METHANE PRODUCTION FROM MAIZE, GRASSLAND AND ANIMAL MANURES THROUGH ANAEROBIC DIGESTION

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ABSTRACT

A world wide increasing demand can be observed to use energy crops for biogas production. The research project aimed at optimising anaerobic digestion of animal manures, maize and clover grass. The highest specific methane yield (166.3 Nl CH_4 (kg VS)$^{-1}$) was produced from manure received from cows with medium milk yield that were fed a well balanced diet. Lignin in the manure reduced the specific methane yield. With energy crops, a maximum methane yield per hectare should be achieved. Influence of variety and harvesting time on the methane yield was investigated. Maximum methane yield from late ripening maize varieties ranged between 7100 and 9000 Nm^3 CH_4 ha^{-1}. Early and medium ripening varieties yielded 5300 – 8500 Nm^3 CH_4 ha^{-1} when grown in favourable regions. On medium to good locations, clover grass yielded 3000 – 4500 Nm^3 CH_4 ha^{-1}. Maize and clover grass are optimally harvested, when the product from specific methane yield and VS yield per hectare reaches a maximum. From the digestion experiments, the new Methane Energy Value System was developed. It estimates the methane yield from the nutrient composition of maize and clover grass silage.
Keywords: *Anaerobic digestion; biogas; harvesting time; methane energy value system.*

INTRODUCTION

A world wide increasing demand can be observed to use energy crops and animal manures for biogas production. In Austria, a recently issued law on green electricity production forms the legal frame for a forward-looking biogas production. Many new agricultural biogas plants will be built in the near future. Biogas plants require a targeted nutrient supply to achieve optimum biogas yields. Currently, specific parameters on the anaerobic digestibility of animal manures and energy crops are unavailable which restricts the exploitation of the promising potentials.

The research project aimed at optimising anaerobic digestion of maize and clover grass. A maximum methane yield per hectare should be achieved. Influence of maize variety and harvesting time on the methane yield was investigated. A regression model was developed that estimates methane yield from the nutrient composition of maize and clover grass. Manure received from dairy cattle with contrasting performance and diet was digested and specific methane yield was measured.

MATERIALS AND METHODS

The Federal Research Institute for Agriculture in Alpine Regions (BAL Gumpenstein) conducted feeding trials with *dairy cattle* at contrasting milk yields and feeding intensities. Milk yield ranged from 11.2 to 29.2 l milk per cow and day. Animal diets differed in their concentrate level and in forage composition (hay, grass silage, maize silage). Methane production from dairy cattle manure was measured in eudiometer batch digesters.

13 early to late ripening *maize varieties* (FAO 240 – 600) were grown on several locations

in Austria. In course of the vegetation period, the following parameters were determined for all varieties: nutrient composition, dry matter and organic dry matter content at milk ripeness, wax ripeness and full ripeness, specific methane yield and biogas quality from anaerobic digestion in eudiometer batch experiments, methane yield per hectare for each harvesting time. In addition, the influence of harvesting technology on the methane yield was investigated. Whole plants, corns only and corn-cob-mix were anaerobically digested and methane yields were compared. Influence of silaging compared to green, non conserved maize was measured, as well. A detailed description of cultivation, plant management, and harvesting of maize can be found in Amon et al. (2002, 2003).

Clover grass was grown in an Alpine region as intensive forage mixture, as permanent grassland mixture and as clover grass mixture and harvested at three different stages of vegetation to find the optimum harvesting time.

Substance and energy turnover during anaerobic digestion were measured in 1 litre *eudiometer batch experiments* at 38°C that were conducted according to DIN 38 414 (1985). Each variant was replicated two to four times. Biogas quality (CH_4, H_2S, NH_3) was analysed 10 times in course of the 6-week digestion. Substrates were analysed prior to digestion for pH, dry matter (DM), crude protein (XP), crude fibre (XF), cellulose (Cel), hemi-cellulose (Hem), lignin (ADL), crude fat (XL), starch (XS), sugar and ash (XA) with standard analysing procedures. A detailed methodology description can be taken from Amon et al. (2002, 2003).

RESULTS AND DISCUSSION

Table 1 gives the nutrient composition of the contrasting *dairy cow manures*. Biogas and methane yield per norm litre of volatile solids are listed as well. The dairy cows of the treatments dairy_1 and dairy_2 had a low milk yield, dairy_3 and dairy_4 had a medium milk yield and dairy_5 and dairy_6 had a high milk yield. In each level of intensity, manures with contrasting crude protein levels were produced. The manures with the higher crude protein levels (dairy_1, 3, and 6) gave higher methane yields during anaerobic digestion. Lignin in the manure reduced the specific methane yield. The higher the feeding intensity and the milk yield, the greater was the reduction in methane yield through an increase in lignin content. Manure of the treatment dairy_3 produced the highest specific methane yield of 166.3 Nl CH_4 (kg VS)$^{-1}$. It was received from cows with medium milk yield that were fed a well balanced diet. Forage consisted of hay, grass silage and maize silage. Concentrate was supplemented according to the cows` requirements.

***Table 1**. Composition of dairy cow manure and specific biogas and methane yield.*

	composition of dairy cow manure [g (kg DM)$^{-1}$]										gas yield[b] [Nl (kg VS^{-1})]	
treatment	pH	DM[a]	XP	XF	Cel	Hem	ADL	XL	XA	GE [MJ]	biogas	methane
dairy_1	6.95	143.7	162.6	265.9	194.7	144.0	162.1	46.4	157.1	15.8	208.2	136.5
dairy_2	6.79	128.8	154.3	265.8	227.3	175.9	128.2	34.5	155.0	17.3	213.1	131.8
dairy_3	6.60	135.0	156.6	310.1	250.8	190.3	124.7	23.8	131.7	14.6	245.8	166.3
dairy_4	6.60	159.6	150.6	279.5	164.1	187.9	183.3	29.1	162.8	19.3	222.5	143.1
dairy_5	6.70	148.5	180.2	273.3	161.8	208.7	190.4	28.5	148.4	15.6	238.9	125.5
dairy_6	6.66	157.3	296.5	248.5	210.1	195.5	121.7	30.3	167.8	16.8	267.7	159.2

[a] [g (kg FM)$^{-1}$] [b] Nl = Norm litre (0°C, 1.0132 bar)

The *maize varieties* that were included in the experiments showed a characteristic methane production potential that was strongly dependent on their nutrient composition. The nutrient composition was mainly determined by the stage of vegetation. Location of maize cultivation, and variety also influenced the nutrient composition of maize silage. Varieties with a high protein and fat content and with a high potential for biomass production were especially suitable for anaerobic digestion. Crude fibre did not give much methane. Nitrogen free extracts slightly reduced methane formation during anaerobic digestion of maize silage.

Crude protein (XP), crude fibre (XF), and cellulose (cel) content declined in course of the vegetation period. Hemi-cellulose (hem), and starch content increased. The C : N ratio rose from *c.* 24 on the first, early harvest (after c. 97 days of vegetation) to *c.* 42 at the last, late harvest (after c. 151 days of vegetation). Anaerobic digestion requires a C : N ratio between 10 and 30 (Schattauer and Weiland, 2004). When the C : N ratio is too wide, carbon can not optimally be converted to CH_4 and the CH_4 production potential is not fully used. When maize was harvested at full ripeness, the C:N ratio was outside the optimum range with regard to producing a maximum specific methane yield. Co-digestion of substrates with a narrower C : N ratio could help to overcome this disadvantage.

With late ripening maize varieties, the optimum methane yield per hectare is achieved, if maize is harvested at > 43 % dry matter. Methane yield from late ripening varieties reached a maximum at full ripeness. It ranged between 7100 and 9000 Nm^3 CH_4 ha^{-1}. Early and medium ripening varieties yielded 5300 – 8500 Nm^3 CH_4 ha^{-1} when grown in favourable regions and harvested at the end of wax ripeness. Dry matter content was 35 – 39 %.

From the results of 34 batch experiments, a new system – the Methane Energy Value System – was developed. Parameters that had a significant influence on methane production were included in a multiple linear regression model. Estimation of coefficients of regression is based on all experiments that delivered a specific methane yield between 250 and 375 Nl CH_4 $(kg\ VS)^{-1}$.

The methane energy value [l CH_4 $(kg\ VS)^{-1}$] gives the methane production potential of nutrients if these are fed as natural organic substrates. Table 2 shows coefficients of regression, standard error, and level of significance of the regression model for the estimation of methane yield from anaerobic digestion of maize silage. Coefficients of regression are highly significant. Crude fat and crude fibre contribute most to the net total methane value of maize silage.

Table 2*. Coefficients of regression, standard error, and level of significance for the estimation of methane yield from maize silage (n = 34).*

nutrient	*coefficient of regression*	*standard error*	*level of significance*
crude protein (XP) [% DM]	19.05	2.95	0.000
crude fat (XL) [% DM]	27.73	7.09	0.000
cellulose (cell) [% DM]	1.80	0.40	0.000
hemicellulose (hem) [% DM]	1.70	0.40	0.000

Table 3*. Coefficients of regression for the estimation of methane yield from clover grass silage (n = 6).*

nutrient	*coefficient of regression*
crude protein (XP) [% DM]	11.77
crude fat (XL) [% DM]	4.46
N free extracts [% DM]	-1.60
crude fibre [% DM]	5.56

Table 3 gives coefficients of regression of the linear regression model for the estimation of methane yield from anaerobic digestion of *clover grass silage*. Estimation of coefficients of regression is based on the data published in Amon et al. (2003). Harvesting time was the key factor that determined methane production from anaerobic digestion of clover grass mixtures. The specific methane production varied between 290 and 390 Nl CH4 (kg VS)$^{-1}$. Harvesting at the vegetation stage "ear emergence" resulted in the highest specific methane yield. Harvesting at a later stage reduced methane yield up to 25 %.

CONCLUSIONS

Maize silage and animal manures are very suitable substrates for anaerobic digestion. Economic biogas production requires the methane yield from organic substances to be calculable. Methane yield depends on the nutrient composition of organic substrates. Anaerobic digestibility of animal manures is determined by the animal diet and performance.

Silaging increases the methane yield from maize and clover grass. Methane yield per hectare is markedly influenced by variety and time of harvesting. Late ripening maize varieties (FAO 600) make better use of their potential to produce biomass than medium (FAO 300 – 600) or early ripening (FAO 240 – 300) varieties. On good to very good locations in Austria they can produce more than 30 t VS ha^{-1}. In course of the vegetation period, specific methane yield per kg VS declines, but net total VS yield per hectare increases. The C : N ratio gets wider. Maize is optimally harvested, when the product from specific methane yield and VS yield per hectare reaches a maximum. With early to medium ripening varieties, the optimum harvesting time is at the "end of wax ripeness". Late ripening varieties may be harvested later, towards "full ripeness". Maximum methane yield is achieved from digestion of whole maize plants. Digesting corn-cob-mix, corns only or maize without corn and cob gives 43 – 70 % less methane yield per hectare (data not shown). Biogas should thus be produced from whole maize plants.

From the digestion experiments, the Methane Energy Value System was developed. It is a suitable tool to optimise biogas production.

Sustainable biogas production from energy crops must not be based on maximum yields from single crops, but on maximum methane yield from sustainable and environmentally friendly crop rotations. Further investigations must make proposals for sustainable crop rotations.

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