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The gas forming potential of pig slurry in biogas production

The efficient use of substrates in biogas production requires the knowledge of their gas forming potential. Sufficiently precise data for pig slurry is still lacking. In this study, the content of "fermentable organic matter" (FOM) in pig slurry is determined using results of digestibility trials with animals. Furthermore, the potential gas yield per kg of FOM from pig slurry is deduced from these data.

Keywords

Biogas, pig slurry, gas forming potential, fermentable organic matter, methane yield

Abstract

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Planning of resources for and feeding of substrates into biogas facilities requires the best knowledge of the specific gas forming potential of the substrates. Provision of reliable data has attracted attention since the range of available substrates is constantly getting wider and, for their most efficient use, suitable combinations thereof are being sought for. For practical evaluation purposes, the method of using the fermentable organic matter (FOM) has been proposed for plant biomass [1, 2, 3]. However, there has not been available such method for farmyard manure so far. The aim of this study was to propose a method for evaluating the gas forming potential of pig slurry.

Objective

Results on biogas yields measured by fermentation tests [4] were compiled by the task group „biogas yields" of the KTBL and were shown to be very variable. Based on a total of 34 evaluated tests with pig slurry, a mean value of 372 norm liters (NL) of biogas per kg organic DM (oDM) was calculated. The coefficient of variation was 33 %, which equals to a standard deviation of 123 NL/kg oDM. If these values are considered typical for the material and the experimental procedure, and if 4 replicate determinations per test are assumed, then the confidence interval of the mean value is 252–492 NL biogas/kg oDM ($\alpha = 0.05$).

By this task group, the reference values for biogas yield and methane concentration of biogas from pig slurry were set at 420 NL/kg oDM and 60 %, respectively [4], which gives 250 NL of methane/kg oDM. If the methane content of 60 % is applied to the confidence interval, which was calculated for biogas yield, then the true mean value of methane yield from pig slurry can lie between 150 and 300 NL/kg oDM.

Taking into consideration the enormous uncertainty regarding the basal data from fermentation tests, it seems worthwhile to check if the expected biogas and methane yields can be more reliably established by using the parameter FOM.

Material and Methods

Slurry is composed of faeces and urine, more or less diluted with water and mixed with feed residues. Of both excreta, only the faeces contribute to the gas forming potential of the slurry. The total DM of urine mainly consists of soluble minerals and urea, and, after commingling of faeces and urine, urea is subjected to enzymatic hydrolysis by bacteria, which are abundantly present in faeces. Urea does not have any biogas forming potential, and the possible presence of other organic compounds in urine is low, and can be neglected. Feed residues (e. g. scattered feed) in pig slurry should also not play an important role due to the current technological standards in pig feeding and keeping. Thus, the gas forming potential of pig slurry can be derived exclusively from the nutrients, which originate from faeces.

There are comprehensive data collections from digestibility trials, which were carried out for the purpose of feed evaluation. These data can be used to address all issues related with the evaluation of pig slurry as substrate for biogas production.

Primarily, this applies to digestibility trials which are made with individual feedstuffs and compound feeds in rearing and fattening pigs [5]. Based on this information, it can be calculated which proportion of the OM (OM = oDM) of pig slurry is represented by each nutrient fraction. These proportions, and their variability, must be known in order to be able stoichiometrically calculate the expected gas forming potential of FOM. Furthermore, the digestibility of the nutrients contained in pig slurry is concerned if they pass through the digestive system of the ruminant. Based on the digestibility in the ruminant´s digestive tract it can be concluded about the fermentability of OM in the biogas fermenter, which has been shown for plant biomass [1, 6].

Two digestibility trials with 6 wethers each were carried out using diets, which contained fresh pig faeces [7]. Faeces were taken from pigs weighing between 100 and 120 kg. These animals were kept individually in cages without bedding and were fed 3.4 kg/day of a commercial compound feed. Faeces were collected twice a day and stored in a freezer until feeding to sheep.

Digestibility was tested using the typical experimental design of difference trials consisting of a basal feeding period and a following virtual test feeding period. The daily basal diet for each animal was composed of 450 g DM from milled oat straw and 450 g DM from milled barley. During the test feeding periods, 50 % of the daily DM supply was replaced by DM from pig faeces. All components of the diets were homogeneously mixed before feeding. After 14 days of adaptive feeding, all sheep consumed the offered diets without any feed refusals. The feeding periods lasted 20 days, and during the last 10 days faecal nutrient excretions of the sheep were measured.

Composition of OM

Results of digestibility trials with pigs are summarized in **Table 1** and refer to the amount of nutrients, which were excreted by the animals after consumption of the respective feeds. The data virtually cover most feedstuffs, which are used in pig feeding, as well as compound feeds of typical composition.

In the upper part of **Table 1**, nutrient excretions are given per kg of consumed feed DM. Obviously, the major proportion of excreted organic matter (OM) is composed of carbohydrates (crude fibre plus N-free extract), and carbohydrate excretion is significantly affected by the concentration of cell wall components in the respective feed, for whose digestion pigs do not produce enzymes in the small intestine so that they pass through to the large intestine and are microbially degraded there.

However, not all chemical substances, of which cell wall components are composed of, are fermented by microorganisms and even the potentially degradable cell wall fractions are not completely utilized. Moreover, as the result of microbial fermentation in the large intestine, microbial biomass is produced and ultimately excreted in the faeces. Therefore, OM of pig faeces always consists of a mixture of undigested substances from the feed and of bacterial biomass. The bacterial biomass itself is composed of about 50 % carbohydrates and it contributes considerably to the overall excretion also of lipids (crude fat) and proteins (crude protein). The degree of utilization of this bacterial biomass in the biogas digester is generally higher then that of the undigestable compounds which originates directly from the feed.

The more cell wall components are contained in the feed, the higher is the excretion of undigested feed compounds, and concurrently, of bacterial biomass. This is the scientific rationale behind the observation, given in the lower part of **Table 1**, that the proportion of the three nutrient fractions of the total faecal OM is consistently rather similar. Thus, it can be expected that the fermentability of OM from fresh pig faeces and, thus, also the gas forming potential per kg FOM are rather independent of the composition of the pig's feed.

Therefore, it seems possible and plausible to postulate typical values for the fermentability of OM from and for the gas forming potential of fresh pig slurry. In the following, these parameters are deduced from available experimental data.

Table 1

Content of organic compounds in faeces from pigs fed different feeds

Verzehrtes Futtermittel ***Intaken feed***	**Anzahl Versuche** ***Number of trials***	**Kohlenhydrate/*Carbohydrates***		**Lipide/*Lipids***		**Proteine/*Proteins***	
		Mittel/*Mean*	**SD**	**Mittel/*Mean***	**SD**	**Mittel/*Mean***	**SD**
Ausscheidung mit dem Kot [g/kg TS-Aufnahme]/*Faecal excretion [g/kg DM intake]*							
Nacktgetreide/*Grain*	15	45	23	10	3	14	3
Spelzgetreide/*Husked grain*	16	141	68	9	3	19	2
Getreidekleie/*Bran*	6	203	73	18	4	34	7
Körnerleguminosen/*Legumes*	7	40	25	8	5	34	8
Extraktionsschrote/*Oil meals*	3	85	51	5	6	38	5
Mischfuttermittel/*Compound feeds*	13	**142**	34	**13**	2	**33**	8
Anteil an der oTS des Kotes [%]/*Proportion of the faecal organic matter [%]*							
Nacktgetreide/*Grain*	15	65		14		20	
Spelzgetreide/*Husked grain*	16	83		5		11	
Getreidekleie/*Bran*	6	80		7		13	
Körnerleguminosen/*Legumes*	7	49		10		41	
Extraktionsschrote/*Oil meals*	3	66		4		30	
Mischfuttermittel/*Compound feeds*	13	**76**		**7**		**18**	

Fermentability of OM

Results on digestibility of pig faeces in sheep are given in **Table 2**. Not only the mean digestibility values of the two trials are similar, but also the standard deviations are typical for this type of animal experiments. Across trials, the mean digestibility of OM was 43 %. If the results of the two trials are considered independent random samples, then the total range of the two overlapping confidence intervals (α = 0.05) is 39 ...47 %. Thus, the mean value for the digestibility of OM can be considered sufficiently verified.

The measured digestibility values refer to „apparent digestibility". The parameter „true digestibility" is obtained if the metabolic excretions of endogenous origin are taken into consideration. For digestibility trials using standardized experimental diets it is possible to quantify the metabolic excretions with sufficient accuracy. The used trials fulfill this pre-requirement. Studies on plant biomasses [1] revealed that the content of truly digestible OM is virtually identical to the content of FOM, rendering FOM suitable as parameter for estimation of the gas forming potential. **Table 3** shows the FOM content and the proportions of the three nutrient fractions in pig faeces as calcul ted from the experimental data described (see **Table 2**). Based on the average nutrient concentrations and digestibility coefficients from the two experiments, the content of truly digestible nutrients, and finally by adding the nutrients of endogenous origin (35 g carbohydrates, 5 g fat, 20 g protein per kg DM feed intake), the content of fermentable nutrients could be calculated.

If the fermentable proportion of OM is related to the total OM, the fermentability quotient (FQ) can be derived as follows:

$$FQ = \frac{435 \text{ g/kg FOM}}{868 \text{ g/kg OM}} = 0{,}50$$

Consequently, it can be assumed that 50 % of the OM of fresh pig faeces is fermentable in biogas production. As the ammonia contained in slurry is lost during drying of slurry samples at 105 °C, and other compounds originating from urine in the drying residues are composed of minerals only, the proposed FQ of organic matter can also be used for pig slurry.

Table 2

Digestibility of faeces from pigs measured in sheep (n = 6 sheep/experiment)

Nährstoffgruppe *Nutrient fractions*	**Verdaulichkeit/*Digestibilty* [%]**				
	Experiment A		**Experiment B**		**Gesamtmittel** *Total mean*
	Mittel *Mean*	**SD**	**Mittel** *Mean*	**SD**	
Rohprotein *Crude protein*	64,7	2,0	66,7	1,4	**65,7**
Rohfett *Ether extract*	40,0	9,1	39,9	10,9	**40,0**
Rohfaser *Crude fiber*	38,6	6,1	37,0	8,1	**37,8**
N-freie Extraktstoffe *N-free extract*	40,6	1,9	28,7	4,7	**34,7**
Organische Substanz *Organic matter*	45,4	2,1	41,0	2,1	**43,2**

Table 3

Content of fermentable nutrients in the faeces from pigs

	Kohlenhydrate *Carbohydrates*	**Lipide** *Lipds*	**Protein** *Proteins*	**Organische Substanz** *Organic matter*
Gesamtgehalt [g/kg TS] *Content total [g/kg DM]*	592	76	202	868
Verdaulichkeit, [%] *Digestibility [%]*	36	40	66	43
Verdaulicher Anteil [g/kg TS] *Digestible proportion [g/kg DM]*	212	30	132	375
Fermentierbarer Anteil [g/kg TS] *Fermentable proportion [g/kg DM]*	247	35	152	435
Anteil an der FoTS [%] ***Proportion of the FOM [%]***	**57**	**8**	**35**	**100**

Gas forming potential of FOM

The proportions of the three fractions of fermentable nutrients in pig faeces, whose sum makes up the total FOM, were shown to be (see **Table 3**):

- 57 % carbohydrates,
- 8 % lipds and
- 35 % proteins.

This relationship was assumed in the stoichiometric deduction of the gas forming potential per kg FOM (**Table 4**).

The fermentable carbohydrates in pig slurry are mainly composed of polymers from hexoses (e.g. cellulose) and, to a lesser extent, of polymers from pentoses (e.g. xylans). The specific methane and biogas forming potential of these fractions were stoichiometrically deducted earlier [2, 3]. Pectins and lower molecular carbohydrates are fully degraded in the large intestine of pigs or during the slurry storage in a short time. They can be neglected here.

Fats and proteins should not be present as complex chemical compounds already after short storage periods of slurry, but only whose hydrolytic degradation products. The previously calculated gas forming potential of mixtures of fatty acids from plant glycolipids was used here for fermentable lipids, whereas that of mixtures of free amino acids from vegetative plant biomass for fermentable proteins was applied [2, 3].

Expressed as weighed arithmetic means, approximate gas forming potentials per kg FOM were calculated of 420 NL for methane and of 800 NL for biogas. These values compare surprisingly well with those derived for forages and cereals, which were experimentally confirmed by balance data from commercial biogas digesters [6]. This consistence presents the substan-

Table 4

Gas forming potential of the fermentable organic matter from pig slurry

	Anteil der Fraktion an der FoTS *Proportion of FOM,* %	Methan		Biogas		Methangehalt *Methane content* %
		Liter/kg der Fraktion *Litres/kg of the fraction*	Liter/kg der FoTS *Litres/kg of FOM*	Liter/kg der Fraktion *Litres/kg of the fraction*	Liter/kg der FoTS *Litres/kg of FOM*	
Kohlenhydrate/*Carbohydrates*						
Hexosen-Polymere (Cellulose u. a.) *Hexosans*	40	394	158	788	315	50,0
Pentosen-Polymere (Xylane u. a.) *Pentosans*	17	403	69	806	137	50,0
Lipide/*Lipids*	8	945	76	1350	108	70,0
Proteine/*Proteins*	35	341	119	662	232	51,5
FoTS insgesamt *Fermentable organic matter (FOM)*	**100**		**421**		**792**	**53,2**

tial advantage that, in formulating efficient substrate mixtures („calculating diets for the digester“), the proportions of FOM from different individual substrate sources are additive, and that, for the total FOM, the same gas production per kg FOM can be assumed.

Conclusions

If the herein deduced parameters for fresh pig slurry – the fermentability quotient of 0.50 and the formation of 420 NL methane and 800 NL biogas, respectively, per kg FOM – are merged, then pig slurry produces on average per kg oDM 210 NL methane contained in 400 NL biogas.

The current reference value of 250 NL methane/kg oDM, recommended by KTBL [4], is about 20 % higher than can be expected, so that its correction seems to be necessary. The main reason for the discrepancy is the methane concentration of 60 % in the biogas from pig slurry, which is assumed by KTBL. Based on the typical chemical composition and the stoichiometric calculations, it is not justified to assume a higher methane concentration in the formed biogas than 53 %. Somewhat higher methane contents may be measured in practice as a result of CO_2 absorption within the digestate but these figures are unsuitable for predicting the real methane yield.

The proposed methane forming potential is applicable for fresh and such slurry which is stored for a limited period only. Longer storage times, especially at summer temperatures, may lead to degradation of organic matter and possibly also to a decrease of the fermentation quotient and, thus, the methane yield.

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