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Livestock Farming and the Environment : Proceedings of Workshop 4 on Sustainable Animal Production, held at Hannover, September 28, 2000

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edited by
Jörg Hartung and Christopher M. Wathes

Proceedings of Workshop 4 on Sustainable Animal Production, organized by the School of Veterinary Medicine, Hannover,

held at Hannover, September 28, 2000

Contents

Workshop Series „Sustainable Animal Production", June - October 2000

Foreword to the Proceedings

How can agriculture provide a reliable source of food of animal origin for the world's population without compromising the basis of life of future generations? In view of the rising demand for food of animal origin in industrialized, emerging and developing countries, how can animal production on a global scale become sustainable?

These were among the key issues under scrutiny in a series of international workshops on sustainable animal production conducted during the world exposition EXPO 2000 by a consortium of scientists from four north German research institutions: the School of Veterinary Medicine Hannover (coordination), the Federal Research Institute for Agriculture (FAL), the Institute for Structural Analysis and Planning in Areas of Intensive Agriculture (ISPA) at the University of Vechta, and the Agricultural Faculty of the University of Göttingen.

A broad spectrum of current issues and problems in modern livestock production were covered: animal production and world food supply; globalization, production siting and competetiveness; product safety and quality assurance; the environmental impact of livestock farming; animal welfare and health; biotechnology and gene technology; animal genetic resources; animal nutrition: resources and new challenges; safeguarding animal health in global trade.

The individual workshops were organized by local coordinators and moderated by international discussion leaders. In all 142 scientists from 23 countries worldwide participated as speakers. The workshops produced a differentiated, inclusive and holistic vision of the future of global livestock farming without national bias and free of emotionally-tinged concepts or ideology. The results of the workshops were summarized and presented to the public in a final plenary session including a roundtable discussion with representatives of agricultural policy, public life and the media.

In addition to the publication of proceedings of the workshops as special issues of *Landbauforschung Völkenrode*, abstracts of the papers and summaries of the results are now documented in the Internet at www.agriculture.de, where a preparatory virtual conference was conducted from October 1999 until October 2000.

Volker Moennig
School of Veterinary Medicine Hannover

Workshopserie „Nachhaltige Tierproduktion", Juni – October 2000

Vorwort für die Tagungsbände

Wie kann die Landwirtschaft in Zukunft weltweit Menschen nachhaltig mit Lebensmitteln tierischer Herkunft versorgen, ohne die Lebensgrundlagen künftiger Generationen zu beeinträchtigen? Wie kann eine nachhaltige Tierproduktion global und angesichts wachsenden Bedarfs an Lebensmitteln tierischer Herkunft in Industrie-, Schwellen- und Entwicklungsländern aussehen?

Diese und ähnliche Fragen waren Anlass zur Organisation einer internationalen Workshopserie zum Thema „Nachhaltige Tierproduktion/Sustainable Animal Production" zur EXPO 2000. Veranstalter waren Wissenschaftler aus vier norddeutschen Forschungseinrichtungen: Die Tierärztliche Hochschule Hannover (federführend), die Bundesforschungsanstalt für Landwirtschaft (FAL), das Institut für Strukturforschung und Planungen in agrarischen Intensivgebieten der Hochschule Vechta (ISPA) sowie die Agrarwissenschaftliche Fakultät der Universität Göttingen.

Ein breites Spektrum von Themen, wie Tierproduktion und Welternährung, Globalisierung, Standortorientierung und Wettbewerbsfähigkeit, Umweltverträglichkeit der Tierproduktion, Tierschutz und Tiergesundheit, Produktsicherheit und Herkunftssicherung, Tierzucht und genetische Ressourcen, Sicherung der Tiergesundheit bei globalen Handelsströmen, Tierernährung: Ressourcen und neue Aufgaben, Bio- und Gentechnologie spiegeln die gesamte Bandbreite der modernen Tierhaltung und ihrer Probleme wider.

Die einzelnen Workshops wurden jeweils durch lokale Koordinatoren organisiert und von internationalen Diskussionsleiter moderiert. Insgesamt 142 Wissenschaftler und Wissenschaftlerinnen aus 23 Ländern weltweit haben als Referenten an der Serie teilgenommen. Die Workshops haben ein differenziertes und umfassendes, ganzheitliches Bild von der Tierhaltung der Zukunft ergeben, das frei von nationalen, teils emotional und ideologisch gefärbten Konzepten ist. In einem Abschlussworkshop wurden die Ergebnisse der Workshops mit Vertretern aus Politik, öffentlichem Leben und Presse diskutiert. Die jetzt vorliegenden Proceedings der Workshopserie in der *Landbauforschung Völkenrode* werden ergänzt und weltweit verfügbar gemacht durch die Veröffentlichung im Internet unter der Adresse www.agriculture.de. Unter derselben Internetadresse hatte vor den Workshops eine virtuelle Konferenz als Vorbereitung von Oktober 1999 bis Oktober 2000 stattgefunden.

Volker Moennig
Tierärztliche Hochschule Hannover

Environmental Impact of Livestock Farming in Europe

Jörg Hartung[1] and Christopher M. Wathes[2]

Abstract

Modern animal production is increasingly regarded as a source of solid, liquid and gaseous emissions which can be both a nuisance and environmentally harmful. Solid and liquid manure and waste water contain nitrogen and phophorus which are the most important plant nutrients, but are harmful when applied to agricultural land in excess amounts thereby leading to pollution of ground water by nitrates, surface water with phosphorous (causing eutrophication) and soil with heavy metals such as zinc and copper which are used as growth promoters in the feed stuff. A third group of potentially hazardous effluents are drug residues, such as antibiotics, which may be present in the excreta of farm animals after medical treatment and which are passed to the environment during grazing or spreading of animal manure where they may conceivably contribute to the formation of antibiotic resistance in certain strains of bacteria. The same risk arises when sludge and waste water from sewage plants containing residues of antibiotics and other drugs from human consumption are discharged as fertiliser in the soil and water body.

The most important aerial pollutants are odours, gases, dust, micro-organisms and endotoxins, also called bioaerosols, which are emitted by way of the exhaust air into the environment from buildings and during manure storage, handling and disposal as well as grazing. More than 130 different gaseous compounds have been identified in the air of animal houses, which are a major source of these pollutants. Aerial pollutants can give cause for concern for several reasons. Firstly, there is strong epidemiological evidence that the health of farmers working in animal houses may be harmed by regular occupational exposure to air pollutants. Secondly, an animal's respiratory health may be compromised by these pollutants. In some herds, half of all slaughter pigs may show signs of pneumonia, pleuritis or other respiratory disease. In broilers, about 30% of the birds which are rejected at meat inspection show lung lesions. The third reason for concern is that aerial pollutants from livestock contribute to soil acidification (ammonia, NH_3) and global warming (eg. methane, CH_4, nitrous oxide, N_2O). For example, animal production emits about 750,000 t of NH_3 per year in Germany. About 20% of global methane production originates from ruminants. Animal production systems which use straw release distinct higher amounts of nitrous oxide than those employing liquid manure systems. Fourthly, particulate emissions, such as dust and microorganisms, from livestock buildings may be a source of complaint from people living in the vicinity of livestock farms. The travel distance of viable bacteria from animal houses via the air is presently estimated at 200 to 300 m downwind; Mycoplasma species may travel about 400 m. From epidemiological modelling and studies, we know that the virus causing Mouth and Foot Disease can be transmitted over more than 75 km while in an airborne state. Very little is known about the distribution characteristics of bioaerosols, such as dust particles, endotoxins, fungi and their spores, in the air surrounding animal houses. Dispersion models for these pollutants are lacking.

Table 1 summarizes our present knowledge of the impact of emissions from livestock farming on farm livestock and man and the distance over which the emissions may have effects. Odours are relevant closer to animal houses only. Ammonia can act directly on needles and leaves of trees close to sources where high amounts are released. It also causes damage in the far environment by overfertilizing soils and water and contributes to the decay of forests (via acid rain). Indoors, ammonia is an irritant for the respiratory tract of man and animal. Hydrogen sulphide is noticed as a prominent odourous compound outside animal houses. Occasionally indoors it can be fatal to animals and man at very high concentrations after the release of high amounts, e.g. when old liquid manure is agitated. Methane and nitrous oxide contribute to the greenhouse effect, but do not cause significant problems

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indoors. Little is known about the fate of dust, microorganisms and endotoxins outside livestock buildings, although there is some concern that these compounds may cause a nuisance to the population living in the vicinity of animal enterprises, particularly in areas with high animal densities. Nitrate and its product nitrite can cause pollution of ground and drinking water. The effects are local and the impact on human health is low. Together with phosphate both nutrients can enhance eutrophication of surface waters. Zinc and copper, which are increasingly used as growth promoters instead of antibiotics in animal feed, are accumulating eg. in pig liver and locally in soils and plants that then cause health problems in grazing sheep. Not much is known about the fate of veterinary drugs such as antibiotics in the environment which are excreted with the faeces. There is some concern that they may contribute to the development of drug resistance in bacteria.

Conclusions

Livestock farming causes significant emissions such as nitrate, phosphate, heavy metals and possibly antibiotics in manure and liquid effluents as well as odour, gases, dusts, microoganisms and endotoxins in the exhaust air from animal houses, from manure storage facilities, during application of manure and during grazing.

- These effluents can have distinct impacts on air, water, soil, biodiversity in plants, forest decay and also on animal and man.
- There are indoor health effects on man and livestock (ammonia, hydrogen sulphide, bioaerosols) and impacts on the local, regional and global environment.
- Odour, bioaerosols, ammonia, nitrogen, phosphorous and heavy metals may either have a local or a regional inpact. Gases such as methane and nitrous oxide contribute to global warming.
- There is equally a lack of knowledge on the airborne transmission of infectious agents such as virus and microorganisms between farms.
- Little is known on the role of drugs such as antibiotics in the environment. There is concern that these residues may contribute to the development of bacterial resistance.
- Local and regional environmental problems are enhanced by high animal densities, insufficient distances between farms and to residential areas.

Recommendations

Adequate and efficient feeding regimes are required with minimal wastage of nitrogen and phosphorous and limited use of growth promoters.

1. The development of low emission production systems should be encouraged including mitigation techniques, eg. biofilters, bioscrubbers, covered manure pits and shallow manure application.
2. The administration of drugs has to be restricted to the treatment of diseases only. The fate of the drugs in the environment has to be investigated.
3. There is an urgent need to establish safe distances between farms and to residential areas to prevent transmission of harmful substances. This should become an essential part of local and regional planning.
4. Environmental standards for animal production should be established and applied to all European countries.
5. An environmental risk analysis is required to compare different production systems and different regions in the world.
6. For the realization of these aims the cooperation of farmers, agricultural engineers, veterinarians and governmental agencies is necessary.

Acknowledgements

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Table 1
Environmental impact from livestock sources

Substance/Compound	**Impact on people**	**Impact on animals**	**Impact on ecology**	**Local**	**Regional**	**Global**
Odour	nuisance	no	no	yes	(yes)	no
Ammonia NH_3	indoors	high	high	high	yes	low
	irritant	irritant	nutrient	direct	PM 2.5 + SOx	
Hydrogen sulphide H_2S	indoors	indoors	no	odour	no	no
	toxic	toxic				
Methane CH_4	no	no	yes	no	(no)	yes
	explosive	global warming	global warming			
Nitrous oxide N_2O	no	no	high	low	low	yes
			global warming			
Dust	allergy?	health	low	yes	(PM 10)	no
Bacteria/Virus	infection	infections	low	yes	yes?	no?
Endotoxin	yes	yes	no	yes	(yes)	no
Nitrate/Nitrite	drinking water	no	eutrophication	yes	(yes)	no
Phosphate			eutrophication	yes	yes	no
Copper/Zinc	low	yes	yes	yes	yes	no
	pig liver	sheep!	soil			
Vet drugs	resistance?	resistance?	?	?	?	?

Greenhouse Gas Emissions from Animal Husbandry

Eberhard Hartung[1]

Introduction

Because of the importance of the nitrogen (N) and carbon (C) cycle in biological systems, the emission of gaseous reaction products such as methane (CH_4) and nitrous oxide (N_2O) during these biochemical processes is unavoidable. However, human activities like agriculture have led to a higher C- and N-input and thus to an increase in the emission of CH_4 and N_2O and, ultimately, to the intensification of global warming. The global warming potential (GWP) of CH_4 and N_2O is estimated to be 20 times CH_4 (IPCC, 1992) or even 300 times (N_2O) (Olivier et al., 1998) the GWP of carbon dioxide (CO_2) (in relation to the mass and a time horizon of 100 years). Furthermore, N_2O emissions contribute to the depletion of ozone in the stratosphere, which is caused by the stratospheric conversion of N_2O to NO (Olivier et al., 1998).

According to current estimates, the global emission of CH_4 and N_2O amounts to 535 (Houghton et al., 1996) and 17.7 MT (Kroeze et al., 1999; 1 MT = Tg = 10^{12} g) respectively. Subak et al (1993) estimated that 103 MT of the man-induced CH_4 emissions originate from livestock production. The emission of N_2O from anthropogenic sources amounts to ca. 8.0 MT per year. Of these, ca. 6.2 MT are attributed to livestock production (Kroeze et al., 1999). Olivier et al. (1998) emphasise that fertiliser consumption and animal excreta are equally important as the largest contributors to agricultural N_2O emissions. Many authors mention that the greatest uncertainties in the greenhouse gas emission data (e.g. IPCC, 1992; Subak et al, 1993; Houghton et al., 1995) are mainly caused by insufficient knowledge about the source-specific emission factors.

Therefor the criteria for scientific investigations and the collection of emission data will be discussed at first because of the significant difference between “data” and “reliable data”. Afterwards the results of a literature survey on the emission levels of N_2O and CH_4 from different animal species and husbandry systems are presented. The emission levels listed below are mainly the result of German and Dutch investigations. Since the marginal parameters indicated in the literature were not always sufficient for the use of one common unit for all emission factors (e.g. kg emission per livestock unit (LU) and day), different reference quantities are employed to describe some of these factors.

Requirements for Measurement Methods and Instruments for the Quantification of Emission Levels

The emission of gases and odour from livestock facilities exhibits a wide range of diurnal and seasonal variation (Keck, 1997, Hartung et al., 1998). Minimum requirements for the measurement of emissions were formulated by Hartung (1995) and Jungbluth and Büscher (1996):

- Continuous measurement of ventilation rates and gas concentrations,
- Long-term experiments for the description of diurnal and seasonal effects.

Amon et al. (1998) call for continuous measurements with highly precise instruments which must be repeated in different seasons. Only measurements carried out continuously over several seasons provide reliable data for the calculation of the emissions caused by different housing systems or production processes (*Table 1*). Setting such high requirements also means that about 80% of the publications do not provide a suitable basis for the calculation of emission levels.

Very expensive measuring instruments, which often cannot be purchased two- or threefold, are one essential prerequisite for the postulated requirements to be met. This leads to the dilemma that, under practical conditions, measurements with highly accurate instruments can usually be taken only at a few selected locations. Therefore, the number of measurements from the same farm or production system is often very low.

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Table 1
Requirements governing the methods and the equipment for the quantification of greenhouse gases and gaseous pollutants from agriculture (Amon et al., 1998)

Requirements	Reasons
• Simultaneous measurement of NH_3, CH_4 and N_2O • Registration of the entire production chain • Emission measurements in practice • Sampling area as large as possible • Continuous, highly accurate measurement of NH_3, CH_4, and N_2O • Simultaneous measurement of gas concentration and air flow rate	• Improvement of the overall environmental compatibility of agricultural production processes • Data close to reality • Emitting substrates are inhomogeneous • Diurnal and seasonal variation of emission rates • Calculation of the emission rate (quantity of gases emitted)

Literature Survey on Greenhouse Gas Emissions

With regard to the literature data concerning greenhouse gas emissions from livestock, a distinction can be made between measurements at the animal level and measurements at the system level. Data at the animal level are generally gained in respiration chamber experiments, whereas system level data are mainly collected during emission measurements in animal facilities.

Animal level

As regards greenhouse gas emissions from animals (i.e. their digestive system), only a few data are available, which are usually limited to CH_4. Kroeze (1998) reports that the percentage of N_2O released by the animals is still unknown and can probably be neglected, at least at the national level. Data on CH_4 emissions from cattle are summarised in *Table 2*. These data are mainly the result of feeding trials in respiratory chambers. The CH_4 emitted originates from breath and flatus.

Table 2
CH_4 emissions (g LU^{-1} d^{-1}) from dairy cows and heifers (animal level)

Animal species	Emission	Notes	Author
Dairy cow, lactating	260-290	24 h respiration trials with two animals each	Brose et al., 1999
	260	methane yield = 5.5 % of BE	Crutzen et al., 1986
	257	153 respiration trials, M = ∅ 17 kg/d, W = ∅ 583 kg	Kirchgessner et al., 1991
	268	methane yield = 5.2 % of BE; LM = ∅ 559 kg	Holter and Young, 1992
Dairy cow, dry period	130-160	24 h respiration trials with two animals each	Brose et al., 1999
	139	methane yield = 5.5 % of BE; LM = ∅ 633 kg	Holter and Young, 1992
Heifer (6-24 months)	140	methane yield = 6.5 % of BE	Crutzen et al., 1986

BE: gross energy intake [MJ], M: dairy performance [kg/d], LM: animal weight [kg]

The data in *Table 2* show that cattle produce substantial amounts of CH_4, which vary depending on the lactation stage and the age. The variation in the formation of CH_4 reported by the authors is most likely caused by differences in diet, the animal weight and dairy performance. The quantity of CH_4 emitted ranges between 5.2 and 6.5% of the Gross Energy (GE) intake (*Table 2*) (Pelchen et al., 1998). Corre and Oenema (1998), however, reported that the amount of CH_4 produced by cattle roughly equals 10% of the digestible feed intake.

With monogastric animals, like pigs and poultry, microbial fermentation only occurs in the large intestine, with an estimated CH_4 production of less than 1% of the digestible feed intake (Corre and Oenema, 1998) or approximately 0.6% of the gross energy intake (Crutzen et al., 1986).

System level

Cattle

Table 3 summarises the measured CH_4 emissions from housing systems for cattle. The CH_4 emissions originate from both the animals and the excrement stored indoors.

Table 3
CH_4 emission (g LU^{-1} d^{-1}) from cattle housing systems (system level)

Housing system		Notes	Author
Dairy cows in tying stall	327	emission from animals only	Kinsman et al., 1995
	120	four 24 h measurements each in the summer and the winter, emission from animals and excrement, volume flow measurement through CO_2 balance	Groot Koerkamp and Uenk, 1997
	194	only for slurry and manure system	Amon et al., 1998
Dairy cows in loose housing	320	emission from animals and excrement, average of 12 days in April, volume flow measurement with tracer gas	Sneath et al., 1997
	265	see above	Groot Koerkamp and Uenk, 1997
	200-250	emission from animals and excrement, measurement over the course of one year, volume flow measurement with measuring fans	Jungbluth et al., 1999
	267-390	emission from animals and excrement, volume flow measurement with tracer gas, random measurements	Seipelt et al., 1999
Fattening bulls on slats	147	see above	Groot Koerkamp and Uenk, 1997
Beef cattle on slats	121	see above	Groot Koerkamp and Uenk, 1997

The data in *Table 3* illustrate that CH_4 emissions from cattle houses range from between 120 and 390 g $d^{-1}LU^{-1}$, with somewhat higher values for dairy cows in loose housing systems (cubicle houses). This range of data is comparable with the range of CH_4 emissions used as normative values for dairy cattle in the Netherlands (63–102 kg per year per animal, corresponding to 173–279 g d^{-1} per animal) (Van Amstel et al., 1993). The highest CH_4 emissions occur during feeding and rumination (Brose et al., 1999). The emission levels are mainly influenced by the animal weight, the diet, and the milk yield. Furthermore, details of the housing system design (e.g. air conduction, type of flooring, type and dimensions of manure removal and storage of excrement) play a role. The large number of influencing factors shows that realistic normative values for the calculation of CH_4 emissions (e.g. in national studies or emission inventories) should be differentiated with regard to housing systems, besides the already stated need for differentiation according to the age of the animals, the type of feed, the diet, the feeding level and the lactation stage.

A comparison of the data listed in *Table 2* (animal level) and *Table 3* (system level) shows that CH_4 emitted from the respiratory system of the cows accounts for the largest part of the CH_4 emissions from cow houses. This is confirmed by data reported by Kinsman et al. (1995), who attributes less than 10% (21 g d^{-1} LU^{-1}) of the total CH_4 emission from a tying stall for dairy cows to the manure stored indoors. However, it is very difficult to measure the percentage of the CH_4 emission caused by manure and animals. Data about the specific CH_4 production from animal excreta (1.3 kg CH_4 per tonne of cattle excreta; Van Amstel et al., 1993) and data about the volumes of slurry produced in cow houses (16 tonnes of excreta per year; Van Eerdt, 1998) lead to the assumption that the CH_4 production from manure stored in dairy cow houses would amount to approximately 21 kg per year per animal (57 g d^{-1} per animal if the animals spend 365 days per year indoor).

This is about 20% of the CH_4 produced during the entire fermentation process and substantially more than the figure reported by Kinsman et al. (1995). This discrepancy clearly shows that there is a need for additional, more specific data for CH_4 emission from cattle stalls.

As regards N_2O emissions from cattle housing systems, only very few data exist, mainly because the accurate measurement of ventilation rates in naturally ventilated houses is difficult, time consuming, and requires extensive equipment. Additionally the measurement of usually very low N_2O concentrations cause considerable difficulties (detection limit, resolution and accuracy of continuously measuring gas analysers). The available data are summarised in *Table 4*:

Table 4
N_2O emission (g LU^{-1} d^{-1}) from cattle housing systems

Housing system	Emission	Notes	Author
tying stall	0.62	Yearly average; seasonal influence	Amon et al., 1998
deep litter (straw)	2.01	summer data	Amon et al., 1998
loose housing system	1.6	Average of 18 measurements	Jungbluth et al., 1999
loose housing system	0.8	-	Sneath et al., 1997

Amon et al. (1998) reported no difference in N_2O emission between tethered housing with solid and liquid manure. At higher temperatures, an increase in N_2O emissions from deep litter systems was recorded. Only deep litter systems with straw seem to produce significant quantities of N_2O, which is most likely caused by nitrification and denitrification in the litter bed. Slurry systems, however, produce no or only little N_2O because slurry generally contains neither nitrate nor nitrite which could be degraded through denitrification in anaerobic areas (Hüther, 1999). Sneath et al. (1997) also reported very low N_2O emissions at the detection threshold of the measuring instrument.

Pigs

Results from studies on CH_4 and N_2O emissions from different pig housing systems are given in (*Table 5*). CH_4 is emitted by all pig housing systems, but the data show great variation mainly caused by the different animal species and housing systems. CH_4 emissions from fattening pigs range between 1.5 and 11.1 kg per animal place per year, whereas emissions of 21.1 and 3.9 kg per animal place per year were reported for sows and weaners, respectively. Excrement temporarily stored indoors is the main source of CH_4 emissions. The quantity of CH_4 emitted by the animal itself should not be neglected because it may amount to up to 8 l of CH_4 per pig and per day (Ahlgrimm and Bredford, 1998). The amount of CH_4 emitted from stalls for fattening pigs is influenced by the diet (digestibility), the daily weight increase of the animals, the temperature, and the kind of housing system (Ahlgrimm and Bredford, 1998; Hüther, 1999). Hahne et al. (1999) found higher CH_4 emissions in autumn and winter when the air exchange rates are lower. They suggested that the CH_4 production might be influenced by the availability of oxygen over the emitting surfaces.

Similar to deep litter stalls for cattle, significant N_2O emissions from pig husbandry exclusively originate from deep litter- or compost systems. The variation in the N_2O emissions is mainly caused by the kind of housing system (no data available for sows and weaners). Fattening pigs kept on partly or fully slatted floor (slurry-systems) emit very little N_2O (0.02-0.31 kg per animal place per year), whereas higher emissions (1.09 - 3.73 kg per animal place per year) were reported for fatteners in deep litter and compost systems (Groenestein and Van Faassen, 1996). At present, no reliable data are available for sows and rearing pigs.

Poultry

The CH_4 and N_2O emissions from housing systems for laying hens (*Table 6*) vary greatly and must be judged very critically because the measured concentrations were very low (sometimes only slightly above the ambient concentration of N_2O). In general, floor husbandry systems for laying hens seem to emit more N_2O than battery cages or aviary systems, which is mainly caused by the presence of material (e.g. wood shavings, straw, litter) on the floor. Reliable CH_4 and N_2O emission data for other kinds of poultry such as broilers, turkeys, ducks etc. and for housing systems with natural ventilation (e.g. Louisiana stalls) are not yet available.

Gas emission values for poultry are low when compared with emissions from cattle and pigs, which is mainly caused by the considerably lower body weight of the hens. If the body weight of one laying hen is assumed to be 2.5 kg, one LU would correspond to approximately 200 hens, and the N_2O emission established by Sneath et al. (1996) would amount to ca. 0.042 kg per animal place and per year.

Table 5
CH_4 and N_2O emissions (kg per animal place per year) from pig housing systems

Animal species/ housing system	CH_4	N_2O	Author
Fattening pigs on fully slatted floors	2.8 – 4.5	0.15	Hahne et al., 1999
	-	0.02 - 0.04	Kaiser, 1999
	-	0.15	Stein, 1999
Fattening pigs on partly slatted floors	4.2	0.02	Sneath et al., 1997
	11.1		Groot Koerkamp and Uenk, 1997
Fattening pigs on fully or partly slatted floors without straw	1.5 - 3	-	Ahlgrimm and Bredford, 1998
	-	0.15	Hoy et al., 1997
	-	0.31	Thelosen et al., 1993
Fattening pigs on deep litter/compost	-	1.9 – 2.4	Döhler, 1993
	-	2.48 - 3.73	Groenestein and Van Faassen, 1996
	-	0.59 – 3.44	Hoy, 1997
	-	1.55 – 3.07	Kaiser, 1999
	-	1.43 – 1.89	Stein, 1999
	-	1.09	Thelosen et al., 1993
Fattening pigs on straw	-	0.05	Kaiser, 1999
Fattening pigs on straw flow system	0.9 – 1.1	-	Ahlgrimm and Bredford, 1998
	-	1.6 – 2.4	Hesse, 1994
Sows	21.1	-	Groot Koerkamp and Uenk, 1997
Weaners	3.9	-	Groot Koerkamp and Uenk, 1997

Table 6
CH_4 and N_2O emissions (kg per animal place per year) from poultry facilities

Animal species/ housing system	CH_4	N_2O	Author
Laying hens, floor system with straw	0.076	0.017	Mennicken, 1998
Laying hens, floor system with wood shavings	0.254 – 0.383	0.043 – 0.079	Mennicken, 1998
Laying hens, floor system with ¾ straw and ¼ wood shavings	0.34	0.155	Mennicken, 1998
Laying hens in battery cages / aviary systems	-	0.95 g h^{-1} LU^{-1}	Sneath et al., 1996
Laying hens in battery cages / aviary systems	not detectable	0.02 – 0.15 g h^{-1} LU^{-1}	Neser et al., 1997
Laying hens in battery cages	0.06	-	Groot Koerkamp and Uenk, 1997
Laying hens on a floor system	not detectable	0.05 – 0.35 g h^{-1} LU^{-1}	Neser et al., 1997
Laying hens in a free range system	0.06	-	Groot Koerkamp and Uenk, 1997
Broilers on litter	0.02	-	Groot Koerkamp and Uenk, 1997

Concluding Remarks

The formation and emission of CH_4 and N_2O from sources in animal husbandry are a very complex phenomenon. Both gases are produced during the biological degradation of nutrients in animal excreta and, to some extent, their formation is influenced by the same parameters (e.g. temperature, substrate availability). Besides these similarities, there are also significant differences, mainly with regard to the conditions under which the gases are produced. CH_4 is mainly a primary product of anaerobic processes, whereas N_2O as a secondary reaction product is formed in process chains where nitrification and/or denitrification occur.

Only very few precise emission rates of CH_4 and N_2O from different animal husbandry systems are available. Some of the data presented in this paper show considerable variation, which must mainly be attributed to the large number of factors that influence the amount of CH_4 and N_2O emissions. Without repeating all the results in detail, it is possible to say that:

- the measuring method and -equipment must meet certain minimum requirements with regard to accuracy, measuring periods, and the repetition of measurements;
- the comparability of the available data is limited due to different measuring methods and experimental sites;
- CH_4 emissions from cattle husbandry are relatively well known, while for other animal species and production systems only very few data are available, which can only be used to a very limited extent;
- N_2O emissions are very difficult to quantify. Therefore, no reliable data are available for emission rates from virtually all animal species and production systems;
- especially data for new housing systems and/or natural ventilation systems are missing.

The standard emission factors which are currently used for national and international emission budget calculations may have to be adapted to future insights and newly found cause-effect relations. With increasing knowledge about the emission rates from different sources, the necessity for a more detailed consideration of the emission factors and the cause-effect relations that characterise them will gain in importance.

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The references are available from the author.

Quantify ammonia emissions from buildings, stores and land application

Gert-Jan Monteny[1]

Introduction

There is general consensus that the emission of ammonia (NH_3) from anthropogenic sources like agriculture has to be reduced to comply with nitrogen (N) deposition levels in environmental protection policies, with a focus to maintain future biodiversity (Erisman et al., 1998). In The Netherlands, with the greatest NH_3 emission per km^2 in Europe (Asman, 1995), NH_3 contributes about 46% to the deposition of potential acid (Erisman & Draayers, 1995). Critical loads of acid deposition on natural ecosystems are exceeded in many European countries nowadays. As a consequence, eutrophication occurs. This has three main effects. First, the composition of the vegetation changes towards N loving species, that supersede the more rare plant species that are typical for ecosystems that are poor with N. Secondly, it leads to nutrient imbalances in the soil, which increases the risk of damage to the vegetation by drought, storms, frost, diseases and plagues (Grennfelt & Thörnelöf, 1992; Bobbink *et al.,* 1995). Thirdly, leaching to the ground water of the surplus N in the form of nitrate occurs (Heij & Schneider, 1991). Deposition of NH_3 to the soil can also lead to soil acidification, which is related to the rate of nitrification in the soil. Under the influence of oxygen, nitrifying bacteria transform NH_3 into nitrate, water and acid (H^+).

Within global agriculture, cattle husbandry is the biggest single source of anthropogenic NH_3 emission (Bouwman et al., 1997). Its NH_3 originates mainly from application of the excreta on the field (grassland, arable land) and housing systems, and to a lesser extent from outdoor stores, grazing and crop residues. On a farm scale, around 25% of the N excreted in the cattle urine and faeces or 20% of the N input is lost as NH_3 (Aarts, 2000). Measures to reduce NH_3 emission from excreta application are used more and more in nowadays dairy farming, either to prevent the loss of fertiliser N value of the excreta or to comply with NH_3 abatement legislation (e.g. in the Netherlands). However, future environmental constraints require the development of farming systems with an nutrient balance, i.e. with minimal losses of nutrients (N, phosphorus, potassium) to the environment. All stages of the dairy farming process have to be taken into account to achieve this.

Nitrogen put in agricultural cycles is partly fixed in animal products and crops. The remainder is lost to the environment mainly as nitrate (NO_3^-) and ammonia (NH_3), assuming no accumulation in the soil on the longer term (Aarts, 2000). Also, volatile losses by nitrogen gas (N_2) and nitrous oxide (N_2O) will occur. The amount of ammonia (NH_3) emitted to the atmosphere on a global scale is estimated at 54 million tons per year (range: 23-88), of which 22 million tons (range: 20-61) originates from animal husbandry. The contribution of cattle husbandry amounts 13 million tons of N per year (Bouwman et al., 1997; Olivier et al., 1998).

Processes, factors and sources

For poultry excreta, urea is produced from the microbiological decomposition of uric acid. This process is relatively slow (within days) compared to urea decomposition (within hours). Most important factors are temperature and water activity. The urea is further converted to NH_3. Also in dairy cow and pig houses and on grazed pastures, NH_3 originates from urea that is converted by the enzyme urease:

$$CO(NH_2)_2 + H_2O \xrightarrow{urease} 2NH_3 + CO_2$$

Following the urea decomposition, with the urease activity as the most important factor, NH_3 is in equilibrium with ionised ammonium. This aquatic equilibrium is temperature and pH dependent:

$$NH_3 + H_2O \xleftrightarrow{pH,T} NH_4^+ + OH^-$$

The unionised NH_3 in the aquatic ('l') environment (e.g. slurry or urine pools upon floors) is in equilibrium with gaseous ('g') NH_3 at the liquid/air boundary according to temperature dependent Henry's law of distribution:

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$$NH_3(l) \xleftrightarrow{T} NH_3(g)$$

The gaseous NH_3 at the boundary ('bound') may now volatilise to the ambient air. This volatilisation process, convective mass transfer, depends on the temperature and the air velocity above the liquid:

$$NH_3(g,bound) \xrightarrow{T,v} NH_3(g,air)$$

Moreover, the ambient air has impact, because the volatilisation is hindered by high NH_3 concentrations in the air. The processes mentioned above are particularly valid for the animal house. During indoor and outdoor storage of excreta, non-urea N compounds are decomposed to NH_3 (Patni & Jui, 1991). Emission levels from outdoor stores greatly depend on the type of excreta, the climatic conditions (temperature, air velocity), the duration of storage and the presence of a cover on the slurry basin (Oleson and Sommer, 1993). The magnitude of the NH_3 emission depends on the application technique, the type and composition of the excreta, and the actual soil and climatic conditions (e.g. Van de Molen et al., 1990).

Emission levels and possibilities for emission reduction

Many investigations have been conducted to determine emission levels for the sources of NH_3 in agriculture. This paper presents an executive summary of the results mostly from Dutch research. Although of great importance, no attention is paid to measurement techniques that were and can be used to determine levels for NH_3 emissions.

Table 1
Overview of the working principle of emission reducing measures and reduction of the NH_3emission for dairy cow houses reported in literature (in % compared to slatted floors).

Measure	Process involved	Control factor	Maximal Reduction	Reference
Feeding strategies	urine and faeces production	urea concentration	39	Smits *et al.*, 1997
Slurry handling:				
* flushing with water	enzymatic conversion	urea concentration	17	Ogink & Kroodsma, 1996
* formaldehyde flushing	enzymatic conversion	urease activity	50	Ogink & Kroodsma, 1996
* slurry acidification	dissociation	pH	37	Bleijenberg *et al.,* 1995
+ additionally flushing slats with acidified slurry	dissociation	pH	60	Kroodsma & Ogink, 199
Floor systems:				
* V-shaped solid floors	air exchange/volatilization	air velocity	52	Swierstra *et al.*, 1995
+ flushing with water	enzymatic conversion	urea concentration	65	Braam *et al.*, 1997b
+ formaldehyde flushing	enzymatic conversion	urease activity	80	Bleijenberg *et al.*, 1995
Housing systems:				
* reduced slatted floor area	volatilization	emitting area of floor/pit	10	Metz *et al.*, 1995
* tie stalls	volatilization	emitting area of floor/pit	28	Metz *et al.*, 1995

This data indicate that technical measures aiming at a reduced pH (acidification) and exclusion of the emission from the pit (floor systems) reduce the NH_3 emission from dairy cow houses over 50%, relative to traditional slatted floor systems. However, these kind of emission reducing measures have high costs. In this perspective, the less costly nutrition measures may be more promising.

In Table 2, NH_3 emission data for traditional and low emission housing systems for fattening pigs are summarised.

Table 2
Overview of ammonia emission levels for various housing systems for fattening pigs in the Netherlands (after: Steenvoorden et al., 1999).

Fattening pig housing system	NH_3 emission (kg per animal place per year)
Traditional – fully slatted	3.0
Traditional – 50% slatted floor	2.3 – 2.7
Traditional – various slatted floor types	2.2 – 2.4
Low emission – 25% slats	2.1
Optimal pen design and phase feeding	1.7 – 1.8
Reduced pit surface area	1.6
Shallow pits + flushing gutter system	2.0
Slurry cooling	1.9

Low emission housing systems for fattening pigs are being introduced on an increasing scale in the Netherlands, because these systems are relatively less costly than in dairy husbandry. Because of the relatively great contribution of the slurry pit (on average 80%) to the emission from the house makes constriction measures (e.g. reduced pit surface area) for the pit greatly effective. Moreover, an optimal pen design results in a drastic reduction of the emission.

Table 3 presents an overview of NH_3 emission levels for laying hen housing systems.

Table 3
Overview of ammonia emissions from various laying hen housing systems.

Laying hen housing system	NH_3 emission (kg per animal place per year)
Battery system; slurry	0,083
Battery system with twice weekly slurry removal	0.034
Battery system with indoor drying (composting)	0.386
Battery system with manure collection on belts, drying and weekly removal to an outdoor storage (emission from the house only)	0.031
Free range system (indoor)	0.327 – 0.362
Aviary system	0.050 – 0.130

Frequent removal of belt dried poultry excreta appears to be very effective to reduce NH_3 emission. This measure takes advantage of the relatively slow rate of decomposition of uric acid. Free range and aviary systems may result in higher NH_3 emission levels, although lessons from the emission reduction for traditional systems can be applied to those systems too.

There is a great deal of discussion on the effectiveness of improved application techniques for animal excreta in the framework of NH_3 emission reduction. This is at least for a part caused by the limited number of full scale measurements conducted. Table 4 summarises the outcome of numerous small scale experiments (small plots, using micro meteorological mass balance method to measure emissions) conducted in the Netherlands.

Table 4
Slurry application techniques for grassland and arable land and their ammonia emissions as percentage of the amount of total ammoniacal nitrogen applied.

Slurry application technique	NH_3 emission in % of the amount of total ammoniacal nitrogen applied
Grassland:	
- Broadcast spreading	27 – 100
- Trailing shoe	9 – 50
- sod injection	2 – 25
Arable land:	
- broadcast spreading	20 – 100
- direct incorporation	1 – 49
- injection	0 – 40

These data show the great variability of emissions found under experimental conditions.

Conclusive remarks

The information presented in this paper is only a summary of many investigations conducted in the Netherlands. It indicates that many options are present to reduce NH_3 emissions from all agricultural sources (animal houses, slurry storage, land application). It is obvious that the costs associated with these options will vary greatly. Application in practice will depend on these economical factors in regions where emission abatement legislation is not yet present. However, the EU has clearly set a policy towards emission ceilings for all member states. This ceiling is for the Netherlands 128 kton NH_3 per year, which is a reduction of around 40% relative to the emission in 1980 (being the reference year for the Dutch government). It has to be noted that the national government aims to a much further reduction (upto 70%) to preserve vulnerable ecosystems.

International agricultural engineering research is now challenged to use the knowledge on the fundamentals of NH_3 production and volatilisation to further optimise the systems that are already present in EU member states, to make EU agriculture economically and environmentally sustainable.

Emission of airborne particulates from animal production

Jens Seedorf[1] and Jörg Hartung[1]

Abstract

The air in animal housing contains gases, odours, dust particles and microorganisms which are discharged by way of the ventilation system into the environment. There is increasing concern within parts of the population that these compounds may affect the respiratory health of people living close to livestock enterprises. Particularly compounds like dust, microorganisms and endotoxins, which are also addressed as bioaerosols, are supposed to play a role in the prevalence of respiratory affections in receptive humans as it is known from occupational health reports of farm workers in animal houses. A brief survey is presented on airborne particulate emissions from livestock buildings. The concentrations of airborne microorganisms in livestock buildings are between some 100 and several 1000 per liter. Staphylococcae, streptococcae, colilike bacteria, fungi, moulds and yeasts are regularly found. The 24 h average concentrations of dust in animal barns vary considerably. In poultry houses the highest inspirable resp. respirable dust concentrations (up to 10 mg/m³ resp. 1.2 mg/m³) were found, followed by pig houses (5.5 mg/m³ resp. 0.46 mg/m³) and cattle barns (1.22 mg/m³ resp. 0.17 mg/m³). The concentrations of endotoxins in the airborne dust can range from 0.6 ng/m³ (cattle, respirable dust) to 860 ng/m³ (laying hens, inspirable dust). The presently discussed occupational health threshold at the workplace is around 5 ng/m³ (50 EU/m³). The emission rate for respirable dust from piggeries is at about 60 mg/h, from poultry houses nearly 300 mg/h and from cattle barns at 20 mg/h, related to 500 kg liveweight of the animals. Little is known about the distances these particles are transported through the air outside the animal buildings. There is a further need for reducing the emission of environmentally harmful substances by implementing recognized abatement techniques. Urgent actions are required to investigate the travel distance of bioaerosols and whether and how particulate emissions from animal farming can cause health effects in residents living in the rural environment.

Introduction

Modern animal production is increasingly regarded as a source of air pollutants which can be both aggravating and environmentally harmful. The pollutants can give cause for concern for several reasons. There is epidemiological evidence that the health of farmers working in animal houses may be harmed by regular exposure to air pollutants such as gases, dust, microorganisms and endotoxins (Donham, 1987; Whyte et al., 1993; Nowak, 1998). Equally, animal respiratory health may be compromised by these pollutants (e.g. BAEKBO, 1990; Hamilton et al., 1993). Elbers (1991) found in about 50 % of the lungs of slaughter pigs signs of freshly or earlier suffered pneumonia, pleuritis or other respiratory affections. In broilers about 30 % of the birds which are rejected at meat inspection showed lung lesions (Valentin et al., 1988). The third reason of concern is the fact that livestock buildings, manure storage facilities, spreading and even grazing cattle are major sources of pollutants which contribute to soil acidification and global warming (Jarvis and PAIN, 1990, Hartung et al., 1990, Ecetoc, 1994, Williams, 1994). Fourthly, particulate emissions such as dust and microorganisms from buildings are supposed to play a role in respiratory affections in people living in the vicinity of animal enterprises. Müller and Wieser (1987) calculated the travel distance of viable bacteria from a laying hen house of 200 to 300 m downwind. Little is known about the emission amounts and the distribution characteristics of dust particles in the surrounding of animal houses. Tentative experiments using high volume sampling and a Lidar technique around a piggery revealed distinctly higher particle concentrations and endotoxins 115 m downwind the building as compared to the reference sampling point upwind (Hartung et al., 1998). However many factors such as wind and weather conditions can have a considerable influence.

This paper summarizes the most important airborne particulate emissions from animal farming

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and discusses aspects of the environmental risks for nearby residents and the farer environment.

Dust emissions

The dust in animal housing originates from the feed, the bedding material and from the animals themselves. A small amount enters the animal house with the incoming ventilation air. The dust particles are carriers for gases, microorganisms, endotoxins and various other substances such as skin cells and manure particles (Donham, 1989). Animal house dust consists up to 90 % of organic matter (Aengst, 1984).

The amount of airborne dust fluctuates greatly both in the course of a day and according to the type of animal. Recent investigations carried out in 329 animal houses in four different EU countries revealed the dust concentrations given in Table 1. The results are given in 24 hours mean values for inhalable and respirable dust (TAKAI et al., 1998). The highest dust concentrations are found in poultry housing followed by pig and cattle.

Most of this dust may leave the animal houses by way of the exhaust air and is distributed in the surroundings. Assuming a mean dust concentration of 2 mg/m^3 in the exhaust air of a piggery housing 1000 fattening pigs and a mean ventilation rate of 200 m^3/LU per hour (LU = livestock unit equals 500 kg live weight) throughout the year the total dust emission per year will be about 500 kg. In Figure 1 the mean dust emissions of the 329 animal houses are given as average values to elucidate the amounts of bioaerosols which are regularly emitted into the environment. The emission rate of respirable dust from piggeries is about 60 mg/LU and hour. Presently it is unknown how far these fine particles are distributed in the environment of animal houses (Hartung, 1998).

The health effects of dust particles depend very much on the nature of the dust (organic, not organic), the compounds the particles are carrying (bacteria, toxins) and the diameter of the particles. Particles with aerodynamic diameters smaller than 4 µm can penetrate deep into the lung. The larger particles are deposited in the upper airways. High dust concentrations can irritate the mucous membranes and overload the lung clearance mechanisms. Together with the dust particles microorganisms can be transported into the respiratory system causing infections. Endotoxins can trigger inflammation and allergic reactions in the airways of susceptible humans, even in low concentrations.

Microorganisms and endotoxins in animal houses

Microorganisms and endotoxins belong to the prominent aerial pollutants in farm animal housings which have been linked with several production diseases (Wathes, 1994; Hartung, 1994) and which are assumed to pose a risk for the health of farmers and workers in the farms (Donham, 1990) and to the neighbouring residential areas around intensive livestock enterprises. Concentrations of airborne microorganisms are particularly high in pig and poultry houses (Clark et al., 1983; Cormier et al., 1990; Ewerth et al., 1983).

Usually microorganisms and endotoxins (lipopolysaccharides, LPS) are associated with dust particles and present a biologically active aerosol (bioaerosol).

The quantities eg of bacteria in animal house air can be very high at times but show vast variations which depend on daily and seasonal influences as well as on the animal species and on the keeping and management system (Müller and Wieser, 1987). Another crucial problem when measuring airborne microorganisms is the sampling method. At present there is no generally accepted standard sampling procedure available.

The concentrations of airborne microorganisms shown in Figure 2 give a current overview of the microbiological status of the air in animal houses mainly in Germany (Seedorf et al., 1998). Total counts of bacteria, Gram-negative bacteria (Enterobacteriaceae) and fungi and yeasts were of general concern. The results of 61 daily and 25 nightly measurements are shown, expressed as average log value for each animal type.

The highest bacteria concentrations were detected in broiler houses. Concentrations of about 6.43 log colony forming units CFU per m^3 air on average were found during the day as well as during the night. In contrast to broiler houses, houses for laying hens had lower concentrations of between 4 and 5 log CFU per m^3**.** For pigs, average concentrations of 5.1 log CFU per m^3 and for cattle of 4.3 log CFU per m^3 were detected. In all cases the concentrations were greater in the day than at night. This diurnal distribution was also observed for *Enterobacteriaceae* with the exception of layers. The overall concentrations differed during the day between 3 and nearly 4 log CFU per m^3. Only fattening pigs and layers had higher yields of *Enterobacteriaceae,* ranging between 4.2 and 4.7 log CFU per m^3. In cattle houses, concentrations of 2.3 log CFU per m^3 and in pig and poultry houses 3.9 log CFU per m^3 were measured during the night. The mean daily fungi concentration was 3.8 for cattle, 3.7 for pigs and 4.0 for poultry log CFU per m^3 , respectively. During the night, the mean fungi concentration was 3.6 for cattle, 3.8 for pigs and 3.7 log CFU per m^3 for poultry.

Based on the concentration of airborne microorganisms, the measurements were ranked by animal type. During the day and night, broiler houses had the highest concentrations of total bacteria and of fungi, while the highest concentrations of *Enterobacteriaceae* were recorded during the day in fattening pig units. The highest concentration was found during the night in houses for laying hens.

The results of endotoxin (ET) measurements are summarised in Tables 2 and 3. Compared with pigs and poultry the ET concentration in cattle houses was clearly low. For inhalable ET, mean concentrations ranged between 7.4 and 63.9 ng m^{-3} and for respirable ET, concentrations ranged between 0.6 and 6.7 ng m^{-3}. Mean ET concentrations were higher for pigs. Inhalable ET concentration ranged between 52.3 and 186.5 ng m^{-3} with related respirable ET concentrations of between 7.4 and 18.9 ng m^{-3}. Concentrations were highest for poultry; mean values ranged between 338.9 and 860.4 ng ET m^{-3} air in inhalable dust fractions and from 29.6 to 71.8 ng ET m^{-3} air in respirable dust. The overall percentage of the RD/ID ratio differed between species, ie. 8.6 % for cattle, 8.8 % for pigs and 5.7 % for poultry. For the RN/IN ratio, values of 13.9, 12.2 and 9.0% were calculated, respectively.

The results of the statistical analysis showed that poultry had the highest ET concentrations in each of the four dust fractions ($p<0.001$), followed by pigs and cattle. Calves had higher ET concentrations in the ID ($p<0.0005$) and IN ($p<0.001$) fractions than dairy cows and beef cattle. For the same dust fractions significant variations between the different housing types were estimated. For ID samples, the ET concentration was higher in cattle buildings with litter ($p<0.01$), while cattle houses with slats showed higher ET concentrations for IN samples ($p<0.04$).

Pig houses in The Netherlands had the highest ET concentrations in the RN fraction ($p<0.03$). The highest ET concentrations for ID ($p<0.007$), IN ($p<0.007$), RD ($p<0.0004$) and RN ($p<0.0002$) in weaner houses were detected with mesh or slat flooring. As a consequence, for nearly all dust fractions the ET concentration was higher in the mesh/slats housing type ($p<0.03$) than in buildings with litter or slats alone. Housing types with litter showed the highest ET concentrations ($p<0.002$) only for ID. Differences between poultry houses were observed. Poultry houses in the UK showed the highest ET concentrations for ID ($p<0.0005$), IN ($p<0.0008$), RD ($p<0.004$) and RN ($p<0.008$). Except for ET in IN, aviaries showed the highest ET concentrations for ID ($p<0. 04$), RD ($p<0. 007$) and RN ($p<0. 0 1$). Significant seasonal interactions with aerial ET concentrations were not observed for cattle, pigs and poultry.

Significance for animal and human health

Airborne microorganisms and endotoxins are supposed to contribute to respiratory disorders, in particular of the „multifactorial-type“ such as shipping fever in cattle, atrophic rhinitis in pigs or infectious bronchitis in poultry (Webster, 1985). Together with dust microorganisms can stress the defence mechanisms of animal or man and can reduce resistance. Over-sensitivity reactions and toxic effects by allergens and toxins are also possible (Zeitler, 1988). There are numerous reports on complaints on respiratory problems among farmers and farm workers. In some investigations up to 70 % of the farmers respond with respiratory symptoms after working in the animal house atmosphere (Heederik et al., 1991). Which of the compounds are responsible is still unclear. Experiments using nasal lavage show that pig house dust containing endotoxins increases the inflammatory reaction of the nasal muceous membranes of humans distinctly (Nowak et al., 1994). Even dusts with low endotoxin concentrations provoke prominent reactions whereas the application of dust which was free of endotoxins was not followed by signs of inflammation. It seems that the role of airborne endotoxins from livestock housing should be given more attention.

Emission of airborne bacteria, fungi and endotoxins

The microorganisms and endotoxins in the air of animal houses are emitted into the environment by way of the exhaust ventilation system. The amount of these emissions is calculated on the base of the ventilation rate and the indoor concentrations. A common method to estimate the air exchange is the carbon dioxide balance method (van OUWERKERK, 1994). The principle is based on the assumption that at a given carbon dioxide production indoors, mainly by the animals, and at a constant level outdoors the indoor concentration is only influenced by the air exchange which is expressed eg as ventilation rate usually related to 500 kg live weight of the animals kept in the animal house (m^3 per 500 kg and h). The following data are mainly given as an average over 24 hrs.

The emission rates for airborne microorganisms were calculated and expressed as log CFU per h and 500 kg live weight (LW). The mean emission levels over 24 h are shown for all livestock buildings and microbial type in Figure 3. The highest emission rates of total bacteria were measured in broiler houses, namely 9.5 log CFU per h and 500 kg LW but the range of emission rates amongst the other species and housing types was much less and the average rate was approximately 7 log CFU per h and 500 kg. The emisson rates of *Enterobacteriaceae* were much lower. Layers had the highest emission rate of 7.1 log CFU per h and 500 kg, sows had the lowest emission rate of 6.1 CFU per h and 500 kg. For fungi the range of emission rates was from 7.7 log CFU per h and 500 kg for broilers to 5.8 log CFU per h and 500 kg for weaners.

In contrast with inert pollutants, emission calculations for microbes have to take into account the biological half-life period of microorganisms under varying environmental conditions. This is especially important when estimating both the number and dispersion of viable microbes**.** These calculations are the theoretical basis for epidemiological and environmental risk assessments. Broiler houses showed the highest emission rates on average. Compared with emission rates from other animal types, the release of total bacteria was more than a 100 fold higher. The health hazard of such high emissions is relevant to the design of ventilation systems. The position of air outlets on the roof or in the wall determine the potential transmission of such pollutants. Furthermore, the weather conditions and the nature of the surrounding area (forest, meadows) also has to be taken into account. A pig unit surrounded by meadows and with roof outlets and relatively low emission rates may distribute the compounds farer than a broiler house surrounded by many trees and with wall outlets.

Recent studies have shown, that emissions can be reduced by installing biofilters or bioscrubbers. These devices have been developed to reduce odour and ammonia emissions but they can also control emissions of bioaerosols. This however depends very much on the quality and management of the filter and of the contamination of the washing water which used to remove most of the dust from the air before entering the filter. The microbial emission from the filter can be several magnitudes higher for certain microorganism species than in the animal house air (Seedorf and Hartung, 1999a). High energy costs and frequent maintenance to guarantee cleaning efficiency are crucial when using such devices.

Role of airborne emissions in the environment

There is increasing concern that bioaerosols which are emitted into the ambient air may pose a health risk to humans living nearby. Investigations on pig farms have shown that the concentrations of airborne bacteria about 100 m off pig farms are around 1700 CFU m^{-3} in winter and 930 CFU m^{-3} in spring (Platz et al., 1995). The indoor concentrations were at 6.04 log CFU per m^3 in winter and 5.76 log CFU per m^3 during summer. Investigations during a whole year at 8 different sampling places in an area with high livestock density revealed pronounced distance dependend bacteria concentrations and a huge seasonal influence on the fungi concentrations in particular. Higher concentrations were found at distances up to 150 and 250 m from the source (Hartung, 1992). Similar results for bacteria are also reported earlier (Müller and Wieser, 1987). Some recent experiments showed distinctly higher particle densities about 115 m downwind of a piggery using a Lidar detection device (Hartung et al., 1998). However, there is still a considerable lack of knowledge on the travel distances of both viable and non viable particles from animal houses.

Table 4 summarises our present knowledge where the emissions may develop effects in the closer and farer environment of animal enterprises. Concerning odours and ammonia sufficient knowledge is available, to give an estimation. Odours are relevant in the near of animal houses only. Ammonia can cause damages close to the sources when high amounts are released. It also acts in the farer environment by overfertilizing soils and water and contributes to the decay of forests (acid rain problem). Methane, nitrous oxide and carbon dioxide contribute to the greenhouse effect, they don't develop significant problems indoors or close to the animals. Hydrogen sulphide is noticed as a prominent odourous compound outside the animal houses. Little is known about the fate of the microorganisms and endotoxins outside the buildings, although there is increasing concern that these compounds may cause harm to the population living in the vicinity of animal enterprises, particularly in areas with high animal densities. From epidemiological studies it is assumed that the virus causing foot-and-mouth disease can travel airborne more than 50 miles. For the bioaerosols from animal production such as fine dust, endotoxins, bacteria, fungi and their spores similar dispersion models are generally lacking. But some few efforts were already done to get an imagination about the particle-related dispersion properties in the environment (Seedorf and Hartung, 1999b; Seedorf and Hartung, 1999c)

Conclusions

- There are loads of dusts, microoganisms and endotoxins present in animal house air.
- There seem to be a health risk for animal and man indoor caused by these substances.
- These substances are emitted in considerable amounts from buildings and manure stores into the environment.
- Suitable abatement techniques for gases such as ammonia and particulates are available. They should be employed in practice.
- There is still a considerable lack of knowledge on the distribution and health effects of airborne particulate emissions from livestock sources in the environment.
- For licensing new animal farms as well as residential areas in the farming environment more precise informations on the travel distance of harmful particles and compounds are required.

For the realization of these aims the cooperation of farmers, agricultural engineers, veterinarians and governmental agencies is necessary.

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Table 1
Mean dust concentrations in the air of livestock housings, mg/m³, n = 329

Animal Species	Inhalable Dust	Respirable Dust
Beefs	0,15 - 1,01	0,04 - 0,09
Calves	0,26 - 0,33	0,03 - 0,08
Cows	0,10 - 1,22	0,03 - 0,17
Fattening pigs	1,21 - 2,67	0,10 - 0,29
Sows	0,63 - 3,49	0,09 - 0,46
Piglets	2,80 - 5,50	0,15 - 0,43
Broilers	3,83 - 10,4	0,42 - 1,14
Laying hens	0,75 - 8,78	0,03 - 1,26

after TAKAI et al. (1998)

Table 2
Means of airborne endotoxin (ET) concentrations (ng ET m^{-3}) for different animal types and daily and nightly ratio (%) between respirable and inhalable ET
(ID: inhalable-day, IN: inhalable-night, RD: respirable-day, RN: respirable-night)

Species	Amount (n)	ID	IN	RD	RN	RD/ID ratio	RN/IN ratio
Cows	31	15.1	7.4	0.6	1.6	4.2	21.7
Beefs	18	11.8	13.6	1.0	1.3	8.5	9.5
Calves	18	48.7	63.9	6.3	6.7	13.0	10.5
Sows	44	114.6	52.3	8.3	7.4	7.2	14.2
Weaners	27	186.5	157.4	17.7	18.9	9.5	12.0
Fatt. pigs	39	135.1	109.1	13.0	11.4	9.6	10.4
Layers	43	860.4	338.9	58.1	29.6	6.8	8.7
Broilers	21	785.7	784.2	35.1	71.8	4.5	9.2

Table 3
Mean endotoxin (ET) concentrations (ng ET m^{-3}) in ID, IN, RD and RN samples in relation to country, animal type and housing type and the ET ratio (%) between RD/ID and RN/IN

Animal and housing type	Country	Amount (n)	ID	IN	RD	RN	RD/ID	RN/IN
Dairy-litter/tied	NL	8	22.5	4.8	0.7	2.5	3.1	53.3
	DK	7	14.9	9.2	0.5	2.1	3.5	22.9
	D	2	44.8	20.2	1.5	0.5	3.3	2.6
Dairy-cubicle	NL	8	6.2	5.2	0.7	0.5	11.7	10.5
	DK	6	7.3	7.2	0.3	1.6	3.5	22.9
Beefs-litter	D	1	41.1	9.9	1.2	0.5	2.9	5.5
Beefs-slats	NL	8	6.6	16.0	1.3	2.4	20.1	15.0
	DK	7	14.4	14.4	0.8	0.4	5.7	3.1
	D	2	8.6	3.3	0.1	0.2	1.7	5.8
Calves-litter	DK	8	31.3	11.6	0.4	0.1	1.4	1.1
	D	1	10.4	14.2	0.0	0.1	0.0	0.5
Calves-slats	NL	9	66.4	110.1	12.2	13.3	18.4	12.1
Sows-litter	UK	9	52.3	23.6	2.2	2.1	4.2	8.7
	D	4	809.0	324.3	52.6	52.2	6.5	16.1
Sows-slats	UK	8	21.3	43.8	1.2	0.5	5.7	1.1
	NL	8	108.7	20.1	2.4	2.2	2.2	10.7
	DK	7	28.8	22.7	3.6	4.8	12.4	21.1
	D	8	4.0	11.5	8.5	4.2	213.6	36.0
Weaners-mesh	UK	9	52.4	30.3	3.4	16.1	6.6	53.2
	NL	8	365.1	337.4	37.3	27.8	10.2	8.3
	DK	7	226.9	160.0	20.2	18.5	8.9	11.5
	D	3	18.3	10.5	2.2	3.2	12.2	30.7
Fatt.pigs-litter	UK	8	111.5	156.5	14.5	5.3	13.0	3.4
	DK	7	204.7	151.3	20.8	21.2	10.2	14.0
Fatt.pigs-slats	UK	6	136.1	75.8	12.1	7.5	8.9	9.9
	NL	8	102.2	100.2	10.8	14.3	10.5	14.3
	DK	6	128.7	71.2	7.6	7.8	5.9	10.9
	D	4	134.5	64.9	10.1	10.7	7.5	16.5
Layers-aviary	UK	10	2815.9	1140.4	171.8	105.3	6.1	9.2
	NL	8	431.3	104.6	19.6	9.5	4.5	9.1
	DK	6	265.3	29.9	26.7	10.4	10.1	34.9
Layers-cages	UK	6	549.2	309.8	67.8	28.0	12.3	9.0
	NL	7	20.8	20.0	2.2	2.0	10.6	9.8
	DK	2	116.0	53.3	14.0	12.4	12.0	23.2
	D	4	30.9	11.4	3.1	1.5	10.1	12.7
Broilers-litter	UK	4	76.2	64.3	7.5	4.9	9.9	7.6
	NL	9	469.3	293.5	17.7	63.8	3.8	21.7
	DK	6	139.7	116.6	18.5	65.4	13.2	56.0
	D	2	5566.2	6434.7	218.3	260.4	3.9	4.0

Table 4
Environmental impact of some emissions from livestock sources

Compound	Vicinity	Farer Environment
Odours	nuisance	n. k.
Ammonia	trees	N inputs, water, soil
Carbon dioxide	n. k.	global warming
Methane	n. k.	global warming
Nitrous oxide	n. k.	global warming
Schwefelwasserstoff	odour nuisance	n. k.
Dusts	allergy (?)	n. k.
Bacteria/Virus etc.	infections	(?), MFD

n. k. = not known

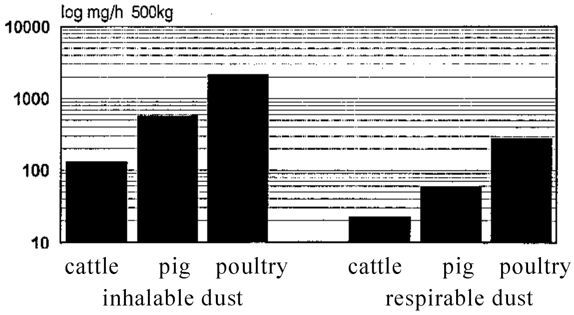
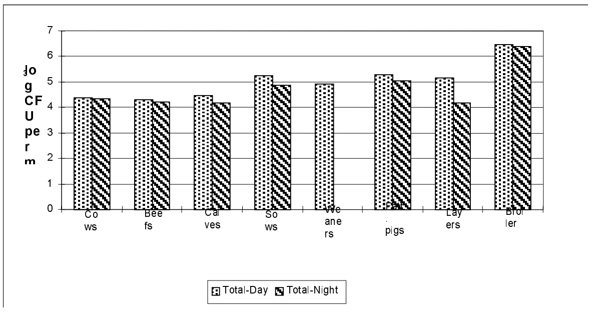
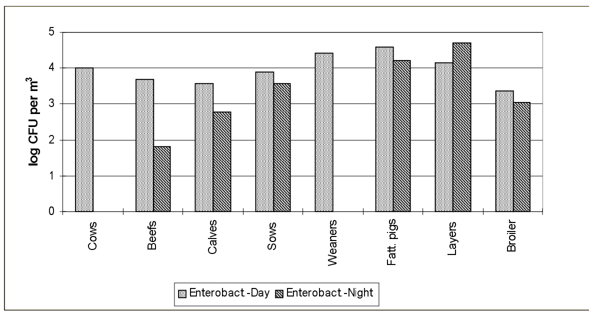
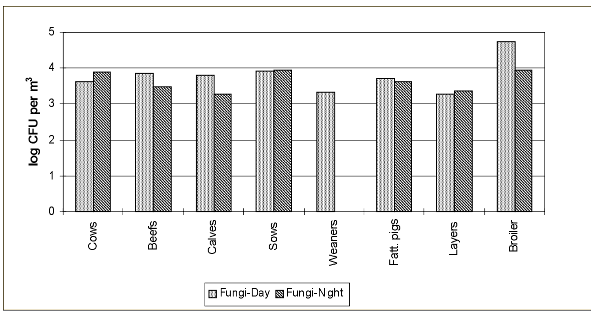


Fig. 1
Dust emissions from cattle, pig and poultry barns







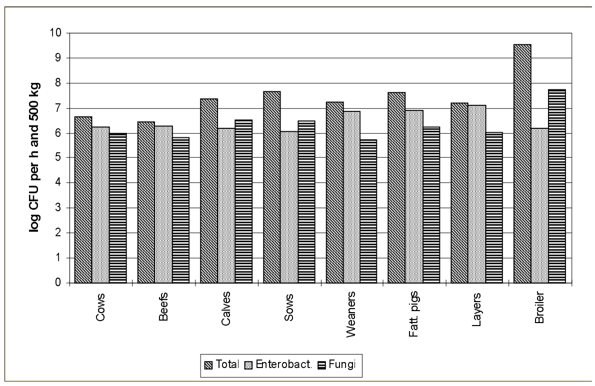


Fig. 2
Concentration of airborne microorganisms in livestock buildings. Day: n = 61; Night: n = 25

Fig. 3
Emission rates of microorganisms. n = 61

Pollutants in animal manure: Factors of emission and strategies for reduction

Wilhelm Windisch[1]

Intensive livestock production is one of the most important bases for supplying the world's population with high-grade, protein-rich foods. It does however also bear an ecological risk by emitting large amounts of manure. By this way, livestock production is one major source of global N emissions and contributes substantially to pollution of the hydrosphere and atmosphere, to forest decline, destruction of the stratospheric ozone layer and formation of ozone close to the ground. Phosphate is a further constituent of animal manure with a high potential to pollute the environment by eutrophication of surface water. Finally, animal manure may contain considerable amounts of zinc and copper, which may be accumulated in the soil.

Indeed, N, P, Zn and Cu are not pollutants per se. Primarily, they are essential components of the feed as well as of the food, which is produced from the animals' products. Also in manure, these substances serve primarily as essential nutrients to plants. Their polluting potential, however, arises from the large quantities of emissions. This frequently results in the public demand to cut livestock production back to the "natural" level. But intensive animal production does not necessarily produce high emissions of N, P, Zn and Cu. The latter indicate mainly a low efficiency in transforming N, P, Zn and Cu from feed into food. Consequently, the major goal is to reduce the primary emissions of N, P, Zn and Cu from the animals by optimizing the efficiency of nutrient transformation within the metabolism. This is mainly a matter of animal nutrition strategies.

Nitrogen

Nitrogen is an essential component of protein in feed as well as in food. N emissions from animal husbandry are therefore inevitably coupled with the production of protein-rich foods (meat, milk and egg). In practice, however, the efficiency of N transformation is quite low. On average only about one third of the feed N is transferred into the protein of animal products, while the rest is eliminated via excrements (mainly urine). Most of these N quantities remain in the manure and are transferred to the agricultural area. But up to one fourth may be emitted into the atmosphere directly after excretion and during storage of manure. Therefore, it seems reasonable to observe the primary N emission from the animal rather than only N contents in manure.

One major reason for high N-losses is an excessive protein content of the feed. Since the capacity of an animal to grow or to produce milk and eggs is limited, any surplus of dietary protein cannot be utilized by the metabolism. The respective N of the protein has to be eliminated from the body. However, in the course of the production cycle (pregnancy/lactation, start/end of fattening) the animals' protein requirement changes to a considerable extent. In order to guarantee a sufficient protein supply, the farmers chiefly adjust the protein content of the feed to the level of the maximum requirement of the animal. Consequently, the animals receive excessive amounts of protein for most of the time.

Another reason for N-losses especially in pig and poultry is the low quality of the feed protein due to deficient contents of essential amino acids (mainly Lys, Thr, Met). In order to secure a sufficient supply of the most limiting essential amino acid, higher quantities of the total protein have to be fed. This generates an additional surplus of non-limiting amino acids, whose nitrogen has to be eliminated from the body.

In ruminants, the aspect of protein quality refers mainly to the extent, to which utilizable protein reaches the final site of digestion (duodenum, small intestine) after it has been transformed by microbes along the passage through the forestomaches. In this context, considerable N-losses may occur due to a high ruminal degradability of feed protein as well as an due to an excessive ratio between N and energy in the feed.

An additional source of N-emission via excrements is the N, which originates from the inevitable and "non-productive" maintenance metabolism.

Thus, there are 3 general strategies available to minimize N-emissions from livestock production:

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1) Applying the official recommendations for protein supply and avoiding dietary protein surplus by adjusting the protein content in the feed to the changing requirement of the animal.
2) Improving the quality of feed protein. This may be achieved in pigs and poultry by adding limiting amino acids in a chemically pure form. In cattle it refers mainly to the use of feed proteins with low ruminal degradability.
3) Increasing the animals' performance in order to "dilute" the indispensable N emission from maintenance turnover among a higher amount of products.

The dominant contribution to reduce the N emissions will arise mainly from the strategy a) and b). Strategy a) may be realized to a large extent by rather simple feeding techniques, like phase feeding (e.g. 3 feed mixes for pigs along the fattening procedure). Also strategy b) may be applied directly to practice, since the relevant amino acids and feed proteins are commercially available. By using such feeding strategies, N emissions from animals may be reduced by 30 to 40 % compared to the present situation (Windisch 2000).

Phosphorus

The high P-emissions from livestock production reflect mainly the low efficiency of the transformation of phosphorus from feed into animal products. On average about 70 % and more of the P fed to animals is lost by excrements and transferred into manure.

Similarly to the situation in N, one major reason for the high P-losses is an excessive P content in the animals' feed. Since the P content of products (meat, milk, egg) is fixed, any surplus in dietary P cannot be utilized and has to be excreted into the manure. However, the animals' requirement for P changes substantially along the production cycle (pregnancy/lactation, start/end of fattening). Like in N, the farmers tend to adjust the P content of the feed to the level of the maximum requirement. This results in a considerable P excess to the animals during most of the time along he production cycle. Additionally, until recent years there were uncertainties regarding the P-demand especially of dairy cows and beef cattle. But in the meantime new assessment standards and recommendations for cattle permit a more precise supply of phosphorus to the animals.

Another reason for high P emissions is the fact that a large proportion of dietary phosphorus is bound in the form of phytate, which is almost indigestible by monogastric animals. This refers in particular to grain and oil seed extracts, which are one of the most important protein feeds to monogastric livestock. Due to the low availability of native P, the feed has to be supplemented with P from mineral origin. However, during the last years phytate-degrading feed additives of microbial origin (phytase) were developed and brought to a stage suitable for practical application. In contrast to pig and poultry, phytate P is no problem to ruminants, because the microflora of the forestomachs degrades phytate P into a digestible form.

A further factor of the extent of P-emissions is the level of the animal performance in relation to the "non-productive" maintenance turnover.

Thus, 3 strategies are available to minimize P-emissions from livestock production. They are in principal the same as in the case of N:

1) Applying the official recommendations for P supply and avoiding P surplus by adjusting the dietary P content to the changing requirement of the animal.
2) Improving the quality (availability) of the P in the feed to pig and poultry by adding phytase.
3) Improving the relation between production and maintenance by increasing the animals' performance.

Like in N, it is especially strategy a) and b) which provides major contributions to minimize P emissions. The tools to achieve these strategies are rather simple (e.g. phase feeding) and commercially already available (phytase). They have a potential to reduce P emissions by 30 – 50 % compared to the present situation (Windisch 2000).

Zinc and copper

Zn and Cu are essential trace elements with various biological functions. However, they may exert also pharmacological effects especially in piglets, such as prevention of diarrhea and promotion of production performance. These effects require dietary doses of about 50 to 100 times above the requirement, which reflects the (mis)use of the toxic potential of a heavy metal rather than the biological function of an essential trace element (Windisch et al. 1998, 2001). Pharmacologically effective doses of Zn are prohibited by feed directives and may be applied only under veterinary control, while equivalent doses of Cu may be used legally in practical piglet diets. In total, the pig feeding practice shows an increasing interest in such excessive doses of Zn and Cu. It obviously reflects the search for substitutes to antibiotic feed additives.

Any dietary quantities of Zn and Cu, which exceed the animal's requirement, are almost completely excreted into the manure. By this way, pure manure of piglets supplemented with excessive amounts of Zn and Cu may contain these heavy metals in the magnitude of about 15 g Zn and 1 g Cu per kg of dry matter (LBP 1997). This would severely exceed the respective limits to sewage sludge. However, piglet manure is usually diluted by manure of other animals. Nevertheless, the excessive use of Zn and Cu in piglet feeding is still visible in the 2fold and 5fold higher mean value for Zn and Cu contents of mixed pig manure compared to the respective contents in cattle manure (LBP 1997).

The average transfer of Zn and Cu via pig manure to the agricultural area was calculated to range at about 0.8 kg Zn and 0.4 kg Cu per hectare and year, which exceeds the withdrawal by plant harvest at about factor 4 (Zn), and up to 20 (Cu) (LBP 1997). In the case of Cu, the mean transfer rates are already higher than the limit given by the German Soil Protection Directive. Since the mobility of Zn and Cu in the soil is extremely low, these heavy metals may be progressively accumulated in areas fertilized with pig manure at rates of about 0.7 kg Zn and 0.4 kg Cu per hectare and year on average (LBP 197).

In total, there is no need to tolerate such high contents of Zn and Cu in the manure, because the pharmacological and growth promoting effect of excessive doses of Zn and Cu may be retrieved also by ecologically compatible alternatives (e.g. by organic acids). If Zn and Cu is fed to animals just according to the nutritional recommendations, the respective transfer rates to the agricultural area will decrease to the level of the withdrawal by plant harvest. In this case, the use of Zn and Cu as dietary supplements to the animals' feed is no risk to the environment.

Final conclusions

Excessive emissions of N, P, Zn and Cu via animal manure may be explained largely by excessive supplies (protein, phosphorus), low quality of feed components (protein, phytate) and partially also by the physiologically inadequate use of nutrients (e.g. essential trace elements). Optimizing feeding strategies may therefore turn N, P, Zn, and Cu from pollutants into valuable nutrients and reduce their emissions to a level, which agrees to the requirements of a sustainable animal production. This is also in favor of the animals, because their physiological needs are met the best by an optimized feed.

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Tetracycline and chlortetracycline residues in soil fertilized with liquid manure

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Introduction

Drug residues in the environment are of growing interest worldwide. In both human and veterinary medicine a large number of drugs are used. After excretion, these drugs and their metabolites can contaminate the environment. Residues of pharmaceuticals used in human medicine occur in water by passing sewage treatment plants. New investigations show, that more than 40 different drugs can be found in surface waters from the low to the very low µg/L concentration range [for review see references 1 and 2].

Veterinary drugs can enter the environment directly by the use in fish farms, by urine and dung or by liquid manure used as fertilizer (see fig. 1). Important drugs in this field are antibiotics and antiparasitic drugs.

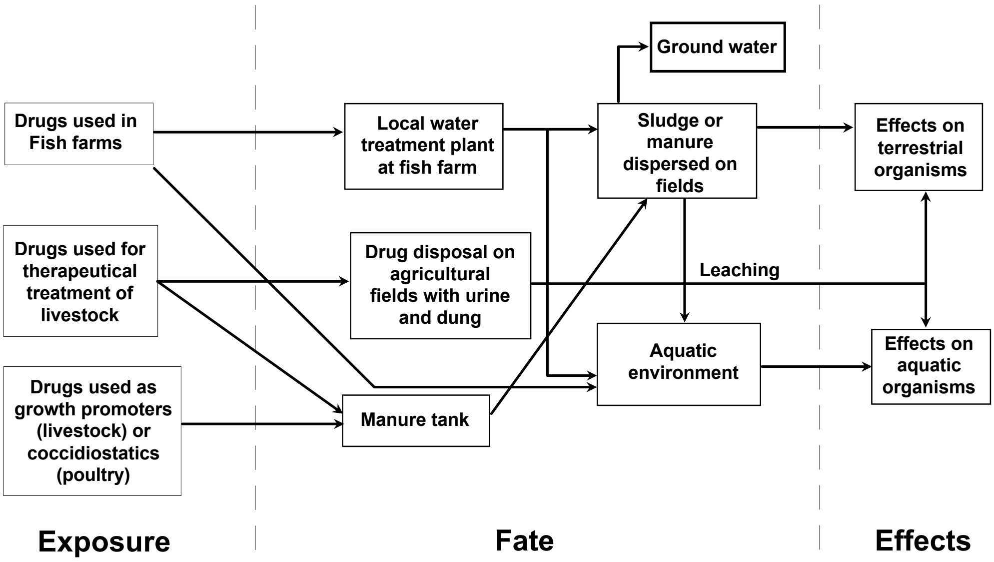

Fig. 1
Anticipated exposure routes of veterinary drugs in the environment [3]

A recently published study of Germanys Federal Environmental Agency showed, that the degradation rate of tetracycline in liquid manure is approximately 50 % in 5 months [4]. In a screening of 62 pig slurry samples 9 were found positive for tetracycline with amounts of 5 to 24 mg/L.

There is still very little known about the amounts of these veterinary drugs in soil. Therefore, we performed first investigations to evaluate the fate of frequently used drugs such as tetracyclines in soils fertilized with liquid manure in regions with intensive livestock farming. In another approach possible leaching of these compounds into seeping water and ground water was also investigated [5].

Sampling, sample preparation and measurement

Soil samples were collected from 12 agricultural fields in Northern Germany in early February 2000, the last fertilization with liquid manure was in September 1999. Samples were collected at depths

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of 10, 20, 30, 60, and 90 cm below soil surface. Control samples from two fields without slurry fertilization since at least 5 years were also taken from this region. Samples were immediately transported under cooling to the laboratory and stored at 4°C prior analysis.

In another approach the distribution of antibiotics in one field used as a long-term soil monitoring area [6] fertilized with pig slurry was investigated in detail: 8 samples were taken in and beside 4 specially marked areas. The area was fertilized in April, soil sampling was performed in May. In addition the pig slurry subjected to this area was investigated for tetracyclines. In 4 areas „crusty“ animal slurry was picked up from the topsoil and in addition soil samples were taken from 0-30 cm.

Water was sampled via pumping from depths of 80 cm and 120 cm in four different areas using 0,5 bar below atmospheric pressure. Two sampling areas were fields belonging to farms housing pigs and cows; the other two places were the control areas mentioned above.

Soil samples were liquid-liquid extracted based on a method for the extraction of tetracyclines from eggs [7], water samples were pretreated with solid phase extraction. Measurement was obtained by the application of liquid chromatography combined with electrospray ionization tandem-mass spectrometry (LC-ESI-MS-MS). The mobile phase of the reversed phase C18-LC-system consisted of 0,5% formic acid in water and a linear gradient from 0 to 50% acetontrile. [M+H]+-ions were obtained from all compounds, (ion-)trapped, fragmented and prominent daughter ions registered.

Results

The main results of our study in February are summarized in figure 2. Leaching of the anaylsed compounds into seeping water sampled at a depth of 80-140 cm could not be detected with the methods employed. The results of tetracycline amounts of the detailed investigation of the long-term soil monitoring area and the slurry used for fertilization are given in table 1. The results of the „crusty“ slurrys and the amounts of tetracyclines in the soil above are given in table 2. All data are corrected for recovery (Average recoveries in soil were 74,7 % for oxytetracycline, 37,7 % for tetracycline and 69,8 % for chlortetracycline; average recoveries in slurry were 100,2 % for oxytetracycline, 104,2 % for tetracycline and 127,1 % for chlortetracycline).

Tab. 1
Detailed investigation of a long-term soil monitoring area after fertilization with pig slurry containing 4 mg/L tetracycline and 0,1 mg/L chlortetracycline. 8 samples in- and outside marked areas within the field were sampled in different soil depths.

Soil depth	Tetracycline [µg/kg] (mean ± SD, n = 4)	Chlortetracycline [µg/kg] (mean ± SD, n = 4)
Sampling inside 4 control areas		
0 – 10 cm	56,4 ± 20,1	4,6 ± 1,1
10 – 20 cm	100,5 ± 68,8	4,7 ± 0,3
20 – 30 cm	90,5 ± 35,4	4,8 ± 1,2
Sampling outside 4 control areas		
0 – 30 cm	117,4 ± 98,1	4,5 ± 0,5
30 – 60 cm	n.d.	n.d.
60 – 90 cm	n.d.	n.d.

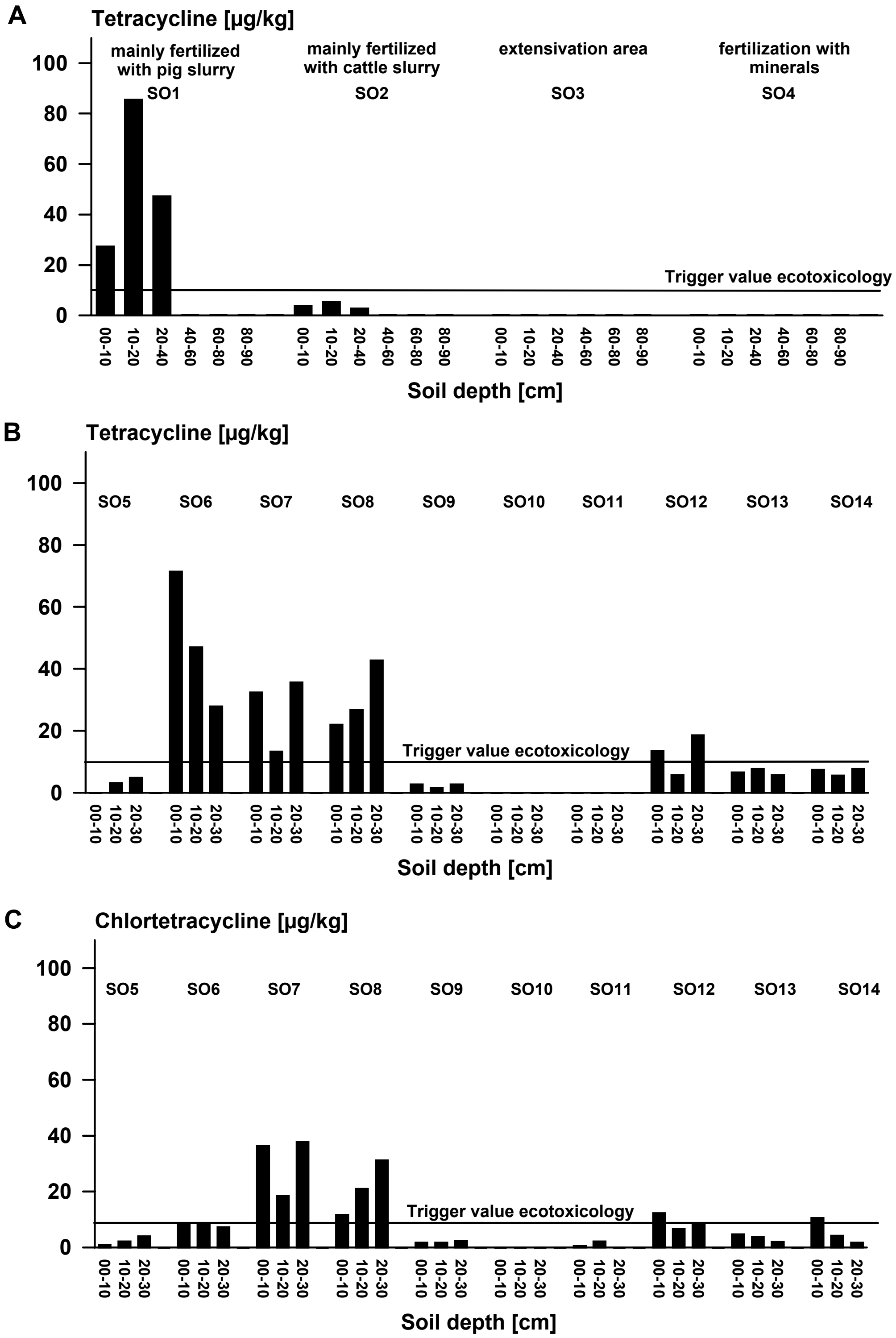

Fig. 2
Investigation of various soil samples with LC-ESI-MS-MS. A und B: Tetracycline in soils 1-14, C: Chlortetracycline in soils 5-14, (average of two replicates). Limit of determination: 5 µg/kg, limit of detection: 1 µg/kg for all compounds

Tab. 2
Results of the investigation of „crusty“ slurrys from 3 different areas.

„Crusty“ slurry / Soil depth	Tetra-Cycline [µg/kg]	Chlortetra-Cycline [µg/kg]
„Crusty“ pig (?) slurry A	349,3	1435,0
0 – 10 cm	33,2	59,9
10 – 20 cm	50,1	12,0
20 – 30 cm	30,3	14,9
„Crusty“ pig (?) slurry B	117,1	4,9
0 – 10 cm	4,0	1,7
10 – 20 cm	2,6	2,6
20 – 30 cm	2,6	2,9
„Crusty“ cattle slurry (n=4)	6,6 ± 3,2	10,9 ± 3,9
0 – 10 cm	5,0	7,2
10 – 20 cm	4,6	6,6
20 – 30 cm	2,3	3,3

Discussion

In a pilot study we detected with sophisticated LC-ESI-MS-MS procedures tetracycline and chlor-tetracycline in agricultural fields fertilized with animal slurry in significant concentrations [5, see also fig. 2. a-c]. In that study samples were taken in February, the last application of slurry was approximately 4-5 months ago. These findings showed, that tetracyclines are persistent in the environment and that the detected amounts were in several areas higher than the so called „phase I trigger value“ of 10 µg/kg soil recommended by EMEA. If this value is exceeded, additional ecotoxicological tests have to be applied since 1997 for the final registration of a new drug [8].

Meanwhile we performed a detailed investigation of a long-term soil monitoring area which received slurry in April and soil sampling took place in May. In that case, we also received a pig slurry sample. It could be shown, that the tetracyclines were distributed evenly over the field and that the antibiotics were ploughed in a soil depth of approximately 30 cm (see table 1). Calculating the predicted environmental concentration (PEC) of tetracyclin in soil following the EMEA guidance [8] and based on the amount of 4 mg/L measured in liquid manure, amounts of 100 µg/kg in the top 10 cm (or approximately 30 µg/kg in the top 30 cm) should be expected. In the field investigated, the average distribution of tetracyline in the top 30 cm was between 56 and 117 µg/kg. These data compared to the calculations show, that the tetracyclines are quantitatively transfered from the slurry into the soil. Furthermore antibiotic residues from past slurry amendmends were already present in the soil and thus were not degraded since the last fertilization measures. Further investigations of this area for at least the next two years will show, if antibiotics can accumulate in the environment.

Acute problems with tetracyclines in the environment may arise, when animal slurry is not sufficiently ploughed into the soil. We found an example of an area where liquid manure dried on the topsoil and the amount of chlortetracycline in this „crusty“ slurry was as high as 1,44 mg/kg (see table 2), which is in the range of the minimal inhibitory concentration for several bacteria, e.g. in plasma.

Leaching of these compounds into seeping or ground water could not be detected with the methods employed. Tetracyclines easily build chelatic complexes with bivalent cations, e.g. with calcium. Currently it is not known, what kind of complexation or adsorption takes place in soil and in seeping water. Therefore, we should not overinterprete our first negative findings in the water samples and work on a further improvement especially of analytical techniques.

Outlook

Finally we conclude, that our studies show that tetracyclines, which are frequently used worldwide, are not only persistent in animal slurry but also in soil in significant amounts, and that these substan-ces represent an actual environmental problem in intensive livestock farming.

Based on reports in the literature [1-4] and on our investigations [5] we propose the following:

Research needs

- Further investigation into the fate of tetracyclines in the environment (e.g. degradation rates, local and global distribution, bioavailability).
- Further improvement and validation of the employed methods for the analysis of tetracyclines in soil, water and liquid manure.
- Development of methods or techniques to accelerate the degradation of tetracyclines in slurry.

- Development of analytical methods for other frequently used veterinary drugs including their metabolites (e.g. sulfonamides).
- Development of suitable ecotoxicological test methods, especially for antibiotics (acute effects / antibiotic resistance).
- Relevant case studies with realistic concentration ranges to perform environmental risk assessment.

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Assessing the Environmental Fate and Effects of Veterinary Medicines

Alistair B. A. Boxall[1], Paul Kay, Paul A. Blackwell

Introduction

Veterinary medicines are widely used across Europe to treat farm animals. Once administered to an animal they may be adsorbed and wholly or partially metabolised before being excreted in urine and faeces. The resulting manure or slurry can then be released directly to the environment or collected and stored before being applied to land.

Once released to land, the medicines may be washed off into surface waters or leach to groundwaters where they may impact environmental and human health. Consequently, under EU Directive 81/852/EEC, an environmental risk assessment is now required on veterinary medicines.

Unlike pesticides, nutrients and other priority pollutants, the behaviour and effects of veterinary medicines in the environment has not been extensively studied. Moreover, differences in the characteristics of veterinary medicines in relation to other chemical classes, mean that methodologies that have been developed for other chemical classes may not be appropriate for veterinary medicines. Guidelines and approaches have been developed for performing these assessments (e.g. CVMP, 1996; Spaepen et al., 1997; Montforts, 1999). Due to a lack of background data, these approaches are generally very simple and have been developed to predict 'worst case' concentrations. Moreover, the methodologies may not adequately consider leaching to groundwaters or runoff to surface waters and extrapolation across member states is problematic.

Cranfield University are therefore co-ordinating a European Framework V project to develop improved approaches for assessing the environmental impact of veterinary medicines released to the environment. The specific aims of the project are to:

a) identify those factors and processes controlling the degradability of veterinary medicines in manure, slurry, soil, sediment and water
b) identify those factors and processes controlling the leaching of veterinary medicines in the environment
c) assess the effects of veterinary medicines on soil fauna and flora
d) assess the environmental distribution of a range of veterinary medicines at the semi-field and field scales
e) develop exposure assessment models and associated scenarios for use by regulators and industry

Three compounds have been selected for the study based on available data on metabolism, degradation and usage, namely: oxytetracycline, sulfachloropyridazine and valnemulin. This paper describes initial work to assess the environmental risk associated with each of these compounds and outlines future work.

Environmental Risk Assessment of Study Compounds

Metabolism

Data was collated on the metabolism by animals of each of the study compounds. Tetracyclines are excreted predominantly in the urine and the faeces as the parent compound, corresponding to between 40-70% of the applied dose. Whilst the metabolism of sulfachloropyridazine has not been investigated, a number of other sulphonamides have been investigated. These studies indicate that a significant proportion (i.e. 30-95%) of the applied dose of a sulphonamide may be excreted unchanged. Valnemulin is extensively metabolised and around 2% of the administered valnemulin is excreted unchanged.

Properties and Persistence

Data was available on the sorption behaviour and biodegradability of oxytetracycline (Table 1). No data were available on the degradability of valnemulin or sulfachloropyridazine. The sorption coefficient for oxytetracycline was high, indicating

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that it is likely to partition extensively to soils and that it has a low potential to leach. Moreover, the degradation rates in water indicate that oxytetracycline will persist. In contrast, the properties of sulfachloropyridazine indicate that it will readily leach. The sorption coefficeint for valnemulin indicated moderate leaching potential.

Table 1
Properties and persistence of study compounds

Compound	Log Kow	Koc	DT50
oxytetracycline	-1.22	28,000-93,000	42-46 d in water >300d marine sediment
sulfachloro-pyridazine	1.3	10	-
valnemulin	2.9	316	-

Prediction of Environmental Concentrations

The concentrations of each of the study compounds in soil water and soil were predicted using the uniform approach developed by Spaepen et al (1997). The input values for the approach are shown in Table 2. Predicted concentrations, assuming no degradation during storage, in soil ranged from 0.035 mg kg^{-1} (valnemulin) to 1.55 mg kg^{-1} (sulfachloropyridazine).

Table 2
Input data used to predict concentrations of study compounds in soil and water following treatment of pigs (OTC=oxytetracycline, SCP=sulfachloropyridazine, VAL= valnemulin)

Parameter	OTC	SCP	VAL
dosage (mg kg^{-1} d^{-1})	20	20	10
length of treatment (d)	5	5	21
number of treatments/animal	2	2	1
fraction excreted unchanged	0.7	0.95	0.02
mixing depth (cm)	5	5	5
average body weight (kg)	95	95	95
number of animals raised per place per year	2.5	2.5	2.5
yearly output of excreta per place (kg $place^{-1}$ yr^{-1})	1764	1764	1764
yearly production of phosphorous (kg P2O5 $place^{-1}$ yr^{-1})	8.32	8.32	8.32
yearly production of nitrogen (kg N $place^{-1}$ yr^{-1})	9.59	9.59	9.59

Due to it's very low Log Koc, predicted concentrations of sulfachloropyridazine in soil water were high (i.e. 5.2 mg l^{-1}) whereas concentrations of oxytetracycline and valnemulin were less than 4 µg l^{-1}.

Table 3
Predicted concentrations of the study compound in soil (mg kg^{-1}) or soil water (mg l^{-1}). (OTC=oxytetracycline, SCP=sulfachloropyridazine, VAL=valnemulin)

	OTC	SCP	VAL
Amount applied (kg ha^{-1})	0.87	1.18	0.026
PEC in soil (mg kg^{-1})	1.14	1.55	0.035
PEC in pore water (µg l^{-1})	0.85 - 2.73	5200	3.69

Effects on organisms

Both experimental and predicted data was available on the effects of the study compounds on aquatic organisms (Table 4). Generally all of the study compounds were of low toxicity to the organisms studied.

Risk assessment of study compounds

Predicted concentrations of the study compounds in soil and water were compared with lowest effective concentration to assess the likely environmental risk posed by each compound (Table 5). Generally, the ratios of predicted concentrations to effects concentrations were all well below 1, indicating that the compounds probably pose a low risk to terrestrial and aquatic organisms.

The exception to this was sulfachloropyridazine in soil water where the ratio was 31. This was determined using toxicity data predicted using QSARs, experimental studies would be required to confirm these predictions. Moreover, predicted concentrations are 'worst case' and probably provide an overestimate of actual concentrations in the environment.

Future Work

The work to date has focused on collating available data on metabolism, properties, degradadability and effects of the study compounds. A number of experimental investigations are currently underway to generate information on: 1) actual concentrations of the compounds in the environment; 2) the degradability of the study compounds in slurry, water, soil and sediment; 3) the sorption behaviour of the study compounds in a slurry, sediment and soil; and 4) the effects of the compounds on terrestrial communities. These studies will be completed in the next 2-3 years.

On the basis of these investigations, the current risk assessment methodologies will be assessed and refined where appropriate.

Table 4
Effects of study compounds on aquatic and terrestrial organisms

Veterinary compound	Test organism and endpoint	Toxicity (mg l^{-1} or mg kg^{-1})
Oxytetracycline	*M. aeruginosa*, EC50	0.207
	S. capricornutum, EC50	4.5
	R. salina, EC50	1.6
	D. magna, 48 h EC50, LOEC	100
	F. fimetaria, LC50	>5000
	F. fimetaria, EC50 reproduction	>5000
	E. crypticus, LC50	>5000
	E. crypticus, EC50 reproduction	2701
	A. calignosa, LC50	>5000
	A. calignosa, EC50 reproduction	4420
	A. calignosa, EC50 growth	>5000
	A calignosa, EC50 hatchability	>5000
	eathworm	>1000*
Sulfachloropyridazine	Fish 96 h LC50	1518*
	Daphnia magna 48 h EC50	5.6*
	Fish ChV	5.555*
	Daphnia magna ChV	0.17*
	Algae ChV	72.63*
	earthworm	>1000*
Valnemulin	*Daphnia magna* 48 h EC50	44.7. 3.4-64.1*
	Aerobic microorganisms	non-toxic at 2 mg l^{-1}
	Fish (yellowtail)	no mortality at dose of 10-15 mg kg^{-1} d^{-1}
	Fish 96 h LC50	28.2-59.7*
	Algae 96 h EC50	2.3-44*
	Earthworm 14 d LC50	>1000

*- predicted using QSARs

Table 5
Ratio's of predicted environmental concentrations to lowest observed effect concentrations for each of the study compounds

Compound	PEC	Effect	PEC:Effect
oxytetracycline	soil = 1.14	>1000	0.0011
	water = 0.0027	0.207	0.01
sulfachloropyridazine	soil = 1.55	>1000	0.0016
	water = 5.2	0.17	31
valnemulin	soil = 0.035	>1000	0.00004
	water = 0.0037	2.3	0.0016

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Organic livestock production

Albert Sundrum[1]

The development towards a sustainable agriculture has been a main objective of organic agriculture from the beginning (IFOAM, 1978), and a declared objective of the newly applied EC-Regulation (1804/1999) on organic livestock production which provides a clear framework for livestock production. The leading idea is based on the voluntary self-restriction in the use of specific means of production with the objectives to produce food of high quality in an animal appropriate and environmentally friendly manner within a nearly complete nutrient farm organism (Sundrum, 1998). With regard to an environmentally friendly production, organic livestock farming is characterised by:

- System-oriented approach,
- Renunciation of mineral nitrogen, pesticides, growth promoters, and GMO's,
- Maximum total stocking density of 2 large animal units per ha,
- Restrictions in the amount and quality of bought-in feedstuffs.

In the following, consequences of the framework and the production method are discussed in relation to the environmental issue.

System-oriented approach

Livestock production forms an integral part of agricultural holdings practising organic farming. Different agricultural fields are interrelated into a 'farm organism' which is driven by a nearly complete innerfarm nutrient cycle. A strict separation into lines of production is inappropriate to the idea of a nutrient cycle. With regard to nutrient losses, level of reference is the farm as a single unit and not a specific level of process engineering as is commonly used in conventional production. For example, it would be inappropriate to assess the emission of nitrogen in relation to the average milk yield per cow without taking the whole farm that is among others nitrogen losses in relation to fodder growing and distribution of manure into account.

Prevention strategy

The general renunciation of mineral nitrogen, risk materials (like pesticides) and controversially discussed substances (like GMO's) is part of a prevention strategy, leading to a comparable low input of substances, into the farm and to a minimized output. Reduction of pollution or energy consumption is reached by a systemic and casually related approach, while conventional strategies are often based on technical and management related measures (Kristensen and Halberg, 1997).

To assess nutrient losses on the farm level, the most common methodologies involve using balance sheets of the whole farm. Calculations demonstrate that the systemic effect of organic agriculture in both cattle and pig production has great implication on the nutrient balance and the balance-surplus in relation to the product (Haas, 1995; Halberg et al., 1995; Martinson, 1998; Sundrum & Trangolao, 2000). There is reason for the assumption that the benefit of the system-related approach on minimising pollution are much more effective as compared to management-related factors, such as increasing animal performance per animal per year. For example, reducing nitrogen input of 100 kg N/ha is more than doubly efficient in relation to the balance surplus than increasing average milk yield for 1.000 kg/cow and year (Mejs and Mandersloot, 1993). However, there is a high variability within organic farms in relation to their efforts and their nutrient efficiency.

Dual strategy in relation to nitrogen

In organic livestock production, feeding is primarily based on home-grown feedstuffs, including a high amount of legumes. As a consequence crude protein content in the diet often clearly exceeds the requirements of the animals and nitrogen in the manure is on a high level. In conventional production farmers are asked to reduce nitrogen in the diet in order to reduce nitrogen in the manure. In organic farming, a high level of crude protein in the diet is a very important nitrogen source for the

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innerfarm nutrient cycle. When trying to utilize this nitrogen source, organic farmers are encouraged simultaneously to minimize nitrogen emission from the manure. Due to the limited nitrogen resource, organic farmers have to find the balance within a dual strategy: increasing nitrogen in the manure and minimizing nitrogen emission form the manure. As nitrogen input in the organic farm is on a low level, organic farms are endowed with a credit in relation to nitrogen losses in the following production process. In the long run, the objective to increase productivity within the framework of organic agriculture goes along with improving management measures to minimize nitrogen emission.

On the other hand, the increase of productivity from a high level as being realised in conventional production leads more or less to a higher efficacy of nitrogen turnover and a reduction in nitrogen losses per cow and milk yield (Kirchgessner et al., 1991). However, there is reason for the assumption that with reference to the conventional farm as a whole, nutrient efficacy will probably decrease due to a reduction in digestibility of feedstuffs and higher demands of bought-in concentrates. Those concentrates increase nutrient input in the farm and cause energy consumption especially due to transport. From these theoretical considerations the question arises whether the efforts to increase productivity will reach or even has already exceeded the marginal utility in relation to environmental effects.

It can be concluded that both, a system oriented approach and a approach on the level of process engineering are needed to proceed in environmentally friendly production. Organic livestock production seems to be in the lead because production starts from a comparable low level of nutrient input.

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Impact of Livestock on Soil

Andy Whitmore[1]

Impacts of livestock on soil fall into two broad categories: firstly the physical impact of the animal on soil as it moves around and secondly the chemical and biological impact of the faeces and urine that the animal deposits to soil. Physically damaged soil can be even more susceptible to the chemical and biological impact of faeces and urine.

Physical impacts

Heavy livestock such as cattle compact soil structure and destroy vegetation on parts of a field that they tread most often. This is visually apparent around drinking water troughs, entrances to fields and other parts of the land where the animals congregate. Destruction of soil structure in this way is known as 'poaching' and can be seen to be harmful because restoration of vegetation does not always occur spontaneously once the grazing animal is withdrawn. Sheath et al. (1998) found losses of 5-10 kg dry matter ha^{-1} d^{-1} where up to 50% of an area was affected by cattle treading but recovery occurred within a few months. Compacted soil becomes strong making it difficult for new shoots to penetrate the soil and emerge; structureless soil is unlikely to drain well and will pond after moderate rainfall. Soil particles from these zones will be susceptible to erosion carrying particles, organic matter and phosphorus to surface waters (Warren *et al.*, 1986). Anaerobic zones in waterlogged soils will encourage denitrification which implies a loss of nitrogen and pollution of the atmosphere with N_2O if conditions for denitrification are sub-optimal in the compacted zone (see below).

Problems with soil structure are not limited to cattle farming. Pig production is notorious for its destructive effects on vegetation. Part of pig behaviour is to dig into soil with the snout. The effect on soil and vegetation is obvious, but without the protective effect of plant roots that confer strength to the rooting zone and without a plant withdrawing water from a field, the soil becomes weak and the structure collapses under the regular passage of the animal. Soil becomes compacted and the same problems listed above ensue. High stocking rates on pig farms exacerbate the problem. Sheep grazing, particularly in the UK is not normally thought of in these same terms because production is largely extensive on upland rough grazing. In some farms, however, sheep are used to graze root cover crops (such as turnips) in the late winter and all but sandy soils are likely to be susceptible to damage. At equivalent (i.e. metabolic weight) stocking densities on wet soils, short-term treading by sheep was, however, found to be less damaging than treading by cattle (Betteridge *et al.*, 1999).

Chemical and biological impacts of manure and urine

Although many of the impacts of animal wastes on the environment concern losses to water or the atmosphere, soil is an intermediary and as such these impacts deserve space here. The amount of urine delivered to soil by a grazing cow is of the order of 2 litre applied to an area of about 0.4 m^2 (*e.g.* Addiscott *et al*, 1991). This represents an instantaneous application of 400-1200 kg N ha^{-1}. Such an amount burns vegetation and is often toxic to plant roots which cannot immediately recover to take up the N (full recovery can take up to 12 months and the problem is obviously worst in areas where animals congregate). Urea in soil is quickly hydrolysed and given that grass can take up perhaps 400 kg N ha^{-1} annually without loss, pollution of groundwater or the atmosphere is almost inevitable whenever urine is applied to soil. Both calcium and magnesium are also lost in substantial amounts from urine patches on pasture soils (Early et al., 1998).

Losses of N from urine and manure will normally be as ammonia, dinitrogen and nitrous oxide (during denitrification) or as nitrate leaching. Two key processes deserve mention. The first is that during dentrification (of nitrate to N_2 or N_2O) the major product is almost always N_2. If conditions for this process are in anyway sub-optimal, especially if there is a deficiency of organic carbon relative to nitrate such as might occur under a urine patch, N_2O production increases (*e.g.* Swerts,

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1996). Since N_2O is a potent greenhouse gas its emission from soil is clearly undesirable. Secondly nitrate is produced from urine and manure during nitrification which is itself a multi-stage process. Where organic matter levels are high such as in or around manure not all the N is converted to the end product, nitrate (NO_3^-), and some remains as nitrite (NO_2^-). Nitrite is equally as susceptible to leaching as nitrate but is far more toxic. Debate about human health in recent years has focussed wrongly on nitrate, which is in fact a precursor in the body to the production of NO (nitric oxide) that is one of the first lines of defence against pathogenic organisms. Most instances of damage to health that have been attributed to nitrate are in fact the result of nitrite: e.g. methaemoglobinaemia from well water contaminated not only with nitrate but also nitrite. The Incidence of stomach cancers has been found to be negatively correlated with nitrate intake (Beresford, 1985 ; Forman, 1985) even though a theoretical link had assumed that nitrate could be reduced *in situ* to nitrite in the stomach. Fortunately nitrite in the wider environment is generally short-lived, but arises during sub-optimal nitrification of ammonia to nitrate, for example where ammonium is washed directly into surface waters either from the soil or because the animal urinates close-by. Nitrite is nonetheless occasionally found in natural waters at levels that exceed EU limits.

Compaction of and damage to soil also limits the growth and use pasture can make of available nutrients. Douglas and Crawford (1998) found between 1.7 and 2.1 t ha-1 reduction in dry matter production in a compacted sward and reduction in recovery of N from 71% to 55% of that applied in the uncompacted and compacted swards respectively.

Cattle sometime spread pathogenic organisms by picking them up from a point source but urinating or defecating elsewhere. Weeds, plant diseases, e-coli O157 are all thought to be spread in this way.

The amounts of nutrients in manure are equally a source of waste, a missed opportunity and potentially of pollution. Manure is partly microbial in composition derived from fermentation during digestion and partly composed of recalcitrant components of the feed. As such it is rather less decomposable than fresh plant material and does not supply N to soil as rapidly or damagingly as urine. It does, however, block light and grass growth underneath manure will be temporarily retarded. Some regrowth occurs with penetration where the pasture is well enough established, some with reseeding directly into the manure.

Application of manure is not necessarily harmful. As implied in much of what has been said above, manure and urine contain nutrients that grass or crops can use. Because manure is relatively long-lived in soil it releases its nutrients slowly and can continue to benefit crop production for many years. Whitmore and Schröder (1996) estimate that applications of slurry to maize during the 1970s and 80's has increased the N-supplying power of Dutch soils by about 70 kg N ha^{-1}. Because the extra fertility is long-lived this extra N-supply is expected to take 10 years to decline to half its current level. This is beneficial, however, only so long as a pasture or crop recovers the N. The N can also mineralise during winter or at some other time when the crop is not growing at its full potential. Under these circumstances losses to the environment are inevitable. The fertility is only maintained as long as the pasture remains in place. Ploughing a grassland soil results in a burst of nutrient availability that slowly declines. Whitmore *et al*. (1992) showed that the intensive ploughing of grassland during the 1940's and 50's in the UK is a probable cause of the increases in nitrate found in aquifers in the 1970's onwards. Watts *et al*. (1996) have shown that increased levels of organic C in soil confers desirable resilience to soils in relation to tillage. Mineral pasture soils almost certainly resist hoof damage in proportion to their organic matter content.

The impact of manure and urine on soil from livestock is not simply one of perturbing nutrient cycles. Additives such as copper, zinc, antihelminthics and antibiotics or other veterinary treatments are given to animals. The presence of Cu and Zn can make manure unsuitable for use as a fertilizer on other farms and metals such as these pose a long-term risk in pasture soils because they can accumulate and are only slowly removed by leaching or offtake in vegetation. Heavy metals have been shown to reduce the microbial life and diversity in soil (Griffiths, 2000) and the activity of N-fixers in particular (Giller, 1999).

Nutrient balances

One rough and ready way of assessing the impact of livestock farming has been to consider the balance between inputs and measured outputs of the nutrients used in livestock farming. The difference is usually large and positive implying enormous loss of nutrients to the wider environment or retention in soil. Given that in the majority of the loss pathways nutrients pass through the soil, this imbalance has a considerable impact on soil. As a very rough rule of thumb a surplus of N is an immediate problem in that more N is lost than retained by soil; concerns about P focus on the gradual build-up over many years that leads to subsequent but sustained losses. On one Dutch dairy farm in the 1980's about 400 kg N, 23 kg P and 56 kg K ha^{-1} annually of 467, 35, and 73 kg ha^{-1} applied respectively was unaccounted for. More generally 75% of the 1.1 x 10^9 kg N applied annually throughout the whole of the Netherlands is thought to be wasted (Whitmore and Van Noordwijk, 1995). Surpluses of N on UK dairy farms were recently reported to range from 63-667 g N ha^{-1} with a mean of 257 kg N ha^{-1} (Jarvis 2000) and exports in produce were estimated to be only 20% of the N applied (Jarvis 1993). Haygarth (1998) estimated gains of P by soil in a typical UK dairy farm to be 26 kg P ha^{-1} annually with a stocking density of 2.26 animals ha^{-1} on average. On an upland sheep farm the gain was 0.24 kg P ha^{-1} only. Strategies to reduce the impact of animal manure and slurry on the environment usually focus on limiting spreading according to the amount of P (e.g. Van der Molen et al., 1998). This is because the relative amounts of NPK required by pasture and arable crops differs from the rate these elements are found in manure; manure is too enriched in P relative to N.

Grazing systems can have an effect on soil and more particularly water courses if manure or silage is not stored properly and leaks out. The resultant point source contamination can affect soil for many years, destroy aquatic life and make water unfit for consumption.

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Ecological Alterations in Biocenoses due to Nitrogen

Hermann Ellenberg[1]

Abstract

Input of ammonia and ammonium compounds into the environment play a crucial role in a type of forest damage particularly common in north-west Germany and The Netherlands, which leads to the death of pines and Douglas firs (Research Council on Forest and Timber Damage and Air Pollution 1986, Dutch Priority Programme on Acidificaton 1990). Ammonia (NH_3) is prevalent in the atmosphere as a highly reactive nitrogen compound or in combination with various anions as ammonium compounds. In the presence of water, ammonia reacts rapidly in the air with sulfur dioxide ($S0_2$), a product of combustion, to form ammonium sulfate $(NH_4)_2SO_4$, which is highly water soluble and a very effective fertilizer. Unlike ammonium, which is usually found within a few hundred meters a few kilometers from its source, nitrogen in ammonium compounds can be transported over wide areas, thus contributing to „long-distance immissions". Only a small part of the ammonia and its derivatives found in the environment comes from industrial processes. Around 90% of the ammonia in north-western central Europe stems from livestock farming and the associated use of slurry as fertilizer. Under cool and damp weather conditions the greatest part of the ammonia remains in solution in the slurry water. But dry, warm weather and associated air movement cause ammonia to evaporate. Huge amounts of nitrogen are then transported in the air to nearby plants, resulting in nutrient imbalances, including acidification of the soil (Roelofs 1989). And in ecosystems with no annual crop harvest such airborne nitrogen input can lead to changes in the living conditions and thus influence the competition among organisms long before toxic effects become apparent. Figure 1 shows how nitrogen input can change individual plants, overall vegetation and even animal populations. When competitively weaker plant species vanish, often those parts of the animal world also vanish which are dependent on specialized low-nutrient niches in the micro-climate. Increased nutrient supply stimulates early, rapid, high and extensive plant growth. In this way decisive changes occur in a biotope's habitat structures, temperature and water equilibrium, with far-reaching effects on many other ecological factors (Figure 1). Such influences on the micro-climate are most pronounced in late spring and early summer, when vegetation is most dense. The effect of these changes are magnified because they occur during the most intensive phase of animal reproduction and when the young are most vulnerable. This is particularly true for many large insects and their predators, for hares, grouse and quail and for many field birds such as larks.

In some areas of Lower Saxony annual levels of airborne nitrogen in the crown branches of firs have now been measured at up to 70 kg N/hectare. In The Netherlands there are large areas with inputs via the air of more than 100 kg/N/hectare per year. But there are more effects of nitrogen input and associated eutrophication. For several decades German authorities have kept official „Red Lists" for the geographical and political borders under their jurisdiction. These lists contain those plant and animal species which to the best of our knowledge are in danger of extinction. These lists contain species which have always been rare, and those which have recently become so. It has been determined (Ellenberg 1983-1989) that approximately three-quarters of all plant species now considered endangered in Germany can compete successfully only on poor soils, i.e. those with low nitrogen supply. These „light-loving hunger artists", which would also thrive under more favorable conditions, now barely survive because they are being crowded out by other, nutrient-loving plants which grow faster and higher, blocking the light necessary for other species. Figure 2 shows the distribution of 2,146 central European vascular plant species in terms of their relative nitrogen requirements (Ellenberg, Sr. 1979). Obviously many more than half of the native plant species in Germany can successfully compete only under conditions with low nitrogen. In Figure 2 „very low nitrogen" is assigned the value of „1", while „3" refers to low nitrogen", and „5" means „sufficient nitrogen"; „7" indicates that the plant grows more often on nitrogen-rich soils, while plants classified as „8" are N indicators, and „9" corresponds to an oversupply of ni-

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trogen. An „X“ in Figure 2 indicates that the species is more or less unaffected by nitrogen. The numbers „2“, „4“ and „6“ refer to intermediate stages. It is obvious from Figure 2 that most species on the „Red List“ can successfully compete and survive only on N-poor soil. This is much less the case for unendangered species. The proportion of endangered plant species among the total number of plant species occurring here declines with increasing N-indicator status and remains constantly low with sufficient nitrogen supply. This means that not all endangered species are negatively affected by eutrophication. Nevertheless it is apparent that the proportion of endangered plant species is clearly higher among those plants acclimated to N-poor soils than those which can thrive on a higher supply of nitrogen.

These brief remarks show that nitrogen emissions from livestock production must be reduced and that closer cooperation is needed between environmental protection, nature and wildlife conservation and agriculture.

N Supply

rich	low	• structural variety of immediate surroundings	high	**poor**
	low	• supply of sunlight	high	
	low	• variations in temperature	high	
	low	• variations in moisture	high	
	low	• continental climate quality	high	
	high	• net primary production	low	
	better	• digestibility (as food for animals)	poorer	
	greater	• ground cover	lower	
	higher	• height of growth	lower	
	higher	• water requirement	lower	
	higher	• cation requirement	lower	
	higher	• „internal“ acid production in the soil	lower	
	lower	• rough/sketchy „crown cover“	higher	
	higher	• absolute respiration	lower	
	lower	• relative respiration	higher	
		• and others		

Fig. 1
The effects of changes in nitrogen supply on crops, vegetation and animal populations

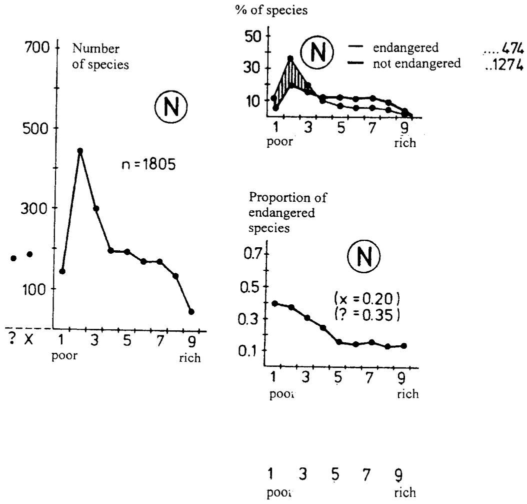

Fig. 2
Distribution of 2,146 central European species of vascular plants according to their relative function as N indicators

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Livestock Farming and the Environment: Impact on man

Martin Iversen[1]

Introduction

Human health effects due to dust exposure has been an area of research in the last twenty years and today it is established beyound doubt that high dust exposure in animal confinement buildings is a respiratory health hazard.

Much has been learned about exposure under different working conditions and their relation to respiratory symptoms and disease and the interest has focused on work in swine confinement buildings because the highest exposure and the highest frequency of symptoms is found here. Poultry farming also carries a substantial, if not higher than swine farming, exposure to dust but the number of working hours spent inside and the number of persons employed is much lower than in swine farming. From a human health perspective dust exposure in pig farming is the most important because of the large number of people involved and the increasing number of working hours inside confinement buildings. Socio-economic changes with disappearence of smaller family-based farms and the development of agricultural industry in pig farming with all working hours spent inside the confinement building has increased exposure and will continue to do so in the future and will have a major impact on the respiratory health of the agricultural workers.

Exposure

The respiratory problems are mainly concerned with the high levels of dust exposure in poultry and pig farming. Much has been learned about dust concentrations, generation and transport of dust, and biological properties of dust in the last decade and the present state of knowlegde is summarized in (Pedersen et al. 2000, Ellen et al. 2000).

Generally exposure is very high compared to other work environments with a high content of microorganisms and endotoxins.

Evidence of harmful effects upon man

The inhalation of irritant substances causes inflammation in the airways which in some ways is analogous to smoking.

Several studies have demonstrated that working in pig confinement buildings is associated with symptoms of chronic bronchitis (cough and plegm), asthma-like symptoms like wheezing and shortnesss of breath during work, and with evidence of mild arways obstruction in cross-sectional studies. Some studies alo shows increased bronchial rectivity to irritants. Most important, dust exposure does not seem to be associated with the development of emphysema as in smokers. It must be emphasized, however, that the present evidence demonstrates that the effect of dust exposure is limited to the airways and not associated with cancer and cardio-vascular disease like smoking.Most studies have shown that work inside pig confinement buildings double or triple respiratory symptoms and that there is a clear dose-response relationship with the number of working hours inside buildings. It has also been learned from several studies that the many respiratory symptoms are not caused by sensitization to pig proteins in spite of high concentrations in the air. This is fundamentally different from the problems encountered by workers in laboratories with rodents like mice and rats where many persons become sensitized and develop allergic asthma. The reason for the lack of sensitization to pig proteins is not known. The problem is mostly irritation of the airways with other possible disease mechanisms (allergic alveolitis, allergic asthma, Organic Dust Toxic Syndrome, emphysema, lung fibrosis) being either rare or of no significance, for a general overview (Iversen 2000).

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What is the major concern from the human health perspective in the future.

The present concern is about development of asthma in young people entering farming and about the development of chronic airways obstruction after many years of working in pig confinement buildings. The close association between asthma-like symptoms and dust exposure was once more confirmed in the largest study of farmers until now, the European study "Prevalence and Risk Factors of Airway Obstruction in Farmers" which includes 7988 farmers in Denmark, United Kingdom, Germany, Switzerland, and Spain (Radon et al., 2000. From the large prospective Danish study on young people trained in farming (Sigsgaard et al., 1999) the results from the first two years of follow-up demonstrated that the development of asthma was related to the total dust exposure with a relative risk of 1.0 in the lowest quartile rising to 5.5 in the quartile with the highest dust exposure).

Because of this dose-response relationship much effort has been put into studies which try to lower exposure under a certain threshold so that symptoms will not appear.

A study with dust reduction with an oil spraying method in a pig confinement facility (Senthilselvan et al., 1997) demonstrated substantial protection against acute effects on lung function measured by FEV_1/FVC, bronchial reacticity measured by metacholine test, and inflammatory reactions measured by blood neutrophile counts in peripheral blood.

It is now beyond reasonable doubt documented that the major respiratory health problems in animal confinement buildings with heavy dust exposure, especially pig and poultry production, is airway inflammation caused by a non-allergic mechanism. This inflammation is associated with asthma-like work-related respiratory symptoms. The endotoxin content of the dust is probably the most important part of the dust for the inflammatory proces.

It has also been demonstrated that dust exposure is associated with an accelerated decline in FEV_1 in pig farmers (Iversen et al. 1994, Senthilselvan et al. 1997, Vogelzang et al. 1998, Iversen et al. 2000). The extra loss in FEV_1 approximately doubles in some farmers and will cause clinically significant disease in some farmers.

The acute reaction with its immediate development of symptoms and signs of inflammation seems to be related to the long term outcome (Schwarz et al. 1995, Kirychuk et al. 1998), a concept that was developed several years ago (Becklake 1995) and which has also been found in cotton industry (Glindtmeyer et al. 1994, Christiani et al. 1994). The acute reaction is now used for studying the effects of intervention and the most elegant and comprehensive study right now is the study by (Senthilselvan, Zhang et al. 1997) which clearly demonstrates the efficacy of this approach. This study also demonstrates that dust and endotoxin concentrations must be vey substantially lowered to abolish or significantly diminish acute inflammatory reactions in the airways.

The future establishment of threshold values for dust in confinement buildings

The exposure in present animal confinement buildings is still substantial (Takai 1999) and in many cases above the levels of endotoxin where long-term deleterious effects have been demonstrated in longitudinal studies in swine farmers (Vogelzang et al. 1998). We know from longitudinal studies of dairy and swine farmers that swine farmers do have an accelerated decline in FEV_1, whereas dairy farmers do not (Iversen et al. 2000) and we also know that exposure in present European dairy farmers is 10-15% of the exposure in swine farmers (Takai et al.1999). These low values are below the values previously put forward as potential threshold values for working in swine confinement units (total dust 3.7 mg/m^3, respirable dust 0.23 mg/m^3, endotoxin 154 ng/m^3) and recently proposed as threshold values in poultry houses (total dust 2.4 mg/m^3, respirable dust 0.16 mg/m^3, endotoxin 61 ng/m^3) (Donham et al. 1999). There is thus an unresolved discrepancy between results from acute exposure studies and results from long term studies. Probably some of the explanation of this is the the use of different populations of persons where some are selected after years of exposure in farming and others, mainly the persons used in acute experiments, are socalled naive subjects to this environment. Important to consider is that the studies of Donham were done on farmers with years of experience.

The establishment of tresholds for exposure in animal confinement buildings is a high priority topic to avoid respiratory disease in farmers in the next generation.

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Abating Pollution from Livestock Production

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Introduction

Intensive animal feeding operations emit sufficient odor, ammonia, hydrogen sulfide, volatile organic compounds, greenhouse gases and particulate matter (PM) to have a significant effect on air quality, requiring abatement solutions (USDA, 2000; Monteny and Voermans, 1998). Whereas NH_3 and greenhouse gas emissions have been the primary abatement goal in Europe, odor control is presently the highest priority of U.S. livestock production. Ammonia volatilization used to be considered in the U.S. as a means to balance N for land application, but is now being viewed as an air quality problem. Dust emission reduction has recently become an important goal for agriculture in both North America and Europe. Regulations in the U.S. have begun to include phosphorus and pathogens in water quality goals and PM, odor and NH_3 in air quality goals. Greenhouse gas emissions have not received as much attention in the U.S. as in Europe. However, since CO_2, CH_4 and N_2O are natural products of manure decomposition, strategies to reduce emissions of odor and odorants are likely to reduce emissions of these gases as well (USDA, 2000).

Table 1 summarizes abatement technologies that may reduce pollutants from livestock facilities. Some of these technologies have been sufficiently tested to prove their efficacy, but most have not been evaluated properly or systematically. Producers, researchers and advisors must realize that measures implemented in one part of the operation may increase emissions from the overall operation. For example, pull-plug manure pits drained frequently to reduce building emissions could increase overall emission from the operation if the drained manure is not properly handled, stored, and treated. Also, deep litter systems reduce NH_3 emissions but increase emissions of greenhouse gases. Well-managed straw bedding systems reduce building NH_3 emissions but overall emissions to the atmosphere are the same because of higher losses during storage and spreading. Also, more dust is emitted with straw bedding.

Buildings

Building emissions can be significantly reduced through proper management of manure, ventilation, feed and building hygiene. For example, emission reduction from poultry houses is achieved by frequent and complete removal of droppings from layer houses, by continuous litter ventilation and drying in houses with birds on litter, and by using pit circulation fans to promote drying of droppings in caged-layer houses (van Horne et al., 1998). Reducing moisture content of litter is critical especially for reducing emissions during outdoor storage. The “fill and empty" principle of manure removal in pig houses produces 70% less NH_3 than fully slatted floors with deep pit and long-term storage (Oosthoek et al., 1990).

Diet modification (phase and split-sex feeding, Yucca-extracted sarponin, reduced crude protein, added fiber, etc.) continues to be regarded as having the most potential for economically improving the nutrient cycle of livestock systems (Sutton, 1999). Research has shown significant reductions of NH_3, odors, and greenhouse gases during storage and land application of slurry (Hartung and Phillips, 1994). These effects are attained by reduced slurry pH and slurry concentrations of total and NH_4-N, , whereas effects on odor emission are probably more related to reduced concentration of volatile fatty acids (Monteny and Voermans, 1998). Minimizing mineral sulfates and sulfur-containing amino acids reduce sulfurous gases. Adding soybean oil or animal fat to diets or using high-oil maize in the diets reduces dust emissions (Jacobson et al., 1998).

Treatment of liquid manure in pits is used to develop aerobic conditions, enhance anaerobic conditions, or stop microbial activity. Aerobic systems are very effective but involve high energy and maintenance costs. Chemical (organic and inorganic acids) and biological (enzymes, microorganisms) additives have been used to abate emissions, but very few independent tests have proven their effectiveness. However, Berg (1998) reported that lactic acid reduces methane and nitrous oxide emissions by 80 to 90% and that the benefits of

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acidification extend not only to the animal house, but also to manure storage and land application.

Air treatment systems can remove multiple pollutants, and low-cost designs are possible. Biofiltration is an aerobic process that breaks volatile compounds into CO_2, water and mineral salts. In one study using compost and dark red kidney bean straw for a biofilter bed, farrowing house odors from a pit fan were reduced by 78% and NH_3 by 50% (Nicolai and Janni, 1997). In another study, gestation/farrowing house odors were reduced by 95% and H_2S by 90% (Nicolai and Janni, 1997). The cost was US$0.22 per pig produced in the gestation/farrowing facility. Innovative designs are being developed to reduce the initial cost and to minimize operating costs and labor. Biofilters are only really applicable to fan-ventilated buildings.

Dust removal techniques also reduce gas and odor emissions because gases adsorb onto the particles. Low maintenance aerodynamic dedusters have removed 80% of odorous dust from swine house exhaust air in university tests. This experimental method requires more field testing but does show potential for removing multiple pollutants. One promising technology for reducing building emissions is sprinkling of oil/water mixtures on surfaces (floors, animals, feed, straw) to keep settled dust from resuspending into the air. About 50 to 75% reductions in dust have been shown. Cost is estimated at US$1.15 per pig marketed, with 70% of the cost in labor (Banhazi et al., 2000). More field research is needed to solve some practical problems associated with oil sprinkling.

Windbreak walls near the exhaust fans (Bottcher et al., 2000) and woodlands further away may remove some of the dust and deflect odorous air upward for better atmospheric mixing. However, the effectiveness of these artificial and natural barriers has not yet been well quantified.

Outdoor Manure Storage, Handling and Treatment

Abatement measures for manure storage and treatment facilities depend greatly on site-specific factors (Monteny and Voermans, 1998). For example, covering storage facilities (silo, tank, lagoon) is beneficial when manure can be utilized on the farm whereas manure treatment is useful when there is a nutrient imbalance.

Permeable covers are utilized by many North American livestock producers on anaerobic treatment basins (lagoons) and open manure storages (PSF, 2000). Such covers limit solar heating and wind-induced volatilization. Permeable covers have high surface contact areas and provide an aerobic zone for degradation of odors and other gases emitted from the slurry. Permeable covers and biocovers including chopped straw, cornstalks and geotextile materials provide 50-90% emission reduction. Manufactured materials in the form of self-dispersing granules or powder have resulted in over 95% reductions in odor, NH_3, and H_2S emissions, according to laboratory tests. The product floats back to the surface after agitation. Peat moss and light expanded clay aggregate (LECA) are also very effective but cost US$2.90 and US$9.68 per square meter, respectively. Impermeable floating plastic covers result in over 99% emission reduction (Jacobson et al., 1999).

Anaerobic digestion systems are very effective air and water pollution control systems and appear to represent the wave of the future for livestock production in the U.S. They pretreat high strength wastewater to reduce biosolids volume and control wastewater system odors (PSF, 2000). Initial capital costs are high but utilization and sales of energy and composted manure solids can provide paybacks of 5 to 7 years. Anaerobic digesters have recently been installed on several large livestock farms in the U.S. and have been shown to:

1. Reduce odor from land-applied slurry by 75%,
2. Enable the sale of electricity and provide a heat source to the farm
3. Maintain the manure's fertilizer value (Pigg and Vetter, 1984),
4. Improve handling and solids separating characteristics of manure,
5. Stabilize manure by converting up to 70% of organic N into NH_4-N,
6. Destroy about 60 to 75% of the volatile solids,
7. Conserve water and produce marketable digester "fiber",
8. Reduce transportation costs by reducing manure solids by 70 to 95%,
9. Reduce BOD levels by up to 90% and COD by 60-70% (AgSTAR, 1997),
10. Reduce odor and gas emissions,
11. Destroy weed seeds and reduce pathogens by more than 99%,
12. Reduce attractiveness of the manure to rodents and flies.

Covered lagoon digesters (NRCS, 1996) are increasing in popularity in the U.S. as a technique to control odor. They are essentially an inefficient digester, because temperature and mixing are not controlled. Biogas is collected and either released to the atmosphere, burned in a flare, or utilized to heat on-farm processes or generate electricity (Safley and Westerman, 1994). They are capable of capturing

0.25 to 0.60 m^3 CH_4 per kg volatile solids (Cheng et al., 1999).

Composting, a biological treatment technique, is possible for all solid manures. Composting reduces weed seeds and pathogens. About 20 to 40% of the total N in the solids is emitted as NH_3 and about 1 and 2% as N_2O and CH_4, respectively. Optimized C/N ratios reduce NH_3 emission (Jacobson et al, 1999).

Innovative emission abatement during land application of slurry includes direct ground injection and incorporation. These techniques are commonly practiced in many countries to improve retention of nutrients, and to reduce NH_3 and odor emissions (Monteny and Voermans, 1998).

Recent Emission Abatement by Large Swine Producer in Missouri

A State of Missouri Consent Decree in 1999 required a large U.S. pork producer Premium Standard Farms (PSF) to develop and implement plans to investigate and implement new technologies that reduce odors and nutrients, reduce effluent volumes and reduce the risk of spills during land application. PSF has facilities for 107,000 sows and 800,000 finishing spaces in Missouri (PSF, 2000) that include 163 single stage anaerobic treatment lagoons. Most of their barns are mechanically ventilated and have shallow flush gutters beneath the fully slatted floors. Lagoon effluent is land applied using high-pressure traveling gun applicators. PSF has recently implemented windbreak walls, permeable covers, aerobic polishing, nitrogen reduction cells and low-emission land application techniques (low-pressure irrigation, subsurface injection) at their pork production sites.

Research Needs

1. Develop effective, practical and economically feasible emission control technologies for confined animals, treatment, and land application systems.
2. Develop potential relationships between emission constituents, concentrations, and potential health indicators, and devise appropriate mitigation strategies accordingly.
3. Test effects of slurry acidification in animal houses (Hornig et al., 1997).
4. Determine how additives affect emissions from slurries.
5. Evaluate effects of abatement techniques on each target pollutant.
6. More research is needed on biofilter maintenance, dust removal, and disposal of saturated material.
7. Develop ways to dispose of wet scrubber wastewater.
8. Develop better knowledge of how abatement methods for different pollutants interact.
9. Standardize reliable emission measurement methods.
10. Develop economic models to evaluate cost-effective abatement strategies (Cowell and ApSimon, 1998, Phillips et al., 1998).

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Table 1
Emission abatement techniques for livestock facilities and their target pollutants

Buildings	Comments	PM	Odor	H2S	NH3	N2O	CH4	CO2	VOC	Path	BOD	NPK
Decrease airflow rate	decreases indoor air quality	√	√	√	√	√	√	√	√	√		
Airflow distribution	reduce air speeds near surfaces		√	√	√	√	√	√	√			
Lower building temperature	slight effect on several pollutants		√	√	√	√	√	√	√			
Remove manure frequently	daily removal is the best		√	√	√	√	√	√	√			
Use low dust emission feed handling		√	√							√		
Maintain feeders to avoid feed loss		√	√							√		
Use smooth cleanable surfaces	less manure residue on surfaces		√	√	√	√	√	√	√			
Use slatted floors with underfloor pit	helps to keep the floor dry		√	√	√	√	√	√	√			
Separate solids and remove urine	under test in the U.S.		√	√	√	√	√	√	√			
Submerge solids with recharge water	lowest ammonia emission		√	√	√	√	√	√	√			
Cool top layer of slurry to <15 C	10 C drop cuts bio activity 50%		√	√	√	√	√	√	√			
Treat pit manure												
Develop aerobic conditions	expensive, but very effective											
Enhance anaerobic conditions	difficult											
Manure additives	very few really work		√	√	√	√	√	√	√			
Chemical deodorants, oxidants												
Digestive/biological additives												
Chemical additives												
Use adequate bedding with solid Systems	use sufficient straw		√		√				√			
Maintain good building hygiene	important management strategy											
Keep animals clean and dry	dirty animals is a major source	√	√		√					√		
Keep floors clean and dry	proper ventilation will help	√	√		√					√		
Oil sprinkling	reduces dust by 50%	√										
Essential oils	not aware of any tests	√	√									
Exhaust Air Treatment												
Biofiltration	still being developed	√	√	√	√	√	√	√	√	√		
Wet scrubbing	impractical, costly	√	√	√	√	√	√	√	√	√		
Aerodynamic dedusting	shows some promise	√										
Catalytic converters	too expensive, impractical	√	√	√	√	√	√	√	√	√		
Ozonation	more work needed		√		√							
On-Site Atmospheric Deposition												
Windbreak walls	removes dust modestly	√										
Use trees to remove pollutants	currently being tested in U.K.	√										
Feed Management												
Phase feeding with synthetic amino acids	common in the U.S.		√		√						√	√
Split-sex feeding	common in the U.S.				√						√	√
Minimize sulfur-containing amino acids			√	√								
Wet feeding (3:1 water/feed ratio)		√	√							√		
Use good quality drinking water	low sulfur and nitrate content			√	√							
Use proper grind and/or pellets	pellets used widely in Europe										√	√
Add fiber sources to lower crude protein					√							√
Add organic acids to feed	expensive				√							
Add yucca extract sarsaponin to feed	common in the U.S.				√							
Add oils and fats to feed	common in the U.S.	√	√									
Add odor absorbers to feed	affects pig performance		√									
Carcass Handling												
Remove mortalities within 24 hours			√					√	√	√		
Refrigerate			√					√	√	√		
Incinerate			√					√	√	√		
Compost			√					√	√	√		
Bury			√					√	√	√		
Grind and treat anaerobically			√					√	√	√		

Table 1
Continued

Manure Handling and Treatment	Comments	PM	Odor	H2S	NH3	N2O	CH4	CO2	VOC	Path	BOD	NPK
Permeable covers on manure storage	Geo-Cover is example, lasts 3 yrs.		√	√	√	√	√	√	√			
Impermeable covers on manure storage			√	√	√	√	√	√	√			
Slurry ozonation	may be too costly, being tried									√		
Solids-liquid separation	reduces load on lagoon		√	√	√					√		
Inclined wedge wire screen	frequent cleaning, inefficient			√	√					√		
Rotary drum screen	more self cleaning			√	√					√		
Vibrating mesh screen	good self cleaning, best screen			√	√					√		
Dissolved air flotation	most efficient, high cost			√	√					√		
Electrocoagulation	not practical			√	√					√		
Hydrocyclone	not practical			√	√					√		
Flocculation and precipitation	high operating cost			√	√					√		
Treatment of Separated Solids												
Impact drying	high operating cost		√	√			√	√		√	√	
Rotary screw press drying	high operating cost		√				√	√		√	√	
Treatment Systems												
Anaerobic treatment lagoons, multi-cell	ammonia volatilization occurs		√					√	√	√	√	
Surface-aerated lagoons	surface aeration for odor control		√	√	√	√	√	√	√		√	
Constructed wetlands (low BOD wastes)	very large area and initial cost		√								√	
Anaerobic digestion, biogas generation			√	√	√	√	√			√	√	
Covered lagoons	best for flushing systems		√	√	√		√	√		√	√	
Completely mixed, heated digesters	best for low solids content manure		√	√	√		√	√		√	√	
Plug-flow, heated digesters	best for high solids content manure		√	√	√		√	√		√	√	
Thermophilic digester	reduced size but control difficult		√	√	√		√	√		√	√	
High-rate anaerobic systems, 10 day HRT	Struvite production		√	√	√		√	√		√	√	√
SBR secondary treatment	reduces effluent pollutants		√	√	√		√	√		√	√	
Solids separation, ozonation, effluent recirculation	less odor in flush water		√					√	√	√	√	
Fully aerobic activated sludge treatment	high-cost, -skill municipal system		√	√						√	√	
Aerobic upflow biofilter	very high operating cost		√								√	
Upflow anaerobic filters with P removal	unproven experimental process		√								√	√
Reuse system, aeration, SBR, etc.	complete waste treatment		√							√	√	√
Land Application												
Inject manure into soil	widespread use											
Incorporate manure into soil	widespread use											
Use low-trajectory, low-pressure spray	replaces high pressure system		√		√							
Lagoon Technologies												
Partial lagoon aeration	reduces odor by oxidation		√	√					√			
Partial lagoon aeration with baffling	25% of inlet side is baffled		√									
Ozone addition to lagoon	oxidizes h2s and odor		√	√								
Impermeable cover	great odor reduction		√	√	√	√	√	√	√	√		
Permeable cover	good odor reduction		√	√	√	√	√	√	√			
Value Added Technologies												
Manure composting	used at some U.S. farms			√	√		√		√	√	√	
Facultative treatment, solids harvesting, BION	solids marketed as produced			√	√				√	√	√	
Chemical stabilization, thermal drying	dry fertilizer produced		√	√	√		√		√	√	√	√

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