Relationships between animal nutrition and manure quality

A literature review on C, N, P and S compounds

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ABSTRACT

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Optimization of the utilization of nutrients in animal manures requires a whole chain approach, from the animal feed via the animal and animal manure to the soil and crop. A literature study was carried out to present "a state of the art" on the relationship between animal nutrition and manure quality. It focussed on the quantitative and qualitative aspects of carbon (C), nitrogen (N), phosphorus (P) and sulphur (S) in animal nutrition and in animal manure. The study shows that there is scope for developing simple mathematical relationships that relate total C, N, P and S in the ration to total C, N, P and S in the manure. However, the quantitative understanding of the relationship between the ration composition and the availability and stability of the various C, N, P and S compounds in the manure is still poor. There is however scope for exploring these relationships further by incubation studies, modelling and chemical analyses using manures produced from different rations.

Keywords: animal nutrition, fertilizer, manure, nitrogen, organic matter, phosphorus, plant-availability, sulphur

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Summary and Conclusions

In livestock farming systems, there is an intense cycling of plant nutrients via animal feed, animals, animal manure, soil and further again to crops used for animal feeding. In traditional (low-input) livestock farming systems, animal production is strongly depended on local crop production, while crop production is strongly depended on the amount of animal manure produced and of the amount and availability of nutrients therein. As such, crop production and animal production are intimately related in these systems. In intensively managed (high-input) livestock farming systems, animal production is primarily depended on external inputs, i.e. purchased animal feed and fertilizer. Animal production has been decoupled to some extent from the local crop production in these systems. As a consequence, animal manure has been considered as a waste in these high-input systems, also because of the availability of cheap fertilizers as sources of plant nutrients. However, the environmental problems associated with high-input livestock farming systems and with inapproriate use of animal manure have given a strong impetus to revalue animal manure as a source of essential plant nutrients and as a mean to improve soil quality. Current legislations in the EU as well as in the Netherlands to protect groundwater and surface waters from contamination with N and P from agriculture will lead again to coupling of animal production to local crop production potentials. Animal manure will become again the major source of plant nutrients for crop production used for animal production.

This report intends to present “a state of the art” on the relationship between animal nutrition and manure quality, and vice versa. It focusses on quantitative and qualitative aspects of the major nutrients, i.e. carbon (C), nitrogen (N), phosphorus (P) and sulphur (S) in animal nutrition and in animal manure, on the basis of a brief literature review. The purpose of the study is to indicate “what we know about the relationship between animal nutrition and manure quality” and “what do we need to know for developing highly productive and sustainable livestock farming systems”. Following a brief introduction, the report describes the state of the art on the role, function and possible side-effects of all four nutrients (C, N, P and S), chapter by chapter. Each chapter summarizes the major conclusions and knowledge gaps for each of the nutrients.

The introductionary chapter emphasizes that understandig the composition of the animal feed and the changes in the composition during digestion in the animals are key to understanding the cascade of effects that animal manure may have during storage and following application to land. Hence, a chain approach is required to improve the utilization of the nutrients contained in manure; the whole cycle ‘feed – animal – manure - manure storage – soil – crop - feed’ needs to be taken into consideration. The weakest step in the chain needs to be improved first, to obtain an optimal result. Such a “cradle to grave approach” may yield new information but also new questions. For example, when a soil has a low amount of organic C for sustainable plant production, the question is to find a feed ration that suits both optimal animal performance and organic C sequestration in the soil. Conversely, when the soil contains too much available P (from an environmental point of view), there is no need to add more P , and the target is to find a ration with low P content.

The available information suggests that the *total* C, N, P and S contents of recently excreted dung and urine can be estimated rather accurately, on the basis of information about the diet of the animals, type of animals and level of animal production. Yet, there is a lack of simple mathematical functions and relationship that relate *total* C, N, P and S in the diet to *total* C, N, P and S in the manure. One reason for this lack is the fact that changes in the composition and losses occur during storage of the manure. Further, the manure may be mixed with bedding material, cleaning water from the milking parlour and drainage water. A second reason is that manure in storage basins is often a mixture of dung and urine from different animals and from different ages. Further, there has been little or no reason to develop these relationships, because there was no need to do so. Currently, however, there is an increasing need for more accurate estimates of manure composition, because environmental legislations become more and more strict.

Though there is scope for developing simple mathematical realtionships that relate *total* C, N, P and S in the diet to *total* C, N, P and S in the manure, we are still far from estimating the availability, or stability or mobility of C, N, P and S compounds from manure after application to soil from quantitative information about the composition of the diet and the digestion in the animal. Yet, the available information in the literature suggest, that the degradability of organic matter in the manure reflects the degradability of the organic matter in the ration. Further, there is evidence that certain organic C compounds contribute more to organic C sequestration, while others may interact with the N cycle in the soil and contribute to denitrification losses. We conclude from the literature review, that the quantitative understanding of the relationship between the various C, N, P and S compounds in the ration on the one hand and the various C, N, P and S compounds in manure and soil on the other hand is still poor. There is however scope for exploring these relationships further.

More knowledge is needed about the various organic C compounds in animal feed in relation to animal nutrition and animal performance and subsequently to animal manure performance during storage (e.g. methane production, mineralization) and after application to land (e.g. C sequestration, organic matter stability). Addition of stable organic compounds to the soil is important to maintain (or increase) the soil fertility status of the soil. Animal manures are an important source of stable organic compounds, but the stability of the C compounds largely differ between manures and quantitative information is lacking so far. Chemical analyses and fractionation of the organic matter in manures are needed in order to predict the stability of the organic matter in animal manures. This information can be used as input parameters in models. Moreover, the effects of manure application on denitrification losses can be better predicted when the stability of organic matter is known. Animal manures with high amounts of easily degradably organic C will strongly increase denitrification potential of the soil.

The utilization of the N from animal manure applied to soil is determined by the effectiveness of mineral N and organic N. Again, the total amount of N in manure can be roughly estimated from nutritional parameters and current knowledge. Alternatively, the total N content can be determined experimentally by chemical analysis. Analysis of both mineral N and organic N is needed for an accurate assessment of N utilization from manure. The ratio of mineral N to organically bound N can change greatly in the dung and urine, as a result of a change in digestibility, interactions between feed components that affect their digestibility and a shift in the site of digestion in the gastrointestinal tract. Such changes in manure composition may also be expected to influence microbial processes in anaerobically stored manure and hence to what extent N mineralisation will occur during manure storage. We conclude that more quantitative information is needed on changes in chemical composition of freshly excreted manure during storage of manure and after application of manure to soil. Such information may provide important clues about the fate of N in the various chains of the whole cycle. Further, a good prediction is needed of the amount of mineral N lost via ammonia volatilization, N leaching and denitrification, in order to predict accurately the N effectiveness of the mineral N in manure. The organic matter of animal manures consists of a large number of compounds, strongly varying in degradability and C/N-ratio. A better knowledge of the type, composition and degradability of the organic compounds in animal manures is needed to predict the N mineralisation during the growing period of the crop. The predictions of mineral N losses and mineralization of organic N can be made with tables in fertiliser recommendation or with models; both tables and models should be tested and evaluated.

There is ample information about the total excretion of P via urine and faeces. Feeding tables for pig and poultry nutrition provide information about the amount of P in a feedstuff that is digestible or available for the animal. However, the P availability is influenced by several factors, which are not yet considered in the feeding tables, for example the solubility of phytate. The control of P digestion and the efficacy of phytase addition to the diet has not been turned out succesfully, yet. Further, there is a continuing debate about the minimal P requirement in the diets. Hence, the P availability from forages and concentrate ingredients in ruminant diets also deserves more attention. The level of feed intake and diet composition not only has a significant effect on the amount but also on the form of P excreted with faeces. A prediction of the quantity of the various P forms in dung necessitates to consider the contribution of microbial, endogenous, recycled, and dietary P to total feacal P.

Animal manures contain both inorganic and organic P. The contents and plant-availability strongly varies between manures. Most of the inorganic P is well-soluble and probably rapidly available for plants. More than 80 percent of the organic P can be easily mineralized and will become available for plants within one year of application. Yet, the utilization of the P from manure by the crop is less than 15% in the year of its application. Further, there is a surprising little information about the realtionship between P compound in the manure and effectiveness in terms of plant nutrition after application of the manure to soil, as function of application method (injection, broadcasting, etc.) and application time. We suggest that chemical analyses of the various P fractions of animal manures may strongly increase the knowledge of the P composition and in turn the utilization of P from manures by the crop.

Currently, information about S nutrition and S cycling is rather limiting. There are tables available that indicate the utilization of S in the ration for pig and poultry production. Whether these data also suffice to predict the total S contents and S compounds in faeces and urine remains to be established. Further, it is unclear how dietary alterations affect S excretion and the composition of manure. So far, no amino acid digestibilities are available for ruminants. This complicates the estimation of the amino acid composition of feed protein that remains undigested and, hence the estimation of excretion of S with urine and faeces by ruminants. Simply using the amino acid profile of feed protein to estimate S digestion seems to be not feasible, because endogenous secretions and microbial synthesis in the large intestine also contribute to faecal S. We conclude that there is a clear need for more information about S in the ration of ruminants and in manure. Studies should focus on the types of S containing compounds (both inorganic and organic) in animal manures and the availability of these compounds. The degradability and mineralisation of the organic S compounds and the relation between N, S and P mineralisation of organic compounds in animal manures are also important.

In conclusion, current legislation will contribute to a more direct coupling of crop production and animal production in the EU and especially in the Netherlands. Utilization of the nutrients contained in animal manure is key to the establisment of a more tight coupling and to the development of sustainable livestock production systems. Optimization of the utilization of animal manure requires a whole chain approach, from the animal feed via the animal, animal manure to the soil and crop again. It also requires a multi-nutrient approach, in which both C, N, P, S and other plant nutrients are taken into account. This study has identified important pathways for an improved utilization of manure. It has also identified some gaps in our knowledge, that hinder a further improvement.

1 Introduction

In livestock farming systems, there is an intense cycling of plant nutrients via animal feed, animals, animal manure, soil and further again to crops used for animal feeding. In traditional (low-input) livestock farming systems, animal production is strongly depended on local crop production, while crop production is strongly depended on the amount of animal manure produced and of the amount and availability of nutrients therein. As such, crop production and animal production are intimately related in these systems. In intensively managed (high-input) livestock farming systems, animal production is primarily depended on external inputs, i.e. purchased animal feed and fertilizer. Animal production has been decoupled to some extent from the local crop production in these systems. As a consequence, animal manure has been considered as a waste in these high-input systems, also because of the availability of cheap fertilizers as sources of plant nutrients. This has lead to an inefficient use of the nutrients and organic matter in animal manures and to unwanted losses of greenhouse gases (CO_2, CH_4, and N_2O), N compounds (NH_3, NOx, N_2, NO_3) and P compounds to the environment (Bussink and Oenema, 1998; Ferm et al., 1999; Husted, 1994; Oenema and Roest, 1998; Smith et al., 1998; Sørensen, 1998). The environmental problems associated with high-input livestock farming systems and with inapproriate use of animal manure have given a strong impetus to revalue animal manure as a source of essential plant nutrients and as a mean to improve soil quality. Current legislations in the EU as well as in the Netherlands to protect groundwater and surface waters from contamination with N and P from agriculture will lead again to coupling of animal production to local crop production potentials. Animal manure will become again the major source of plant nutrients for crop production used for animal production.

Animal manures are a mixture of urine, faeces, cleaning water and bedding materials (e.g. straw). The chemical composition of these manures are affected by the ratio of these compounds, feeding of the animal, the housing system, system of manure collection, storage time, and microbiological and chemical processes during the storage. Manures consist both of organic and inorganic compounds. In figure 1 the major pathways for breakdown of animal manures are presented.

Animal manures can be considered as multi nutrient fertilisers, because they contain all essential plant nutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), chlorine (Cl), and manganese (Mn). Moreover, animal manures contain elements that are not essential, but that are beneficial for the growth of some crops, such as sodium (Na,) cobalt (Co), silicium (Si), and selenium (Se). The contents of the nutrients, the plant-availability of the nutrients and the ratio between the nutrients strongly determine the effectiveness of animal manure as a fertiliser.

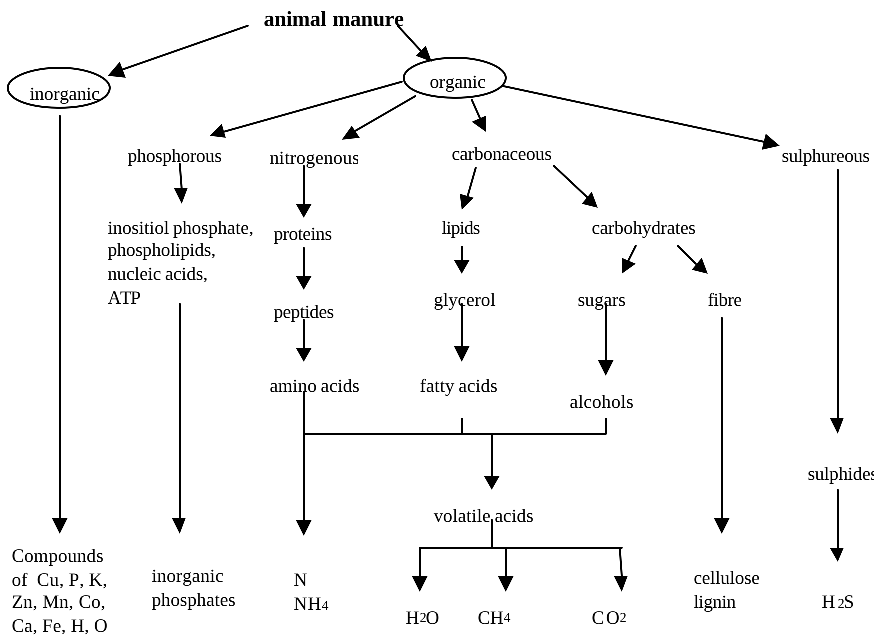

Figure 1. Major pathways for breakdown of animal manures (after Merkel, 1981; slightly modified).

When used as a fertiliser, the short-term (i.e. within several months) release of nutrients is important. Animal manures may also be used as soil amendment to increase (or maintain) soil fertility status of the soil and to increase the C sequestration (C sequestration is one of the proposed measures in greenhouse gas mitigation policies). In this context, the long-term release of nutrients and the stability of the organic matter in the manure are important. The soluble inorganic fractions in urine will be available in soil almost immediately, the gastrointestinal secretions and microbial matter excreted with faeces will be rapidly degradable and available on the short term, whereas the undigested feed fraction will probably be slowly degradable in soil and become available on the long term only.

Manure applied to soil has a cascade of multiple effects, and we know that the nutrition of the animal is a key to understand these effects (e.g. Kreuzer et al., 1998; Misselbrook et al., 1998; Mroz et al., 1995; Paul et al., 1998). However, the quantitative understanding of the relationships between the composition of animal feed and the agronomic and environmental consequences of the manure that is produced from this feed is still very poor. Research was always focussed on the relation between animal feed and animal performance, without assessing the effects of the feed on the manure composition and its value as fertiliser. On the other hand, the effects of manure on soil conditions and crop growth was always studied without taking the effects of animal feed into consideration.

The use of animal manures may be strongly improved by modifying the chemical composition of the animal feed to site-specific conditions and animal types, taking both agricultural, environmental, and socio-economical consequences into consideration. This asks for a multidisciplinary approach of the C and N flows in the whole chain 'feed – animal – manure - manure storage – soil – plant' (Figure 2). In this report a first step in this approach is given, namely the state of the art of the knowledge of the relation between the chemical composition of animal feed and the composition of the animal manure produced from this feed, and the type of chemical compounds in manures and the agricultural value of manures as fertiliser and/or soil amendment. The purpose of the study is to indicate "what we know about the relationship between animal nutrition and manure quality" and "what do we need to know for developing highly productive and sustainable livestock farming systems". The plant-availability of organically bound nutrients in manure is much more difficult to predict than that of inorganic nutrients. Therefore, this report focusses on the major essential plant nutrients that are (partly) organically bound in manure: N, P, and S. Furthermore, attention is paid to the stability of organic matter, as it affects the value of the manure as soil amendment and the C sequestration in soils. In each chapter the state of the art on the role, function and possible side-effects of all four nutrients (C, N, P and S) are described and the major conclusions and knowledge gaps are summarized for each of the nutrients.

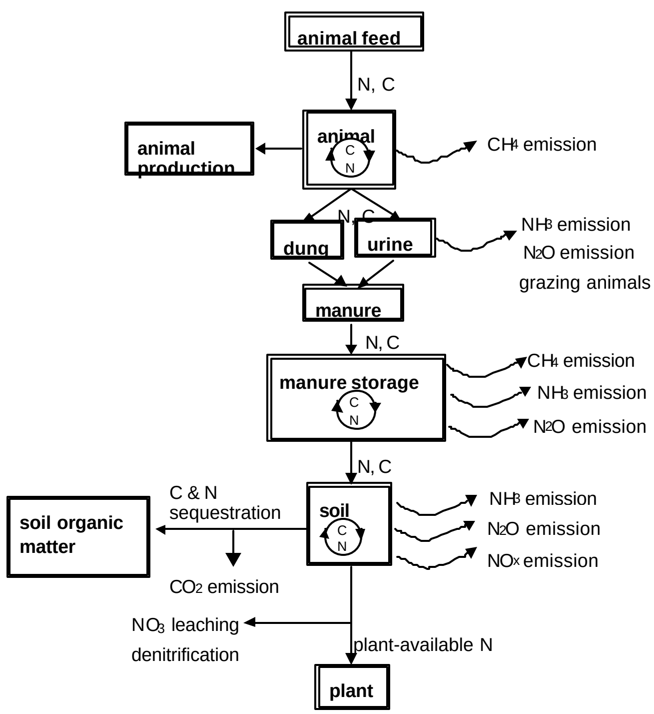

Figure 2. Schematic presentation of the C and N flows in the chain animal feed – animal - dung/urine – stored manure – soil – plant, showing that the composition of the animal feed affects the agricultural (C and N sequestration, plant-available N) and environmental (NH_3, N_2O, NOx and CH_4 emission and NO_3 leaching) performance of manure

Table 1 Composition of animal manures in g kg^{-1} product (Mooij, 1996). Average (av.) and standard deviation (sd.)

Type of manure	Dry matter		Organic matter	Total N		Mineral N		Organic N		P_2O_5	
	av.	sd.	av.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
Slurry											
cattle	90	19	66	4.9	0.8	2.6	0.5	2.3	0.6	1.8	0.4
fattening pigs	90	32	60	7.2	1.8	4.2	1.1	3.0	1.3	4.2	1.5
sows	55	28	35	4.2	1.4	2.5	0.8	1.7	1.0	3.0	1.7
calves	20	-[2]	15	3.0	-	2.4	-	0.6	0.6	1.5	-
laying hens	145	41	93	10.2	1.9	5.8	1.4	4.4	1.8	7.8	2.6
Liquid manure											
cattle	25	-	10	4.0	-	3.8	-	0.2	-	0.2	-
fattening pigs	20	-	5	6.5	-	6.1	-	0.4	-	0.9	-
sows	10	-	10	2.0	-	1.9	-	0.1	-	0.9	-
Solid manure											
cattle	235	80	153	6.9	3.2	1.6	0.8	5.3	3.1	3.8	1.4
pigs (straw)	230	-	160	7.5	-	1.5	-	6.0	-	9.0	-
laying hens[1]	515	81	374	24.1	3.5	2.4	0.7	21.7	-	18.8	2.9
poultry litter manure	640	-	423	19.1	-	8.6	-	10.5	-	24.2	-
broiler breeders[3]	610	86	-	19.0	4.0	-	-	-	-	28.5	3.0
broilers	605	55	508	30.5	3.6	5.5	1.1	25.0	-	17.0	2.4

[1]conveyor battery; dry manure removal
[2]not determined
[3]partly slatted floor

2 Organic matter

2.1 Introduction

Organic matter plays an important role in physical, chemical and biological fertility of the soil. A certain level of organic matter should be maintained in order to maintain optimal soil fertility and to increase C sequestration in soils. Organic matter is broken down in the soil by micro-organisms, by which the organic matter content of the soil will decrease in case no fresh organic materials are added. The amount of organic matter that returns to the soil as crop residues is often not sufficient to maintain the organic matter content of the soil, especially in arable land. Therefore, an additional input of organic matter via green manures, organic fertilisers and/or animal manures is needed to maintain organic matter content in the soil. Animal manures consist of a mixture of organic compounds (figure 1), both easily degradable and stable. The stable organic compounds are important in view of maintaining organic matter content and soil fertility.

Composition of the organic matter in faeces depends strongly on animal species, the composition of the diet and diet digestibility. Ruminants are able to digest low quality feeds with a high fibre content compared to monogastrics, and as a consequence ruminant faeces also contain relatively more fibrous material. Also the type and site of digestion is important for manure composition (Figure 3). In poultry, digestion will mainly be enzymatic and fermentative processes have a minor contribution to the digestion of the feed. Pigs take an intermediate position by the fermentative capacity of their large intestine. Thus, differences in manure composition for animal species arise from differences in nutrition as well as in functioning of the gastrointestinal tract.

Animal manures with high contents of easily degradable organic compounds and low contents of stable organic compounds may be efficient fertilisers, from which the short-term release of plant nutrients may be well predicted. However, easily degradable organic compounds can be used by denitrifying bacteria as energy source, by which soil NO_3 may be lost as N_2 or N_2O (Beauchamp et al., 1989). Thus, addition of easily degradable organic compounds to soils via manures may increase N losses via denitrification. Animal manures with high contents of stable organic compounds are suitable as soil amendment to maintain or increase soil organic matter content, but are less suitable as short-term fertiliser. Manipulation of the feeding and system and time of manure storage are options to change the stability of the organic matter in animal manures and may be used to create an optimal fertiliser or soil amendment.

2.2 Present knowledge

2.2.1 Effects of animal nutrition

The information that is gathered in routine digestion trials with farm animals is normally restricted to measures of the amount of organic matter, starch, neutral detergent fibre, acid detergent fibre, protein and fat recovered in faeces, and the amount of N recovered in urine. The precise origin of these fractions is not always clear, however. The fraction of neutral detergent fibre, for example, is not necessarily completely of feed origin, and the protein fraction is of feed, microbial as well as endogenous (animal) origin (Figure 3). Further, the endogenous and microbial fractions do not only deliver faecal protein but also contribute to fat, polysaccharides, or other compounds. Despite these complications, the faecal recovery of carbohydrate fractions (cell walls, starch) in digestibility trials is frequently assumed to equal the fraction ingested with feed that was not digested.

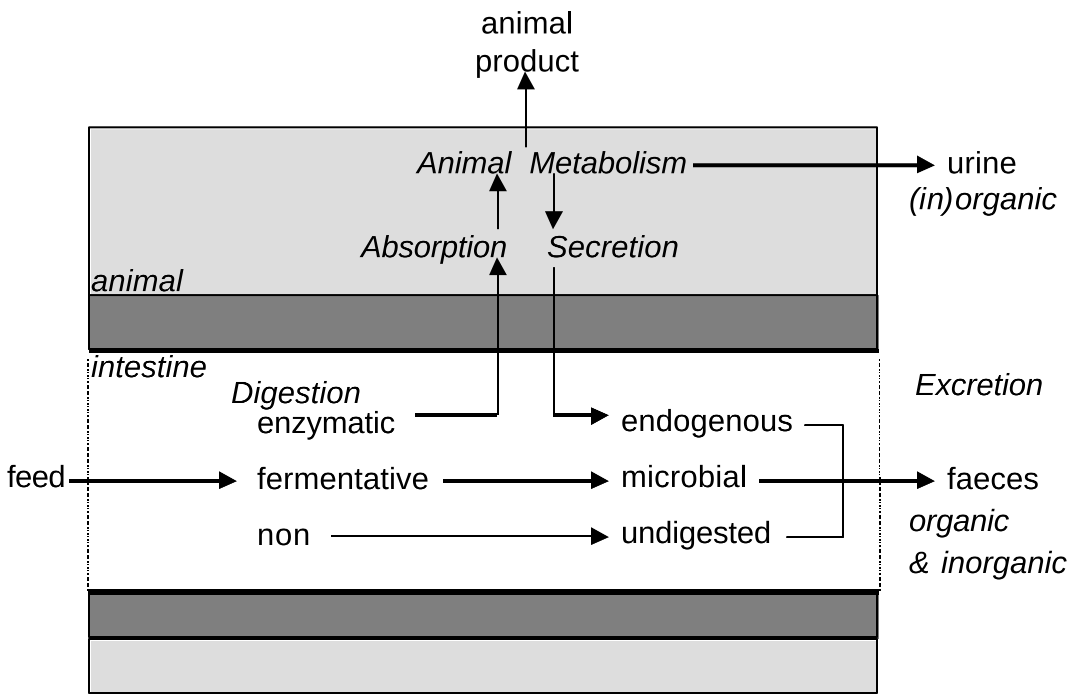

Figure 3. Schematic representation and explanation of the terminology used to describe the effect of type of digestion, of nutrient absorption, of endogenous secretions, and of efficiency of nutrient utilisation on excretion with faeces and urine by farm animals.

The C, N, P and S composition of microbial material can be estimated from the more frequently studied rumen micro-organisms. However, an accurate prediction of the amount of microbial material that is synthesised in the large intestine is more difficult and it has seldom been investigated. The reason is that microbial fermentation in the large intestine is often presumed to be relatively unimportant for understanding energy metabolism of the animal. Nevertheless, to generate energy for biosynthesis micro-organism convert a considerable amount of substrate to volatile fatty acids, comparable to the fermentation processes in the rumen. A considerable amount of volatile fatty acids is excreted with faeces (Bakker, 1996) and constitutes rapidly degradable C compounds when manure is applied to soil. The most of the volatile fatty acids will be absorbed by the animal however. Besides the microbial fraction, also the quantity and the composition of the endogenous fractions are not clear. Further, the composition of undigested feed, for example feed protein, can not be assumed to equal that of feed (Van Straalen, 1995). An accurate prediction of the degradation of organic matter from manure in soils requires an improved insight in the chemical structure of compounds and their C, N, P and S content, and of the relative contribution of microbial, endogenous and undigested feed material to faecal organic matter (Figure 3).

2.2.2 Agricultural value

Organic matter from cattle manure is more stable after application to soil than that from poultry and pig manure and that of poultry manure is more stable than that of pig manure, in general (Castellanos & Pratt, 1981; Catalan & Janssen, 1990; Dendooven et al.,1998a; Kirchmann, 1991; Kirchmann & Lundvall, 1993; Sørensen, 1998). Figure 4 shows the typical time course of degradation of manure-C in the soil after application of pig, cattle and poultry slurry. During the first 6-12 months after application, the amount of manure-C in the soil strongly decreases, due to degradation of the easily degradable organic compounds. Thereafter, the degradation of C is slow and the stable organic compounds remain in the soil. These stable organic compounds play an important role in soil fertility and C sequestration. The figure shows that poultry manure contains more C (in kg C per ton slurry) than the pig and cattle slurry, but most of this C is easily degradable (e.g. uric acid). Cattle manure contains relatively stable organic compounds. Pig slurry contains less C than cattle and poultry slurry and the C in pig slurry is relatively easily degradable. Therefore, pig slurry is less effective as a soil amendment than cattle and poultry slurry. The differences in stability of the C compounds between the manures is due to differences in digestion processes between the animals and to differences in feed.

Models that can be used to estimate the N mineralisation of organic N in animal manures (e.g. Chambers et al., 1999; Janssen, 1996; Velthof et al., 1999; Whitmore & Schröder, 1996) mostly can also be used to predict the amount of stable organic C that is added to the soil (e.g. Figure 4). Insight into the fractions of easily degradable and stable C compounds in animal manures may improve the prediction of the model calculations. For example, in anaerobically stored animal slurries, considerable amounts of volatile fatty acids may accumulate; up to more than 30 percent of the total C (Cooper & Cornforth, 1978; Guenzi & Beard, 1981; Kirchmann & Lundvall, 1993; Kirchmann & Witter, 1989; Patni & Jui, 1985; Paul & Beauchamp, 1989; Sørensen, 1998; Spoelstra, 1979; Williams, 1983). Volatile fatty acids do not contain N and rapidly volatilise or are broken down by micro-organisms after application to the soil. Therefore, volatile acids play only a minor role when animal manures are used as N fertiliser or soil amendment.

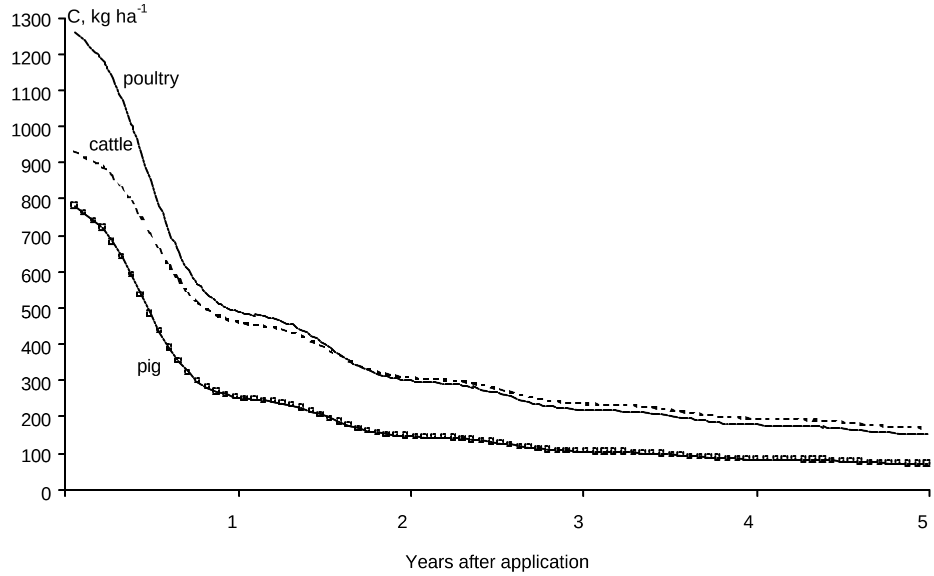

Figure 4. Degradation of manure-C in the soil after application of 30 ton ha^{-1} of cattle, pig and poultry slurry. Calculations with the model MINIP (Janssen, 1996), assuming average weather conditions and manure composition of the Netherlands (Table 1).

Storage conditions play an important role in the stability of the organic matter in animal manure (Sørensen, 1998; Sommer and Sherlock, 1996). Kirchmann (1991) showed that the stability of organic matter in cattle and poultry manure decreased when the manure was composted and increased when the manure was digested. During the maturity process of manure, the chemical composition and the stability of the organic matter may strongly increase. Levi-Minzi et al. (1986) showed that during the maturity process of farmyard manure, contents of total N, water-soluble contents and lignin increased and that of total C, lipid, hemicellulose + cellulose and the C/N-ratio decreased. Also Tarre et al. (1987) showed a relative high content of lignin in comparison to cellulose and hemicellulose in mature manures. The ratio between the contents of lignin : (cellulose + hemicellulose) is closely related to the degradability of the organic manure: when the ratio of lignin: (cellulose + hemicellulose) increases, the stability of the organic matter in the manure increases (Jedidi et al., 1995; Volker et al., 1989).

Denitrification is the microbiological process in which NO_3 is transformed under anaerobic conditions into N_2 and the greenhouse gas N_2O. Denitrification is both from an agricultural point of view (N loss) and environmental point of view (N_2O emission) an important process. The availability of organic C in the soil is one of the most important factors regulating denitrification (Knowles, 1982). Many studies showed that addition of easily degradable organic matter (e.g. glucose) strongly enhances denitrification activity en N_2 and N_2O losses. Animal manures contain a large number of organic compounds from which a part may be used as readily available substrate by denitrifiers (Comfort et al., 1990; Dendooven et al., 1998a&b; Ellis et al., 1998; Paul and Zebarth, 1997). Paul & Beauchamp (1989) showed that volatile fatty acids may be used by denitrifiers and enhance N losses. This is only a very short-term effect because volatile fatty acids are only present during a few days after soil application. Dendooven et al. (1998a) also mentioned that fatty acids had an important effect on denitrification. Also other C compounds in animal manures may increase denitrification,

2.3 Conclusions and gaps in knowledge

The available information suggests that the *total* C, N, P and S contents of recently excreted dung and urine can be estimated rather accurately, on the basis of information about the diet of the animals, type of animals and level of animal production. Yet, there is a lack of simple mathematical functions and relationship that relate *total* C, N, P and S in the diet to *total* C, N, P and S in the manure. One reason for this lack is the fact that changes in the composition and losses occur during storage of the manure. Further, the manure may be mixed with bedding material, cleaning water from the milking parlour and drainage water. A second reason is that manure in storage basins is often a mixture of dung and urine from different animals and from different ages. Further, there has been little or no reason to develop these relationships, because there was no need to do so.

More knowledge is needed about the various organic C compounds in animal feed in relation to animal nutrition and animal performance and subsequently to animal manure performance during storage (e.g. methane production, mineralization) and after application to land (e.g. C sequestration, organic matter stability). Addition of stable organic compounds to the soil is important to maintain (or increase) the soil fertility status of the soil. Animal manures are an important source of stable organic compounds, but the stability of the C compounds largely differ between manures and quantitative information is lacking so far. Chemical analyses and fractionation of the organic matter in manures are needed in order to predict the stability of the organic matter in animal manures. This information can be used as input parameters in models. Moreover, the effects of manure application on denitrification losses can be better predicted when the stability of organic matter is known. Animal manures with high amounts of easily degradably organic C will strongly increase denitrification potential of the soil.

3 Nitrogen

3.1 Introduction

Nitrogen is the most important plant nutrient and strongly controls the yield and quality of the crop. A good N supply of the crop in the period in which the crop requires most N (generally in March-August) is important to obtain optimal yields and quality. A low N use efficiency of the applied animal manure (and other N fertilisers) is generally accompanied by N losses to the environment, including ammonia volatilization, nitrate leaching, denitrification and nitrous oxide emission. When animal manures are used as N fertiliser, a good knowledge of the amounts of directly plant-available N (=inorganic or mineral N) and the amounts and time course of mineralisation of organic N are needed to obtain a high N use efficiency and low N losses towards the environment.

In evaluating a diet for its potential of animal production, the first two aspects to consider are the amount of energy and the amount of protein that becomes available for animal metabolism. The value of dietary protein is not only determined by its amount but also by its profile of amino acids. The more imbalanced the profile of amino acids for utilisation by the animal, the more absorbed amino acids will not be retained but will be oxidised. Extensive oxidation of amino acids results in production of large amounts of ammonia. Because of the toxic effect of high concentrations of ammonia on animal tissue, ammonia is efficiently transported by blood to the liver where it is converted to urea, and subsequently removed from blood by the kidneys. Apart from a small fraction entering the gastrointestinal tract, most of the urea will be excreted with urine. Also excessive amounts of digestible protein will result in large amounts of urea excreted with urine.

The composition of N compounds in freshly excreted manure can be estimated from nutritional parameters and animal performance. Consideration of protein digestibility, microbial fermentation, endogenous secretions, efficiency of protein utilisation by the animal, and protein requirements for maintenance is needed to estimate the amount and type of N compounds excreted with faeces and urine.

3.2 Present knowledge

3.2.1 Effects of animal nutrition

Current feed evaluation systems may be used to estimate the digestion of feed protein and hence already give an indication of the excretion of feed protein with faeces and urine. Nevertheless, part of feed N may not be related to feed protein but to cell wall structures that are difficult to degrade. Besides feed N, also N of endogenous (animal) origin and microbial N will be excreted with faeces (Figure 5). Endogenous N will be constituted mainly of proteinous compounds, whereas microbial matter will be constituted of nucleic acids as well. Although relationships between diet characteristics and endogenous secretions have been claimed, a precise quantification is not available, yet. Inclusion of more structural carbohydrates in the diet of monogastrics is likely to increase the endogenous secretion in faeces and will stimulate microbial activity in their large intestine (Langhout, 1998; Bakker, 1996). Particularly with pig nutrition, the fermentative potential of the large intestine can be significant when ingredients rich in structural carbohydrates are added to the diet. With respect to the estimation of the composition of faeces, these fermentative processes should not be neglected. A large fraction of fermentable carbohydrates entering the large intestine can even result in an uptake of urea from blood as an N source for microbial synthesis (Figure 6). This uptake of urea then causes a shift from excretion of urea with urine to excretion of microbial protein with faeces (Bakker, 1996; Figure 5).

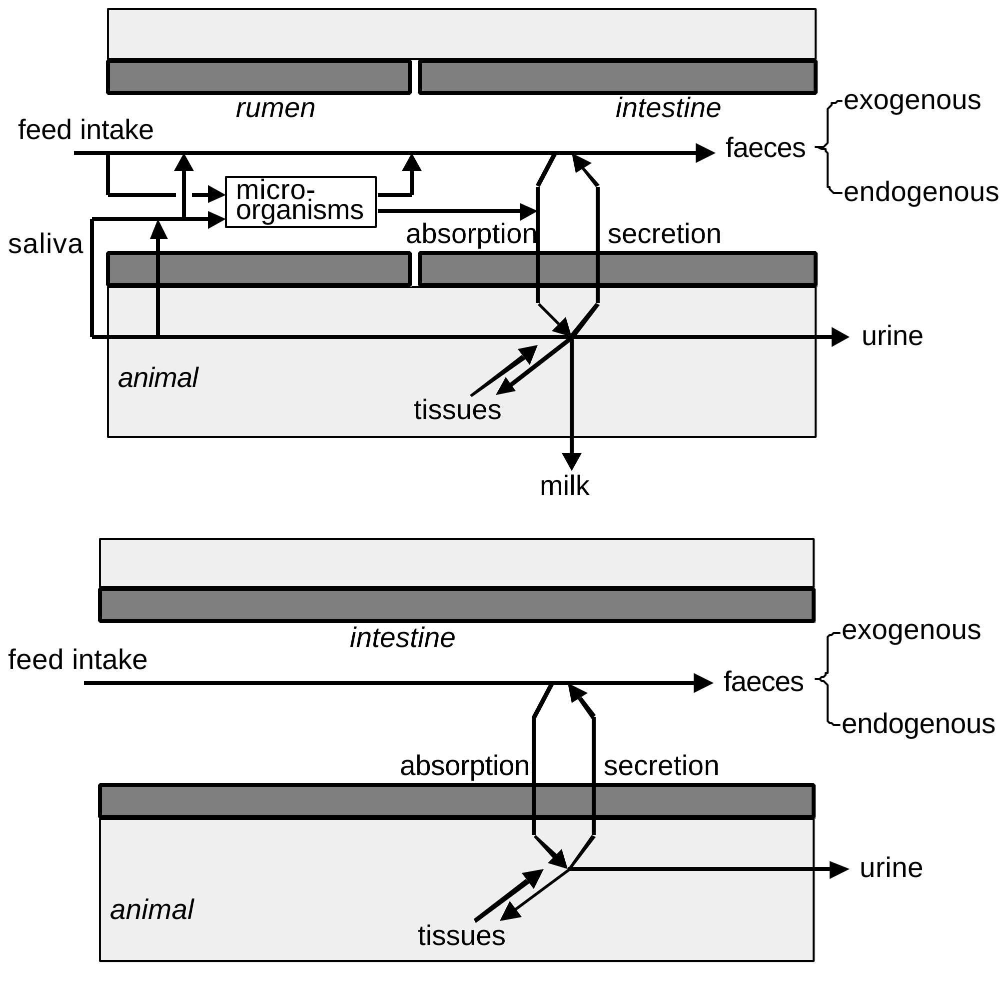

Figure 5. Schematic representation of N flows in lactating ruminants (upper figure) and growing monogastric animals (lower figure).

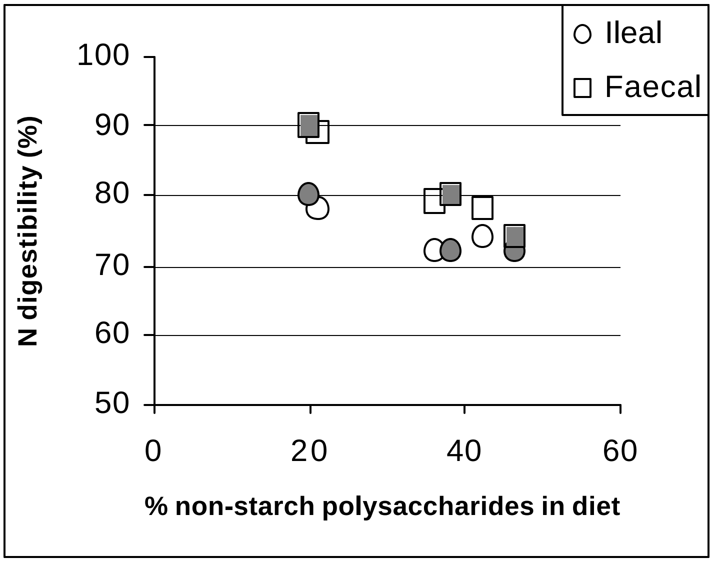

Figure 6. Effect of dietary content of non-starch polysaccharides (diets near 20%, just below 40% and more than 40% non-starch polysaccharide contained a major component of maize gluten feed, soya-hulls or cellulose, respectively) and of the addition of fat (open symbols low fat, closed symbols fat added) on the apparent digestion of N at the end of the small intestine (ileum) and of the total gastrointestinal tract (faecal) in growing pigs (Bakker, 1996).

Ruminants take a special place in that micro-organisms in the rumen degrade large amounts of protein and most of the protein entering the small intestine is of microbial origin (Figure 5). However, with high protein levels in the diet, rumen micro-organisms ferment a large fraction of the protein to generate energy which results in formation of large amounts of ammonia. Although ruminants are capable of recycling urea to the rumen, diets with large amounts of rapidly degradable proteins give rise to large amounts of urea excreted with urine (Valk et al., 1990; Kappers & Valk, 1996). As a consequence, efficiency of N utilisation by lactating high-yielding dairy cows is low, unless the protein rich diet is supplemented with energy rich by-products with a low protein content (Valk et al., 1990).

Urea excretion with urine will be determined by the efficiency of utilisation of absorbed protein and the protein requirements for maintenance. Several N compounds are present in urine of which urea is the most abundant. Small fractions of organic N compounds are metabolites of purine metabolism (allantoin) and turn-over of body protein (creatinine). Most varying in response to dietary measures will be the urea content of urine. For ruminants, the allantoin fraction has frequently been suggested as a marker for microbial synthesis in the rumen (Stangassinger et al., 1995). Hence, with varying microbial efficiencies in the rumen in response to dietary changes, also allantoin excretion with urine is expected to vary. Creatinine excretion with urine will depend on protein metabolism of the animal and may be considered a less variable fraction.

Urea is the most abundant N compound in urine and is quickly hydrolysed and converted to ammonia and carbon dioxide following excretion. Ammonia will be formed almost immediately and its volatilisation may represent a considerable loss of N before manure is even stored. Hence, estimates of manure composition must be corrected for these losses. Dietary measures (e.g. salt supplements) for monogastrics may significantly affect urine or manure pH (Cahn, 1998) and hence ammonia volatilisation. Because of the large amount of cations in roughages, ruminant urine will normally be alkaline (Bannink & van Vuuren, 1998).

3.2.2 Agricultural value

Animal manures consist of mineral and organic N. The total N effectiveness of the N in animal manures is controlled by both the N effectiveness of the mineral N and the N effectiveness of the organic N. The total amounts of organic N and mineral N and the ratio between organic N and mineral N strongly vary between animal manures (table 1). The mineral N percentage (% of total N) of solid manures is about 20 percent, that of animal slurries 60 percent and that of liquid manures more than 90 percent.

The mineral N in animal manures is mainly present as NH_4 and is derived from the hydrolysis of urea and, in poultry manures, uric acid. The oxygen concentrations in stored animal manures are mostly very low, by which no or only trace amounts of NH_4 are nitrified into NO_3. Therefore, NH_4 is by far the major mineral N compound in animal manures. Bicarbonate is produced during the hydrolysis of urea, by which the pH of the manure is generally high and the risk on ammonia volatilization is also high. The amount of ammonia that escapes after application of animal manure to the soil strongly determines the N effectiveness of the mineral N in the manure. Factors affecting ammonia volatilization are, besides the chemical composition of the manure, the application technique, soil moisture content, weather conditions (rainfall and temperature), crop type and soil type (Bussink and Oenema, 1998). In case the manure is applied in autumn or winter, the amount of N lost via leaching and denitrification during winter also determines the N effectiveness of the mineral N.

There are a large number of organic N and C compounds in manure (Figure 1). The N effectiveness of the organic N is controlled by the amount and rate of N mineralisation. When the organic N is mineralized just before or during the growing period of the crop, the N use effectiveness of the organic N in animal manure may be high. When most of the N is mineralized far before or after the growing period, considerable N losses towards the environment may occur. Thus, a synchronization of the N mineralisation of animal manure and the N uptake by the crop may strongly increase the N use effectiveness of the organic N and decrease N losses towards the environment. A good timing of application and a good prediction of the N mineralisation is therefore required.

Organic matter in animal manures consists of easily degradable compounds with high N contents such as uric acid, proteins, and peptides, easily degradable compounds with low N content such as sugars and (volatile) fatty acids and poorly degradably compounds such as fibers and lignin (Amberger et al, 1982b; Nicholson, 1996; Smith, 1973; Van Faassen & Van Dijk, 1987). Both the degradability of the organic matter and the C/N ratio of the organic matter are important factors controlling the nett N mineralisation (or immobilization) of organic N (Janssen, 1996). The N mineralisation starts already in the (mostly anaerobic) manure storage and proceeds and is enhanced after soil application. The temperature, oxygen content and soil moisture content are important factors controlling the mineralisation in soil (Jenkinson, 1988).

Estimates of the mineralisation of organic N in manures in N fertiliser recommendations are in the Netherlands mostly based on tables in which a rough estimate of the N mineralisation is presented on basis of the month of application and the type of manure (Anon.1999a&b). In tabel 2 the relative effectiveness of manure N is presented for different types of manure, different application techniques, land use systems, and application times. The tables in the fertiliser recommendations are derived for only a few manures, are mostly derived in seventies and do not take into account specific N contents of manures. It is questionable whether these tables are a good basis for an efficient use of manure N.

Models that use the actual chemical composition of the manure, site-specific information (soil type, crop, soil cultivation) and actual weather data can be used to derived a more accurate estimate of the N mineralisation of organic N of animal manures than tables (Chambers et al., 1999; Janssen, 1996; Velthof et al., 1999; Whitmore & Schröder, 1996). The model prediction of the amount of mineralized N and the time course of the mineralisation may be strongly improved when there is a better knowledge of the organic compounds in animal manures and the role that these compounds play in the N mineralisation. For example, poultry manures contain large amounts of uric acid (Groot Koerkamp, 1998). Uric acid is organic N, but is transformed into NH_4 witin a few days after soil application (Kirchmann & Lundvall, 1993; Paul & Beauchamp, 1989). Therefore, the estimation of the N effectiveness of poultry manures is strongly improved when uric acid is treated as mineral N in stead of organic N (Velthof et al., 1999). Other studies show a good relationship between N mineralisation and (the ratio between) organic compounds in the manure, such as cellulose, hemicellulose, lignin, free amino acids (Jedidi et al., 1995; Volker et al., 1989).

3.3 Conclusions and gaps in the knowledge

The N effectiveness of animal manure is determined by both the N effectiveness of mineral N and organic N. Knowledge of the amounts of N in manure can be roughly estimated from nutritional parameters and current knowledge (CVB, 1997) or accurately determined by chemical analysis. A chemical analysis of the manure in which both mineral and organic N is measured may strongly improve the efficient use of manure N. Dietary changes can cause a considerable change in manure composition as a result of a changed digestibility, interactions between feed components that affect their digestibility and a shift in the site of digestion in the gastrointestinal tract. Such changes in manure composition may also be expected to influence microbial processes in anaerobically stored manure and hence to what extent N mineralisation will occur during manure storage. Both on the detailed descriptions of the chemical composition of freshly excreted manure, and on the fate of compounds during storage of manure and application of manure to soil, more knowledge is required. A good estimation of the amount of mineral N that is lost via ammonia volatilization, N leaching and denitrification is required to predict the N effectiveness of the mineral N in manure. The organic matter of animal manures consists of a large number of compounds, strongly varying in degradability and C/N-ratio. A better knowledge of the type, composition and degradability of the organic compounds in animal manures is needed to predict the N mineralisation during the growing period of the crop. This prediction can be made with the tables in the fertiliser recommendation or with models. These models should be tested and evaluated.

Table 2 Relative N effectiveness[1] of the mineral N, organic N, and total N of different manures in the Netherlands (summary of tables in fertiliser recommendations in the Netherlands, Anon.,1999a &b)

Land use, type of manure, application technique	Time frame	Relative N effectiveness, %			
		mineral spring[2]	organic spring	total spring[3]	total autumn
Arable land					
Cattle slurry; deep injection	year of application	95	30	65	20
Cattle slurry; surface-applied +cultivator	year of application	75	30	50	20
Pig slurry; deep injection	year of application	95	45	70	20
Pig slurry; surface-applied + cultivator	year of application	75	45	60	20
Poultry slurry; deep injection	year of application	95	45	80	20
Poultry slurry; surface-applied + cultivator	year of application	75	45	65	20
Grassland					
Cattle slurry; deep injection	1st grass cut	44	4	25	-
Cattle slurry; deep injection	year of application	92	28	62	-
Cattle slurry; shallow injection	1st grass cut	56	4	32	-
Cattle slurry; shallow injection	year of application	76	24	52	-
Cattle slurry; sliding shoes	1st grass cut	60	6	35	-
Cattle slurry; sliding shoes	year of application	66	24	46	-

[1] relative N effectiveness = (N uptake crop with manure)/(N uptake crop with mineral N fertiliser) * 100

[2] for grassland: 1-2 months before 1st cut

[3] based on the average composition of manures. When the real composition is known, the total relative effectiveness can be calculated from the mineral N and organic N contents of the manure.

4 Phosphorus

4.1 Introduction

Phosphorus is one the major essential plant nutrients and plays an important role in photosynthesis and energy transfer in plants. In agricultural systems in which animal manures are used, these manures are the major source of P for the crop. In general, only a little amount of mineral P fertiliser are used in these systems. Therefore, a good knowledge of the P contents of animal manures and the plant-availability of the P compounds in the manure is needed.

After application the soil, inorganic P is adsorbed by soil particles (hydro)xides, clay), by which only a small part of the applied P is available for the plant. Soil properties such as texture, chemical composition and the pH largely control the plant-availability of the applied P. Losses of P via leaching are generally low, except when P has strongly accumulated in the soil and the amount of P in the soil exceeds the capacity of the soil to adsorb P.

Organic P may be mineralized into inorganic P after soil application and may become available for plant uptake. Part of the organic P is stable and is not mineralized after soil application (Anderson, 1980).

4.2 Present knowledge

4.2.1 Effects of animal nutrition

The P in the diet is present in either the inorganic (phosphate) or the organic form (phosphosugars like phytate, phosphorylated amino acids and phosphonucleotides). The P is absorbed from the gastrointestinal tract mainly as inorganic phosphate, and organic P becomes available for absorption only after its hydrolysis at the brush border of the gastrointestinal wall which liberates inorganic phosphate. Some organic P may be absorbed however with certain phospholipids (Jongbloed, 1987).

The part of dietary organic P that is available for absorption depends on the origin of the feedstuff and also on several other feed factors. In concentrate feeds of plant seed origin a high percentage of P, up to 80% of total P, is in the form of phytate (inositol hexa phosphoric acid) because phytate serves as storage of P in plant seeds. Phytate contributes only about 25% to total P content in forages. In ruminants, most of the phytate consumed will be hydrolysed by rumen micro-organisms and only trace amounts appear in faeces (Morse et al., 1992). Despite a high phytase activity in the rumen, there are still considerable differences in P availability from forages and concentrates (Valk et al., 1999). Ruminants are capable to recycle large amounts absorbed P to the lumen of the gastrointestinal tract with the production of saliva (rumination; Figure 7).

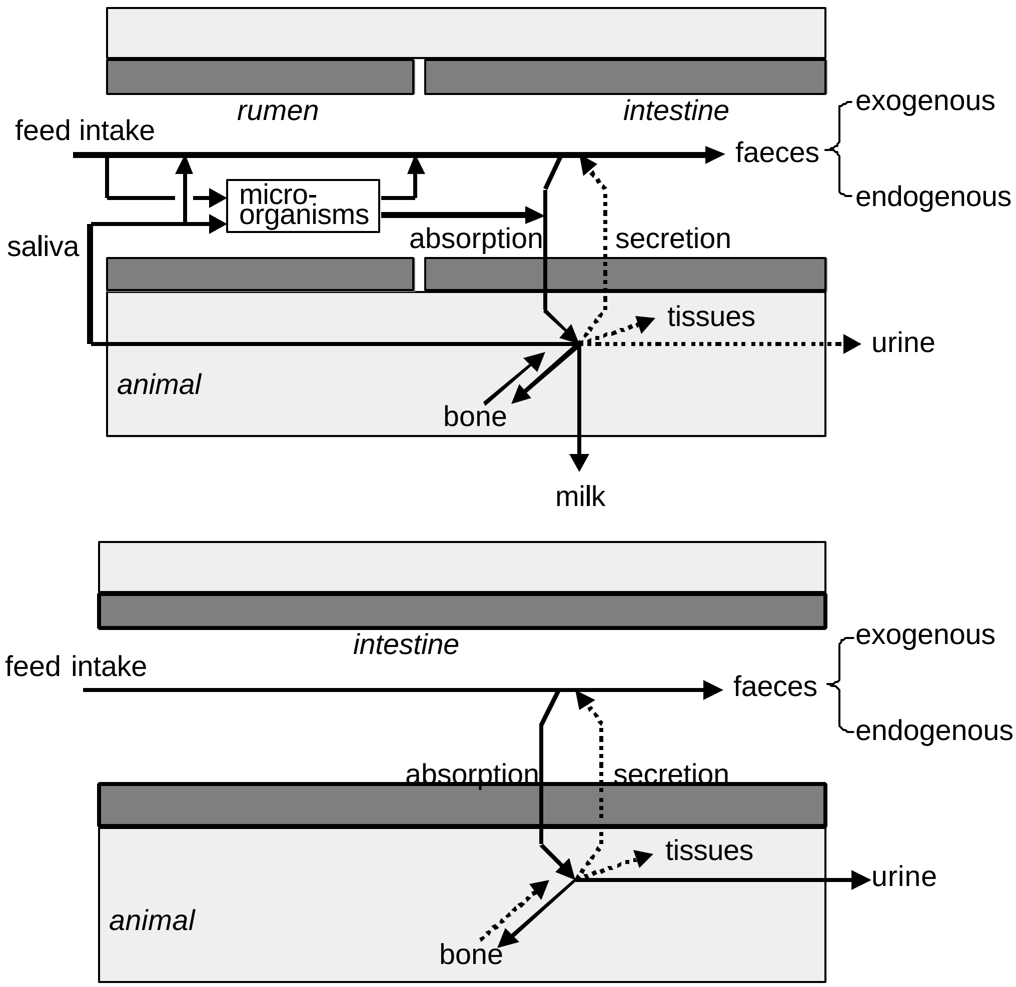

Figure 7. Schematic representation of P flows in lactating ruminants (upper figure) and growing monogastrc animals (lower figure). Dashed lines indicate flows that are quantitatively less important compared to those indicated by solid lines

As a result of this recycling, an excess of absorbed P is not excreted with urine because of a high renal threshold for P excretion, but is recycled to the gastrointestinal tract and eventually excreted with faeces (McDowell, 1992; Valk et al., 1999; Table 3). About 80% of the endogenous P recycled to the gastrointestinal tract is of saliva origin. The P content in faeces largely depends on the level of P intake in comparison to the requirements. Feacal P content depends strongly on P intake and an excessive intake of P leads to a strong increase in faecal P, whereas a P deficiency becomes apparent in a very low P content of faeces.

Table 3. Effect of three different levels of P allowance for dairy cows (100%, 80% or 67% of recommendations according to CVB, 1997) in different stages of lactation on the excretion of P in faeces, the faecal digestibility (given between brackets) and the excretion of P in milk (Valk et al., 1999; Valk & Sebek, 1999).

		50-125 d	125-200 d	dry
DM intake		21	19	11
Milk yield, kg d^{-1}		26	21	-
P intake, g P d^{-1}				
	P100	80	71	21
	P80	60	54	17
	P67	52	50	16
P milk, g P d^{-1}				
	P100	34	25	-
	P80	30	24	-
	P67	32	25	-
P faeces, g P d^{-1}				
	P100	44 (45%)	41 (42%)	18 (14%)
	P80	29 (52%)	29 (46%)	15 (12%)
	P67	27 (48%)	23 (54%)	14 (13%)

Although some fermentation takes place in the large intestine of pigs, phytase activity is not as extensive as in the rumen and also retention time of digesta is short (Figure 7). About 20% of P in pig faeces is in the form of phytate (Jongbloed, 1987). Stimulation of fermentation by nutritional measures (inclusion of more non-starch polysaccharides in the diet) hence may result in a significant shift from phytate P to microbial and inorganic P. The digestion of P by poultry resembles that of pigs, but there is less fermentation in the gastrointestinal tract. Therefore, poultry manure contains relatively high amounts of phytate. To increase P availability in pig and poultry nutrition, the diet may be supplemented with phytases to stimulate the hydrolysis of phytate and make P better available for absorption by the animal (Jongbloed, 1987; Kemme, 1998; Figure 8). Several feed factors influence the activity of the supplemented phytase and hence also influence P availability and faecal P composition (Kemme, 1998). Because pigs lack the mechanism of ruminants of recycling P to the gastrointestinal tract by salivation, an excess of P absorbed will largely be excreted with urine.

Nutritional measures may influence the content of inorganic and organic P compounds in manure by a different content and chemical form of dietary P, a changed microbial activity in the gastrointestinal tract, a changed solubility of P sources in the gastrointestinal tract and a changed P absorption, or a changed rate of P recycling or endogenous secretion.

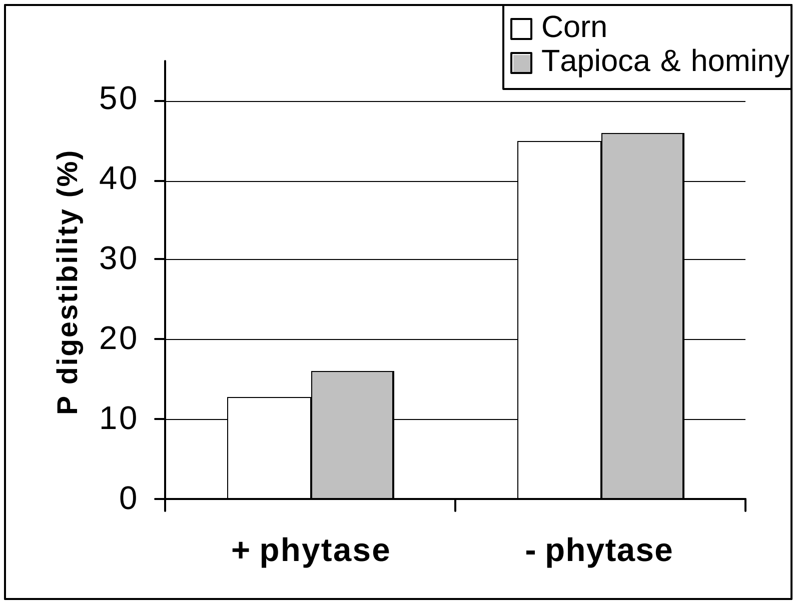

Figure 8. Effect of addition of microbial phytase to a diets with a major component of corn or of tapioca and hominy feed on faecal P-digestibility in growing pigs (Kemme, 1998).

4.2.2 Agricultural value

The P contents and type of P compounds in animal manures are strongly dependent on the animal type, feeding, housing, storage system and time etc. Therefore, the P contents, type of P compounds and the plant availability of the P strongly vary between manures. Urine contains no or only small amounts of P compounds and, therefore, essentially all P in animal manures is derived from faeces (Wilkinson & Lowrey, 1973). Manures contain both inorganic and organic P compounds. On basis of several studies in literature (Bril & Salomons, 1990; Chardon, 1995; Fordham & Swertmann, 1977a & b; Gerritse, 1981; Peperzak et al., 1959; Prummel & Sissingh; 1983) the following P fractions in manure can be derived: 60-90 percent inorganic P and 10-40 percent organic P.

Inorganic compounds that are typically found in animal manures are struvite ($NH_4MgPO_4.6H_2O$), trimagnesiumphosphate ($Mg_3(PO_4)_2.8H_2O$), octacalcium-phosphate ($Ca_4H(PO_4)_3.3H_2O$) en dicalciumphosphate ($CaHPO_4.2H_2O$) (Bril & Salomons, 1990; Chardon, 1995; Fordham & Swertmann, 1977). Model calculations of Chardon (1995) indicated that most of the inorganic P compounds in manure have equal or even better solubility than the most common and well-soluble P fertiliser triple superphosphate, which contains mono-calciumphosphate ($(Ca(HPO_4)_2.H_2O$). This suggests that the plant-availability of these inorganic P compounds is similar to the P in triple superphosphate.

Typical organic compounds in animal manures are phytate (especially in pig and poultry manures), nucleic acids, phospholipids, and P esters (Peperzak et al., 1959; Gerritse, 1981). Phytate forms relatively stable Ca, Fe and/or Al compounds in the soil, by which it is only slowly mineralized (Anderson, 1980). Nucleic acids are mineralized rapidly and part of the esters are stable. In general, more than 80 percent of the organic P in animal manures is rapidly mineralized during the season of application and will be available for plants. Yet, most of this available (inorganic P) is adsorbed by soil particles, by which the utilization of the P from manure by the crop is generally less than 15% in the year of its application.

In several studies the P effectiveness of animal manures was tested (Amberger, 1982a; Arnold, 1978; Den Boer et al., 1995a&b; Hanley & Murphy, 1976; Pain & Sanders, 1980; Sherwood, 1980; Prummel & Sissingh, 1983; Tunney & Pommel, 1987; Van Dijk, 1989). The results of these studies strongly vary (relative P effectivenss in comparison to mineral P fertiliser ranging from 0 to 90 percent), both due to the differences in manure type and experimental conditions (e.g. soil type, P status of the soil) and to the method of assessing the P effectiveness (effect on dry matter yield, P uptake of the crop or on available P in the soil). Moreover, in some studies side effects of the applied manures (application of other micronutrients and macronutrients, damage of the crop by application technique) hamper a clear assessment of the P effectiveness of manure (Prins & Snijders, 1987). In grasslands, there is a tendency that the P effectiveness of cattle slurry decreases when the slurry is deeper injected (table 4). Moreover, it is shown that the P uptake during the first grass cut increases when the slurry is applied earlier in spring; this is probably due to mineralisation of organic P. In general, the studies show that the relative P effectiveness of manure P is about 20-75 on the short-term (e.g. the first grass cut) and about 100 percent for a whole year. In table 4 estimates of the relative P effectiveness of manure are presented for arable land and grassland. This table is used in the P fertiliser recommendations in the Netherlands.

4.3 Conclusions and gaps in knowledge

There is ample information about the total excretion of P via urine and faeces. Feeding tables for pig and poultry nutrition provide information about the amount of P in a feedstuff that is digestible or available for the animal. However, the P availability is influenced by several factors, which are not yet considered in the feeding tables, for example the solubility of phytate. The control of P digestion and the efficacy of phytase addition to the diet has not been turned out succesfully, yet. Further, there is a continuing debate about the minimal P requirement in the diets. Hence, the P availability from forages and concentrate ingredients in ruminant diets also deserves more attention. The level of feed intake and diet composition not only has a significant effect on the amount but also on the form of P excreted with faeces. A prediction of the quantity of the various P forms in dung necessitates to consider the contribution of microbial, endogenous, recycled, and dietary P to total feacal P.

Animal manures contain both inorganic and organic P. The contents and plant-availability strongly varies between manures. Most of the inorganic P is well-soluble and probably rapidly available for plants. More than 80 percent of the organic P can be easily mineralized and will become available for plants within one year of application. Yet, the utilization of the P from manure by the crop is less than 15% in the year of its application. Further, there is a surprising little information about the relationship between P compound in the manure and effectiveness in terms of plant nutrition after application of the manure to soil, as function of application method (injection, broadcasting, etc.) and application time. We suggest that chemical analyses of the various P fractions of animal manures may strongly increase the knowledge of the P composition and in turn the utilization of P from manures by the crop.

Table 4 Relative P effectiveness[1] of different manures (Anon.1999a&b)

Land use	Type of manure, application technique	Time frame	Relative P effectiveness, %
Arable land	cattle solid manure/slurry	year of application	60
	cattle solid manure/slurry	long-term	100
	pig solid manure/slurry	year of application	100
	pig solid manure/slurry	long-term	100
	poultry solid manure/slurry	year of application	70
	poultry solid manure/slurry	long-term	100
Grassland	cattle slurry; deep injection	1st grass cut	0-20
	cattle slurry; deep injection	year of application	100
	cattle slurry; shallow injection	1st grass cut	50
	cattle slurry; shallow injection	year of application	100
	cattle slurry; sliding shoes	1st grass cut	75
	cattle slurry; sliding shoes	year of application	100

5 Sulphur

5.1 Introduction

Sulphur is an essential plant nutrient. In the past, crops were unconsciously but sufficiently supplied with S via atmospheric deposition, animal manures and mineral fertilisers. During the last decade S emissions from industry strongly decreased in W. Europe, by which the S deposition towards the soil also strongly decreased. Thereby, the amounts of applied animal manures also decreased due to environmental legislation. Moreover, also the S content in animal manure probably has also decreased,
as a result of the continuous effort to improve the efficiency of N and P utilisation in current intensive animal husbandry.

In the early nineties, the first signals of possible S deficiency in crops with a high S requirement, such as rape, were observed. Later also possible S deficiency was observed in wheat and grassland. Bussink (1999) showed that application of S fertiliser significantly increased dry matter yield of of the first cut of grassland. This indicates that S defiency may occur in grasslands in the Netherlands. The risk on S deficiency may increase in the near future when both the decrease in atmospheric S deposition and the use of animal manure and the S content in manure further level off. S deficiency may lead to reduction of the crop yield and quality and to a less efficient use of other nutrients, such as N and P. A good S supply of crops is required to obtain optimal yields. S may be applied via S-containing mineral fertilisers and animal manures. Knowledge of the contents of plant-available S in animal manures is therefore important.

5.2 Present knowledge

5.2.1 Effects of animal nutrition

In animal feeds S is found mainly in the non-oxidised state as the S-containing amino acids methionine, cystine and cysteine in proteins. Under normal conditions the intake of oxidised forms of S, like sulphate with drinking water, is negligible. In feeding of livestock specific attention is given to the allowance of the S-containing amino acids because these acids can become limiting for animal production. Methionine is the main limiting S-containing compound in animal diets (Georgievskii et al., 1982). In poultry and pig feeding the S-containing amino acids methionine and cysteine belong to the group of amino acids that are potentially limiting growth performance. Hence, in intensive animal production systems their availability from the diet is carefully controlled. The ileal digestibility (determined at the end of the small intestine) of these amino acids is reported in feeding tables for all frequently used feedstuffs (CVB, 1997). The amount of a specific amino acid that the animal absorbs from the gastrointestinal is estimated then by summation of the amino acid digestibilities for all diet ingredients. Combining this information with that of the composition of animal product gives an estimate of the extent to which these amino acids are absorbed from the gastrointestinal tract, are retained in animal product and are metabolised. Therefore, for pig and poultry nutrition it seems possible to derive the total amount of S excreted with urine and faeces from current knowledge on protein metabolism.

For ruminants in general, S content in the diet is considered sufficient and feeding tables do not offer digestibilities for individual S-containing amino acids as with monogastrics. The intense microbial activity in the rumen results in a conversion of a large fraction of feed protein to microbial protein. However, if S content of diets becomes low because of a low input of S to the animal production system, S may become a limiting factor that impairs microbial activity in the rumen and rumen digestion (Black et al., 1981). As long as ruminants are offered protein rich feeds, S deficiency will not occur however. However, more recently it has been suggested that methionine is a potentially limiting amino acid for milk production by dairy cattle (INRA, 1988). Nevertheless, the effects on milk production appear much less drastic than the effects of amino acid limitation on performance of monogastric animals. As a result of the extensive metabolism of amino acids and protein by animal tissues, only a fraction of the S-containing amino acids actually absorbed from the gastrointestinal tract will be retained in animal product. The remainder will be oxidised and converted to other S containing metabolites that are mainly excreted with urine. Furthermore, besides protein synthesis from absorbed amino acids also a continuous degradation of protein occurs in animal tissues and adds to the metabolism of S-containing amino acids and subsequent excretion of sulphurous metabolites. Metabolism of S-containing amino acids will result mainly in urinary excreted S.

Animals excrete S with faeces as well as urine. Urinary S is present in mineral (80-85%), esterified (5-8%) or neutral (10-14%) form (Georgievskii, 1982). Mineral S originates from amino acid oxidation by animal metabolism, esterified S (e.g. phenol and cresol sulphates) originates from bacterial decomposition in the gastrointestinal tract, and neutral S (e.g. cystine, taurine and biotin) is composed of several types of amino acid and their content in urine increases with an increase in decomposition of endogenous protein (protein secreted by gastrointestinal tissues). Faecal S is composed of feed protein that escaped degradation in the gastrointestinal tract and of microbial protein formed by fermentation of substrates in the large intestine in particular. Faeces also contain esterified S compounds as a result of microbial degradation of proteins in the gastrointestinal tract. These compounds probably constitute only a minor fraction of S in freshly excreted faeces.

5.2.2 Agricultural value

In scientific literature only little attention is paid to S contents and S-availability in animal manure. Animal manures contain both inorganic and organic S. The inorganic S in urine and manure is probably direclty available for plant uptake. The organic S is released during mineralisation. Eriksen (1997) indicated that, although animal manure may contain considerable amounts of S, the plant-availability of S in the year of application was low. Also the long-term effects of manure on soil S status were small (Eriksen & Mortensen, 1999). These results suggests that animal manures are only a poor source of both short-term and long-term plant-available S. A study of Lloyd (1994) with grass cut for silage showed that the relative S effectiveness of cattle slurry was 55 percent in comparison to gypsum. The amounts of plant-available S applied with the cattle slurry to the cut grassland were insufficient to satisfy annual requirements for silage in S-deficient soils.

5.3 Conclusions and gaps in knowledge

Currently, information about S nutrition and S cycling is rather limiting. There are tables available that indicate the utilization of S in the ration for pig and poultry production. Whether these data also suffice to predict the total S contents and S compounds in faeces and urine remains to be established. Further, it is unclear how dietary alterations affect S excretion and the composition of manure. So far, no amino acid digestibilities are available for ruminants. This complicates the estimation of the amino acid composition of feed protein that remains undigested and, hence the estimation of excretion of S with urine and faeces by ruminants. Simply using the amino acid profile of feed protein to estimate S digestion seems to be not feasible, because endogenous secretions and microbial synthesis in the large intestine also contribute to faecal S. We conclude that there is a clear need for more information about S in the ration of ruminants and in manure. Studies should focus on the types of S containing compounds (both inorganic and organic) in animal manures and the availability of these compounds. The degradability and mineralisation of the organic S compounds and the relation between N, S and P mineralisation of organic compounds in animal manures are also important.

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