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On Assessing the Gas Production Potential of Renewable Primary Products

Biogas production depends on the gas formation potential of the substrates used and to what extent that potential is exploited by fermentation technology. The focus of substrate assessment can only be its gas formation potential, independent of fermentation technology. To calculate the gas formation potential of harvested crops and the silages produced from them a new parameter is proposed, which is the "content of fermentable organic matter" (FOM). This parameter can be computed from the results of relatively simple laboratory analyses. Equations for estimation are proposed, which were derived from a large number of digestion experiments with sheep.

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Literature

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When substrates for biogas production are characterized, it is currently usual to eliminate the effects of differing contents of crude ash (XA) by subtracting XA from DM and expressing the substrate-specific biogas yield per kg of organic matter (OM). However, the substrate-specific gas yield per kg of OM is an extremely varying parameter. In substrates of plant origin, the main cause for this variability mostly is not the differing content of the three major nutrient fractions: protein, fat and carbohydrates, which form different volumes of biogas per kg [2, 10]. Even more important seems to be the proportion of OM which can be biologically utilized. A very close relationship between „digestibility of OM in the biogas fermenter" and the methane yield per kg OM has been found by Kaiser [6] recently.

Therefore, for characterization of substrate-specific biogas yield, it could be useful not only to subtract XA from DM but also that part of OM which cannot be utilized biologically. This would result in a new parameter for characterization of substrates, which could be named the content of „fermentable organic matter"(FOM). The study reported here aims at clarifying the prerequirements and the opportunities of such an assessment of renewable primary products for biogas production.

Materials and methods

A method for calculation of expected biogas yield which, has been employed yet [7] is based on analysing all substrates according to Weende Feed Analysis and using digestibility coefficients from the DLG feed tables for ruminants. Contents of the individual nutrient fractions are multiplied with the respective digestibility coefficients and values for the specific biogas forming potential: The latter are taken over from a paper published by Baserga [2]. According to this author, specific biogas forming potential for carbohydrates, fats and proteins are 790, 1250 and 700 litres per kg, respectively; methane contents in biogas of 50%, 68% and 71% were assigned to carbohydrates, fats and proteins, respectively. There is evidence provided that the general validity of these values must be questioned [10]. Apart from this and other weaknesses, which cannot be discussed in this paper, the main constraint to this method lies in the fact that the calculation of biogas yields gives substantially lower values than those obtained from laboratory fermentation experiments on the same substrate.

This is mainly caused by the false assumption that the apparent digestibility measured in sheep is identical to biological degradability of the nutrients. However, animal faeces do not only contain indigestible compounds of the feed intake, but also metabolic and endogenous matter arising from the process of digestion [9]. The truly biologically not utilizable proportion of nutrients can be calculated, if the metabolic nutrient excretion is known and if that will be subtracted from the total amount of excreted nutrients. But this is only possible if the procedure of digestibility trials is strictly standardized so that approximately constant metabolic nutrient excretions can be assumed [11]. This high level of standardization cannot be expected generally if feed table values are used.

For the study reported on in this paper, numerous results from digestibility trials were available, which meet the necessary high standardisation level [13, 14]. Data from the following number of digestibility trials carried out each with typically 4 individual sheep could be used for: 44 trials on grains and grain by-products, 63 trials on forage maize and different maize products, 72 trials on whole-crop cereals, 75 trials on lucerne, 52 trials on green rye, 41 trials on green oats as well as 135 trials on grass from different sward types.

Results

At first, it was tested as to whether different nutrient concentrations and biological degradability of OM affect biogas yield. Biogas yields were calculated from the content of true digestible nutrients for a wide range of different crops using the gas forming potential of nutrients according to Baserga [2].

Results are presented in *Table 1*. Crops are listed in descending order of their FOM content. Additionally, fermentation coefficient (FC = DOM/OM) as an indicator for biological degradability of OM (analogous to the digestibility coefficient DC) is given.

It is shown that the calculated gas production yields do not differ between crops if values are based on FOM. The main reason for this finding is that the vast majority of fermentable compounds are composed of carbohydrates in all crops and that differences in other nutrients are insignificant. The average yield of biogas and methane per kg FOM was found to be about 800 litres and 420 litres, respectively. Error of prediction of substrate-specific gas yield, which can be expected for such method was – compared with the typical measurement error of some laboratory fermentation methods – unexpectedly small.

Subsequently, it was investigated as to which extend the non-utilizable proportion of OM can be estimated by use of basic laboratory analysis numbers. Previous studies provided evidence [11] that animal faecal excretion from crude protein (XP) and crude fat (XL) expressed as proportion of intake of feed dry matter – so to speak „the contents of indigestible nutrients“– varies insignificantly within a given kind of crop. Therefore, it is possible to use crop-specific average values for animal excretions of these two nutrients.

On the contrary, the carbohydrates (sum of crude fibre and nitrogen-free extract) excreted by animals with faeces is extremely variable and must be estimated by using at least one suitable laboratory parameter. *Figure 1* shows the model, which we have used for that purpose.

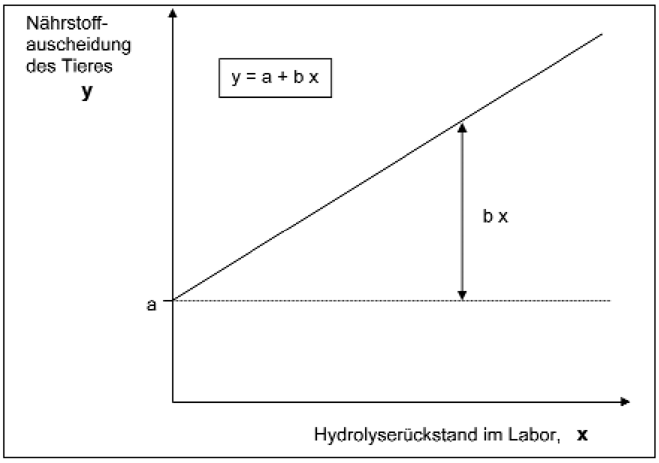

Fig. 1: Model to estimate the nutrient excretion, measured with standardized digestion trials in sheep, by means of hydrolysis residues in laboratory methods

The organic residue provided by certain laboratory hydrolyses methods (x), e.g. crude fibre (XF) content in DM, is analogous to the animal faecal excretion of carbohydrates (y), expressed as proportion of intake of feed DM. The relationship between these two parameters can be described by a simple regression function. Intercept “a” of this function represents the metabolic excretion, whereas the regression coefficient „b“ reflects the increase of excretion, e.g. by increasing crude fibre content. Product „b•x“ represents the amount of carbohydrates, which are truly indigestible and thus non-utilizable. These functions for most kinds of feed are not linear and request approximation of polynomial equations of second grade. For instance, regression curves for non-utilizable carbohydrates increase progressively with increasing XF content.

Under the standardized conditions of the used digestibility trials, a mean metabolic excretion of 35 g carbohydrates, 20 g crude protein and 5 g crude fat per kg feed dry matter was determined, which amounts to a total of 60 g OM per kg feed DM.

Table 1: Calculation of potential biogas yield, based on the content of fermentable organic dry matter (FoDM)

Substrates	Content [g per kg DM]		FC	Biogas		Methane	
	OM	FOM	(FOM/OM)	l_N per kg OM	l_N per kg FOM	l_N per kg OM	l_N per kg FOM
Grain and beets:							
Maize grain	980	950	0,97	756	**780**	402	**415**
Wheat grain	981	933	0,95	749	**788**	399	**419**
Sugar beets, fresh	953	908	0,95	750	**787**	384	**403**
Whole crop maize and cereals:							
Whole crop maize, good	950	763	0,80	638	**794**	335	**417**
Whole crop maize, medium	950	744	0,78	622	**794**	327	**418**
Whole crop wheat, good	940	671	0,71	567	**794**	299	**419**
Whole crop wheat, medium	923	632	0,68	543	**793**	288	**421**
Green crops:							
Green rye	894	766	0,86	670	**782**	364	**424**
Gras, intensive use	889	762	0,86	672	**783**	368	**429**
Lucerne	882	642	0,73	567	**779**	319	**438**
Grass, extensive use	913	507	0,56	437	**787**	240	**432**
Straw from cereals:							
Barley straw	941	530	0,56	448	**796**	231	**409**
Wheat straw	922	493	0,53	425	**795**	220	**412**
Mean	932	715	0,77	603	**789**	321	**420**
Standard deviation	32	155	0,15	118	**6**	63	**9**
Variation coefficient [%]				20	**1**	20	**2**

Deriving equations for prediction of FOM is now be described by using one example on forage maize. All laboratory parameters as well as FOM are given in the dimension g per kg DM. The mean excretion of XP and XL were 36 g and 5 g per kg DM, respectively (standard deviation s_x = 4 g and 1 g per kg DM, respectively). Excretion of carbohydrates could be described by the following regression equation:

$$y = 35 + 0.47\,(XF) + 0.00104\,(XF)^2$$

$$s_R = 24 \text{ g/kg}.$$

The model for prediction of FOM is:

$$FOM = 1000 - (XA) - 36 - 5 - [35 + 0.47\,(XF) + 0.00104\,(XF)^2] + 60$$

from which finally follows:

$$\mathbf{FOM = 984 - (XA) - 0.47\,(XF) - 0.00104\,(XF)^2}$$

Equations for all investigated crops are summarized in *Table 2*. Crude fibre content was found to be in most crops a suitable analytical parameter for estimating biologically non-utilizable carbohydrates and non-utilizable OM, respectively. Using other fibre fractions, like NDF, ADF or ADL, did not improve the performance of the estimation significantly. The only kind of crop, where neither XF nor another named fibre fraction resulted in sufficiently accurate estimations was grass from different swards. Therefore, it is proposed to preferably use in the prediction of FOM the content of „enzyme-resistant organic matter“(EROM) of grasses and grass silages. EROM is the organic residue after hydrolyzing the sample by means of enzymes [13, 14]. It is expressed in g per kg DM and can be understood as analog of XF. The difference between is that hydrolysis is attained by treatment with digestive enzymes (pepsin and cellulase) at 40 °C and not by boiling in acids and bases, which is done in the determination of XF.

All equations can be used for fresh forages and silages thereof as well as gently dried material. However, the crucial pre-requirement for the applicability of these equations to silages remains that DM is corrected for

Substrates	Equations to estimate FOM [g per kg DM]
Grain and grain silages:	
Wheat, rye	$FOM = 990 - (XA) - 1.89\ (XF)$
Barley, oats	$FOM = 991 - (XA) - 1.38\ (XF)$
Grain, altogether	$FOM = 991 - (XA) - 1.53\ (XF)$
Whole crop maize, maize ears and maize kernels and silages thereof:	
	$FOM = 984 - (XA) - 0.47\ (XF) - 0.00104\ (XF)^2$
Whole crop cereal silages:	
Wheat, triticale	$FOM = 982 - (XA) - 0.53\ (XF) - 0.00102\ (XF)^2$
Rye	$FOM = 983 - (XA) - 0.82\ (XF) - 0.00022\ (XF)^2$
Barley	$FOM = 981 - (XA) - 0.81\ (XF) - 0.00006\ (XF)^2$
Other green crops and silages thereof:	
Green rye	$FOM = 975 - (XA) + 0.23\ (XF) - 0.00230\ (XF)^2$
Green oats	$FOM = 976 - (XA) + 0.30\ (XF) - 0.00297\ (XF)^2$
Lucerne	$FOM = 971 - (XA) - 0.41\ (XF) - 0.00101\ (XF)^2$
Grass, intensive use (only first and second cut)	
	$FOM = 969 - (XA) + 0.26\ (XF) - 0.00300\ (XF)^2$
Grass, all intensity levels and cuts	
	$FOM = 1000 - (XA) - 0.62\ (EROM) - 0.000221\ (EROM)^2$

Table 2: Equations to estimate the content of fermentable organic dry matter (FoDM) in source materials for biogas production

the loss of volatile fermentation products during sample drying [12, 15, 16].

The calculated values for biogas yield by using the equations given above and by assuming 800 litres biogas and 420 litres methane per kg FOM, respectively, do not always agree with published results from laboratory fermentation tests [1]. This may be caused by several factors. The findings compare reasonably well with results from Hohenheimer Biogas Test [8], given that gas volumes were calculated for norm conditions [1]. Data in *Table 3* support this statement exemplarily for forage maize samples of which information on measured biogas yield and nutrient contents were available. For both, magnitude of substrate-specific methane yields and differences in quality between samples, a reasonably well comparison between the two methods can be stated.

Conclusions

As demonstrated, the content of FOM is suitable to characterize the gas production potential of renewable primary products. Using this parameter bears the advantage that it is not affected by influences of different protocols of fermentation tests in individual research facilities. In addition, it is much faster and cheaper to determine. Content of XA is already measured generally. Only by determination of one additional parameter (XF or EROM) a substantial gain of information can be attained.

FOM is to be defined as that amount of OM which can potentially be metabolized by microorganisms under anaerobic conditions and which can therefore be utilized for biogas production under optimal process conditions and in sufficiently long process time. FOM is identical to the content of true digestible organic matter calculated from strictly standardized digestibility trials with sheep [11, 13, 14]. It should, however, preferably be measured by suitable laboratory fermentation techniques in future.

Conversion of FOM contents into biogas or methane volumes has not to be carried out necessarily for assessing gas production potential of renewable primary products. The content of FOM per se is a good characteristic of the gas production potential of substrates. Where required, substrate-specific gas yields should be expressed as gas volumes per kg FOM rather than per kg OM.

It should be possible to use constant coefficients for calculating the volumes of biogas and methane per kg FOM of the most renewable primary products as has been shown in this study. But these coefficients have to be qualified. The coefficients used so far are only based on numbers for gas forming potential of the individual nutrient fractions given by Baserga [2]. The validity of these coefficients has to be checked by further studies.

For special substrates there may be also a need for using gas yields per kg FOM different from average values. This may apply to e. g. sunflowers (due to its high fat content) and for ensiled sugar beets (due to its high ethanol content). Using FOM as the basal parameter for substrate-specific gas yield data eliminates the impact of differences in fermentability of OM. Thereby new opportunities may arise for deriving and biochemically accounting for gas formation potential values of nutrients and substrates by means of stoichiometric calculations [3, 4, 5].

Acknowledgment

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Table 3: Comparison of biogas yields from silage maize by using the FoDM approach versus measured data using the Hohenheimer biogas test.

Variety	Maturing-number	DM [%]	Content [g/kg DM] XA	XF	OM	FOM	Methane yield [l_N/kg OM] measured	calculated*	Yield relative**
Banguy	240	38	29	142	971	867	370	375	99
GIXXAC	270	34	34	176	966	835	380	363	105
Chamboro	290	36	36	172	964	836	370	364	102
Laurest	300	42	32	168	968	844	380	366	104
Moissac	420	30	33	188	967	826	380	359	106
DK 604	580	23	41	208	959	800	350	350	100
Doge	700	35	38	183	962	825	380	360	105
Doge, early harvest	700	20	48	315	952	685	310	302	103
unknown		39	33	137	967	867	370	377	98
Mean							366	357	102

* 420 l_N/kg FOM ** calculated = 100

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Table.2: Equations for estimating the content of fermentable organic matter (FOM) in substrates for biogas production

Substrates
Equations to estimate FOM [g per kg DM]

Grain and grain silages:
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Table. 3: Comparison of biogas yields from forage maize as affected by method of determination: measured by Hohenheimer Biogas Test versus calculated by use of FOM

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