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Matrix parameters and storage conditions of manure

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Matrix parameters and storage conditions of manure

by

Karlheinz Weinfurtner

Fraunhofer Institute for Molecular Biology and Applied Ecology (IME), Schmallenberg

On behalf of the Federal Environment Agency (Germany)

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Germany
Phone: +49-340-2103-0
Fax: +49-340-2103 2285
Email: info@umweltbundesamt.de
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5. Autor(s), Family Name(s), First Name(s)

Weinfurtner, Karlheinz

6. Performing Organisation (Name, Address)

Fraunhofer Institute for Molecular Biology and Applied Ecology
Auf dem Aberg 1
57392 Schmallenberg

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16. Abstract

The literature study presents an overview of storage conditions for manure and information about important matrix parameters of manure such as dry matter content, pH value, total organic carbon, total nitrogen and ammonium nitrogen. The presented results show that for matrix parameters a dissimilarity of cattle and pig manure can be observed but no difference within the species for different production types occurred with exception of calves. A scenario for western and central European countries is derived.

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manure, cattle, pig, manure storage conditions, manure matrix parameter, dry matter content, pH value, redox potential, total organic carbon content, total nitrogen, ammonium nitrogen, storage conditions

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16. Kurzfassung Die Literaturstudie präsentiert eine Zusammenfassung über Lagerungsbedingungen und wichtige Matrixparameter wie Trockensubstanzgehalt, pH-Wert, TOC, Gesamtstickstoff und Ammoniumstickstoff von Güllen. Die Ergebnisse zeigen, das sich die Matrixparameter zwischen Rind und Schwein unterscheiden, innerhalb der Art bei verschiedenen Produktionsrichtungen jedoch keine Unterschiede mit Ausnahme der Kälbermast auftreten. Es wird ein Szenario für west- und mitteleuropäische Länder vorgeschlagen.		
17. Schlagwörter Gülle, Rind, Schwein, Güllelagerungsbedingungen, Gülle-Matrixparameter, Trockensubstanzgehalt, Redoxpotential, pH-Wert, TOC, Gesamtstickstoff, Ammoniumstickstoff		
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1. Abbreviations

BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz
BOD	Biological Oxygen Demand
dEB	dietary electrolyte concentration
DEFRA	Department for Environment Food and Rural Affairs, United Kingdom
DOC	dissolved organic carbon
EU	European Union
IME	Fraunhofer Institute for Molecular Biology and Applied Ecology
EMA, EMEA	European Medicines Agency
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
LfL	Bayerische Landesanstalt für Landwirtschaft
LIZ	Landwirtschaftlicher Informationsdienst Zuckerrübe
LUFA	Landwirtschaftliche Untersuchungs- und Forschungsanstalt
mio	Million
NH_4-N	Ammonium nitrogen
NRW	North Rhine-Westphalia
NSP	non-starch polysaccarides
TOC	total organic carbon
Total N	total nitrogen
UK	United Kingdom

2. Note

In this report the term “manure” is used for the german term “Gülle” and describes a mixture from urine, faeces and water which result in a waste material with a dry matter content of about 10 % or less. By contrast in the agricultural literature the term “manure” is used as umbrella term for all kinds of animal wastes including urine, faeces, litter, water and all mixtures of that materials. For the term “Gülle” the terms “slurry” and “(semi) liquid manure” are normally used in agricultural publications.

3. Background

Currently there are no standard methods for studies on the degradation behaviour of substances in manure. Such methods are of great importance for the authorisation process for biocides and veterinary medicinal products, as the respective active ingredients are introduced into the environment via manure spreading. In the framework of the Environmental Risk Assessment (ERA) Working Party (WP) of the European Medicines Agency (EMA[1]) a guidance document on degradation in manure is being drafted at the moment. In the long term perspective an internationally accepted test guideline (OECD Guideline) should be developed.

The EMA guideline will focus on basic considerations concerning the test design and evaluation of results but so far does not specify detailed composition of the manures used for the studies or specify limits for matrix parameters.

The composition of manure is dependent on species and production system. Taking into consideration cattle and pig manure the EMEA guideline (EMEA, 2008, Table 3) differentiates in:

- calves
- beef fattening (0 - 1 year)
- dairy cattle
- cattle > 2 years

- piglets/weaner pigs
- pig fattening
- sow housing

Presently, information on the variability of the composition of different types of manure is not available. Essential questions are:

- How can realistic storage conditions be mimicked in the laboratory?
- Can limits for different matrix parameters be established, taking into account the occurring variability?
- How do the characteristics and composition of the manure change during the storage with regard to its degradation capacity and sorption capacity for veterinary medicinal products?

[1] EMEA has changed ist name to EMA whilst this report was in preparation. Therefore both abbreviations are used in this document

In previous research projects (Kreuzig et al., 2006) the determination of a range of matrix parameters has been shown to be crucial for matrix characterisation of different manure matrices. From the suggested parameters the following ones form a minimum set:

- dry matter content
- nitrogen content (N_{tot} and NH_4-N)
- organic matter
- redox potential (or oxidation/reduction potential)
- pH
- microbial activity

4. Aim of the literature study

The aim of the project is to gather information on the conditions that prevail in manure storage tanks in the EU. The present project consists of two tasks:

Task 1: Determination of conditions for manure storage in the EU. Of importance are the following parameters: animal species, housing system, storage system, storage time before application, and temperature of the manure as well as their variability.

Task 2: summary of matrix parameters of manures (see above) and determination of parameter dependence on the animal species, the age of the animal or production type, as well as on housing conditions and feeding composition. The research will be limited to cattle and pigs, taking into account for the following production type/ age should be taken for cattle,

- calves
- dairy cattle
- beef fattening > 1 year

and for pigs:

- piglets
- pig fattening
- sow housing (sows with piglets).

The relevant matrix parameters as dry substance content, pH-value, redox potential, total nitrogen and NH_4-Nitrogen, TOC (total organic carbon) or organic matter content are to be considered. It should be analysed if some other parameters of manure characterisation (e. i. S, P, Cu), which can influence the process of degradation of substances, should be also taken into consideration or whether a positive control would be more suitable as a comprehensive sum parameter.

For the sorption process of veterinary medicinal products and biocides in manure and division of those into solid and liquid matrix, the DOC-content (dissolved organic carbon) plays an important role as DOC can increase the solubility in the aqueous phase because of its ability to bind the components.

Of importance is also the influence of time, as during storage degradation processes take place, leading to a change of parameters in the manure (“manure ageing”). Therefore the age of the manure as well as changes during the storage period should be taken into consideration.

Finally, it should be pointed out that an estimate for the variability of the matrix parameters should be given. Of special interest is the comparison of the variability of different age stages/ production types and feeding conditions on the one hand and the variability within farms with comparable conditions on the other. If possible the variability between single animals should also be also studied.

5. Research method

The literature study was carried out by using scientific journals, publications of statistical agencies (Statistisches Bundesamt, Eurostat, BMELV), information from agricultural administrations and research institutes and agricultural associations. Public search engines in the internet were used (e.g. Google) to get additional information.

Before starting the search a list of keywords was generated taking into consideration the needed information as given in the two tasks. For the search in scientific publications the search engines “scienedirect.com”, “scirus.com”, “current contents” and, as special search engine for ecological agriculture, “Forschung im ökologischen Landbau” were used. For the most publications an online-access was possible, other publications could be ordered by the document service “Subito”.

The results were sorted according to the questions which have to be dealt with in the study:

- Task 1: information about manure storage conditions (duration of storage, storage systems, storage temperature)
- Task 2: information about important matrix parameters such as dry mater content, pH-value, redox potential and nitrogen concentration.

For both tasks the questions were discussed taking into account the animal species and production types as described in chapter 4.

6. Results

6.1 Storage conditions

6.1.1 Animal species

The livestock grouped into production types as in EMEA/CVMP/ERA/418282/2005-Rev.1 is presented in table 1. Calves include about 9.2 mio. (1.7 mio. for Germany) animals for beef fattening. The most important production type is the dairy cattle with about 24 mio. (4.3 mio. in Germany). The group of cattle > 2 years are mostly female animals with about 12 mio. heads (0.73 mio. in Germany). The production type of these animals is not further subdivided for the EU. In Germany the most animals of that group (cattle > 2 years) are suckling cows with about 660.000 animals (Statistisches Bundesamt, 2007). In pig production the most important production type is pig fattening (live weight > 50 kg).

Table 1: livestock in the EU (27) an in Germany for cattle and pigs in 2008 (in mio), (Eurostat, 2010)

	EC (27)	Germany		EC (27)	Germany
calves	25.82	4.02	piglets	36.40	6.66
Beef fattening > 1 year	6.86	1.09	Pig fattening	61.64	11.18
Dairy cattle	24.25	4.23	Sow housing	13.95	2.30
Cattle > 2	13.84	0.83			

6.1.2 Housing system

Statistics about the manure management systems ((semi)-liquid, solid, pasture) are not available for the EU. Oenema et al. (2007) give a short overview about manure management systems in the EU. Thereafter between 60 and 70 % of livestock excreta is collected in housing systems and this percentage increases. Between 30 and 40 % of livestock excreta is dropped by grassing cattle in pasture where it is unmanaged. Between 50 and 65 % of the manure management systems in the EU produce a (semi)-liquid manure. In Germany at least 50 % of the livestock husbandry in housing systems produce a (semi)-liquid manure (BMELV, 2007). Oenema et al. (2007) reported that there is a huge regional variation in manure management systems across the EU-27 and there is only little quantitative information about the actual storage of manure in practice. (Semi)-liquid manure is dominant in the Netherlands (> 95 % of manure in housing systems), in other countries such as UK, France and Eastern Europe separate collection of liquids and solids dominates (< 50 % (Semi)-liquid manure) in housing systems.

6.1.3 Storage system

For the manure storage different storage systems are available (Oenema et al., 2007, KTBL, 2005):

- Pit storage; storage of manure in a pit beneath the confinement
- Storage in tanks; storage of manure in concrete/lined tanks, tanks can be constructed as high-level or subsurface tanks
- Anaerobic lagoons; the manure is stored in open lagoons, mostly diluted with water
- Anaerobic digesters; digestion with other materials to produce biogas
- Anaerobic/aerobic treatment; Animal excrements are treated (an)aerobically to decrease the amount of suspended solids, organic and N before discharge to surface waters

Within the EU and within Germany unfortunately no statistics are available about the percentage of the different systems. From the information presented by Oenema et al. (2007) it can be estimated that between 70 and 80 % of all produced and sampled manures within the EU are (semi)-liquid manure. Hence pit storage (storage directly beneath the animal stable) and storage in tanks (storage not directly beneath the animal stable, e.g. in an adjacent tank) have a percentage of about 40 % each on the storage systems and only about 20% are stored in other systems. For Germany neither the “Statistisches Bundesamt” nor the agricultural administrations, research institutes and agricultural associations (e.g. Landwirtschaftskammer (LK) Nordrhein-Westfalen, LK Niedersachsen, KTBL) have information about the percentage of the different storage systems. According to Mrs. Dr Eurich-Menden (KTBL, 2010) the percentage of the systems is very different on a regional level and depends on internal and external factors like distance to residential areas, available area on the farm, geology and groundwater level. Lagoons and treatments (e. g. composting) are of less importance (< 2 % of total manure) but the percentage of anaerobic digesters is increasing because of promotion of energy production from biomass especially in Austria, Denmark and Germany. The proportion of manure used directly in anaerobic digestion is in the range of a few percent (<5 % for Germany).

6.1.4 Storage time

The storage time depends on field crops, fertilizer requirements, vegetation period, and storage capacity. The field crops and fertilizer requirement is different between farms and management types and change every year. The storage time can range from some days to some months depending on the management system and regulatory requirements. In agricultural practice a first application of manure will be performed in spring with the start of the vegetation period and increasing nutritional requirements of the plants. Depending on the cultivated field crops and the management system several applications of manure can be performed till the end of the vegetation period. Especially in intensive pasture systems up to 5 or 6 applications are possible. A time limitation for the application of manure is regulated by legal requirements in the countries of the EU. For the implementation of the “Nitrates Directive” (Directive 91/976/EEC) the member states prohibit the application of manure other than in the vegetation period. Additionally some member states regulate a minimum storage capacity for manure to avoid storage problems within the prohibition period. The period of prohibition and the required minimum storage capacity (up to 10 months) differ between the member states and depend on soil texture and management system. An overview of regulations in several countries is presented in Table 2.

Taking into consideration the legal regulations and the requirements of management practice it can be assumed that the average age of the manures from the first application in spring is about 3-4 months whereas the manures of the following applications have an average age of 1-2 months.

Table 2: regulations for storage capacity for manure and limitations for application

source	Information	comment
Landwirtschaftskammer NRW, 2008	Storage capacity for manure at least 6 months, for pigs up to 10 months	Germany
German fertilisation ordinance, 2007	Ban of manure application between 01.11. and 31.01. on tillage land and between 15.11. and 31.01. on grass land	Germany
EU-Nitrates Directive 91/676/EWG – Österreichischer Bericht, 2004	Storage capacity for manure a least 6 months, Ban of manure application between 15.10. and 15.02. on soils without vegetation and between 15.11. and 15.02. on soils with vegetation	Austria
Third Dutch action programme (2004-2009) concerning the nitrates directive (2005)	Storage capacity for manure a least 6 months, Ban of manure application between 01.09. and 31.01. on sandy and loess soils and between 15.10. and 31.01. on clay and peat soils under grass	The Netherlands
Ireland consultation paper (Good Agricultural Practice for Protection of Water), 2008	Storage capacity for manure a least 6 months, Ban of manure application between 15.10. and 12.01 till 31.01. depending on region	Ireland
Chambre d'Ágriculture Vienne, 2009	Ban of manure application between 01.11. and 15.11. respectively to 15.01. depending on type of cultivation	France
DEFRA, 2008	Storage capacity for manure a least 6 months for pigs and 5 months for cattle, Ban of manure application between 01.09. and 31.12. for sand and shallow soils under grass and between 01.08. and 31.12. for sand and shallow soils under tillage; in other soils between 15.10. and 15.01 under grass and between 01.10. and 15.01. under tillage	Great Britain
Hrustel-Majcen and Kos, 2006	Storage capacity for manure at least 4 or 6 months depending on region	Slovenia

6.1.5 Storage temperature

The manure temperature during storage depends on climate, season and storage system. Arrus et al. (2006) determined the temperature profiles in an above ground pile and an earthen reservoir in southern Manitoba, Canada. The manure temperature in the above ground tank ranged between -4 °C in winter and 22 °C in summer and depended on season and depth. The highest variation of temperature was observed close to the surface in a depth of 10 cm. The variations of temperature decreased with increasing depth (table 3). In the earthen storage reservoir the seasonal variation of temperature was higher in a depth of 10 cm compared with the above ground tank, but with increasing depth the variations decreased.

Patni et al. (1986) measured the manure temperature in four depths between January and October 1985 at a research farm near Ottawa, Ontario, Canada. The tanks were built with their top tops extending 0.2 m above ground. In a depth of 30 cm the temperature ranged between 2 (February) and 23 °C (July). In a depth of 2.5 m the range of temperature was only between 4 and 15 °C. Similar results were observed by Arrus et al. (2006) on farms in southern Manitoba. These data have been included for information purposes but should not be taken into account to derive relevant temperatures for the EU.

Montfort et al. (2003) gave an overview of several publications in different climate regions (table 3). The observed temperatures range from ambient (freezing) to about 50 °C. For underground systems the seasonal variations were lower with temperatures between 4 and 18 °C. Under western and central European conditions (e. g. Netherlands) the temperatures vary only within a small range.

In conclusion, it is not possible to define an “average” temperature for manure storage. It can be assumed that under middle European conditions and for underground storage the smallest variation of temperature within the year can be expected and larger variations in aboveground storage and under colder or warmer climate. Therefore two scenarios are proposed One scenario with an average temperature of 10 °C for cold climate conditions (e.g. northern European countries) and a second scenario with a temperature of 20 °C for warmer climate (e. g. southern Europe). If that is not possible a worst case of 10 ° C should be assumed.

Table 3: storage conditions: storage temperature

source	Information	comment
Montfort et al. (2003)-	pit temperature for cattle about 15 °C in period June to September and 10 °C in remaining months for underground storage, for pig manure 15 °C during the whole year Temperature in above pits for pig	In conclusion, depending on climate, season and storage systems temperatures can range from ambient (freezing) to about 50 °C. For underground storage systems this range is narrowed down to 4-18

	manure ranged from 15 to 19°C (Netherlands); Pig manure temperatures under rearing facilities ranged from 16 to 23 °C in Canada and from 15 to 35 °C in Illinois, USA. Temperatures in manure/bedding packs used in hooped structures for finishing pigs ranged from -1 °C to 47 °C in Iowa, USA In a calf manure pile erected outdoors in winter (New York, USA) the temperature rose from initial 10 °C to 29 °C in the first five days, fell to 15 °C after 30 days, was at its lowest(4 °C) after 80 days and steadily increased till the end of the study. In a biogas production plant in Texas, USA the temperature in a beef cattle manure pile was initially about 25 °C, but the temperature dropped rapidly during the first month as the manure became anaerobic. Temperature began rising during summer months and peaked around begin of August at 22 °C. The temperature dropped below 15 °C in the middle of October and has remained there until May.	°C.
Arrus et al. 2006	Temperatures ranged between -2 to -4 °C in winter and up to 22 °C in summer in a depth of 10 cm in an above ground pile. In a depth of 2 m the temperature ranged between -1 to 3.4 °C in winter and between 14 to 19 °C in summer. At about 6 m depth in winter and spring temperature was consistently 3 to 7 °C, in late summer and fall the temperatures ranged at this depth between 14 and 17	Temperature profiles were recorded between December 2003 and May 2005 in the above ground pile and from April 2004 to May 2005 in the earthen storage pile

	°C. In earthen manure storage the temperatures ranged between -14 to 27 °C in December and April, respectively in a depth of 10 cm. In 2 m depth the temperature ranged from 0.7 to 8.7 °C (winter), 1.0 to 19.7 °C (spring), 15 to 18 °C (summer) and -.7 to 16.5 (fall). At the bottom of the earthen manure storage facility the temperatures ranged form 0.3 to 5.8 °C, 3 to 19.3 °C, 16 to 17.7 °C, and 1.7 to 16.9 °C, during winter, spring, summer and fall, respectively	
Patni et al., 1986	In a depth of 0.3 m a variation of temperature was measured between 2° C in February and 23° C in July. The range of temperature decreases with increasing depth: In 2.5 m depth the range was only between 4° C and 15° C.	Tanks with a top 0.2 m above ground; measurement from January to October 1985

6.2 Matrix parameters of manure

This chapter gives an overview of important matrix parameters of manures taking into consideration different species and production types. Relevant matrix parameters which may influence sorption and degradation of substances are dry matter content, pH-value, redox potential, total nitrogen and ammonium nitrogen (NH_4-N), total organic carbon (TOC) and dissolved organic carbon (DOC). Another aspect of the study is the change of parameters during storage induced by degradation processes.

6.2.1 Dry matter content

As shown in table 6 the dry matter contents of manures vary within a large range. In these data the results of publications with single measurements as well as from some thousands of measurements are included.

The dry matter contents for cattle manure (between 6 and 10.1 %) mentioned by LIZ (2009), Schaaf (2002), LUFA NRW (2008) and LUFA Nordwest (2010) are mean values of an unspecified amount of analysis (table 7). LUFA NRW and LUFA Nordwest declared that these data are the mean value of at least some hundred analyses. The data given by Kreuzig et al. (2006) are data from 2000 analysis. The median of 8.7 % is close to the information mentioned above. A lower mean value (3.47 %) was observed in southern EU countries by Martinez-Suller et al. (2008). For manure from dairy cattle the range of dry matter content is a less variable. The mean values given by LfL (2007) and LUFA Nordwest (2010) (8.6 % and 7.5 % respectively) are slightly higher than the data (6.23 % and 5.68 %) given by Martinez-Suller et al. (2008) and Safely et al. (1986). The mean values for beef fattening are within the range between 7 and 10 % (e.g. LUFA NRW, LUFA Nordwest) for large sample collectives, the data from Gerl (1998) are a lower. For calve manure the available data are very similar and lie in between 3 and 4 % dry matter content (Martinez-Suller et al., 2008. LUFA NRW, 2008 and LUFA Nordwest, 2010).

Table 4: range of dry matter content for different productions types (summarized results of table 5)

	Dry matter (%)		Dry matter (%)
Cattle (unspecified)	0.4 – 12.3	Pigs (unspecified)	0.11 – 12.0
Dairy cattle	1.99 – 12.0	Pig fattening	3.0 – 15.4
Beef fattening > 1 year	4.0 – 10	Sow housing	0.3 – 7.4
calves	3 – 12	piglets	2.7 – 5

For pig manure the range of data is comparable with cattle manure but the mean values given by several authors are lower than for cattle manure. The mean values from german data (LIZ, 2009 and Schaaf, 2002) are considerably higher (6 and 7.78 %) than the data from south European countries (1.78 % and 2.27 %) given by Martinez-Suller et al., (2007) and Moral et al. (2005). For fattening pigs german data are within the range between 3 and 7 % with mean values at about 5 % (e. g. LUFA NRW, 2008, LUFA Nordwest, 2010, LfL, 2007) whereas south European data (Martinez-Suller et al., 2007 and Moral et al. 2005) are again at an lower level with 2.3 % and 3.1 %, respectively. The higher dry matter contents in the publications of Canh et. al. (1998), Kreuzer et al. (1998) and Le et al. (2009) can not be directly compared with the data given above. The manures in the experiments of Canh, Kreuzer and Le were a mixture of urine and faeces. In the other publications farm manures from storage containers were analyzed. These manures contain additional water from cleaning processes in the barn and - in a lot of cases - rainwater which flowed into the storage containers. Therefore a dilution in the farm containers can be expected compared to manure which is obtained directly at the animal. For manures from sow housing the german data indicate a dry matter content of 2 to 5 %. Lower data are observed by Martinez-Suller et al., 2007 and Moral et al. 2005 (1.46 – 1.69 %). Even for piglets a small difference in dry matter content between german data (3.6 – 5 %) and the data from Moral et al. (2005) can be observed (2.72 %).

Only little information is available about the influence of season on the dry matter content. Sommer et al. (1993) found a higher dry matter content in pig manure during a spring period compared with an autumn period. But they could not find a difference in dry matter content between a winter/spring manure and a summer manure of cattle whereas Hermanson et al. (1980) found higher dry matter contents for dairy cattle in the summer period than in the spring or winter period. In the experiment of Hermanson et al. manure of an open lagoon was used and it was argued that the higher dry matter content in summer was caused by lower precipitation and higher evaporation during the summer months.

Martinez et al. (2003), Hermanson et al. (1980) and Amon et al. (2006) reported a decrease of dry matter content during storage. Hermanson et al. (1980) and Amon et al. (2006) found a decrease of dry matter content of about 40 to 50 % within periods of 80 days in an open system whereas Martinez et al. (2003) reported a decrease of 10 to 20 % within a period of 50 days in a closed system. Kreuzer et al. (1998) observed an increase in dry matter within a period of 8 weeks by using an open system and explained that result with evaporation of water in the open system.

Stevens et al. (1993) tested the influence of different diets on some parameters of manure from dairy cattle. They used four diets with a combination of different protein concentrates (17 % and 34 % protein) and low- and high-digestibility silage. Only the combination of high protein concentration and high-digestibility silage resulted in a change to a lower dry matter content. More information is available for pig production. Canh et al. (1998/1-4) tested several diets at fattening pigs and found that dry matter content was reduced if dEB (dietary electrolyte balance) and crude protein content was reduced and the carbohydrates were increased. Dourmad & Jondreville. (2007) and Portejoie et al. (2005) confirmed the results of Canh et al. that a reduction of crude protein in the diet reduces dry matter content. Sørensen and Fernandez (2003) showed that a diet with low fibre fermentability and high fibre level increases dry matter content of pig manure. Velthof et al. (2005) presented similar results because high concentrations of non-starch polysaccharides increase dry matter.

Table 5: dry matter content of manures

source	Information	comment
Cattle: without differentiation between production types		
LIZ, 2009	cattle manure 8 %	Germany, Mean value
Schaaf, 2002	cattle manure 10.1 %	Germany, Mean value of a not specified amount of analysis between 1998 and 2000 at LUFA Kassel
Kreuzig et al., 2006	cattle manure: minimum 0.4 %, median 8.7 %, maximum 12.3 %	Germany, Data of 2000 Analysis between 1997 to 2004
Sommer & Husted,	cattle manure: 20.8-114.2 g/kg	Denmark, 4 cattle manures

1995		
LUFA NRW, 2008	6-8 %	Germany
LUFA Nordwest, 2010	8.6 %	Germany, Median
Møller et al., 2004	95.2 g/L	Denmark, No information about number of animals which produce the manure
Sommer et al., 1993	cattle: period 1 and 2: 5.9 %, pig: period 1: 4.6 %; period 2: 7.4 %	Denmark, Cattle period 1: 21 Dec 1989- 15 June 1990, period 2: 6 July 1990-2 Sep. 1990; pig: period 1: 18 Sep 1990-10 Dec 1990, period 2: 27 Feb 1991-25 June 1991;
Martinez-Suller et al., 2008	combined cattle manure (N=49): 5.00-120.0 kg/ m^3, ∅ 34.7 kg/m^3	Farms in northern Italy; N: number of farms
Sørensen &Eriksen, 2009	Cattle manure: 47 g/m^3	Denmark, cattle manure, several treatments; data only for untreated manure
Dairy Cattle		
Hermanson et al., 1980	spring: 23,580 mg/L; summer: 40,420 mg/L; winter: 29,800 mg/L	Washington, USA, Dairy cattle manure; spring period: 4 May-23 June, Summer period 31 August-4 October, winter period: 19 January -22 February, 65 animals
Sommer et al., 2000	62.0-75.5 g/kg	Denmark, 2 manures from dairy cattle
Amon et al., 2006	5.74 % - 7.84 %	Austria, Dairy cattle, end of storage, 2 treatments
Stevens et al., 1993	88-110 g /kg	UK, 4 dairy cattle manures, different diets
Martinez-Suller et al., 2008	dairy cows (N=22): 19.9-120.0 kg/ m^3, ∅ 62.25 kg/m^3	Farms in northern Italy; N: number of farms
Safely et al., 1986	dairy cattle manure: 5.68 ± 1,98 %	North Carolina, USA, 29 samples from dairy farms, average and standard deviation
Sommer et al., 2000	62.0-75.5 g/kg	Denmark, Dairy cattle, one farm , two samplings
LUFA Nordwest, 2010	8.6 %	Germany, Median
LfL, 2007	7.5 %	Germany, Mean values
Beef fattening > 1 year		
Landwirtschaftliches	bull manure 10 %	Germany, Mean values

Wochenblatt, 2008		
LUFA NRW, 2008	bull manure 7-10 %	
LfL, 2007	7.5 %	Germany, Mean values
LUFA Nordwest, 2010	9 %	Germany, Median
Gerl, 1998	4.0 – 8.3 % ∅ 6.38 %	Germany, Data from 16 manures of two farms with several samplings between March, 1993 and April, 1995
calves		
Martinez-Suller et al., 2008	calves (N=27): 5.00-120.0 kg/ m^3, ∅ 32.00 kg/m^3	Farms in northern Italy; N: number of farms
LUFA NRW, 2008	4 %	Germany, mean value
LUFA Nordwest, 2010	3 %	Germany, Median
pig: without differentiation between production types		
LIZ, 2009	pig manure 6 % dry matter	Germany, Mean values
Schaaf, 2002	pig manure 7.78 % dry matter	Germany, Mean values of a not specified amount of analysis between 1998 and 2000 at LUFA Kassel
Martinez-Suller et al., 2008	combined pig manure (N=83): 1.13-67.44 kg/m^3, ∅ 17.82 kg/m^3	Farms in northern Italy; N: number of farms
Sommer & Husted, 1995	pig manure 14.5-28,6 g/kg	Denmark, 7 pig manures
Hisset et a., 1982	pig manure 25 g/L	UK, Material of 10 pigs
Møller et al., 2004	86 g/L pig manure	Denmark, No information about amount of animals which produce the manure
Martinez et al., 2003	pig manure: 24-106 kg/m^3	France, 4 manures from three different farms,
Moral et al., 2005	Total: 2.27 ± 3.08 %	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Sørensen &Eriksen, 2009	pig manure: 23.8 g/kg	Denmark, One pig manure, several treatments; data only for untreated manure
Pigs fattening		
Landwirtschaftliches Wochenblatt, 2008	fattening pig manure 5 %	Germany, Mean values
Canh et al., 1998/1	pig manure: 62.4-101.5 g/kg	Netherlands, 18 different diets, every diet with 5 pigs fattening

		pigs, about 40 kg per animal
Canh et al, 1998/2	pig manure: 64.6-84.8 g/kg	Netherlands, 4 different diets, every diet with 4 growing finishing pigs (about 81 kg per animal)
Canh et al, 1998/3	pig manure: 92-154 g/kg	Netherlands, 9 different diets, every diet with 3 growing pigs (about 40-55 kg per animal)
Canh et al, 1998/4	pig manure: 42.7-81.2 g/kg	Netherlands, 3 different diets, every diet with 6 growing pigs about 55 kg per animal
Dourmad & Jondreville 2007	pig manure: 4.4-5.9 %	France, 3 different diets, fattening pigs (30-102 kg per animal)
Kreuzer et al., 1998	pig manure: 58.5-107.4 g/kg, ∅ 83.4 kg/m^3	Switzerland, 18 diets, every diet with six fattening pigs (starting with about 30 kg per animal), different storage time
Le et al., 2009	pig manure: 100.1-100.3 g/kg	Netherlands ?,2 diets, every diet with six fattening pigs
Martinez-Suller et al., 2008	finisher pigs (N=30): 5.39-66.44 kg/ m^3, ∅ 22.99 kg/m^3	Farms in northern Italy; N: number of farms
Moral et al., 2005	finishers: 3.10 ± 4.13 %	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Portejoie et al., 2004	pig manure: 4.4-5.9 %	France, Three diets, every diet with 5 fattening pigs with an initial weight of about 50 kg
Sørensen & Fernandez, 2003	growing pigs: 22-64 g/kg	Denmark, 8 Different diets for growing pigs (40-60 kg), 5 animals per diet, data at end of storage
LUFA NRW, 2008	3 – 7 %	Germany,
LUFA Nordwest, 2010	5,5 %	Germany, Median
LfL, 2007	5 %	Germany, Mean value
Laurenz, 2009	5 %	Germany, Mean value of 240 manure samples
Sow housing		
Landwirtschaftliches Wochenblatt, 2008	suckling sows 4 % dry matter	Germany, Mean value

Martinez-Suller et al., 2008	farrowing sows (N=40) : 3.00-42.57 kg/ m^3, ∅ 15.02 kg/m^3	Farms in northern italy; N: number of farms
Sørensen & Fernandez, 2003	Dry sows: 29-74 g/kg	Denmark, 4 diets for dry sows (about 220 kg) , 5 animals per diet, data at end of storage
Moral et al., 2005	gestating Sows: 1.46 ± 1.73 % farrowing Sows: 1.69 ± 3.11 %	Pig manure of 36 farms in Southeast Spain; average and standard deviation
LUFA NRW, 2008	2-4 %	Germany,
LUFA Nordwest, 2010	3 %	Germany, Median
LfL, 2007	5 %	Germany, Mean value
piglets		
Moral et al., 2005	weaners: 2.72 ± 3.41 %	Pig manure of 36 farms in Southeast Spain; average and standard deviation
LUFA NRW, 2008	5 %	Germany, Mean value
LUFA Nordwest, 2010	3,6 %	Germany, Median

6.2.2 pH value

As presented in table 6 the pH values in manure show a large variation within the different production types. Even if the variations are large the shown results indicate that the range of variation is larger in the pig production (more than 2.5 pH units) as in the cattle production (max. 2.4 pH units). Nevertheless it is not possible and necessary to differ between pig and cattle manure or the single production types related to pH due to the large variations of about two pH units within the single production types.

Table 6: range of pH value in manure for different productions types (summarized results of table 7)

	pH		pH
calves	6.56 – 7.87	piglets	
Beef fattening > 1 year	7,54	Pig fattening	6.3 – 9.14
Dairy cattle	6.2 – 8.8	Sow housing	5.55 – 8.11
Cattle (unspecified)	6.56 – 8.11	Pigs (unspecified)	5.55 – 8.29

Compared with the information about dry matter content or amount of nutrition there is less information on pH-value available because pH is normally not determined by manure analysis for farmers. As noted above the range of pH-value is a little bit narrower for cattle than for pigs. Taking into consideration the data from Martinez-Suller et al. (2008), Sommer and Husted (1995) and Gerl (1998) the mean values for cattle manure do not differ a lot (table 8). For pigs some more information is available and the mean values for the different production types do not differ a lot, too (Martinez-Suller et a., 2008, Sommer and Husted, 1995, Canh et al., 1998).

Møller et al. (2004) reported about changes of pH during storage. In all trials the pH increased within the first few days after begin of storage due to degradation of urea to ammonia. After about five days pH decreased because acetogenic bacteria produced acid pH buffers in form of volatile fatty acids (VFA) and CO_2. After about 50 days pH increased again when the manure was kept at 20° C while pH decreased even further after more than 100 days when the manure was kept at 15 ° C. Canh et al. (1998/2) found an increase of pH within the first day of 1-2 pH units depending on diet and then a stable pH for the experimental period of 7 days with. An exception was a diet with sugar-beet pulp where a decrease of pH of about one pH unit was observed between day one and seven. Kreuzer et al. (1998) reported a decrease of pH in all trials after eight weeks. The decrease ranged between 0.3 and 0.6 pH units depending on the content of fermentable non-starch polysaccarides (NSP) in the diet. The decrease of pH got lower with increasing amount of NSP in the diet. Yang et al. (2004) reported about an increase of pH of about one pH within three days unit during two weeks of aeration. Amon et al. (2006) found an increase of pH within a period of 80 days of about 0.8 units in untreated and of 0.3 units in aerated manure.

The influence of diet on pH was studied by several authors. Stevens et al. (1993) varied the protein concentration in a diet of dairy cattle and found a decreasing manure pH when decreasing the protein concentration. Similar results were presented by Dourmad & Jondreville (2007), Le et al. (2008/2009), Canh et al. (1998/4) and Portejoie et al. (2004). All the authors reported a decreasing pH when decreasing the protein concentration in the diet of fattening pigs. Canh et al. (1998/1) found an influence of dEB and Ca-supplements on pH. The pH decreased at low dEB and was lower by using Ca-benzoate than $CaSO_4$ and $CaCO_3$ as supplement. In another experiment of Canh et al. (1998/3) cornstarch in the control was replaced by coconut expeller, soybean hulls and dried sugar beet pulp in three levels. They found a decrease of 0.2 to 0.3 pH units for coconut expeller, 0.3 to 0.4 pH units for sugar beet pulp and of 0.5 to 1.2 pH units for soybean hulls. Velthof et al. (2005) reported a decrease of pH with increasing amounts of NSP in the diet.

Table 7: pH-value

source	Information	comment
Cattle without differentiation between production types		
Sommer & Husted, 1995	Cattle manure: 7.71-8.11, ∅ 7.90	Denmark, 4 cattle manures
Sommer et al., 1993	Cattle: period 1: 7.5, Period 2: 7.7;	Denmark, Cattle period 1: 21 Dec 1989- 15 June 1990, period 2: 6

		July 1990-2 Sep. 1990;
Martinez-Suller et al., 2008	combined cattle manure (N=49): 6.2-7.9, ∅ 7.31	Farms in northern italy; N: number of farms
Sørensen & Eriksen, 2009	Cattle manure: 7.03	Denmark, One cattle manure, several treatments; data only for untreated manure
Dairy cattle		
Hermanson et al., 1980	spring: 7.5, summer: 7.3, winter: 7.3	Washington, USA, Dairy cattle manure; spring period: 4 May-23 June, Summer period 31 August-4 October, winter period: 19 January -22 February, 65 animals
Amon et al., 2006	7.55 – 7.8	Austria, Dairy cattle, end of storage, two treatments
Stevens et al., 1993	7.6-8.0	UK, 4 dairy cattle manures, different diets
Martinez-Suller et al., 2008	Dairy cows (N=22): 6.2 - 7.9, ∅ 7.34	Farms in northern italy; N: number of farms
Sommer et al., 2000	7.4-7.7	Denmark, Dairy cattle, one farm , two samplings
Paul & Beauchamp, 1989	Dairy cattle manure: 7.00-7.21	Ontario, Canada, 2 manures
Beef fattening > 1 year		
Paul & Beauchamp, 1989	Beef cattle manure: 7.54	Ontario, Canada, 1 manure
Gerl (1998)	Beef cattle manures: 7.2 – 8.2, ∅ 7.7	Germany, Data from 12 manures of two farms with several samplings between March, 1993 and April, 1995
calves		
Martinez-Suller et al., 2008	calves (N=27): 6.56-7.87, ∅ 7.28	Farms in northern italy; N: number of farms
pig: without differentiation between production types		
Sommer & Husted, 1995	pig manure 7.72-8.29, ∅ 7.59	Denmark, 7 pig manures
Sommer et al., 1993	pig: period 1: 7.3 period 2: 7.4	Denmark, pig: period 1: 18 Sep 1990- 10 Dec 1990, period 2: 27 Feb 1991-25 June 1991;
Martinez-Suller et al., 2008	Combined pig manure (N=83): 5.55-8.17, ∅ 7.46	Farms in northern italy; N: number of farms

Moral et al., 2005	Total: 7.43 ± 0.31	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Paul & Beauchamp, 1989	Swine manure: 6.30	Ontario, Canada, 1 manure
Sørensen &Eriksen, 2009	Pig manure: 7.45	Denmark, 1 pig manure, several treatments; data only for untreated manure
Pig fattening		
Canh et al., 1998/1	Pig manure: 6.31-8.65, ∅ 7.62	Netherlands, 18 different diets, every diet with 5 pigs fattening pigs, about 40 kg per animal
Canh et al, 1998/2	Pig manure: 8.07-8.9	Netherlands, 4 different diets, every diet with 4 growing finishing pigs (about 81 kg per animal), mean pH over 7-day period
Canh et al, 1998/3	Pig manure: 6.3-8.4, ∅ 7.58	Netherlands, 9 different diets, every diet with 3 growing pigs (about 40-55 kg per animal)
Canh et al, 1998/4	Pig manure: 7.21-9.14	Netherlands, 3 different diets, every diet with 6 growing pigs about 55 kg per animal
Dourmad & Jondreville , 2007	Pig manure: 7.57-8.92	France, 3 different diets, fattening pigs (30-102 kg per animal)
Kreuzer et al., 1998	Pig manure: 6.68-8.42, ∅ 7.56	Switzerland, 18 diets, every diet with six fattening pigs (starting with about 30 kg per animal), different storage time
Le et al., 2009	Pig manure: 7.26-7.77	Netherlands ?, 2 diets, every diet with six fattening pigs
Le et al., 2008	Pig manure: 7.75-7.89	Netherlands, 3 diets, every diet with six fattening pigs (starting with about 41 kg per animal)
Luo et al., 2002	Pig manure: 6.47	Minnesota, USA, Finishing pigs, aeration experiments over 16 days
Martinez-Suller et al., 2008	finisher pigs (N=30): 6.7-8.17, ∅ 7.41	Farms in northern italy; N: number of farms
Moral et al., 2005	Finishers: 7.54 ± 0.34 %	Pig manure of 36 farms in Southeast Spain; average and standard deviation

Portejoie et al., 2004	Pig manure: 7.57-8.92	France, Three diets, every diet with 5 fattening pigs with an initial weight of about 50 kg
Sørensen & Fernandez, 2003	Growing pigs: 7.5-7.9	Denmark, 8 Different diets for growing pigs (40-60 kg), 5 animals per diet, data at end of storage
Sow housing		
Martinez-Suller et al., 2008	farrowing sows (N=40) : 5,55-8.11, ∅ 7.46	Farms in northern italy; N: number of farms
Sørensen & Fernandez, 2003	Dry sows: 7.9-8.4	Denmark, 4 diets for dry sows (about 220 kg), 5 animals per diet, data at end of storage

6.2.3 Redox potential

There is only few information available on the redox potential of manures. This parameter is normally not determined by characterisation of manures for agricultural purposes and no data are available at agricultural administrations, research institutes and agricultural associations. The publications listed in table 8 give only information for pig manure and present similar results. Luo et al. (2002) studied the effect of different aeration procedures on chemical parameters of pig manure and found in all cases a redox potential between -350 and -300 mV at the end of the experiment. But within the first two days the untreated manure and the two aerated (intermittent and continuous aeration) manures differed in redox potential. Whereas the untreated manure showed a small increase from -350 mV to about -330 mV in both aerated manures the redox potential increased within the first 4-5 hours up to about – 170 mV. Then the redox potential decreased rapidly to around -300 mV and fluctuated slightly in the rest of the aeration period. Moral et al. (2005) studied the chemical composition of 36 farms in southeast Spain and found an average redox potential between -319 and -389 mV for different production types but a high standard deviation. Park et al. (2006) measured the redox potential in storage tanks depending on season and found the lowest redox potential during fall with about – 333 mV and the highest redox potential (-232 mV) in winter.

Table 8: redox potential

source	Information	comment
Luo et al., 2002	Pig manure: -350 - -300 mV at end of experiment	Finishing pigs, aeration experiments over 16 days
Moral et al., 2005	Total: -361 ± 72 mV Gestating Sows: -374 ± 70 mV Farrowing Sows: -352 ± 134 mV	Pig manure of 36 farms in Southeast Spain; average and standard deviation

	Weaners: -319 ± 75 mV Finishers: -389 ± 41 mV	
Park et al., 2006	Summer: -318.3 mV, fall: -333.4 mV, Winter: -232 mV, spring: -284.2 mV	Farm in Ontario, Canada

6.2.4 Total organic carbon (TOC) and dissolved organic carbon (DOC)

Only little information is available about TOC and DOC in manures. For cattle TOC found in several studies ranged between 0.88 and 4.2 % of wet weight (table 9). The higher TOC concentrations reported by Kreuzig et al. (2006) are caused by differences in manure sampling. Kreuzig et al. used “artificial” manures which had an adjusted dry matter content of 10 % and therefore a higher TOC than the farmyard manures for which TOC was presented by Gerl (1998) and Amon et al. (2006). For pig manure the observed range of TOC is smaller than for cattle but with mean values at about 20 g/kg similar to the TOC concentration of cattle manure.

Park et al. (2006) found similar concentrations of TOC in manures from fall, winter and spring but about twice that amount in summer. Amon et al. (2006) tested different treatments of manure storage from dairy cattle and found a reduction of TOC in the untreated trial of more than 40 % (35.4 g/kg to 20.1 g/kg) and a reduction of only 18 % (32.7 to 26.7 g/kg) in the aerated trial within the period of 80 days. Opposite results were presented by Luo et al. (2002). In their experiment in the untreated sample of pig manure only a small reduction of TOC from 14.5 to 14 g/kg was observed. In the aerated samples the TOC was reduced to 13 g/kg by intermittent aeration and to 11 g/kg by continuous aeration within a period of 15 days. Sørensen and Fernandez (2003) studied the influence of different diets and found for growing pigs TOC concentrations between 9.6 g/kg and 28.9 g/kg. In an experiment with dry sows a diet with high fibre level increased TOC more than twice (11.5 to 32.5 g/kg).

Table 9: total organic carbon (TOC) and dissolved organic carbon (DOC)

source	Information	comment
total organic carbon (TOC)		
cattle		
Gerl, 1998	8.8 – 29 g/kg wet weight, cattle manure, ∅ 18.2 g/kg	Germany, Data from 8 manures of two farms with several samplings between March, 1993 and April, 1995
Kreuzig et al., 2006	Cattle manure: 39-42 g/kg, ∅ 40 g/kg	Germany, 4 cattle manures
Amon et al., 2006	20.05 – 26.73 g/kg wet weight	Austria, Dairy cattle, end of storage, two treatments

pig		
Luo et al., 2002	Pig manure: 11-14 g/L at end of experiment	Minnesota, USA, Finishing pigs, aeration experiments over 16 days, end of experiment
Sørensen & Fernandez, 2003	Growing pigs: 9.6-28.9 g/kg, ∅ 19.1 g/kg Dry sows: 11.5-32.5 g/kg, ∅ 18.8 g/kg	Denmark 8 Different diets for growing pigs (40-60 kg) and 4 diets for dry sows (about 220 kg) , 5 animals per diet, data at the end of storage
Kreuzig et al., 2006	Pig manure: 20-25 g/kg, ∅ 22.25 g/kg	Germany, 4 pig manures
dissolved organic carbon (DOC)		
Sørensen & Fernandez, 2003	Growing pigs: 0.56-4.49 g/kg Dry sows: 1.14-2,29 g/kg	Denmark, 8 different diets for growing pigs (40-60 kg) and 4 diets for dry sows (about 220 kg) , 5 animals per diet, data at the end of storage

For DOC only Sørensen and Fernandez (2003) presented some results. The DOC concentration in the manure of growing pigs ranged between 0.56 for a diet with high fibre fermentability and a normal fibre level and 4.49 g/kg for a diet with low fibre fermentability and a high fibre level. In the manure of dry sows DOC ranged between 1.14 g/kg for a normal fibre level and 2.29 g/kg for a high fibre level.

6.2.5 Total nitrogen

Table 10: range of total nitrogen (total N) for different productions types (summarized results of table 11)

	Total N kg/m^3 wet weight		Total N kg/m^3 wet weight
Cattle (unspecified)	0.43 – 5.7	Pigs (unspecified)	0.2 – 8.7
Dairy cattle	0.76 – 4.8	Pig fattening	0.85 – 11.1
Beef fattening > 1 year	2.2 – 4.5	Sow housing	0.45 – 5.8
calves	0.78 – 3.3	piglets	2.3 – 4.6

As shown in table 10 the total nitrogen concentrations of manures vary within a large range. The total N concentrations for cattle manure (between 3.2 and 4.6 kg/m^3 wet weight) mentioned by LIZ (2009), Schaaf (2002) and LUFA NRW (2008) are mean values of an unspecified amount of analysis (table 11). As mentioned above the data from LUFA NRW and

LUFA Nordwest are the mean value of at least some hundred analysis. The data given by Kreuzig et al. (2006) are data from 2000 analysis. The median of 4.0 kg/m^3 wet weight is close to the information given by LIZ, Schaaf and LUFA NRW. A lower mean value (2.16 kg/m^3 wet weight) was observed by Martinez-Suller et al. (2008). For manure from dairy cattle the range of total N is a little bit narrower. The mean values given by LfL (2007), LUFA NRW and LUFA Nordwest (2010) (3.5 – 3.8, 3.2 – 4.8 and 4.1 kg/m^3 wet weight respectively) are higher than the data (2.54 kg/m^3 wet weight) given by Martinez-Suller et al. (2008) but within the same range as the data (4.67 kg/m^3 wet weight) of Safely et al. (1986). The mean values for beef fattening are within the range between 2.2 and 4.5 kg/m^3 wet weight (e.g LUFA NRW, LUFA Nordwest) for large sample collectives, the data from Gerl (1998) are a little bit lower. For calve manure the available data are very similar and lie in between 1.84 and 3.3 kg/m^3 wet weight and again Martinez-Suller et al. (2008) found lower concentrations than LUFA NRW (2008) and LUFA Nordwest, (2010).

For pig manure the range of data is comparable with cattle manure but the mean values given by several authors are a little bit higher than for cattle manure. The mean values from german data (LIZ, 2009, Kreuzig et al., 2006 and Schaaf, 2002) are considerably higher (at about 5 kg/m^3 wet weight) than the data from south European countries (2.43 and 2.58 kg/m^3) given by Martinez-Suller et al., (2007) and Moral et al. (2005). For fattening pigs german data for mean values are within the range between 2.7 and 5.3 kg/m^3 depending on diet (e. g. LUFA NRW, 2008, LUFA Nordwest, 2010, LfL, 2007) whereas south European data (Martinez-Suller et al., 2007 and Moral et al. 2005) are again at a lower level with 2.81 and 3.42 kg/m^3, respectively. The higher total N concentrations in the publications of Canh et. al. (1998), Kreuzer et al. (1998) and Le et al. (2009) can not be directly compared with the data given by other authors. The manures in the experiments of Canh, Kreuzer and Le were a mixture of urine and faeces. In the other publications farm manures from storage containers were analyzed. These manures contain additional water from cleaning processes in the barn and - in a lot of cases - rainwater which flowed into the storage containers. Therefore a dilution of manure in the farm containers can be assumed in comparison with manures which are obtained directly at the animal. For manures from sow housing the german data indicate a total N concentration of 2.8 to 4 kg/m^3 wet weight, lower data are observed by Martinez-Suller et al., 2007 and Moral et al. 2005 (2.29 – 2 kg/m^3). Even for piglets a small difference in dry matter content between german data (3.3 – 4.6 kg/m^3) and the data from Moral et al. (2005) can be observed (2.3 kg/m^3).

It is not surprising that the range for total N is similar as the range for dry matter because the total N concentration depends on dry matter content. The german data for total N are taking into account the dry matter content (rise of dry matter content causes increase of total N). In figure 1 a moderate relation between dry matter content and total nitrogen for fattening pigs can be seen (on basis of data from Canh et al. (1998) and Kreuzer et al. (1998)).

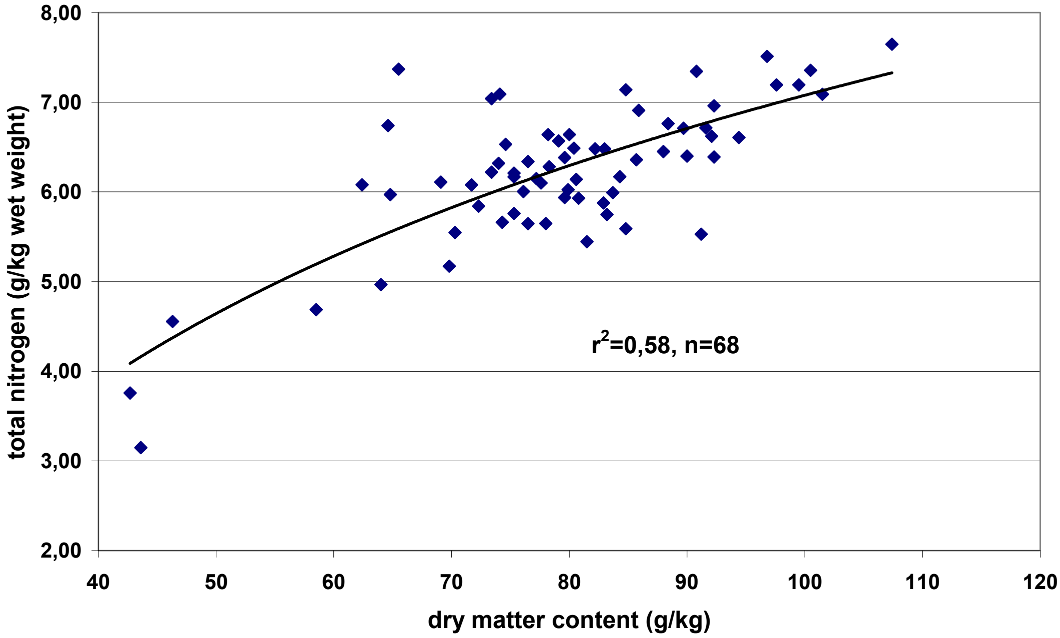

Figure 1: relation between dry matter content and total nitrogen in pig manure

Sommer et al. (1993) studied the influence of season on total N and found for cattle manure a higher total N concentration in a winter/spring period than in a summer/autumn period (5.2/4.1 kg/m^3). For pig manure in the summer/autumn season the observed concentrations were a little bit higher than in the winter/spring season (6.1/5.8 kg/m^3). Hermanson et al. (1980) observed in dairy cattle manure similar total N concentrations in summer and winter but lower concentrations in spring. Hermanson et al. (1980) also found a decrease of total N in cattle manure of about 30 % within a storage period of six weeks unrelated to the season. Similar results were observed by Kreuzer et al. (1998) with a decrease of total N in manure of fattening pigs of 20 to 30 %. Amon et al. (2006) reported about a decrease of total N of about 20 % within 80 days in an untreated manure and of only 2 % in an aerated manure. Canh et al. (1998/2) measured the difference in total N with a storage period of one week and found a reduction of total N of about 10 %. Luo et al. (2002) studied the influence of aeration in manure parameters and found within a period of 16 days no change of total N in an untreated manure but a reduction of total N of about 15 % and 25 % for a manure with intermittent aeration and continuous aeration respectively.

Stevens et al. (1993) studied the influence of different diets and found in dairy cattle manure the lowest total N concentration with a diet with low protein concentration and a low-digestibility silage and the highest total N with a diet with low protein concentration and high-digestibility silage. Canh et al. (1998/1-4) tested in several studies the influence of different diets on manure of fattening pigs. The concentrations of total N were lower in diets with a low dEB and rose with increasing amount of crude protein. Dourmad & Jondreville (2007), Le et al. (2009), Sørensen & Fernandez (2003), Velthof et al. (2005) and Portejoie et al. (2005)

confirmed these results and showed a close relation between rising of crude protein concentration and increasing total N. Le et al. (2008) presented results which showed that not only the protein concentration but also the fermentability of protein can influence total N. In a diet with low fermentable protein total N was low (6.0 kg/m^3) too. The total N concentration increased in diets with medium (6.3 kg/m^3) and high fermentability (7.0 kg/m^3). Kreuzer et al. (2006) studied the influence of different polysaccharides and found higher total N concentrations in diets with a high content of Hemicellulose and Pectin and low concentrations in diets with starch as main component. They also demonstrated that with an increasing amount of fermentable non-starch polysaccharides the total N concentration increased.

Table 11: total nitrogen

source	Information	comment
Cattle: without differentiation between production types		
LIZ, 2009	cattle manure 4 kg/m^3	Germany, Mean values, wet weight
LUFA NRW, 2008	3.2 – 4.8 kg/m^3, wet weight	Germany, Depending on dry matter content
Schaaf, 2002	cattle manure 4.16 % of dry matter	Germany, Mean values of a not specified amount of analysis between 1998 and 2000 at LUFA Kassel
Kreuzig et al., 2006	Cattle manure: minimum 0.43 kg/m^3, median 4.0 kg/m^3, maximum 5.7 kg/m^3, wet weight	Germany, Data of 2000 Analysis between 1997 to 2004, wet weight
Møller et al., 2004	cattle manure: 4.64 kg/m^3, wet weight	Denmark, No information about amount of animals which produce the manure
Sommer et al., 1993	Cattle: period 1: 5.7 g/L, Period 2: 4.1g/L	Denmark, Cattle period 1: 21 Dec 1989- 15 June 1990, period 2: 6 July 1990-2 Sep. 1990
Martinez-Suller et al., 2008	combined cattle manure (N=49): 0.78-4.11 kg/ m^3, ∅ 2.16 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Sommer et al., 1993	Cattle: 4.1-5.2 g/L, wet weight	Denmark, 2 cattle and 2 pig manures
Sørensen &Eriksen, 2009	Cattle manure: 2.65 g/kg, wet weight	Denmark, One pig and cattle manure, several treatments; data only for untreated manure
Dairy Cattle		
LUFA NRW, 2008	3.2 – 4.8 kg/m^3, wet weight	Germany, Depending on dry

		matter content
LUFA Nordost, 2010	4.1 kg/m^3, wet weight	Germany, Median
LfL, 2007	3.5 -3.8 kg/m^3, wet weight	Germany, Mean values, on basis of 7.5 % dry matter for feed stuff from grassland or arable land
Hermanson et al., 1980	spring: 761 mg/L, summer: 973 mg/L, winter: 1017 mg/L	Washington, USA, Dairy cattle manure; spring period: 4 May-23 June, Summer period 31 August-4 October, winter period: 19 January -22 February, 65 animals
Sommer et al., 2000	3.8-3.9 g/kg wet weight	Denmark, 2 manures from dairy cattle
Amon et al., 2006	3.25 g/kg wet weight	Austria, Dairy cattle, end of storage
Martinez-Suller et al., 2008	Dairy cows (N=22): 0.94-4.11 kg/m^3, ∅ 2.54 kg/m^3, wet weight	Farms in northern italy; N: number of farms
Safely et al., 1986	Dairy cattle manure: 2.65 ± 0.82 kg/m^3, wet weight	29 samples from dairy farms in North Carolina, USA; average and standard deviation
Sommer et al., 2000	3.8-3.9 g/kg, wet weight	Denmark, Dairy cattle, one farm , two samplings
Beef fattening > 1 year		
Landwirtschaftliches Wochenblatt, 2008	bull manure 4.5 kg/m^3 , wet weight	Germany, Mean values
LUFA NRW, 2008	3.7 – 4.5 kg/m^3, wet weight	Germany, Mean values, depending on dry matter content
LUFA Nordwest, 2010	4.4 kg/t, wet weight	Germany, Median
LfL, 2007	3.8 kg/m^3	Germany, Mean value, calculated on basis 0f 7.5 % dry matter
Gerl, 1998	0.22 % wet weight	Germany, Data from 16 manures of two farms with several samplings between March, 1993 and April, 1995
calves		
LUFA NRW, 2008	3.3 kg/m^3, wet weight	Germany, Mean value
LUFA Nordwest, 2010	2.7 kg/m^3, wet weight	Germany, Median

Martinez-Suller et al., 2008	calves (N=27): 0.78-2.73 kg/ m^3, ∅ 1.85 kg/m^3	Farms in northern Italy; N: number of farms
pig: without differentiation between production types		
LIZ, 2009	pig manure 5.1 kg/m^3, wet weight	Germany, Mean values
Schaaf, 2002	pig manure 7.2 % of dry matter	Germany, Mean values of a not specified amount of analysis between 1998 and 2000 at LUFA Kassel
Kreuzig et al., 2006	pig manure: minimum 0.6 kg/m^3, median 4.6 kg/m^3, maximum 8.3 kg/m^3, wet weight	Germany, Data of 2000 Analysis between 1997 to 2004
Hisset et al., 1982	Pig manure 1.7 g/L, wet weight	UK, Material of 10 pigs
Møller et al., 2004	pig manure: 5.99 kg/m^3, wet weight	Denmark, No information about amount of animals which produce the manure
Sørensen & Eriksen, 2009	Pig manure: 4.37 g/kg	Denmark, One pig and cattle manure, several treatments; data only for untreated manure
Sommer et al., 1993	pig: period 1: 5.8 g/L period 2: 6.1 g/L, wet weight	Denmark, pig: period 1: 18 Sep 1990- 10 Dec 1990, period 2: 27 Feb 1991-25 June 1991;
Martinez-Suller et al., 2008	Combined pig manure (N=83): 0.20-5.62 kg/m^3, ∅ 2.43 kg/m^3	Farms in northern Italy; N: number of farms
Moral et al., 2005	Total: 2.58 ± 1.29 kg/m^3	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Pig fattening		
Landwirtschaftliches Wochenblatt, 2008	fattening pig manure 5.6 kg/m^3, wet weight	Germany, Mean value
LUFA NRW, 2008	4.2 – 6.6 kg/m^3, wet weight	Germany, Mean values, depending on dry matter content
LUFA Nordwest, 2010	5.1 - 5.3 kg/m^3, wet weight	Germany, Median, depending on diet
LfL, 2007	2.7 – 3.2 kg/m^3, wet weight	Germany, Mean values, depending on diet
Laurenz, 2009	Min.: 2.8 kg/m^3, mean value: 5.6 kg/m^3, max.: 8.7 kg/m^3, wet weight	Germany, Result of 240 analysis

Canh et al., 1998/1	Pig manure: 6.08-7.09 g/kg, ∅ 6.35 kg/m^3, wet weight	Netherlands, 18 different diets, every diet with 5 pigs fattening pigs, about 40 kg per animal
Canh et al, 1998/2	Pig manure: 5.59-7.37 g/kg, ∅ 6.46 kg/m^3, wet weight	Netherlands, 4 different diets, every diet with 4 growing finishing pigs (about 81 kg per animal)
Canh et al, 1998/3	Pig manure: 4.8-7.3 g/kg, ∅ 6.92 kg/m^3, wet weight	Netherlands, 9 different diets, every diet with 3 growing pigs (about 40-55 kg per animal)
Canh et al, 1998/4	Pig manure: 7.22-11.13 g/kg, wet weight	Netherlands, 3 different diets, every diet with 6 growing pigs about 55 kg per animal
Dourmad & Jondreville, 2007	Pig manure: 1.92-4.32 g/kg, wet weight	France, 3 different diets, fattening pigs (30-102 kg per animal)
Kreuzer et al., 1998	Pig manure: 4.69 – 7.65 g/kg wet weight matter, ∅ 6.29 kg/m^3	Switzerland, 18 diets, every diet with six fattening pigs (starting with about 30 kg per animal), different storage time
Le et al., 2009	Pig manure: 5.2-6.8 g/kg, wet weight	Netherlands?, 2 diets, every diet with six fattening pigs
Le et al., 2008	Pig manure: 6.0-7.0 g/kg, wet weight	Netherlands, 3 diets, every diet with six fattening pigs (starting with about 41 kg per animal)
Luo et al., 2002	Pig manure: 2.88 g/L (initial amount)	Minnesota, USA, Finishing pigs, aeration experiments over 16 days
Martinez-Suller et al., 2008	finisher pigs (N=30): 0.85-5.40 kg/m^3, ∅ 2.81 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Moral et al., 2005	Finishers: 3.42 ± 1.75 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Portejoie et al., 2004	Pig manure: 3.05-5.48 g/kg, wet weight	France, Three diets, every diet with 5 fattening pigs with an initial weight of about 50 kg
Sørensen & Fernandez, 2003	Growing pigs: 2.91-5.21 g/kg, wet weight	Denmark, 8 Different diets for growing pigs (40-60 kg), 5 animals per diet, data at end of storage
Sow housing		

Landwirtschaftliches Wochenblatt, 2008	suckling sows 3.9 kg/m^3, wet weight	Germany, Mean value
LUFA NRW, 2008	2.8 – 3.9 kg/m^3, wet weight	Germany, Mean values, depending on dry matter content
LUFA Nordwest, 2010	3.3 – 4.0 kg/m^3, wet weight	Germany, Median, depending on diet
LfL, 2007	2.9 – 3.3 kg/m^3, wet weight	Germany, Mean values, depending on diet
Sørensen & Fernandez, 2003	Dry sows: 5.37-5.86 g/kg, wet weight	Denmark, 4 diets for dry sows (about 220 kg) , 5 animals per diet, data at end of storage
Martinez-Suller et al., 2008	farrowing sows (N=40) : 0.45-5.62 kg/ m^3, ∅ 2.29 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Moral et al., 2005	Gestating Sows: 2.35 ± 1.09 kg/m^3 Farrowing Sows: 1.80 ± 0.88 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation
piglets		
LUFA NRW, 2008	4.6 kg/m^3, wet weight	Germany, Mean value
LUFA Nordwest, 2010	3.3 kg/m^3, wet weight	Germany, Median
Moral et al., 2005	Weaners: 2.30 ± 1.25 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation

6.2.5 Ammonium nitrogen (NH_4-N)

As presented in table 12 the range of NH_4-N varies within a large range, too. The NH_4-N concentrations for cattle manure (between 1.8 and 2.4 kg/m^3 wet weight) noted by LUFA NRW (2008) are mean values of an unspecified amount of analysis (table 13). The data given by Kreuzig et al. (2006) are data from 2000 analysis. The median of 1.7 kg/m^3 wet weight is close to the information given by LUFA NRW and similar to the data from Sommer & Husted (1995). A lower mean value (1.39 kg/m^3 wet weight) was observed by Martinez-Suller et al. (2008).

For manure from dairy cattle the range of NH_4-N is a little bit narrower. The mean values given by LfL (2007), LUFA NRW (2007) and LUFA Nordwest (2010) range between 1.7 and 2.5 kg/m^3 wet weight and are higher than the data (1.12 kg/m^3 wet weight) given by Martinez-Suller et al. (2008) and those of Safely et al. (1986) (1.05 kg/m^3 wet weight). The mean values for beef fattening are within the range between 1.9 and 2.5 kg/m^3 wet weight (e.g LUFA NRW, LUFA Nordwest) for large sample collectives, the data from Gerl (1998) are a little bit lower. For calve manure the available data range between 1.20 and 2.5 kg/m^3 wet weight and there could be observed no difference in concentration between data of Martinez-Suller et al. (2008) and LUFA NRW (2008) or LUFA Nordwest, (2010).

Table 12: range of Ammonium nitrogen (NH_4-N) for different productions types (summarized results of table 13)

	NH_4-N kg/m^3 wet weight		NH_4-N kg/m^3 wet weight
Cattle (unspecified)	0.25 – 3.13	Pigs (unspecified)	0.15 – 5.63
Dairy cattle	0.23 – 2.5	Pig fattening	0.44 – 8.83
Beef fattening > 1 year	0.5 – 2.5	Sow housing	0.19 – 5.07
calves	0.57 – 2.5	piglets	1.53 – 3.3

For pig manure the range of data for NH_4-N is wider than for cattle manure and the mean values given by several authors are higher than for cattle manure. The mean values from german data (Kreuzig et al., 2006 and Landwirtschaftliches Wochenblatt, 2008) and the data of Sommer and Husted (1995) are considerably higher (between 2.6 and 3 kg/m^3 wet weight) than the data from south European countries (1.83 and 2.01 kg/m^3 wet weight) given by Martinez-Suller et al., (2007) and Moral et al. (2005). For fattening pigs german data for mean values are within the range between 1.9 and 4.7 kg/m^3 depending a on diet (e. g. LUFA NRW, 2008, LUFA Nordwest, 2010, LfL, 2007) whereas south European data (Martinez-Suller et al., 2007 and Moral et al. 2005) are again at a lower level with 2.03 and 2.73 kg/m^3 wet weight, respectively. For manures from sow housing the german data indicate a NH_4-N concentration of 1.9 to 2.9 kg/m^3 wet weight, the data are obtained by Martinez-Suller et al., 2007 and Moral et al. 2005 (1.38 – 1.93 kg/m^3 wet weight) are a little bit lower. Even for piglets a small difference in NH_4-N between german data (1.9 – 3.3 kg/m^3) and the data from Moral et al. (2005) can be observed (1.63 kg/m^3).

In contrast to the total N concentration NH_4-N does not depend on dry matter (Fig. 2) or total N (Fig. 3) (data for fattening pigs on the basis of data from Canh et al. (1998) and Kreuzer et al. (1998)).

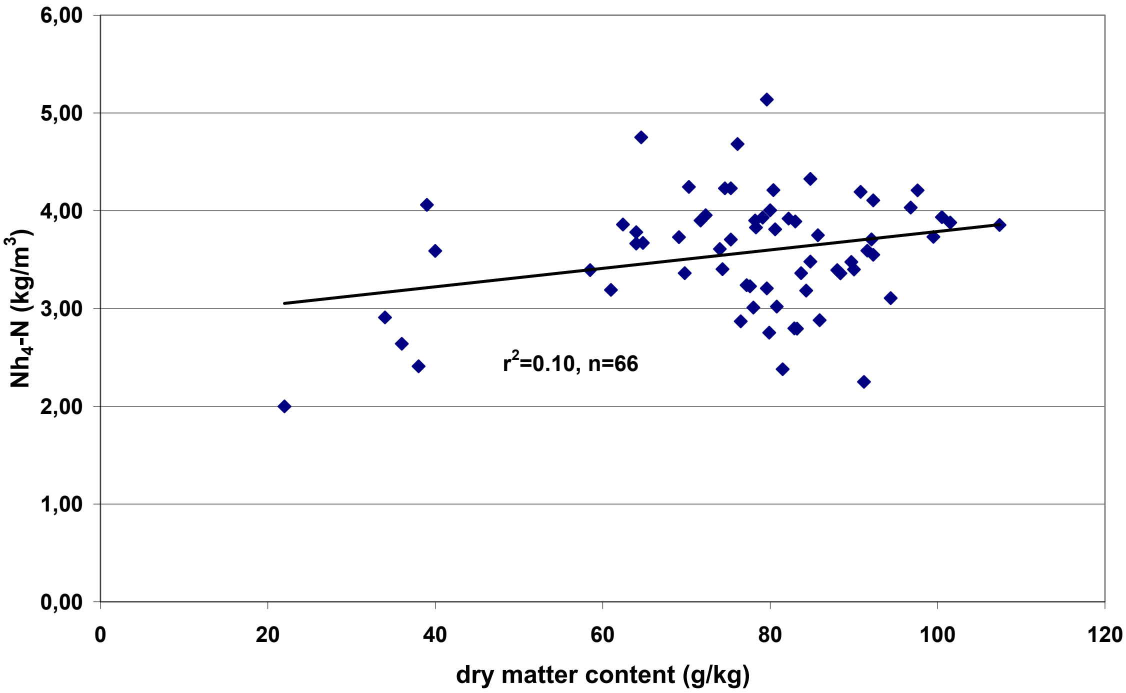

Figure 2: relation between dry matter content and NH_4-N in pig manure

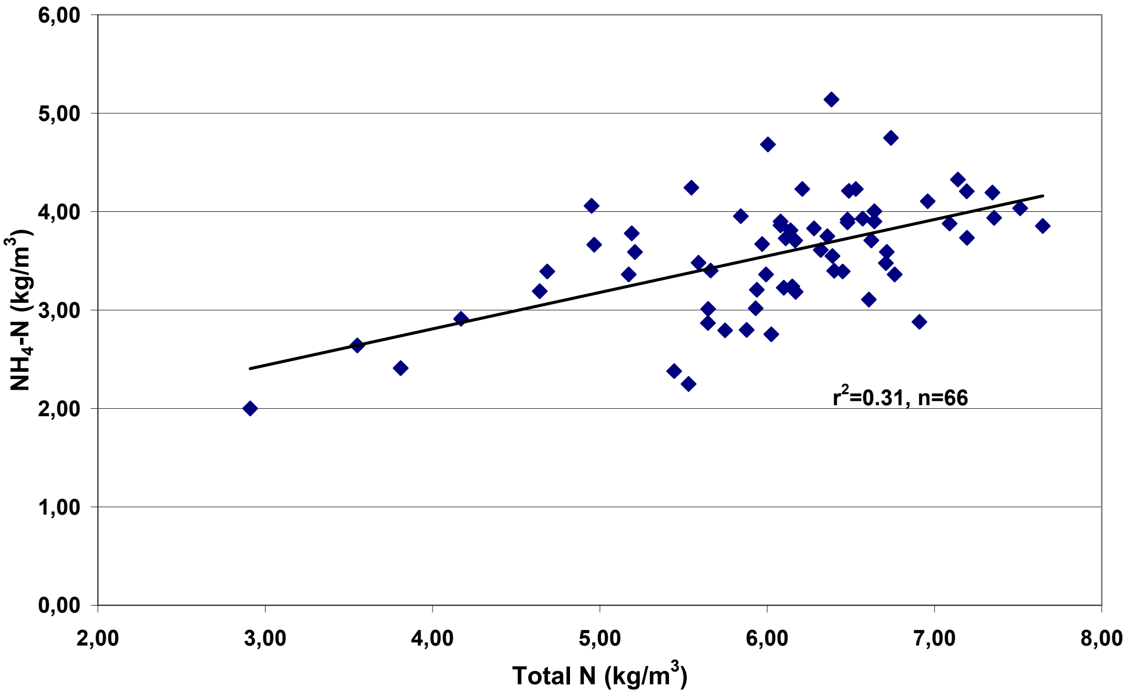

Figure 3: relation between total N and NH_4-N in pig manure

Sommer et al. (1993) studied the influence of season on NH_4-N and found for cattle manure and pig manure no difference in NH4-N concentrations between the seasons. Park et al. (2006)

found similar concentrations of NH_4-N in manures from fall, winter and spring but the concentrations in summer were about 180 % of the concentrations in the other seasons. Hermanson et al. (1980) observed in dairy cattle manure similar NH_4-N concentrations in summer and spring but higher concentrations in winter. Hermanson et al. (1980) also found a decrease of NH_4-N in cattle manure of about one third within a storage period of six weeks in winter and of 15 % in summer. Similar results were observed by Kreuzer et al. (1998) with a decrease of NH_4-N in manure of fattening pigs between 20 to 30 % within seven weeks. Amon et al. (2006) reported about an increase of NH_4-N of about 20 % within 80 days in untreated manure and of a decrease of 15 % in aerated manure. Canh et al. (1998/2) measured the difference in NH_4-N with a storage period of one week and found a rise of NH_4-N of about 200 to 700 % related to the diet. Luo et al. (2002) studied the influence of aeration in manure parameters and found within a period of 16 days a slight increase of NH_4-N in untreated manure but a reduction of NH_4-N of about 15 % and 40 % for manure with intermittent aeration and continuous aeration respectively. Paul & Beauchamp (1989) found a reduction of NH4-N in a short-term experiment of 33 % within 4 days.

The influence of different diets on NH_4-N in dairy cattle manure was studied by Stevens et al. (1993). They found the lowest NH_4-N concentration in a diet with low protein concentration and low-digestibility silage and the highest total N in a diet with high protein concentration and high-digestibility silage. Canh et al. (1998/1-4) tested in several studies the influence of different diets on manure of fattening pigs. The concentrations of NH4-N were not influenced by dEB and the type of acidifying salts but rose with increasing amount of crude protein. Dourmad & Jondreville (2007), Le et al. (2009), Sørensen & Fernandez (2003), Velthof et al. (2005) and Portejoie et al. (2005) confirmed these results and showed a close relation between increasing of crude protein concentration and rising NH_4-N. Kreuzer et al. (1998) studied the influence of different polysaccharides and the amount of fermentable non-starch polysaccharides and found no influence on NH4-N concentration in manures after eight weeks of storage in contrast to total N.

Table 13: Ammonium nitrogen

source	Information	comment
Cattle: without differentiation between production types		
LUFA NRW, 2008	1.8 – 2.4 kg/m^3, wet weight	Germany, Mean values, depending on dry matter content
Kreuzig et al., 2006	Cattle manure: minimum 0.01 kg/m^3, median 1.7 kg/m^3, maximum 2.9 kg/m^3, wet weight	Germany, Data of 2000 Analysis between 1997 to 2004
Sommer & Husted, 1995	Cattle manure: 1.26-3.13 kg/m^3, wet weight, ∅ 2.06 kg/m^3, wet weight	Denmark, 4 cattle manures
Møller et al., 2004	cattle manure: 1.80 kg/m^3, wet	Denmark, No information about

	weight	amount of animals which produce the manure
Sommer et al., 1993	Cattle: period 1: kg/m^3, Period 2: 2.6 kg/m^3, wet weight	Denmark, Cattle period 1: 21 Dec 1989- 15 June 1990, period 2: 6 July 1990-2 Sep. 1990
Martinez-Suller et al., 2008	combined cattle manure (N=49): 0.25-2.4 kg/m^3, ∅ 1.39 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Sørensen & Eriksen, 2009	Cattle manure: 1.50 kg/m^3, wet weight	Denmark, One cattle manure, several treatments; data only for untreated manure
Dairy Cattle		
LUFA NRW, 2008	2.2 – 2.5 kg/m^3, wet weight	Germany, Mean values, depending on dry matter content
LUFA Nordwest, 2010	1.7 kg/m^3, wet weight	Germany, Median
LfL, 2007	1.7 – 1.9 kg/m^3, wet weight	Germany, Mean values, on basis of 7.5 % dry matter for feed stuff from grassland or arable land
Hermanson et al., 1980	spring: 0.27 kg/m^3, summer: 0.23 kg/m^3, winter: 0.37 kg/m^3, wet weight	Washington, USA, Dairy cattle manure; spring period: 4 May-23 June, Summer period 31 August-4 October, winter period: 19 January -22 February, 65 animals
Sommer et al., 2000	1.9-2.1 kg/m^3, wet weight	Denmark, 2 manures from dairy cattle
Amon et al., 2006	1.82 kg/m^3, wet weight	Austria, Dairy cattle, end of storage
Martinez-Suller et al., 2008	Dairy cows (N=22): 0.26-1.86 kg/m^3, ∅ 1.12 kg/m^3, wet weight	Farms in northern italy; N: number of farms
Paul & Beauchamp, 1989	Dairy cattle manure: 1.35-2.27 kg/m^3, wet weight	Ontario, Canada, Two dairy cattle manures
Safely et al., 1986	Dairy cattle manure: 1.05 ± 0.40 kg/m^3, wet weight	29 samples from dairy farms in North Carolina, USA; average and standard deviation
Sommer et al., 2000	1.9-2.1 kg/m^3, wet weight	Denmark, Dairy cattle, one farm , two samplings
Beef fattening > 1 year		
LUFA NRW, 2008	2.2 – 2.5 kg/m^3, wet weight	Germany, Mean values,

		depending on dry matter content
LUFA Nordwest, 2010	1.9 kg/m^3, wet weight	Germany, Median
LfL, 2007	1.9 kg/m^3, wet weight	Germany, Mean value, calculated on 7.5 % dry matter content
Gerl (1998)	0.5 – 1.9 kg/m^3, ∅ 0.98 kg/m^3, wet weight	Germany, Data from 13 manures of two farms with several samplings between March, 1993 and April, 1995
Landwirtschaftliches Wochenblatt, 2008	bull manure 2.5 kg/m^3, wet weight	Germany, Mean value
Paul & Beauchamp, 1989	Beef cattle manure: 2.06 kg/m^3, wet weight	Ontario, Canada, One manure
calves		
LUFA NRW, 2008	2.5 kg/m^3, wet weight	Germany, Mean value
LUFA Nordwest, 2010	1.2 kg/m^3, wet weight	Germany, Median
Martinez-Suller et al., 2008	calves (N=27): 0.57-2.40 kg/ m^3, ∅ 1.62 kg/m^3	Farms in northern italy; N: number of farms
pig: without differentiation between production types		
Landwirtschaftliches Wochenblatt, 2008	pig manure 3 kg/m^3, wet weight	Germany, Mean value
Kreuzig et al., 2006	pig manure: minimum 0.27 kg/m^3, median 2.7 kg/m^3, maximum 4.9 kg/m^3, wet weight	Germany, Data of 2000 Analysis between 1997 to 2004
Sommer & Husted, 1995	pig manure 1.03-5.63, kg/m^3, wet weight, ∅ 2.61 kg/m^3, wet weight	Denmark, 7 pig manures
Hisset et al., 1982	Pig manure 0.8 g/L	UK, Material of 10 pigs
Møller et al., 2004	2.29 kg/m^3, wet weight	Denmark, No information about amount of animals which produce the manure
Sommer et al., 1993	pig: period 1: 4.1 kg/m3, period 2: 4.2 kg/m^3, wet weight	Denmark, pig: period 1: 18 Sep 1990- 10 Dec 1990, period 2: 27 Feb 1991-25 June 1991;
Martinez-Suller et al., 2008	Combined pig manure (N=83): 0.15-4.97 kg/m^3, ∅ 1.83 kg/m^3 1.62 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Moral et al., 2005	Total: 2.01 ± 1.06 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation

Paul & Beauchamp, 1989	Swine manure: 3.72 kg/m^3, wet weight	Ontario, Canada
Sørensen & Eriksen, 2009	Pig manure: 3.66 kg/m^3, wet weight	Denmark, One pig and cattle manure, several treatments; data only for untreated manure
Pig fattening		
Landwirtschaftliches Wochenblatt, 2008	fattening pig manure 3 kg/m^3 wet weight	Germany, Mean values
LUFA NRW, 2008	3.3 - 4.7 kg/m^3 wet weight	Germany, Mean values, depending on dry matter content
LUFA Nordwest, 2010	2.6 – 3.0 kg/m^3 wet weight	Germany, Median, depending on diet
LfL, 2007	1.9 – 2.3 kg/m^3 wet weight	Germany, Mean values, depending on diet
Laurenz, 2009	Min.: 1.5 kg/m^3, mean value: 4.2 kg/m^3, max.: 6.4 kg/m^3 wet weight	Germany, Data from 240 manures
Canh et al., 1998/1	Pig manure: 2.25-4.23 g/kg, ∅ 3.66 kg/m^3, wet weight	Netherlands, 18 different diets, every diet with 5 pigs fattening pigs, about 40 kg per animal
Canh et al, 1998/2	Pig manure: 0.56-4.75 g/kg, ∅ 2.32 kg/m^3, wet weight	Netherlands, 4 different diets, every diet with 4 growing finishing pigs (about 81 kg per animal)
Canh et al, 1998/3	Pig manure: 2.03-2.35 g/kg, ∅ 2.23 kg/m^3, wet weight	Netherlands, 9 different diets, every diet with 3 growing pigs (about 40-55 kg per animal)
Canh et al, 1998/4	Pig manure: 4.49-8.83 kg/m^3, wet weight	Netherlands, 3 different diets, every diet with 6 growing pigs about 55 kg per animal
Dourmad & Jondreville., 2007	Pig manure: 3.05-5.48 kg/m^3, wet weight	France, 3 different diets, fattening pigs (30-102 kg per animal)
Kreuzer et al., 1998	Pig manure: 2.38 – 5.14 kg/m^3, ∅ 3.59 kg/m^3, wet weight	Switzerland, 18 diets, every diet with six fattening pigs (starting with about 30 kg per animal), different storage time
Le et al., 2009	Pig manure: 3.32-4.57 kg/m^3, wet weight	Netherlands?, 2 diets, every diet with six fattening pigs
Le et al., 2008	Pig manure: 2.6-2.7 kg/m^3, wet weight	Netherlands, 3 diets, every diet with six fattening pigs (starting

		with about 41 kg per animal)
Luo et al., 2002	Pig manure:2.0-2.7 kg/m^3, wet weight at end of experiment	Minnesota, USA, Finishing pigs, aeration experiments over 16 days
Martinez-Suller et al., 2008	finisher pigs (N=30): 0.44-3.50 kg/ m^3, ∅ 2.03 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Moral et al., 2005	Finishers: 2.73 ± 1.51 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Portejoie et al., 2004	Pig manure: 1.92-4.32 kg/m^3, wet weight	France, Three diets, every diet with 5 fattening pigs with an initial weight of about 50 kg
Sørensen & Fernandez, 2003	Growing pigs: 2.0-4.06 kg/m^3, wet weight, ∅ 3.07 kg/m^3, wet weight	Denmark, 8 Different diets for growing pigs (40-60 kg), 5 animals per diet, data at end of storage
Sow housing		
LUFA NRW, 2007	2.2 – 2.9 kg/m^3, wet weight	Germany, Mean values, depending on diet
LUFA Nordwest, 2010	1.9 – 2.2 kg/m^3, wet weight	Germany, Median, depending on diet
LfL, 2007	2.0 – 2.3 kg/m^3, wet weight	Germany, Mean values, depending on diet
Martinez-Suller et al., 2008	farrowing sows (N=40) : 0.19-4.97 kg/ m^3, ∅ 1.76 kg/m^3, wet weight	Farms in northern Italy; N: number of farms
Moral et al., 2005	Gestating Sows: 1.93 ± 0.82 kg/m^3 Farrowing Sows: 1.38 ± 0.79 kg/m^3, wet weight	Pig manure of 36 farms in Southeast Spain; average and standard deviation
Sørensen & Fernandez, 2003	Dry sows: 4.32-5.07 kg/m^3, wet weight	Denmark, 4 diets for dry sows (about 220 kg) , 5 animals per diet, data at end of storage
piglets		
LUFA NRW, 2007	3.3 kg/m^3, wet weight	Germany, Mean value
LUFA Nordwest, 2010	1.9 kg/m^3, wet weight	Germany, Median
Moral et al., 2005	Weaners: 1.53 ± 0.91 kg/m^3	Pig manure of 36 farms in Southeast Spain; average and standard deviation

7. Discussion

Storage conditions

The available information on storage conditions within the EU is fragmentary. Information on housing systems and storage systems is lacking. Yet the information given by Oenema et al. (2007) and BMELV (2007) indicate that at least 50 % of the produced manure is a (semi)-liquid manure within the EU and also within Germany and therefore the most relevant form of manure. The influence of housing systems and storage systems on matrix parameters is small or not detectable. Only the manure temperature is influenced by storage systems because underground systems show a narrower seasonal range of temperature than aboveground systems (Arrus et al., 2006, Montfort et al., 2003). The storage time is mostly influenced by such agricultural requirements like field crop, vegetation period and storage capacity. Because of regulatory requirements in the most countries of the EU a minimum of storage capacity of six months is regulated. As described in chapter 4.1.4 for the storage time two main scenarios can be assumed. A “long-term” storage with an average storage time of 3 to 4 months and an application in late winter or early spring and a “short-term” storage during the vegetation period with an average storage time of 1 to 2 months. The maximum storage times as defined in EMEA/CVMP/ERA/418282/2005-Rev.1 of 91 days for pig and cattle except for weaner pigs (53 days) are therefore justified for winter times. However, in summer the storage period might be shorter. For this period of the year a maximum value of 53 days, as presently in EMEA/CVMP/ERA/418282/2005-Rev.1 for weaner pigs, seems more appropriate.

Matrix parameters

The availability of information for matrix parameters of manure is highly variable. Data for the matrix parameters such as dry matter content, pH value, total N and NH_4-N are available in a lot of publications and in information from agricultural administrations and research institutes because these data are of importance for the use of manure as fertilizer. For other matrix parameters such as redox potential less information is available. Since a redox potential of less than - 100 mV is an indicator for anaerobic conditions (OECD, 2002) it can be concluded that all tested manures were in anaerobic status. All values derived from the limited data available are in the range of -230 to -400 mV (Table 4: storage conditions: redox potential). Also for TOC and DOC the data base is limited. From the available data it can be assumed that the TOC concentrations in cattle and pig manure do not differ and range from 8.8 to 42 g/kg.

More information is available for the dry matter content, pH value, total N and NH_4-N. It can be assumed that manures from cattle and pigs vary in the dry matter content with higher dry matter contents for cattle but not within production types of the species. The exception seems to be the production of calves where the dry matter content is twice smaller than that of the other production types. Whereas for cattle manure no difference in dry matter content between different countries could be observed it seems especially for fattening pigs that a regional/ country-specific difference in dry matter content occurs. This should be further determined with the help of the national agricultural institutions of other countries. The pH value shows only small variations. Values ranging from 5.5 to 9.1 were observed for both species and all production types. The data for total N and NH_4-N range from 0.2 to 11.1 kg/m^3 for total N and from 0.15 to 8.83 kg/m^3 for NH_4-N and indicate that within the two species the average concentration of both parameters is a little bit different with a slightly higher concentration for pig manure. Total N concentration does not differ a lot within the production types. The exception is calf production because calf manures contain 25 to 30 % less total N than the other production types. This is probably due to the lower dry matter content generally observed for calf manures (see above). As already observed for dry matter there is a difference pointed out in total N between northern and southern European countries because data of south Europe indicate lower concentrations, supposedly caused by lower dry matter content. In manure of fattening pigs the NH_4-N concentrations show slightly higher values in comparison to the other production types and span a wider range. The results also indicate a difference in NH_4-N concentrations between northern und southern European countries as the data of Martinez-Suller et al. (2007) and Moral et al. (2005) in southern Europe show mostly lower values.

Seasonal influences on matrix parameters were reported only by a few publications. Sommer et al. (1993), Hermanson et al. (1980) and Park et al. (2006) found small variations for the parameters in dry matter content, total-N and NH_4-N. Higher concentrations during summer months can be explained by evaporation and lower precipitation (e.g. Hermanson et al., 1980, Park et al., 2006). But this can not explain observations from Sommer et al. (1993) because they found higher total N concentrations in cattle manure during a winter/spring period. Possibly different feedstuff between winter/spring and summer/autumn had influenced the composition of manure.

Most publications which studied the influence of storage on matrix parameters reported on a decrease of dry matter content with increasing storage time (e. g. Martinez et al., 2003, Hermanson, 1980, Amon et al. (2006). This is not surprising because due to biological degradation of organic matter by microorganism during storage a decrease of dry matter content is expected. Only Kreuzer et al. (1998) observed an increase of dry matter and explained that by evaporation during the storage in open tanks. No clear observations were made with regard to the pH value. Some authors (e.g. Canh et al., 1998, Amon et al., 2006 and Yang et al. (2004) reported on an increase of pH during storage in closed systems (e.g Tanks), whilst Kreuzer et al. (1998) found decreasing pH values in an open system. A possible reason for these differing observations could be that methanogenic conditions are not obtained in an open system and therefore volatile fatty acids accumulate and induce a decrease of pH. In contrast in a closed system volatile fatty acids are degraded to methane and therefore the pH increases. Møller et al. (2004) could show that during the storage an increase and decrease of pH can be observed due to different microbial reactions in the manure. For total N the most publications reported a decrease during storage between 10 to 30 % induced by biological degradation. The available data indicate that the storage time influences the degradation because with a rise of storage time the degradation increases. From the available data it can be assumed that a 10 % reduction of total N occurs within the first two weeks of storage and a 30 % reduction within 40 and 80 days. Nevertheless it is not possible to calculate the degradation of total N only on basis of storage time because degradation is influenced by other parameters (e.g. manure treatment). The level of lowering of total N is in the same range as for dry matter which confirms the close relation between dry matter content and total N. Hermanson et al. (1980), Kreuzer et al. (1998), Amon et al. (2006) and Paul & Beauchaump ((1989) observed decreasing NH_4-N concentration during the storage whereas Amon, (2006), Canh et al. (1998) and Luo et al. (2002) observed a rise of NH_4-N. The studies of Amon et al. (2006) and Luo et al. (2002) indicate that the manure treatment during the storage (e.g. aeration) can influence the change of NH_4-N concentration but whereas Amon et al. (2006) observed a rise of NH_4-N in an aerated manure, Luo et al. (2002) found a decrease of that after aeration.

The influence of diet on matrix parameters was studied mainly for pig production. Several authors (e. g. Canh et al., 1998, Dourmad & Jondreville, 2007, Velthof et al., 2005) showed that the amount of crude protein and the amount and type of polysaccarides influences the dry matter content and other matrix parameters. A reduction of protein in the diet reduces the dry matter content and also pH value, total N and NH_4-N. The total N concentration is additionally influenced by protein fermentability (Le et al., 2008) and the type, amount and fermentability of polysaccarides. Low fermentability of polysaccarides and a high fibre amount increases dry matter content and total N (e.g. Kreuzer et al., 1998, Le et al., 2009).

By way of concluding the present report can be summerized in the following way:

- The storage time is mostly influenced by agricultural and regulatory requirements. Therefore two main scenarios for storage time can be assumed: a “long-term” storage with an average storage time of 3 to 4 months and an application in late winter or early spring and a “short-term” storage during the vegetation period with an average storage time of 1 to 2 months.

- The data availability for matrix parameters of manure is highly variable and depends on their importance for the assessment of manure as fertilizer. For some matrix parameters such as redox potential, TOC and DOC the data availability is limited.

- It can be assumed that the matrix parameters such as dry matter content, total N and NH_4-N are different for cattle and pig manure. Cattle manure has a higher dry matter content and a lower total N and NH_4-N concentration than pig manure. No difference in pH value could be observed. Within the production types of the two species no significant differences in matrix parameters could be observed. The only exception is the production of calves because the dry matter content and total N concentration in calf manure is 50 and 30 % lower, respectively.

- The data indicate differences in matrix parameters for pig manure between northern and southern Europe because manures of southern Europe show lower dry matter contents and lower total N and NH_4-N concentrations.

- Seasonal influences on matrix parameters were pointed out by some publications.

- During storage most studies observed a reduction on dry matter content and total nitrogen caused by microbial degradation. Some controversial observations were made as for pH value and NH_4-N whereas some studies detected an increase of pH and NH_4-N some others showed a decrease of these parameters.

- An influence of diet on matrix parameters was observed especially for manure of fattening pigs. The protein concentration and fermentability and also the amount and type of polysaccarides influences dry matter content, pH value and total N.

- It can therefore be concluded, that the variability in between different animals due to different feeding conditions is comparable to the observed variability of matrix parameters between different animal types. Thus it is not necessary to differenciate between different animal types and one set of matrix parameters for pigs and cattle are sufficient.

- The matrix parameters dry matter content, total nitrogen concentration, ammonium nitrogen, pH, redox potential, and TOC seem appropriate for matrix characterisation. The determination of the oxygen concentration is difficult and detection limits do not allow to draw meaningful conclusions.

However, it must be pointed out that the available data are sometimes sparse. The data on storage conditions and matrix parameters are fragmentary and mainly rely on data from central European countries. The observations that dry matter content, total N and NH_4-N of pig manures in southern Europe is less than in northern Europe are based only on two publications with measurements of less than 100 manures. To confirm these observations additional data of other national agricultural administration or research institutions from the respective region would be necessary.

Nevertheless a scenario for western and central European countries with a moderate climate can be proposed because most data presented in this study were collected in these countries. This scenario includes the following countries: Ireland, United Kingdom, France, Belgium, Luxembourg, Netherlands, Germany, Denmark, Austria, Poland, Czech Republic and Slovakia. In these countries semi-liquid manure represents between 30 and 65 % of total livestock excreta. 5%-40 % of livestock excreta belong to other types of manure (e.g. liquid, solid manure) and about 30 % are dropped on pasture by grassing cattle. These countries represent about 75 % of the total livestock for cattle and about 65 % for pigs within the EU (27). The storage temperature in these countries ranges between about 10 and 20 °C within the year. The lower temperature is observed in winter and the higher temperature in summer. Due to agricultural practice it can be assumed that the average age of the manures from the first application in spring is about 3-4 months whereas the manures of the following applications have an average age of 1-2 months. A range for estimated mean values for some matrix parameters is given in table 14. These data show that the dry matter contents used in the EMA guideline (10 % for cattle, 5 % for pig) are within the range of the measured data.

Table 14: total range of values and average for matrix parameters in manure

parameter	average pig	range pig	average cattle	range cattle
storage time (d)	30 - 120	15 - 240	30 - 120	15 - 240
storage temperature (°C)	[a]	[a]	[a]	[a]
pH	6 - 9	5.5 – 9.14	6.5 – 8.5	6.2 – 8.8
redox potential (mV)	range: -230 - -400 [b]			
dry matter content (%)	4 - 7	0.11 – 12.0	7.5 10 (calves 3-4)	0.4-12.3
total nitrogen (g N/kg) (N)	3 - 5	0.2 – 11.1	3 – 4.5	0.43 – 5.7
ammonium nitrogen (g N/kg) (NH_4-N)	range: 0.15 -8.83 [b]			
total organic carbon (g/kg) (TOC)	range: 8.8 – 42 [b]			

a: storage temperatures vary between central/northern Europe and the southern European countries. For the northern european countries, 10°C is a reasonable average temperature (see 6.1.5 Storage temperature), whereas for the southern part of Europe this conclusion is not valid.
b: for the matrix parameters redox potential, ammonium nitrogen and total organic carbon not as much information is available as for other matrix parameters. For that reason no values are given for the average and only the range of the values found in the literature combined for pig and cattle is displayed.

In the table the complete observed range for some matrix parameters is given. It has to be kept in mind, that as described in detail for dry matter and total nitrogen concentration the parameters are partly interdependent. This is unlikely to affect the parameters pH and redox potential, but has an important effect for the parameters dry matter content, nitrogen content (total and ammonium), and TOC.

At present there is not enough information to determine the influence of matrix parameters on degradation of substances in manures for each matrix parameter. Therefore up to now it is not possible to determine how many different manures are necessary for a basic set for testing. More information on the degradation behaviour could be obtained by using a model substrate in different types of manure as a kind of positive control. At Fraunhofer IME a research project is dealing with this question in more detail, results will be available soon.

8. Summary

Currently there are no standard methods for studies on the degradation behaviour of substances in manure. Such methods are of great importance for the authorisation process for biocides and veterinary medicinal products. Presently, information on the variability of the composition of different types of manure with regard to species and production type is not available. Therefore the aim of the present study is to gather information on the conditions that prevail in manure storage tanks.

The literature study was carried out by using scientific journals, publications of statistical agencies (Statistisches Bundesamt, Eurostat), information from agricultural administrations and research institutes and agricultural associations. Public search engines in the internet were used (eg. Google) to get additional information. Information was collected about manure storage conditions (duration of storage, storage systems, storage temperature,) and matrix parameter such as dry matter content, pH-value, redox potential, total carbon and nitrogen concentration.

The availability of data is highly variable. Information is sparse concerning housing systems and storage systems. From the available information it can be concluded that in the EU at least 50 % of produced manure is a (semi)-liquid manure with a large regional variation. The storage time ranges between 1 and 2 months in summer and 3-4 months in winter and is mostly influenced by agricultural and regulatory requirements. Matrix parameters such as dry matter content, total N and NH_4-N are different for cattle and pig manure but do not differ within a species with exception of calf production. In cattle manure a higher dry matter content and a lower total N and NH_4-N concentration as in pig manure was observed. The data indicate differences in matrix parameters for pig manure between northern and southern Europe because manures of southern Europe show lower dry matter contents and lower total N and NH_4-N concentrations. Seasonal influences on matrix parameters were pointed out by some publications but the main influence of season was observed on storage temperature. During storage a reduction of dry matter content and total nitrogen was observed by the most studies. For pig fattening an influence of diet on matrix parameters such as dry matter content, pH value and total N was observed. It can therefore be concluded, that the variability in between different animals due to different feeding conditions is comparable to the observed variability of matrix parameters between different animal types. Thus it is not necessary to differenciate between different animal types.

The following ranges for matrix parameters were found:

parameter	range pig	range cattle
storage time (d)	15 - 240	15 - 240
pH	5.5 – 9.14	6.2 – 8.8
redox potential (mV)	-230 - -400	
dry matter content (%)	0.11 – 12.0	0.4-12.3
total N (g N/kg)	0.2 – 11.1	0.43 – 5.7
NH_4-N ((g N/kg)	0.15 -8.83	
TOC (g/kg)	8.8 - 42	

9. Zusammenfassung

Aktuell gibt es keine Standardmethoden für Untersuchungen zum Abbau von Stoffen in Gülle. Sie sind jedoch von großer Bedeutung für Zulassungsverfahren für Biozide und Veterinärpharmazeutika. Aktuell liegen keine Informationen über die Variabilität der Zusammensetzung von verschiedenen Güllen in Abhängigkeit von Tierart und Tiernutzung vor. Daher ist es das Ziel dieser Literaturstudie Informationen über Bedingungen während der Güllelagerung zu sammeln.

Für die Literaturstudie wurden wissenschaftliche Veröffentlichungen, Veröffentlichungen von Statistikbehörden (Statistisches Bundesamt, Eurostat) sowie Informationen der Landwirtschaftsbehörden, landwirtschaftlichen Forschungseinrichtungen und Verbänden ausgewertet. Ergänzend wurden öffentliche Suchmaschinen im Internet (z. B. Goggle) für zusätzliche Informationen untersucht. Die Ergebnisse wurden entsprechend der Fragestellungen der Studie aufgeführt. Zum einen wurden Informationen über Güllelagerungsbedingungen (Lagerdauer, Lagerungssysteme, Lagerungstemperatur) gesammelt, zum anderen wurden Informationen zu wichtigen Matrixparametern wie pH-Wert, Redoxpotential, Trockensubstanzgehalt, TOC, Gesamtstickstoff und Ammonium-Stickstoff erfasst.

Die Datenverfügbarkeit ist sehr unterschiedlich. Über Haltungs- und Lagerungssysteme liegen nur wenige Informationen vor. Aus den verfügbaren Daten lässt sich ableiten, dass mindestens 50 % des anfallenden Wirtschaftsdüngers in Form von Gülle anfällt. Allerdings variiert dieser Anteil regional stark und Informationen zum Anteil der einzelnen Lagerungssysteme sind nicht verfügbar. Die Lagerungsdauer variiert zwischen 1-2 Monaten im Sommer und 3-4 Monaten im Winter und wird hauptsächlich durch die Anforderungen der landwirtschaftlichen Praxis und durch gesetzliche Vorgaben beeinflusst. Die Matrixparameter (z. B. Trockensubstanzgehalt, Gesamt-N und NH_4-N) unterscheiden sich zwischen Rind und Schwein, jedoch nicht innerhalb einer Tierart bei unterschiedlichen Produktionsrichtungen mit Ausnahme der Kälbermast. In Rindergüllen wurden höhere Trockensubstanzgehalte und niedrigere Gesamt-N- und NH_4-N-Konzentrationen als in Schweinegüllen gemessen. Für Schweinegüllen weisen die Daten auf Unterschiede zwischen Nord- und Südeuropa hin, da in südeuropäischen Güllen geringere Trockensubstanzgehalte und niedrigere N-Gesamt und NH_4-N-Konzentrationen als in den nordeuropäischen Güllen gemessen wurden. Jahreszeitliche Einflüsse auf Matrixparameter wurden von einigen Autoren untersucht, hauptsächlich beeinflusst die Jahreszeit jedoch nur die Gülletemperatur während der Lagerung. Bei der Schweinemast zeigten sich deutliche Einflüsse der Fütterung auf Matrixparameter wie Trockensubstanzgehalt, pH-Wert und Gesamt-N. Da die beobachteten Variabilitäten zwischen einzelnen Tieren, z. B. aufgrund unterschiedlicher Fütterung so hoch sind, wie die Variabilitäten zwischen einzelnen Typen/Altersstufen, reicht pro Tierart ein Satz an Matrixparametern aus.

Folgende Spannweiten für die Matrixparamter wurden gefunden:

Parameter	Spannweite Schwein	Spannweite Rind
Lagerungsdauer (d)	15 - 240	15 - 240
pH	5.5 – 9.14	6.2 – 8.8
Redoxpotential (mV)	-230 - -400	
Trockensubstanzgehalt (%)	0.11 – 12.0	0.4-12.3
Gesamt-N (g N/kg)	0.2 – 11.1	0.43 – 5.7
NH_4-N ((g N/kg)	0.15 -8.83	
TOC (g/kg)	8.8 - 42	

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Annex 1:

Biological oxygen demand (BOD)

Only a few publications gave information about the BOD (table 10). Hisset et al. (1982) tested one pig manure with a BOD of 8.8 g/L. Pig manures with higher BOD values between 32.5 and 71.8 kg/m^3 were observed by Martinez et al. (2003). Moral et al. (2005) studied pig manures of 36 farms in southeast Spain and found mean values for BOD between 9.0 and 25.0 g/L but with high standard deviations depending on production type.

Table 15: biochemical oxygen demand (BOD)

source	**Information**	**comment**
Hisset et al., 1982	Pig manure 8.8 g/L	Material of 10 pigs
Martinez et al., 2003	Pig manure: 32.5-71.8 kg/m^3	3 manures from two different farms
Moral et al., 2005	Total: 14.5 ± 9.4 g/L Gestating Sows: 11.7 ± 13.4 g/L Farrowing Sows: 9.0 ± 5.0 g/L Weaners: 25.0 ± 23.6 g/L Finishers: 21.6 ± 12.4 g/L	Pig manure of 36 farms in Southeast Spain; average and standard deviation