BIOGAS PRODUCTION FROM MAIZE AND CLOVER GRASS ESTIMATED WITH THE METHANE ENERGY VALUE SYSTEM

Thomas Amon[1], Vitaliy Kryvoruchko[1], Barbara Amon[1], Werner Zollitsch[2], Erich Pötsch[3]

[1]Department of Sustainable Agricultural Systems, Division of Agricultural Engineering, University of Natural Resources and Applied Life Sciences, Peter-Jordanstrasse 82, A-1190 Wien; e-mail: barbara.amon@boku.ac.at

[2]Division of Livestock Sciences, Department of Sustainable Agricultural Systems, University of Natural Resources and Applied Life Sciences, Gregor-Mendel-Strasse 33, A-1180 Vienna

[3]Federal Research Institute for Agriculture in Alpine Regions, A – 8952 Irdning

ACSTRACT

A world wide increasing demand can be observed to use energy crops for biogas production. The research project aimed at optimising anaerobic digestion of maize and clover grass. 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

INTROCUCTION

A world wide increasing demand can be observed to use energy crops 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.

Maize and clover grass are of vital importance for biogas production from energy crops. Decisions on the investment in agricultural biogas production and calculation of the size of the biogas plant are only possible if reliable data are available on specific methane yield and on methane yield per hectare that can be expected from anaerobic digestion of maize and clover grass. The potential to produce methane – the methane energy value – of maize and clover grass must be calculable.

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 composition of maize and clover grass.

APPROACH

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

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, fat, cellulose, hemi-cellulose, and starch content and with a high potential for biomass production were especially suitable for anaerobic digestion. Crude fibre did not give much methane.

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 1 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 1. 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 2 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 CH_4 (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 %.

Table 2. 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

CONCLUSIONS

Maize and clover grass silage 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.

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, the specific methane yield per kg VS declines, but the 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.

With clover grass, harvesting at the vegetation stage „ear emergence“ resulted in the highest methane yield. Harvesting at a later stage reduced methane yield up to 25 %.

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.

Acknowledgements. The work was funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, by Pioneer Saaten Ltd. Parndorf, by Raiffeisen Ware Austria AG, by KWS Austria Saatzucht Ltd. and by the Austrian Federal Ministry for Transport, Innovation and Technology under the subprogram "Energy Systems of Tomorrow"

REFERENCES

[1] Amon T., Kryvoruchko V., Amon B., Moitzi G., Lyson D., Hackl E., Jeremic D., Zollitsch W., Pötsch E., Mayer K. and Plank, J. (2002). Methanbildungsvermögen von Mais – Einfluss der Sorte, der Konservierung und des Erntezeitpunktes. Endbericht Oktober 2002. Im Auftrag von Pioneer Saaten Ges.m.b.H. Parndorf (Austria).

[2] Amon T., Kryvoruchko V., Amon B., Moitzi G., Lyson D., Hackl E., Jeremic D., Zollitsch W. and Pötsch E. (2003). Optimierung der Biogaserzeugung aus den Energiepflanzen Mais und Kleegras. Endbericht Juli 2003. Im Auftrag des Bundesministeriums für Land- und Forstwirtschaft, Umwelt- und Wasserwirtschaft. Forschungsprojekt Nr. 1249.

[3] DIN 38 414 (1985). Bestimmung des Faulverhaltens „Schlamm und Sedimente“. Beuth Verlag, Berlin.

[4] Schattauer A. and Weiland P. (2004). Handreichung Biogasgewinnung und –nutzung. Endbericht. Förderkennzeichen 22027200. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow.