmes must include measures to ensure that, for each farm or livestock unit, the amount of livestock manure applied to land each year (including by animals themselves) shall not exceed 170 kg N per hectare. This corresponds to a limit of 2 LU per hectare.

Integrated pollution control

Integrated pollution control (IPC), as a principle of environmental protection and management, aims to minimize the overall environmental impact of human activities by taking into account pollution of air, water, land and the human environment, and identifying the action that causes on balance the least damage. As a legal system, IPC has been adopted by the European Union and, with an extended remit, been put in force as integrated pollution prevention and control (IPPC). IPPC covers intensive animal rearing for farms with a capacity of greater than 40,000 animal places for poultry, 2000 for fattening pigs and 750 for sows. New farms and those with extensive modifications have to comply immediately whereas existing farms will have to do so by 2007.

Care has been taken to point out not only the advantages of certain techniques, but also their potential disadvantages, necessary follow-on action, and cost. This was so in order to promote «integrated» manure management, which aims to avoid waste (and if this is not possible make best use of it) and to take a holistic approach at protecting the environment. Such integrated manure management has advantages in environmental protection over non-integrated management. This is because non-integrated manure management may look at single effects only (e.g. pollution of water due to nitrogen content of slurry) and fail to consider other effects (e.g. pollution of air with ammonia from air stripping of slurry). However, there are cases when integrated management is not only desirable but also a compulsory legal requirement.

4. TREATMENT TECHNOLOGIES BASED ON AEROBIC TREATMENT

The essential prequesite for every aerobic treatment system, being either designated for the decomposition of liquid or solid biomass is to maintain a sufficient air supply for the microbes. Adequate aeration in liquid effluents (slurries) involves dissolving enough oxygen into the substrate in order to replace an anaerobic system (chemically reducing) with an aerobic environment for microbial activity (Burton, 1992). As a result, organic matter, characterised by BOD (biochemical oxygen demand), is rapidly oxidised to relatively harmless products such as carbon dioxide and water.

Aerobic treatment can be divided into psychrophilic, mesophilic and thermophilic processes. While psychrophilic processes (below 20°C) show a very slow carbon degradation and no nitrification, they are not taken into further consideration. Mesophilic systems are working in a temperature range of 20 to 40°C, thermophilic processes achieve temperatures above 45°C. For mesophilic proceses the BOD load of the system should not exceed 1-2 kg $BOD_5/(m^3$ reactor volume). For the maintenance of aerobic conditions the redox potential should be at minimum +100 mV and the oxygen concentration should be above 0.5 mg/l. Mesophilic treatment can be divided into short and long time aeration processes with low and high aeration rates Several manure systems with different characteristics have been tested in practice. The main types of aeration systems can be divided into (i) pressure aeration (e.g. bore pipes, disk diffuser, tube diffuser), (ii) suction aeration (venturi, turbojet) and (iii) surface aeration. The selection of a suitable aeration system depends on several factors including:

- investment costs;
- specific energy consumption (kWh/m^3 of throughput) and oxygen transfer efficiency (kgO_2/kWh);
- treatment aims (e.g. odour reduction, stabilisation, nitrogen removal, disinfection);
- amount of manure to be aerated.

Aerobic treatment with aeration periods of more than three days lead to nitrification processes which result in an accumulation of nitrite and nitrate. Nitrite and nitrate can be used by micro-organisms under oxygen limiting conditions as an oxygen source for de-nitrification processes. This process results in a di-nitrogen (N_2) emission and only under unfavourable conditions in a nitrous oxide formation and is therefore suited to reduce a nitrogen surplus. The efficiency of denitrification is depending on a quantitative oxidation of ammonia and a sufficient concentration of easy degradable carbon sources.

Béline et al. (2002) monitored three typical pig slurry pilot plants mainly based on aeration and found a nitrogen removal in gaseous forms between 62-72% of the total nitrogen of the raw slurry: between 8 and 10% of the total nitrogen of the raw slurry was contained in the solid phase from mechanical separation, while 2-7% and 20-29% were located in the liquid effluent and sludge respectively (Fig.1).

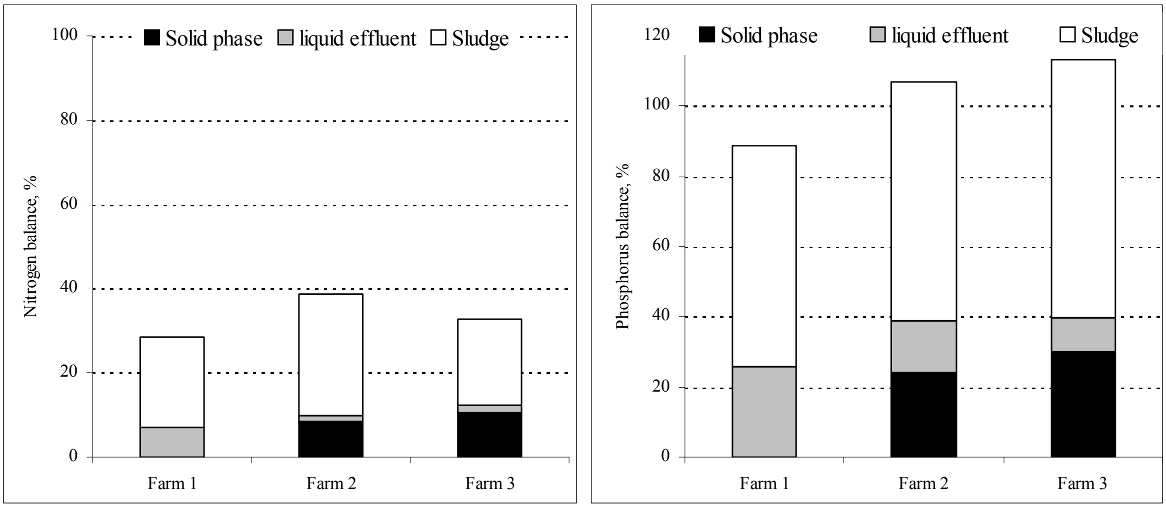

Figure 1. *Nitrogen and phosphorus balance between input and output of three farm treatment units (aerobic treatment) in France, Brittany.*

For phosphorus, between 25 and 30% of phosphorus was found in the solid phase while 10-25% and 63-73% were located in the liquid effluent and the sludge respectively.

If higher temperatures are held in animal slurries, pathogens can be inactivated. To obtain a secure pathogen control by means of intensive aerobic treatment it is essential that the substrate is rich in easily metabolisable nutrients and energy carriers and that the heat generated by the intensive metabolism is not wasted (e.g. by insulation of the reactor). The aerobic thermophilic is a potential option for the sanitation of animal slurries and other liquid wastes. *Salmonellae*, *Escherichia coli* and other *Enterobacteriacae* are sensitive to temperatures above 45°C (Doll, 1999). Under these conditions aeration times of 48h are sufficient for inactivation. Viruses that cause Aujesky disease can be inactivated at 50°C within 48h aeration (Böhm et al. 1980).

Treatment of solid material-composting

Animal manures, except poultry substrates, generally have low contents in plant nutrients but are characterised by relatively high shares of organics in the dry matter. Composting is therefore a good way to improve the fertilising value of animal manures by concentrating the mineral nutrient fraction and by transforming the organic matter into quite stable humus substances in a ripening process.

The application of composting processes in the livestock production sector seems to be advisable for a number of reasons:

- volume and mass reduction of manures due to decomposition of organic matter by emitting carbon dioxide and due to water losses;
- inactivation of weed seeds and pathogens;
- blending of organic material with manures, but also with additional mineral nutrients to create a balanced product for soil improvement or to create a special potting substrate or peat substitutes;
- enabling the export of surplus nutrients in a drier, stabilised, concentrated and deodorised form to areas of demand.

A range of composting systems have been developed which have evolved to serve the needs of various types of substrates and treatment circumstances. These systems can be categorised on a scale ranging from low to high levels of technical sophistication. The four broad types of composting systems can be described as:

- passive aeration;
- windrow/mechanical agitation;
- forced aeration/aerated static pile;
- in-vessel systems i.e. composting reactors.

5. ANAEROBIC TREATMENT OPTIONS FOR ANIMAL MANURES

Anaerobic digestion is one of the most important treatment measures available for animal manure and other organic wastes. It is a common technology for the purification of municipal and industrial waste waters which not only allows to reduce the environmental impact of the problematic substrates, but which also allows to produce a quite universal energy carrier, methane. The use of anaerobic fermentation for waste treatment is of large traditional importance with several million small scale biogas plants in the Peoples Republic of China and with a nearly similar distribution in India. But in Europe the development of this promising technique was and is still strongly influenced by the political framework and the will to promote this basic technique for a sustainable utilisation of renewable energy source from waste and plant material.

After the oil crisis in the 1970's, the interest for regenerative energy increased again for a while in most parts of Europe and so did the interest for biogas plants.

The anaerobic degradation of organic substances to its most reduced form, methane (CH_4), is a purely microbial process. The energy released during the degradation steps which was originally stored in the substrate is predominantly recovered by the methane formed (equation 1)

$$33\text{g org.material (C:H:O)} = 22\text{ g } CO_2 + 8\text{ g } CH_4 + 3\text{ g Biomass}$$

For an estimate of gas yield the following equation can be used:

$$V(CH_4) = 0.35\ (COD_{inf} - COD_{eff}).\ Q$$

Where COD_{inf} is the chemical oxygene demand for the influent, (kg/m^3) and COD_{eff} is the effluent COD, Q the influent flow rate, (m^3/d) and $V(CH_4)$ the methane production rate, m^3/d at standard pressure and temperature.

For an anaerobic process, COD is a conservative parameter; the sum of all COD inputs to a digester is equal to the sum of all its COD outputs. Hence, the removal of one gram of COD from the feed results ine one gram of gaseous COD. Because the COD of carbon dioxide is zero, the COD of biogas represents the COD of methane.

The practical biogas yield in a digester will always be lower than the theoretical, due to several factors. A fraction of the substrate will be used to synthesise bacterial mass, a fraction of the organic material will be lost in the effluent, and finally, lignin containing compounds will only be degraded to a limited degree. In practise, the methane potential in manure is assessed on the basis of the content of volatile solids in the manure and empirical standards for the production of methane per kg of VS. This has been 0.29 m^3 CH_4/kg of VS in pig manure and 0.21m^3 CH_4/kg of VS in cattle manure.

Typical gas yields for some organic substrates are shown in Table 3.The co-fermentation of cattle slurry with different shares of fodder sugar beet resulted in extremely high biogas and methane yields, due to high content in the easily fermentable organic matter. This substrate and other not fibrous and not lignified plant materials are ideal co-ferments for animal farms with no hygienic risks compared to other organic wastes (Abdel-Hadi et al, 2002).

Substrate	Range of biogas yield (litres/kg VS)	Mean biogas yield (litres/kg VS)
Pig manure	340-550	450
Cattle manure	150-350	250
Poultry manure	310-620	460
Horse manure	200-350	250
Sheep manure	100-310	200
Straw from cereals	180-320	250
Corn (maize) straw	350-480	410
Fodder sugar beets	344-982	810 (thermophilic) 690 (mesophilic)
Grass	280-550	410
Vegetable residues	300-400	350
Sewage sludge	310-640	450

Table 3. *Typical biogas yields from various agricultural biomass*
(Werner & al, 1986 ; Abdel-Hadi & al, 2002)

6. OTHER TREATMENT METHODS FOR MANURE

Although biological treatment is a common feature of many treatment systems, there are also a range of other methods available including physical and chemical systems. In many cases, these are quicker than the biological processes in that they do not rely on the growth and activity of micro-organisms; they are often more robust for the same reasons.

6.1 Separation processes

The easiest way to remove undissolved material from liquid manure is by utilising natural settling or sedimentation (Martinez *et al.*, 1995). The sedimentation option appears to be an attractive method for removing fine solids from slurry owing to the low cost of the equipment involved, because of the relative simplicity of the process, and because of its secondary function in providing storage capacity.

A quicker separation can be obtained using mechanical screening, a technique easily applicable to farms. Such separation is thus used for several purposes in order to fulfil three essential requirements:

- improved penetration of manure into the soil following spreading;
- easier handling enabling better spreading accuracy (even distribution of nutrients);
- nutrient reduction in slurries in case of nutrient excess.

These requirements can be put into practice by separating the coarse solids from the slurry. The remaining liquid is spread on the land. The removed solids represent a reduced environmental risk as the nutrients contained are less mobile. Such material can be spread locally or exported to other farms or regions after composting.

Mechanical screening is also an initial process step in many complete treatment processes. Some disadvantages have to be accepted:

- storage, handling and spreading techniques for *both* liquid and solid manure is required;
- higher investment for machinery have to be made;
- more farm management skill is needed.

The ammoniacal nitrogen stays relatively constant reflecting the simple fact that physical separation has little effect on the dissolved fraction; likewise potassium is equally unaffected. The phosphorus compounds in the whole slurry are largely removed into the solid fraction but pH can have a large effect (Møller et al., 2002).

6.2 Soil filters

The movement of manures through soil results in a high degree of purification so long as the capacity is not exceeded. This is the result of physical separation processes and biological activity which actually breaks down and utilises the nutrients contained. These features have been used in the construction of soil filter systems. One example is the 'Solepur' process set up in Brittany, France (Martinez, 1997). The process involves the following operations:

- overdosing the managed field with surplus slurry;
- collecting and treating the nitrate-rich leachate produced;
- irrigating the finally treated water over other fields.

6.3 Membrane processes

Osmosis is based on the principal of a semi-permeable membrane, where water flows from the side with the lower salt concentration to the side with the higher concentration, thus creating the cell turgor (hydrostatic pressure). Reverse osmosis works with pressure on the side of the higher salt concentration, thus forcing the permeate (water) through the membrane, holding back the minerals and salts. Experiments carried out by Van Gastel & Thelosen (1995) using a pilot plant ($8m^2$ of membrane surface) under different conditions with settled sow slurry have demonstrated a 99% salt retention (which decrease as the membranes aged). The use of membrane technology in the dewatering of sow slurry is possible but an important prequisite is, that the organic fraction should have been decomposed and the solids must be removed by effective sedimentation, separation or filtering processes before the liquid enters any membrane treatment step.

6.4 Chemical processes

Additives

Chemical treatment options are able to deal with some of the problems of manure very effectively. However, the further input of additional minerals or chemicals may have a limited net advantage as one problem is solved by generating another one.

Additives to liquid manure are used to influence certain properties (*e.g.*, to stimulate or to inhibit microbial conversion processes). Selected microbial cultures can be added but it is questionable if they offer anything that the natural population can not do. Other additives stimulate microbial activity; these may include for example specific nutrients. The use of additives containing enzymes is proposed as a method to enhance digestion of part of the manure (especially slurries) but supporting evidence is scant. Even more subjective are a range of products that allegedly control odour. Many of these additives are unproven but can be used normally without problems; the cost can be high (between 5 and 30ecu per livestock unit). The treatment effects are often not reproducible in different manures from different animals and farms.

Ammonia emissions from liquid manure can be reduced also by *acidification* of the slurry in order to drive the balance between NH_4^+ and NH_3 on the ammoniacal side. One option is to acidify liquid manure by adding a mixture of organic acids at a dosage of 70 kg acid per animal place and year. The effect was that methane and ammonia emissions were cut back significantly, but the high amounts of acid and its high costs reduce the chances for practicability.

Phosphate precipitation with lime-milk

Following decomposition of most of the organic matter in the slurry (by aerobic or anaerobic treatments) 60-70% of the phosphorus can be removed with the suspended solids by mechanical separation. It is possible to precipitate the remaining phosphoric compounds with lime-milk. About 35 to 40 kg CaO per m^3 of slurry has to be added to the pre-treated manure, (because of the high buffer capacity of animal manures). (In some cases it may be appropriate to combine precipitation with a parallel ammonia stripping process). After precipitation phosphorus concentration in the clarified liquid can be less than 2 ppm. (Weiland 1997).

Precipitation of ammonium-magnesium-phosphate (MAP-process)

Magnesium-ammonium-phosphate (MAP) is the result of a chemical reaction between the three nutrients, magnesium, ammonia, and phosphorus in equal (stoichiometric) proportions, resulting in a crystalline substance which is naturally found in *guano* excrements of seabirds. The mineral is also called "Struvit". To obtain a precipitation from animal manures, the magnesium content needs to be increased by factor of six and the phosphorus by a factor of three or four by the addition of soluble compounds. The MAP-precipitation can be done continuously or in a batch process. The crystal sludge is easily removed as a sediment.

The chemicals for the precipitation of 1 kg ammoniacal-N amount to around 6 ecu, meaning that the chemicals for the purification of 1 m^3 of pig slurry (8 kg N per m^3) cost about 48ecu. In additional, the operation costs for the treatment must be included. The commercial value of the final product MAP will certainly not be high enough to offset the cost of the chemicals in the economic calculation. Hence, the process is not a serious option at present.

Manure as an input in the production of organic-mineral fertilizer

Systems for adding deficient nutrients to organic wastes and livestock manure for processing in an industrial plant have received a great deal of attention (*e.g.*, so-called Agronova system developed in Norway). The product typically contains 50-60% stable organic matter. It is produced as dry granules, suitable for standard fertilizer spreaders. The nutrient concentration is about a third of normal mineral fertilizers, and the commercial price per kg nitrogen will be the same as for mineral fertilizers. The product enables organic waste to be exported from regions with manure surplus to regions with a deficiency of organic material and plant nutrients. The profitability is mainly based on the conversion of sludge from municipal sewage treatment plants being added to the final product; animal manure is a secondary input in the processing plant. The organic-mineral product is a full value fertilizer designed mainly for grain production. Another nutrient supply for crop production is not required. Field tests show that the grain utilized 80 - 90 % of the total nitrogen.

A comparable approach has been taken by a French fertilizer manufacturer (Kaltenbach-Thuring). The heart of the process is an exothermic chemical reaction between a base (ammonia, phosphate) and an acid (sulphuric, nitric, phosphoric,...). The reaction takes place in the animal manures. Its exothermicity induces the evaporation of a high quantity of the water contained in the manures. The water steam generated is used to supply some of the energy required by the process.

The commercial success of schemes to produce such organic fertilizer products depends on the development of the prices per kg of nitrogen, phosphorus and potassium on the world market. So long as inorganic products are available at low cost, the utilization of nutrients from animal sources will be very limited.

7. CONCLUSIONS

The problem of livestock manure can only be effectively dealt with by a combined approach involving the farmers, the governing authorities, research organisations providing technical solutions and agricultural suppliers to enable the implementation of such techniques. The action required can be summarized as (i) information, communication and education, (ii) legislation and guidelines and (iii) the development of key technologies to enable further improvement of manure management systems. The final set of points will concentrate on the third heading, the key findings summarising as:

1. *Manure-soil interactions*: studies are required on the effect that various treatments have on the subsequent interactions of the manure with the soil to verify that subsequent pollution is reduced.
2. *Process and process equipment development*: eg, process equipment that involves lower capital and running costs and which is more straightforward to operate; evaluation procedures for processes to enable comparison and optimisation; development of technologies that enable re-use of dilute effluents for washing and irrigation purposes.
3. *Better use of the nutrients in organic material*: development of integrated systems to use of other organic materials (eg, wastes from the food industry) in co-processing to enable a more balanced and consistent product; processes to produce competitive organo-fertilizers either as concentrates or granules.

Acknowledgments

This paper represent an excerpt from a book (second edition) produced within the framework of a project funded by the European Commission. Thirty organisations involved in varying aspects of livestock manure treatment were represented in the series of workshop that made up a three-year collaboration. We would like to acknowledge all the participants including I Arkhipchenko, J Beck, R Bohm, M P Bernal, G Bogun, J R Bicudo, O Carton, M Dohanyos, R Geers, D Georgacakis, J Hahne, M Hayes, H Heinonen-Tanski, W Martens, R W Melse, H Menzi, H B Moller, J Morken, K Navickas, O Pahl, O Palm, S Piccinini, C Pinto, W Romaniuk, M Rogulska, F Sangiorgi, D Starmans, I Svoboda, C Turner, J Venglovsky, S Williams.

8. REFERENCES

Abdel-Hadi, M.; J. Beck, T. Jungbluth 2002. Methanerträge bei der Kofermentation flüssig silierter Gehaltsrüben. (Methane yields from co-fermentation of liquid fodder sugar beet silage.) Landtechnik, 2, (57), Germany, in print

Aumaitre, A.L. 2001. Technical and economic changes in pig production en the European Union: past, present and future trends. Pig News and Information, 22 (1), 11N-20N.

Béline, F., Daumer, M.L., Guiziou, F., Rapion, P. 2002. Biological treatment of pig slurry in Brittany, France: efficiency and end-products characteristics. ASAE Annual International Meeting/CIGR XVth World Congress, Chicago, Illinois, USA, July 28-July 31, 2002. ASAE paper number: 024129.

Böhm, H. O., C., Sieber, D. Strauch, 1980. Das Umwälzbelüftungsverfahren (System Fuchs) zur Behandlung von flüssigen tierischen und kommunalen Abfällen. 9. Mitteilung: Die Wirkung der Umwälzbelüftung auf das Virus der Aujeszkyschen Krankheit. [The circulation aeration process (system Fuchs) for the treatment of liquid animal and municipal wastes. 9th information: The effect of circulation aeration for the virus of Aujeszky disease]. Berl. Münch. Tierärzt. Wschr. 93: 112 114, Germany.

Burton, C.H. 1992. A review of the strategies in the aerobic treatment of pig slurry: purpose, theory and method. Journal of Agricultural Engineering Research, 53, 249-272.

De Clercq, P., Gertsis, A.C., Hofman, G., Jarvis, S.C., Neetson, J.J., Sinabell, F. (eds) 2001. Nutrient Management Legislation in European Countries. 343pp. Wageningen Press, The Netherlands. ISBN 90-806537-2-1.

Doll, L. 1999. Verfahrenstechnische Untersuchungen zur Entseuchung von Flüssigmist mittels thermophiler Faulung und aerob-thermophiler Stabilisierung. [Process engineering investigations about pasteurisation of liquid manure with the help of thermophilic and aerobic thermophilic stabilisation], Agrarwissenschaftliche Dissertation, Universität Hohenheim, Germany.

Giller, K.E., Cadisch, G., Palm, C. 2002. The North-South divide! Organic wastes, or ressources for nutrient management? Agronomie, 22, 703-709.

Jongbloed, A.W., Lenis, N.P. 1998. Environmental Concerns about animal manure. Journal of Animal Science, 76, 2641-2648.

Martinez, J. 1997. Solepur: a soil treatment process for pig slurry with subsequent denitrification of drainage water. Journal of Agricultural Engineering Research, 66, 51-62.

Martinez, J., Burton, C.H., Sneath, R.W., Farrent, J.F. 1995. A study of the potential contribution of sedimentation to aerobic treatment processes for pig slurry. Journal of Agricultural Engineering Research, 61, 87-96.

Møller, H.B., Sommer, S.G., Ahring, B.K. 2002. Separation efficiency and particle size distribution in relation tomanure type and storage conditions. Bioresource Technology, 85, 189-196.

Nicholson, R.J., Webb, J., Moore, A. 2002. A review of the environmental effects of different livestock manure storage systems, and a suggested procedure for assigning environmental ratings. Biosystems Engineering, 81 (4), 363-377.

Schröder, J. 2002. Restoring farmer's confidence in manure benefits the environment. In Proceedings of the 10th International Conference of the FAO European System of Cooperative Research Network in Agriculture (Ramiran), held in Strebsko, Slovak Republic, 14-18 May 2002.
Turner, C., Burton, C.H. 1997. The inactivation of viruses in pig slurries: a review. Bioresource Technology, 61, 9-20.
Van der Hoek, K.W. 2001. Nitrogen efficiency in agriculture in Europe and India. In Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The scientificWorld1.
Van Gastel, J.P.B.F.; Thelosen, J. G. M. 1995. Reduction of the volume of sow slurry with reverse osmosis. P1.129, 48p. Research Institute for Pig Husbandry, the Netherlands.
Weiland, P. 1997. Stand und Perspektive der Gülleaufbereitung. In: Statusseminar "Umweltverträgliche Gülleaufbereitung und -verwertung" congress-proceedings, editor: KTBL, Arbeitspapier nr. 242, 136-146, Münster Hiltrup, Germany.
Werner, U.; Stöhr, U.; Hees, N. 1986. Praktischer Leitfaden für Biogasanlagen in der Tierproduktion. Sonderpublikation der GTZ Nr. 180, Eschborn, Germany.

Useful web site addresses:

http://soilman.rug.ac.be/numalec/index.html
www.thescientificworld.com
www.sri.bbsrc.ac.uk/science/matresa