Seasonal Pattern of Biomethanisation of Grass from Landscape Management

Annette Prochnow, Monika Heiermann, Axel Drenckhan, Hannelore Schelle

Leibniz-Institute of Agricultural Engineering Bornim, Max-Eyth-Allee 100,
14469 Potsdam, Germany, aprochnow@atb-potsdam.de

ABSTRACT

A rising demand for substrates for the increasing number of biogas plants in Germany and a growing percentage of extensively used grassland sites mean that landscape management grass is increasingly considered for use as a substrate for biomethanisation. Harvesting periods from mid-June until February lead to a highly inhomogeneous material with extremely variable substrate characteristics.

In order to obtain seasonal patterns of biogas and methane yields from landscape management grass, samples were taken each month from the first cut of a Meadow Foxtail fen grassland over three years from 2001 to 2004 and anaerobically digested in laboratory-scale batch experiments.

Substrate-specific biogas yields decrease linearly throughout the season from 547 l_N/kg VS in June to 299 l_N/kg VS in February. Methane contents stay largely constant over the year with a mean value of 52 Vol.-%. The seasonal pattern of substrate-specific methane yields runs parallel to the biogas yields and declines from 298 l_N/kg VS in June to 155 l_N/kg VS in February. Area-specific methane yields show a maximum of 1604 m^3 ha^{-1} a^{-1} in September. Biogas and methane yields from landscape management grass are relatively low in comparison to those of other crop substrates.

Keywords: biogas, grass, landscape management

1. INTRODUCTION

At present, two basic trends in Germany are leading to intensified considerations on biogas production from landscape management grass.

First there is a fast growth in the biogas sector promoted by the Renewable Energy Sources Act (Anonymous 2000, 2004) which forces power supply companies to take over electricity from renewable sources and to pay guaranteed minimum prices. Hence, the number of biogas plants has increased from 850 to 1760 between 1999 and 2003 whilst the installed electrical power rose from 40 MW to 190 MW (Thrän et al. 2005). This development has strongly intensified the search for appropriate substrates that are reliably available in adequate amounts and suitable for the biomethanisation process by giving high methane yields and profits (Heiermann and Plöchl 2004, Linke et al. 1999).

Second there is the tendency to extensify agricultural use in favour of nature conservation requirements or to give up agricultural use in marginal regions. It is the general scope of landscape management to preserve the open, diverse and species-rich cultural landscape of Europe created over centuries by a small-scale, differentiated and extensive land use. Thus, landscape management in Central Europe mainly comprises measures to manage grassland biotopes by extensive grazing or mowing. The growing percentage of area dedicated to landscape management leads to the question on how to utilise the biomass of these sites.

The use of landscape management grassland biotopes involves reduced cutting frequencies at a maximum of twice a year and late harvesting periods. Due to specific conservation objectives, the first cut of grassland biotopes for landscape management may range from mid-June until February.

There are various ways to utilise the biomass harvested from landscape management grassland. With more than 90 % the main form is the use as forage in extensive livestock farming. The rest is mulched, used as organic manure on arable land or composted in stacks (Prochnow 2000). However, all these possibilities are restricted either by material quality or ecological, technical and economic problems. Bioenergy production by combustion or biomethanisation seems to be a promising alternative. So repeatedly for the last 10-15 years, there have been considerations on using landscape management grass for biogas production (Elsäßer 2003, Hamin 2002, Köttner 2001/2002, Gross et al. 2003, Schröder 2004).

In contrast to vegetation cut early from intensive grassland, landscape management grass is a highly inhomogeneous material with extremely variable substrate characteristics for biomethanisation depending on harvesting period, vegetation and weather conditions. Several parameters that are relevant for the biogas production process change significantly over the year. Contents of total solids and crude fibre as well as C:N-ratio rise while contents of crude proteine, crude fat and saccharides decrease (Table 1).

Table 1. Seasonal variation of characteristics of landscape management grass (Drenckhan 2005, Prochnow 1994)

parameter	unit	June	February
total solids	% in FM	18	75
crude proteine	% in TS	15	4
crude fibre	% in TS	23	55
saccharide	% in TS	7.3	0.5
crude fat	% in TS	1.9	0.3
C:N-ratio	-	20:1	75:1

It is very likely that the changing substrate parameters of landscape management grass will influence the yield and composition of biogas. Particularly, the increasing content of crude fibre is expected to limit the maximum biogas production potential since crude fibre consists mainly of hemicellulosis and lignin, both described as hardly biodegradable under anaerobic conditions (El Bassam 1998, Shiralipour and Smith 1984, Weiland 2001). Furthermore, methane contents in the biogas produced are assumed to be small as landscape management grass contains only little crude protein and crude fat which are the components to achieve large methane contents (Weiland 2001).

The basic suitability of grass for biomethanisation has been proved in scientific investigations and practical applications. A number of publications deal with the biogas yield from grasses of several species, biotopes and cutting periods under varying conditions of trial (Table 2). The biogas yields obtained differ by one order of magnitude (80 – 860 l/kg VS). These figures cover almost the entire range of possible biogas yields from organic matter.

Table 2. Overview of investigations on biogas production from grassland vegetation

substrate (e.g. grasses, intensity of grassland use, cutting period, conservation)	biogas yield [l / kg VS]	methane yield [l / kg VS]	conditions (scale / operation mode / temperature / retention time / mono- or co-digestion)	reference
intensive grassland cut, first cut in June, fresh and ensiled	700 – 720	not reported	laboratory scale / batch / 35°C / 25 d	Baserga and Egger 1997
extensive grassland cut, first cut in August, fresh, silage and hay	540 – 580	not reported		
extensive grassland cut, silage and hay	500 – 600	not reported	laboratory scale / semi-continuous / 35°C / 18-36 d / co-digestion	
extensive grassland cut, silage	500 – 550	not reported	farm scale (fermenter volume 100 m^3) / continuous / 35°C / 20 d / co-digestion	Baserga 1998
three grass species, first cut in mid-May, fresh and ensiled	650 – 860	310 – 360	laboratory scale / batch / 35°C / 28 d / mono-digestion	Mähnert 2002, Mähnert et al. 2002
three grass species, second cut, ensiled	560 – 610	300 - 320	laboratory scale / semi-continuous / 35°C / 28 d / mono-digestion	

Table 2.(cont.) Overview of investigations on biogas production from grassland vegetation

substrate (e.g. grasses, intensity of grassland use, cutting period, conservation)	biogas yield [l / kg VS]	methane yield [l / kg VS]	conditions (scale / operation mode / temperature / retention time / mono- or co-digestion)	reference
intensive forage mixture of grasses and clover, ensiled, mid-May (before anthesis) end of May (anthesis) mid-June (after anthesis)	 532 474 427	 370 326 297	laboratory scale / batch / 37-39°C / 58 d / mono-digestion	Amon et al. 2003
grass from intensively used sites, 4 cuts per year, ensiled grass from extensively used sites, 2 cuts per year, ensiled grass from landscape management	390 220 80	not reported not reported not reported	laboratory scale and farm scale / semi-continuous / 37°C / 25 – 60 d / co-digestion	Lemmer and Oechsner 2002

The figures confirm the enormous substrate variability of grass and indicate that early cut intensive grassland vegetation can give high biogas yields while the older vegetation of extensive grassland results in lower biogas yields. However, the available figures on biogas yields cannot be generalised regarding certain cutting periods and the corresponding substrate characteristics. The results are not comparable with each other since both substrates and conditions of trial differ. Furthermore, the harvesting periods of most experiments end when landscape management begins. Systematic investigations on biomethanisation of grassland vegetation under the same conditions and from the same sites but from varying cutting periods are missing.

It is, thus, impossible to draw conclusions on biogas yields from landscape management grass from currently available data. The present lack of knowledge on biogas and methane yields is the main obstacle for the planning of biogas plants and profound economic calculations.

2. SCOPE

The scope of this study is to carry out systematic investigations on biomethanisation of landscape management grass from different cutting periods. Seasonal patterns of biogas and methane yields are obtained in order to identify optimum harvesting periods. Thus bases for the planning of biogas plants and later economic assessment are provided.

3. APPROACH

For systematic investigations on the seasonal pattern of biomethanisation of landscape management vegetation, grass samples were collected monthly over three years and anaerobically digested under laboratory conditions.

The grass samples were taken in the nature reserve Nuthe-Nieplitz-Niederung south-east of Berlin from a eutroph fenland site covered with a Meadow Foxtail grassland vegetation (*Alopecuretum pratensis association*) mainly consisting of Couch (*Elymus repens*), Meadow Foxtail (*Alopecurus pratensis*), Smooth Meadow Grass (*Poa pratensis*), Stinging Nettle (*Urtica dioica*), Creeping Thistle (*Cirsium arvense*) and Cow Parsley (*Anthriscus sylvestris*). The site is dedicated to extensive grassland use without any input of fertilizer or pesticides. Once a year at the end of July, the vegetation is cut for haymaking.

For collecting grass samples throughout the season a plot was excluded from the normal use and not mown at all. Grass samples were taken from this plot from 2001 to 2004 in the middle of each month from June to March (fig. 1 and 2). So for each sample it was always the first cut when it was taken. The samples were chopped to a length of less than 30 mm in the laboratory and preserved by deep-freezing at a temperature of –18°C.

After collecting and storing the samples over three years, they were put to anaerobic digestion in laboratory scale according to German Standard Procedure (VDI 4630 Entwurf 2004). Before and after the digestion process, the substrates or residues were analysed for total solids, volatile solids, pH, C:N-ratio, crude protein, crude fibre, crude fat, saccharide and volatile fatty acids according to standard methods.

The digestion laboratory-investigations were carried out as mono-digestion batch experiments in 2 l-bottles with double replication using completely digested cattle slurry as inoculum. Each bottle was filled with 1500 g inoculum slurry and 50 g grass sample according to an inoculum-feed-ratio of > 2 based on volatile solids. The grass samples were digested over a retention time of 28 days at mesophilic temperature of constantly 35°C maintained by a water bath (fig 3).

The total volume of biogas produced was measured daily by a wet scaled gas meter. The biogas composition was determined weekly by infrared detection (landfill gas analyser ANSYCO GA94) thus obtaining the percentages of CH_4, CO_2, O_2 and H_2S. Biogas and methane yields were converted to standard conditions with a temperature of 273,15 K and a pressure of 101,325 kPa.

Accumulated biogas yields over the retention time were fitted by regression analysis with an exponential form of the Chapman function (according to Mähnert et al. 2002):

$$y(t) = y_{\max}(1 - e^{-a*t})^{b} \qquad (1)$$

y (t)	biogas yield at time *t* [l_N / kg VS]
y_{max}	maximum biogas yield [l_N / kg VS]
t	time [d]
a,b	coefficients

Figure 1. Sample of landscape management grass harvested in June

Figure 2. Sample of landscape management grass harvested in February

Figure 3. Laboratory digestion experiments: digestion bottles filled with substrate and inoculum in the water bath (foreground) and wet scaled gas meters (background)

Methane contents in the biogas were also fitted by regression analysis using an empirical equation of the Hill function (according to Mähnert et al. 2002):

$$p_{CH_4}(t) = p_0 + a\frac{t^b}{c^b + t^b} \qquad (2)$$

p_{CH4}	methane content at time t [Vol.-%]
p_0	minimum content of methane [Vol.-%]
a, b, c	coefficients

Accumulated methane yields over the retention time can be calculated by multiplication of equations (1) and (2).

For the same months of the three years of the study, mean values of biogas and methane yields were calculated to obtain the average seasonal patterns of the two parameters. Monthly biogas and methane yields in combination with monthly grass yields of a Meadow Foxtail grassland (*Alopecuretum pratensis association*) and monthly contents of volatile solids gave the seasonal patterns of biogas and methane yields per unit area. The grass yields were transferred from previous investigations at the same type of biotope and the same region. Averaged for two years they amount to 4.6 t TS/ha in June, 8.1 t TS/ha in August and September and 1.1 t TS/ha in February (Prochnow 1994).

4. RESULTS AND DISCUSSION

4.1 Biogas Yields

Three exemplary curves of accumulated biogas yields from landscape management grass show that the biogas yields are the lower the later in the growing season the vegetation is harvested (fig. 4). Compared to the high yielding crop maize even early cut landscape management grass from mid-June produces substantially less biogas. Remarkable as well is the low gradient of the curves at the beginning of the digestion process.

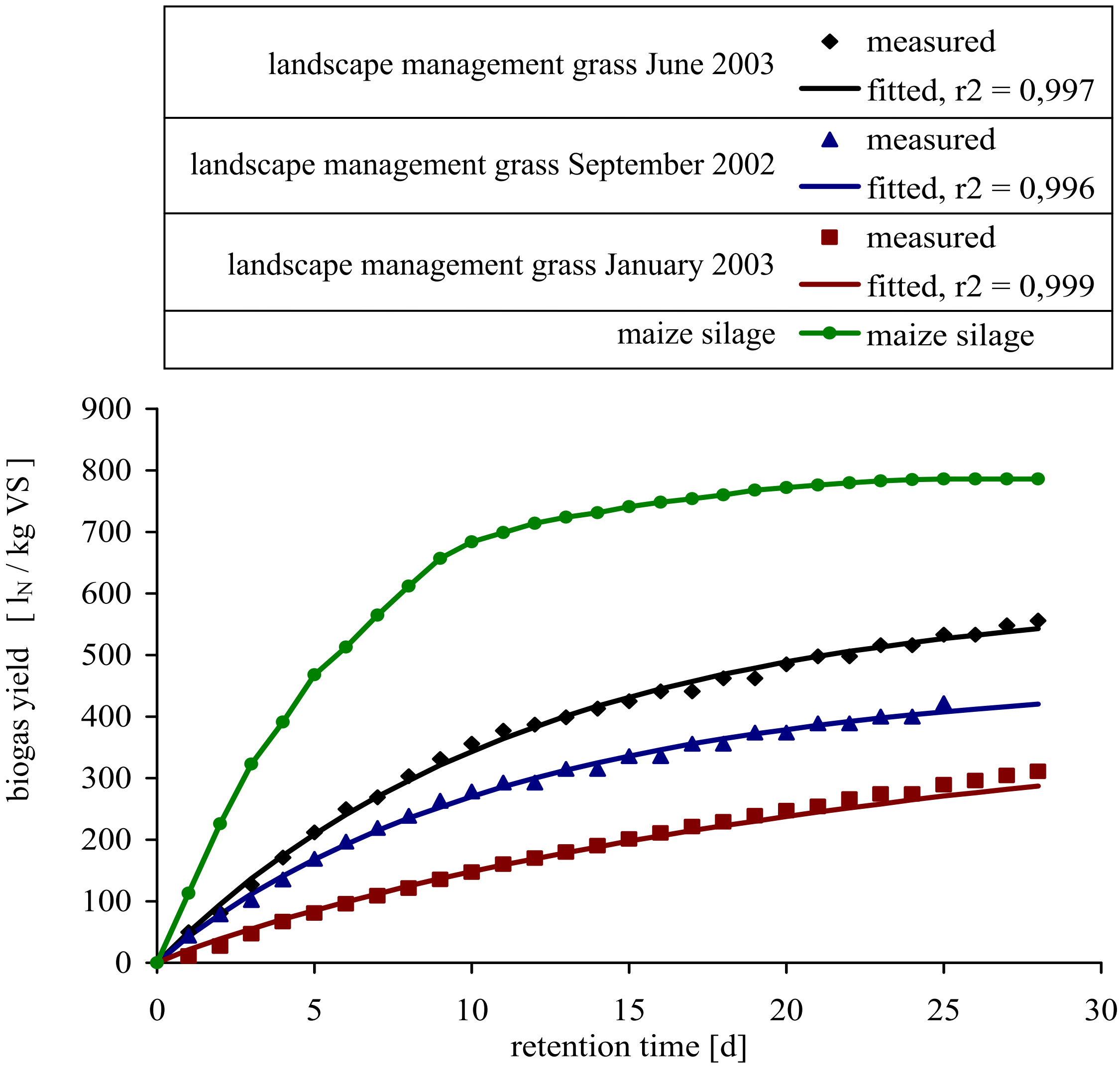

Figure 4. Accumulated biogas yields of landscape management grass from different cutting dates, measured and fitted by regression analysis (maize silage for comparison)

The mean variation coefficient of the biogas yields from the two duplicates of all batch series accounts for 17.0 %. Since the method of the batch experiments is standardised and the variation coefficient of many series is much lower the deviation between the duplicates has to be led back mainly to substrate inhomogeneity.

Subsuming the biogas yields of landscape management grass obtained over three years to monthly mean values, there is an obvious decline of the biogas yields in the seasonal pattern (fig. 5). Starting at an already relatively low level of 547 l_N/kg VS in mid-June, biogas yields decrease to a range of 400 - 450 l_N/kg VS in the period from July to October and end up at 299 l_N/kg VS in February. The results confirm the expectation that the substrate-specific biogas production will be reduced with growing age of vegetation due to increasing contents of crude fibre that is not easily available for anaerobic degradation.

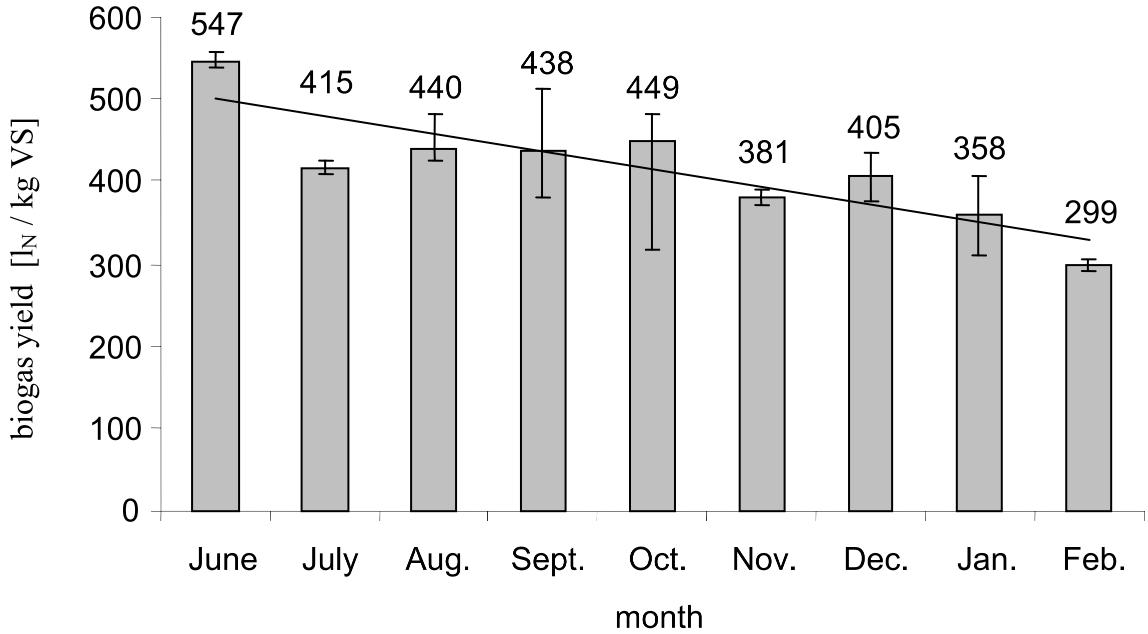

Figure 5. Seasonal pattern of substrate-specific biogas yields from landscape management grass (mean, minimum and maximum values and trend line)

Comparing biogas yields from landscape management grass to those of other crop substrates, it has to be stated that as a rule they are clearly lower (Table 3). Maize, cereals and early cut intensive grasses give biogas yields that are up to 1.6 times higher than even the highest possible yield of landscape management grass from mid-June. The results found for landscape management grass from mid-June are conform with the biogas yields of extensive grassland cut known from literature with 500 - 600 l/kg VS (Baserga and Egger 1997, Table 2). Throughout the season, biogas yields from landscape management grass decrease more and more below that range. However, with a minimum of 299 l_N/kg VS in February they are by far not as low as reported by Lemmer and Oechsner 2002 with 80 l/kg VS (Table 2).

Table 3. Biogas yields of landscape management grass and other crop substrates

crop		comments	biogas yield [l_N/kg VS]	reference
maize		different varieties and harvesting dates, ensiled	680 - 860	Linke et al. 2003
		different varieties and harvesting dates, ensiled	700 - 780	Oechsner et al. 2003
		different varieties and harvesting dates, fresh and ensiled	330 - 745	Amon et al. 2003, 2004
cereals	barley	milk stage, whole crop silage	920	Linke et al. 2003
	triticale	milk stage, whole crop silage	740	
	rye	milk stage, whole crop silage	730	

4.2 Methane Yields

Measured methane contents in the biogas are largely constant throughout the season within a range of 48 – 55 Vol.-% and with a mean value of 52 Vol.-%. The mean variation coefficient of the methane contents from the two duplicates of all batch series accounts for 6.4%.

The figures confirm the expectation of small methane contents in relation to other substrates. As known from literature and practice, methane contents of 50 –75% are usually attainable (Weiland 2001). Thus, the methane contents obtained from landscape management grass fall in the lower range. Methane contents of 69 - 70 Vol.-% in the biogas from an ensiled intensive forage mixture of grasses and clover are much larger while results for maize with 49 - 56 Vol.-% resemble those found for landscape management grass (Amon et al. 2003).

Methane contents in biogas from landscape management grass were assumed to be small because the contents of crude protein and crude fat of the substrate are small in general and particularly at late cutting periods (Table 1). However, the tendency of decreasing contents of crude protein and crude fat with growing age of vegetation is not reflected in the even seasonal pattern of methane contents in the biogas produced.

Whilst methane contents remain constant, substrate-specific methane yields decline throughout the season as a result of the decline in biogas yields (fig. 6). Methane yields decrease linearly from 298 l_N/kg VS in June to 155 l_N/kg VS in February.

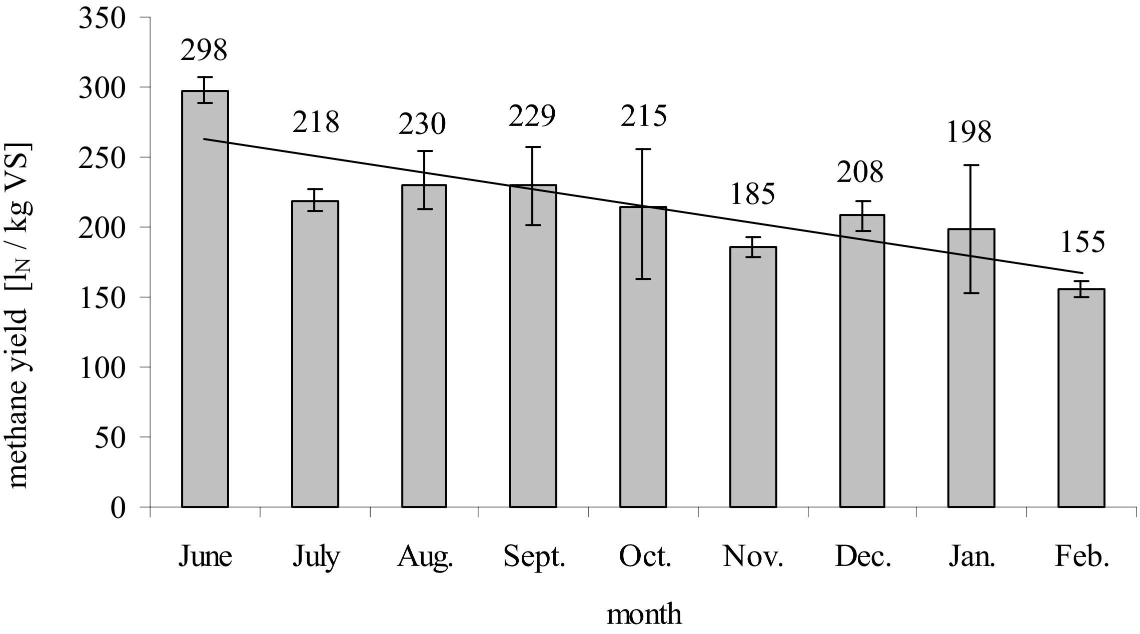

Figure 6. Seasonal pattern of substrate-specific methane yields from landscape management grass (mean, minimum and maximum values and trend line)

The methane yields obtained are consistent with those from grass reported by other authors for similar harvesting periods. The methane yield of 298 l_N/kg VS from landscape management grass from mid-June is nearly the same as from an intensive forage mixture of grasses and clover from mid-June with 297 l_N/kg VS (Amon et al. 2003, Table 2). As expected, methane yields from intensive grasses early cut at mid-May are larger with 310 - 360 l_N/kg VS (Mähnert et al. 2002, Table 2).

In relation to other crop substrates, methane yields from landscape management grass seem to be low as was found for the biogas yields. For example, methane yields from maize are reported to be 422 l/kg VS (Linke et al. 1999), 310 - 380 l_N/kg VS (Oechsner et al. 2003) and 342 l_N/kg VS (Gunnaseelan 1997). In contrast to these figures, methane yields from maize of 195 - 286 l_N/kg VS reported by Amon et al. 2003 are similar to those of landscape management grass.

Referring to crop substrates, area-specific methane yields are of special interest since they show the possible methane and monetary yields per unit area and indicate the competitiveness of biogas crops with other crops and among each other. Regarding landscape management grass in particular, only the seasonal pattern of area-specific methane yields provides the needed information on the optimum cutting period.

Looking for the seasonal pattern of the area-specific methane yields from landscape management grass, the seasonal patterns of (i) substrate-specific methane yields, (ii) grass yields, and (iii) contents of volatile solids in the grass have to be taken into consideration:

- Substrate-specific methane yields follow a linear tendency of decrease in the seasonal pattern (fig. 6).

- Grass yields of landscape management biotopes are rising at the beginning of the vegetation period, reach a maximum in August/September and decrease subsequently until the beginning of the next vegetation period in spring (Prochnow 1994).
- The contents of volatile solids remain nearly the same throughout the season within a range from 86.2 to 92.0% in TS and accounting for a mean value of 89.7% in TS.

The combination of these three seasonal patterns results in area-specific methane yields (fig. 7). They amount to 1164 m^3 ha^{-1} a^{-1} in June then increase to a maximum of 1604 m^3 ha^{-1} a^{-1} in September and fall rapidly after that until 155 m^3 ha^{-1} a^{-1} in February. These figures show that from the point of the highest possible methane yields per unit area, the optimum cutting period of landscape management grassland is late summer.

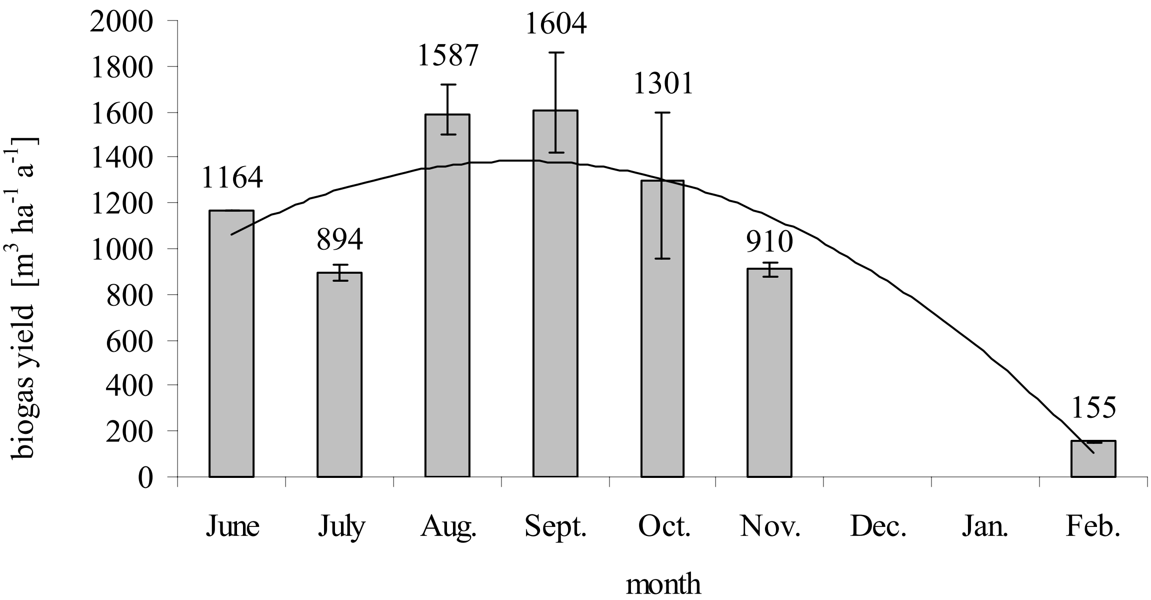

Figure 7. Seasonal pattern of area-specific methane yields from landscape management grass (mean, minimum and maximum values and trend curve)

Comparing landscape management grass to other crop substrates, once again it arises that even the maximum area-specific methane yields from September distinctly stay behind those of maize, early cut intensive grasses, perennial legumes or grain (Table 4). Area-specific methane yields from maize are 2.3-6.2 times higher and from rye grass or alfalfa 2.5 times higher than from landscape management grass.

Table 4. Area-specific methane yields from crop substrates

crop	comments	area-specific methane yield [$m^3\ ha^{-1}\ a^{-1}$]	reference
maize	different varieties and harvesting dates, ensiled	4400 - 10000	Oechsner et al. 2003
	different varieties and harvesting dates, fresh and ensiled	3743 - 8529	Amon et al. 2003
	calculated for yields in Thuringia, South-East Germany	5780	Vetter 2004
wheat	calculated for yields in Thuringia, South-East Germany	2960	Vetter 2004
alfalfa		3965	
clover		2530	
rye grass		4060	
intensive forage mixture of grasses and clover	varying harvesting dates, biomass yields from 2.5 – 14 t VS/ha	743 - 5180	Amon et al. 2003
grass from landscape management	September (maximum in the seasonal pattern)	1604	(fig. 7)

4.3 Further Considerations

Biomethanisation of landscape management grass is possible, but with relatively low biogas and methane yields. Regarding the use of the grass as a substrate for biomethanisation some further considerations have to be paid attention to.

Extended investigations on different management regimes and types of vegetation are necessary. Previous research work on aerobic decomposition of landscape management grass shows that the process runs faster with biomass from the second cut than from the first cut (Prochnow et al. 2000). Since grass from the second cut is characterised by more favourable conditions for biodegradation it can be expected that anaerobic digestion leads to similar results. A general survey has to include the total area-specific methane yields of one- and two-cut meadows. The type of vegetation has no significant influence on the rate of aerobic decomposition (Prochnow et al. 2000). It has to be proved whether this is valid for anarobic digestion, too.

Since landscape management grass accumulates seasonally, but biogas plants have to be fed continuously, the substrate has to be conserved. Considering the favourable contents of total solids for the digestion process as well as the weather conditions during late cutting periods, the main form of conservation will be ensilaging. But with growing age of vegetation, serious problems in the ensilaging process occur. Decreasing contents of water soluble carbohydrates lead to a reduced production of lactic acid by the lactic bacteria. Rising contents of crude fibre diminish compactability of the grass. Silages of grass harvested from September on are reported to be of poor quality (Prochnow 1994).

The conservation of landscape management grass cut late has to be regarded as an unsolved problem.

Landscape management sites often are either wet biotopes with poor trafficability or dry biotopes with steep slopes. Machinery has to be adapted to these unfavourable conditions. This usually restricts machine capacities and enhances costs (Kraschinski et al. 2001). Hence, costs for harvesting biomass from landscape management grassland will generally exceed those from intensive grassland.

For finally estimating the profitability of using landscape management grass for biomethanisation comprehensive economic calculations are needed. They have to comprise the whole chain of substrate supply including harvest, transport, conservation and storage as well as building and running the biogas plant and using the biogas. The results obtained from this study will contribute to an intended economic assessment.

5. CONCLUSIONS

Using landscape management grass as a substrate for the biomethanisation process is generally possible. Biogas and methane yields are subject to characteristic seasonal variations. Substrate-specific biogas and methane yields show a linear decrease with proceeding age of vegetation while area-specific yields reach a maximum in late summer. Even the highest possible biogas and methane yields from landscape management grass remain on a low level in relation to other crop substrates. Profitability has to be quantified by economic calculations.

Abbreviations

FM	Fresh Mass
l_N	Norm-Litre (converted to standard conditions with 273,15 K ; 101,325kPa)
TS	Total Solids
VS	Volatile Solids

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