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The gas forming potential of dry chicken dung in biogas production

In order to utilize substrates for biogas production efficiently, the knowledge of their gas forming potential is crucial. Until now, sufficiently precise data has been lacking for poultry excrements without bedding. These excrements are usually referred to as dry chicken dung (DCD). It has not been determined as to whether differences exist in quality between different batches and which laboratory analyses are meaningful to cover them. The aim of this study was, therefore, to address the differences in composition of DCD. Based on data from digestibility measurements in sheep, the content of fermentable organic matter (FOM) was calculated. Additionally, the potential gas yield per kg FOM of DCD was determined, and recommendations were made regarding quality assurance of DCD.

Keywords

Biogas, poultry faeces, dry chicken dung, gas forming potential, fermentable organic matter, methane yield

Abstract

Landtechnik 67 (2012), no. 4, pp. 299–304, 1 figure, 4 tables, 9 references

The production of eggs in large housing units always results in high amounts of chicken dung without bedding material. These dries up partly during the production process and subsequent storage, and are usually referred to as dried chicken dung (DCD). In the past, this material has been almost exclusively used as fertilizer. As fresh poultry excrements contain significant amounts of organic compounds, which are easily fermentable by bacteria, its use as feed for ruminants was studied and in some countries also practices any decades ago [1]. In the meantime, this type of use has been given up due to hygienic reasons. For several years, however, DCD has attracted attention as substrate for biogas production. Practical experience showed differences in methane yield, which can mainly be attributed to variations in quality between batches of DCD. Therefore, a method to evaluate and control the quality of DCD is proposed.

Components of DCD

Poultry excrements are composed of the faeces, which are excreted together with the urine via the cloaca. The faeces contain all indigestible nutrients from the feed as well as endogenous excretions from the intestine. Urine consists of excretions from the kidneys, of which uric acid is the most important component. Uric acid is characterized by a very high content of nitrogen. It covers the faeces as a white mass. Uric acid can be degraded by bacteria, which are abundant in the faeces, to ammonia and carbon dioxide via numerous different intermediates. Rate and extent of the degradation process are largely affected by the extent by which faeces and urine are mixed, as well as by storage conditions and storage length. Moreover, DCD contains a certain amount of mineral particles (grit), which are ingested by the animal with the feed or in the free-range areas. Bedding material or scattered feed are, if at all, qualitatively only of minor importance as components of DCD.

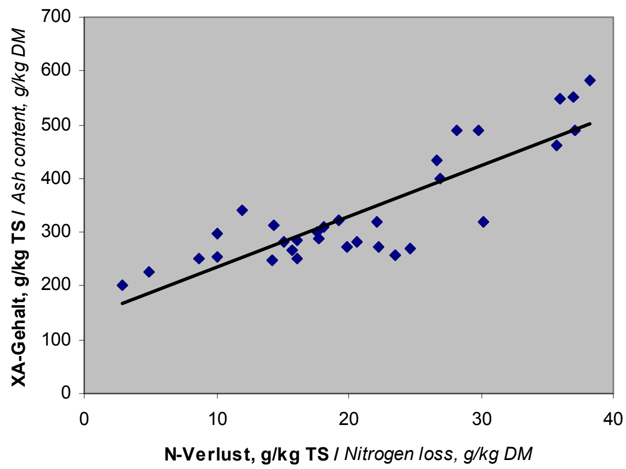
As far as the use as biogas substrate is concerned, DCD is normally analyzed according to Weende feed analysis. Analytical results of a number of samples (n = 32) showed, among others, the following values:

Dry matter (DM)	24.8 to 75.6% (mean: 44.5)
Ash (XA)	200 to 582 g/kg DM (mean: 340)
Crude protein (XP)	161 to 383 g/kg MD (mean: 269)

The large variation in DM content between samples is caused by degree of drying up, which mainly depends on housing conditions. The DM content of fresh chicken excrements varies between 25 and 30 %. Monitoring of DM content of stored DCD is always advisable and meaningful.

Obviously, the enormous differences in XA and XP concentration depend on the storage length, which greatly affects the extent of bacterial degradation of organic matter. Thereby, the contents of XP and XA are changed in opposite directions. The higher XP, the lower is XA and vice versa. **Figure 1** demonstrates the relationship between the decrease of XP content, expressed as the loss of nitrogen in comparison to fresh chicken excrements, and the increase of XA content.

Fig. 1



Relation between loss of nitrogen and increase of ash content of dry chicken dung

Apparently, uric acid is degraded by microbial activity leading to a decrease in crude protein and an increase in crude ash. Some of the ammonia, which is released in the process of uric acid metabolization, also evaporates during sample drying for analysis and is therefore incompletely captured by using routine methods for XP analysis. Thus, the XP content as well as XA content are suitable parameter to evaluate the extent of conversion processes. Fresh, hardly decomposed DCD shows XP values between 350 and 400 g/kg DM and a XA content of about 200 g/kg DM.

If one wants to evaluate how much organic matter is lost during the degradation of uric acid and by how much the XA content would consequently increase, it must be taken into consideration that uric acid contains considerably more nitrogen (33.3 %) than does crude protein from plant biomass (16 %). The regression analysis of the relationship between N loss during storage and drying up of chicken excrements (decline in N content as compared to 400 g XP/kg DM = 64 g N/kg DM as assumed initial concentration) and the expected XA content revealed the following equation:

XA [g/kg DM] = 141 + 9,5 (N-loss [g/kg DM]) (Eq. 1)

$s_y = 56$ $R^2 = 0,73$

This means that a decrease in nitrogen concentration by 1 g/kg DM results in an average increase in XA by 9.5 g/kg DM. If the degradation of uric acid would be the sole cause for this observation, then the value would have been only 3 g/kg DM (100/33.3 % = 3). Consequently, considerably amounts of N free substance are metabolized always together with uric acid and, thereby, gas forming potential is lost.

The determination of other nutrients according to Weende analysis, in addition to XP and XA, does not result in any benefits regarding the evaluation of the gas forming potential of DCD. This already alone is caused by the fact that complete feeds for laying hens kept indoors are highly optimized, leading to only very small variations in the nutrient composition and feed materials used. The knowledge of the digestibility of the organic matter (OM) in DCD is much more important.

Data on the digestibility of poultry excrements in ruminants by several authors [1] are available from times when they were used as feed. These results can be fully made use of in the evaluation of DCD as substrate for biogas production. In this study, the well documented data are considered which are given by Poppe and Grugel [2] on dried excrements without bedding material from laying hens. Digestibility was measured in sheep by using the difference method. Initially, conventional dry feeds were tested and subsequently, diets in which those feeds were partly replaced by the excrements.

Composition of OM

Table 1 summarizes data on the composition of two batches of dried excrements from laying hens. In the upper section of **Table 1** (1.1), crude nutrient concentrations according to Weende feed analysis are given. Batch 1 was nearly fresh excrements, whereas batch 2 had already been subject to significant bacterial decomposition, as reflected by the contents of XP and XA.

In the lower section of **Table 1** (1.2), nutrient fractions were calculated by taking into consideration that crude protein is not only composed of true protein. On average it can be assumed that the total N of laying hen excrements is composed of about 25 % from undigested protein, 50 % from uric acid and another 25 % from urea and ammonia [1]. The total N content was subdivided into these three fractions according to this relation. Furthermore, crude fibre and N-free extracts was summed up to the total fraction of carbohydrates. Lastly, the proportion of the OM was calculated for each nutrient fraction.

It was shown that the total OM of excrements from laying hens is mainly composed of carbohydrates (70 %), only 10 % from proteins, but another 10 % originate from uric acid. Lipids, the true fat fraction (analyzed after extraction with HCl) contribute to OM only to a low extent (4 %).

Fermentability of OM

As known from plant biomass [3–6] and pig slurry [7], under certain circumstances, fermentability of OM can be derived from digestibility of organic matter in sheep. Data on digestibility are available for the two above mentioned batches of DCD and given in **Table 2**. On average of those two trials the digestibility of organic matter of DCD revealed to be considerably high (68 %).

Based on the mean composition (**Table 1**) and the mean digestibility of each crude nutrient fraction (**Table 2**), it was possible to calculate the total content of fermentable organic matter (FOM) and the contribution of each fraction to it (**Table 3**).

Again, the total N content was split up into 25 % from true protein, 50 % from uric acid and 25 % from other, non-protein N (NPN) compounds, and urea was considered to be representative for the NPN fraction. From the N content of uric acid and

Table 1

Content of organic compounds in dried faeces of laying hens [2]

1.1 Weender Futtermittelanalyse/*Nutrient fractions according to Weende analysis*						
Charge ***Charge***	**Rohprotein** ***Crude protein***	**Rohfett** ***Ether extract***	**Rohfaser** ***Crude fibre***	**N-freie Extraktstoffe** ***N-free extract***	**Rohasche** ***Ash***	**Organische Substanz** ***Organic matter***
Gehalt [g/kg TS]/Content *[g/kg DM]*						
1	382	37	50	331	200	800
2	262	24	72	325	318	682
Mittel/*Mean*	**322**	**30**	**61**	**328**	**259**	**741**
1.2 Organische Stoffgruppen/*Fractions of organic compounds*						
Charge ***Charge***	**Proteine** ***Proteins***	**Harnsäure[1]** ***Uric acid***	**Andere NPN-Verbindungen[2]** ***Other NPN compounds***	**Lipide** ***Lipids***	**Kohlenhydrate** ***Carbohydrates***	**Organische Substanz** ***Organic matter***
Gehalt [g/kg TS]/*Content [g/kg DM]*						
1	95	92	33	37	543	800
2	65	63	22	24	508	682
Mittel/*Mean*	**80**	**77**	**28**	**30**	**526**	**741**
Anteil der Fraktionen an der oTS [%]/*Proportion of the fractions in the organic matter [%]*						
1	12	11	4	5	68	100
2	10	9	3	3	74	100
Mittel/*Mean*	**11**	**10**	**4**	**4**	**71**	**100**

[1)] 50 % des Gesamt-N angenommen/*50 % of the total N assumed.*
[2)] 25 % des Gesamt-N angenommen und als Harnstoff berechnet/*25 % of the total N assumed and calculated as urea.*

Table 2

Digestibility of dried faeces of laying hens measured in sheep [2]

Nährstoffgruppe ***Nutrient fractions***	**Verdaulichkeit/*Digestibilty* [%]**		
	Charge 1	**Charge 2**	**Mittel** ***Mean***
Rohprotein *Crude protein*	81	68	**74**
Rohfett *Ether extract*	93	65	**79**
Kohlenhydrate *Carbohydrates*	59	61	**60**
Organische Substanz *Organic matter*	69	67	**68**

urea it can be calculated how much of the organic matter originated from the respective fraction. The content of carbohydrates is, thus, the difference between the total organic matter and the sum of the tree fraction of N containing compounds and the lipids. In analogy to this approach, the calculation of the concentration of digestible carbohydrates was carried out, wherein uric acid and urea were considered fully digestible (100 %).

In plant biomass, the content of „true digestible“ OM was shown to be practically identical with the content of FOM. Therefore, FOM was proposed as parameter to estimate the gas forming potential [3; 4]. The concentration of “true digestible” nutrients, which – in sum – give FOM, was calculated by addition of the endogenous nutrient excretions of the sheep (35 g carbohydrates, 5 g lipids and 20 g proteins per kg DM) [3] to the „apparent digestible“ nutrient concentrations.

If the fermentable proportion of FOM is divided by the total content of OM (both given as g per kg DM), then the fermentability quotient (FQ) is obtained:

$$FQ = \frac{565 \text{ g FoM}}{741 \text{ g OM}} = 0{,}76 \qquad \text{(Gl. 2)}$$

The fermentability of OM from excrements of laying hens in biogas production was shown to be considerably higher than that of excrements from other animal species. Exemplarily, the FQ of fresh pig slurry was determined to be only 0.50 [7], and the same FQ (0.50) was deducted for cattle slurry from the respective KTBL orientation value of its methane yield [9].

Gas forming potential of FOM

The percental proportion of the nutrient fractions of FOM, as calculated and shown in **Table 3**, was used to derive the gas forming potential of the FOM stoichiometrically. In doing this, the same methodical approach was used as previously described for evaluation of plant biomass [5; 6]. Results are given in **Table 4**.

Table 3

Content of fermentable substances in dried faeces of laying hens

	Proteine *Proteins*	**Harnsäure** *Uric acid*	**Andere NPN-Verbindungen** *Other NPN compounds*	**Lipide** *Lipdis*	**Kohlenhydrate** *Carbohydrates*	**Organische Substanz** *Oganic matter*
Gesamtgehalt [g/kg TS] *Total content [g/kg DM]*	80	77	28	30	526	741
Verdaulichkeit [%] *Digestibility [%]*	74	100	100	79	60	68
Verdaulicher Anteil [g/kg TS] *Digestible proportion [g/kg DM]*	60	77	28	24	316	505
Fermentierbarer Anteil [g/kg TS] *Fermentable proportion [g/kg DM]*	80	77	28	29	351	565
Anteil an der FoTS [%] ***Proportion of the FOM [%]***	**14**	**14**	**5**	**5**	**62**	**100**

Table 4

Gas forming potential of the fermentable organic matter in dried faeces of laying hens

	Anteil der Fraktion an der FoTS [%] ***Proportion of the fraction of FOM [%]***	**Methan**		**Biogas**		**Methangehalt [%]** ***Methane content [%]***
		Fraktion [l/kg] ***Fraction [l/kg]***	**FoTS [l/kg]** ***FOM [l/kg]***	**Fraktion [l/kg]** ***Fraction [l/kg]***	**FoTS [l/kg]** ***FOM [l/kg]***	
Kohlenhydrate/*Carbohydrates*						
Hexosen-Polymere (Glucane) *Hexosans*	31	394	122	788	244	50,0
Pentosen-Polymere (Pentosane) *Pentosans*	31	403	125	806	250	50,0
Lipide/*Lipids*	5	970	49	1360	68	71,3
Proteine/*Proteins*	14	457	64	901	126	50,7
Harnsäure/*Uric acid*	14	95	13	633	89	15,8
Andere NPN-Verbindungen [1)] *Other NPN compounds*	5	0	0	354	18	0
FoTS insgesamt ***Fermentable organic matter (FOM)***	**100**		**373**		**795**	**46,9**

[1)] Berechnet als Harnstoff/*Calculated as urea.*

The vast proportion of FOM is composed of carbohydrates which were not digested by the laying hens, but were fermentable. The undigested carbohydrates mainly consist of so-called non-starch polysaccharides (NSP), of which the cell walls of the endosperm, the seed coat and the husks of grain from cereals and legumes are composed of. Depending on the plant species, β-glucans and arabino-xylans, in addition to cellulose, are most abundant. In this study it was assumed that polysaccharides consisting of hexoses and pentoses occur in equal amounts. Lipids were considered to be triglycerides, and proteins having amino acid compositions as to be typical for grain including maize [6].

It is of importance that a significant proportion of FMO of poultry excrements consist of uric acid and other NPN compounds. Uric acid only gives low methane yield in biogas production (95 Liter/kg), but nevertheless high amount of carbon dioxide, and consequently biogas (in total 633 Liter/kg). The other NPN compounds deliver even less methane. Urea, for example, produces only carbon dioxide but no methane. Hence, the specific methane forming potential of fresh, not or only less bacterially decomposed poultry excrements, is markedly lower than that of plant biomass.

The average production per kg FOM was found to be about 375 norm liters methane contained in about 800 norm liters biogas, which results in a methane concentration of only 47 %. In comparison with cereals and forages, which produce 420 l of methane per kg FOM, the formation of methane by DCD is much lower. The inferior methane forming potential as well as the humble methane concentration of the biogas can be attributed to uric acid, which only gives very low amounts of methane.

As already mentioned, one batch of the tested DCD was relatively fresh, whereas the second batch has already been subjected to microbial degradation to some extend. A separate evaluation of each batch – including nutrient composition, digestibility and stoichiometrical calculation of gas formation – did not reveal any significant difference in terms of specific methane forming potential per kg OM, although a decrease would have been likely due to the storage. This phenomenon can be explained by the fact that bacterial degradation of components valuable for methane formation (e. g. carbohydrates) was compensated for by the decomposition of uric acid during storage.

Conclusions

By bringing together the parameters found in this study, namely the fermentability quotient of 0.76 and the potential gas formation of 375 liters methane and of 800 liters biogas per kg FOM, respectively, dried chicken dung delivers per kg OM: 285 norm liters methane in 610 norm liters biogas.

The proposed specific methane volume confirmes reasonably well that of KTBL [8] of 280 norm liters, whereas the calculated biogas forming potential exceeds considerably the therein given 500 norm liters. However, KTBL addresses the general term „poultry manure“. Moreover, explicitly is pointed to the fact that the gas forming potential is affected by the ratio between straw and faeces.

It seems necessary in the future to clearly distinguish between DCD without bedding material and the actual poultry manure which contains regularly this material. The gas forming potential, which was determined in this study, is only valid for DCD. In this regard, a reliably precise sample labeling has to be implemented in substrate analytics. Whenever there are doubts, the crude ash content can be taken as an indicator as CDC normally contains more than 150 g XA per kg DM.

Samples having considerably lower concentrations of this fraction point at actual poultry manure, where cereal straw was presumed as bedding material. A proposal for evaluating this type of biogas substrate is already available [9], which is compatible with the KTBL orientation values [8]. This proposal is based on, firstly, the multiplication of OM by 0.67 (FQ) to give the content of FOM. Secondly, the resulting value is transformed into methane and biogas volume by using the factors 420 liters/kg FOM for methane and 800 liters/kg FOM for biogas, respectively.

It should also be considered in the future that the gas forming potential of DCD per kg DM substantially decreases with increasing storage length. Therefore, as substrate for biogas production, DCD should preferably be used as fresh as possible. The loss of gas forming potential by microbial degradation during storage is reliable and precise indicated by the increase in XA content up to a level of about 350 g/kg DM. Up to this level, a decline in the specific methane yield per kg FOM could not be proven, but is highly probable with further progressing of microbial degradation of OM and increase of the XA content.

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Acknowledgement

The author is deeply indebted to Cornelia Strubelt, Managing Director of Analytiklabor für Landwirtschaft und Umwelt, Blgg Deutschland GmbH, Parchim, and to Aldo Arndt, LUFA Rostock der LMS, for the permission to use the most recent analytical results regarding the composition of dry chicken dung.