Weissbach, Friedrich; Parr, Klaus; Reinsdorf, Uwe; Warnke-Gurgel, Christina and Losand, Bernd

Losses of methane forming potential of pulpified sugar beets stored in open ground basins

The aim of this study was to examine the losses of methane forming potential during storage of pulpified sugar beets in open lagoons. A method was developed enabling the quantification of the losses without the need of a mass balance.For the use as substrate for biogas production, it has been proposed to pulpify sugar beets and to store this material in open ground basins (lagoons) which are lined with plastic film. The organic matter (OM) in the inner regions of the lagoon is preserved by anaerobic conditions and lactic acid fermentation. In the surface layer, which is exposed to the atmosphere, additional losses are generated by aerobic substrate degradation and evaporation of volatile compounds.

Keywords
Biogas, sugar beets, conservation, open ground basins, lagoons, methane forming potential

Abstract
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In order to enable the use of sugar beets as a substrate for biogas production continuously throughout the year, they have to be preserved. But sugar beets are not suitable for silage making by conventional technology like in use for forages, because their main constituent is the water-soluble sugar. During ensiling, large amounts of effluent are produced which contains this sugar and fermentation products generated from it. This effluent must be retained within the silo. In addition, due to intensive lactic acid fermentation, sugar beet silage has a very low pH and is extremely corrosive to concrete and metals. Therefore, ensiling of sugar beets requires water-tight corrosion-resistant silos. At the other hand, the use of sugar beets as a substrate for biogas needs thorough processing of the whole beets before they can be fed into the fermenter. Therefore, it is obvious to process sugar beets to a pumpable mass already before preservation. This offers the advantage that the daily removal of the sugar beet silage from the storage and its supply to the biogas facility can be done by pumping. However, the protection of the surface of such a soft mass against ingress of air by sealing with plastic film, which is the typical procedure in silage making from forages, does not seem to be a viable option here. In conclusion, based on all the aforementioned reasons, the use of water- and gas-tight storage facilities made from corrosion-resistant material would be desirable to perfectly preserve this biomass, but are obviously too expensive.

The storage of whole sugar beets in plastic tubes was proposed and studied as a technological alternative [1, 2]. This technology results in lowest conservation losses but it has its constraints due to the required processing steps prior to storage (removal of stones, cleaning and washing, surface treatment with a preservative) as well as during feed-out (processing). All these processing steps are time-consuming and costly. Storage of sugar beets in plastic tubes is therefore only meaningful under specific circumstances, e. g. to prolong their use for a certain period of time beyond the feeding of fresh sugar beets.

As a potential solution of the problem, the possibility of the storage of pulpified sugar beets in open ground basins (lagoons) which are lined with plastic film have been discussed and tested since 2009 [3]. This preservation technology offers numerous advantages, e. g. low building costs, resistance to corrosion, complete retention of the effluent and easiest possible feed-out technology of the silage. However, this technology is accompanied by additional conservation losses, which occur in the surface layers of the mass. The magnitude of these losses has not yet been evaluated sufficiently. Therefore, the aim of this study was to determine the losses of methane forming potential during storage of pulpified sugar beets in open lagoons.

Biological processes during storage

It was observed that shredded sugar beets spontaneously change from solid state to a pumpable mass within 24 hours. The reason behind this is the death of plant tissue in anaerobic conditions which prevail in the inner section of the pile of shredded sugar beets. The cells lose their turgescence, and cell sap is released. The formed suspension of solid particles from died-off beet tissue and released sap disperses across the lagoon by itself resulting in a pumpable pulp which cannot be walked on.

This pulp is immediately subjected to spontaneous fermentations. Initially, lactic acid fermentation is the dominating metabolic pathway but is terminated once a pH value of 3.3 to 3.5 is attained. At this very high degree of acidity, virtually no bacteria can be grow but fungi (yeasts and moulds) can still be metabolically active. In the core of the pulp, yeasts utilize residual sugar to produce ethanol, thereby releasing significant amounts of carbon dioxide (CO_2) (**Figure 1**). This gas escapes from the deeper layers of the pulp at preferred, sometimes well-visible emersion points.

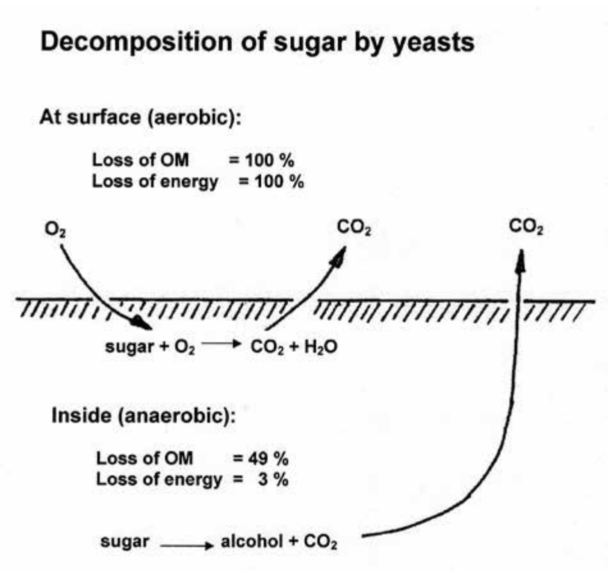
At the surface, where the mass is exposed to oxygen, yeasts and other fungi degrade sugar, and at later stages also lactic acid and other compounds of the sap and the beet pith (mainly pectins) are converted into CO_2 and water. Consequently, pH rises so that bacteria can again thrive, thereby contributing to further organic matter decomposition. Not or hardly degradable substances remain unchanged. Depending on the weather conditions, those form a more or less dry, dark-brown crust at the surface. A few centimetres beneath this crust, also moulds are metabolically active which can be seen by the frequently occurring, mostly reddish discolorations of the material. The colour of mould spots is affected by the species which develops. Like yeasts, moulds are well adapted to low pH conditions, but they require at least minute concentrations of oxygen to grow. However, moulds are not visible right on the surface. This finding may be explained by the fact that the production of mycelium is inhibited by the direct action of the UV radiation of the sun at the surface. It can be expected that every form of shading of the surface, e. g. by erecting a rain-protection roof or by covering of the lagoon with dark plastic film, alleviates the inhibitory effect and results in intensified substrate decomposition by moulds.

Methodological problems and their solution

The determination of conservation losses by mass balance of input and output is technically not feasible for lagoon storage. Neither it is possible to accurately measure the amount of sugar beets brought into the lagoon nor to exactly determine the amount of silage removed. In addition, the mass balance based on fresh matter will unavoidably be biased by uncontrollable influx of rain water and water evaporation. It also seems impossible to take representative samples from a lagoon to be used as scientific basis for the transfer of results from laboratory analyses to defined amounts of fresh matter and observation periods. Although model experiments using small open containers (e. g. with 1 m^3 capacity) enable mass balances and give an indication on the magnitude of losses, they cannot entirely simulate the processes in the lagoon due to, for instance, too a low filling height.

These constraints can only be overcome by using the increase in concentration of such substances which are not subjected to biological decomposition processes. The working hypothesis was therefore that the content of crude ash (XA) or mineral soil components (HCl-insoluble ash) can be used as suitable internal markers.

Fig. 1



Substrate degradation by yeasts in silage from pulpified sugar beets stored in an open ground basin (loss figures related to monosaccharides)

If changes in concentration shall be used as indicator for losses, then there is the crucial need to define a basis for the concentration values. On account of the uncontrollable water influx and water evaporation only the dry matter (DM) of the silage can be used, which must be corrected for the loss of all volatiles organic compounds evaporated during sample drying (DM_c). A method for this DM correction of sugar beet silages is available [4].

Material and methods

Within the scope of this experiment, a lagoon filled with pulpified sugar beet was studied. At the upper slope edge, the lagoon was 35 m long and 30 m wide. At the bottom of the slope edge, the dimensions were 27 m by 22 m. The lagoon was on average 4 m deep, and the slope angle was 45°. The lagoon was filled with about 2,200 t of shredded sugar beets in late October 2011. Prior to storage, the sugar beets were de-stoned and superficially cleaned by using kainite-solution in a so-called “Weber-Wanne” (Strube GmbH & Co. KG).

Removal of the pulpified mass by means of a thick matter pump began in January 2012 and continued until the 2012 sugar beet harvest. During this period, pulp samples from the bottom of the lagoon were taken at 4 weeks intervals and subsequently analysed. A total of 7 samples taken from February until August 2012 could be used for evaluation. Additional 6 samples from the bottom of the lagoon were taken within one week in May 2012.

In order to determine the effects of unrestricted air ingress, different types of core samplers were used to retrieve samples from beneath the surface at defined intervals. In April 2012, samples were taken from a platform which was connected to the side of a crane boom. By this technique, samples could be taken only from the edges of the lagoon. To take samples from the centre of the lagoon and from different, well defined layers below the surface, special installations had to be used. These contained a walk-on raft and a sample corer which could be opened and closed below the surface at each desired depth. With this corer, all of the 18 samples, which are decisive for the study, were taken in July 2012.

The following parameters were determined in the samples: dry matter (DM), crude ash (XA), hydrochloric acid insoluble ash (SOIL), the organic fraction of acid detergent fibre (ADF_{org}), sugar, fermentation acids and alcohols as well as pH.

The DM concentration of the silages was corrected by the loss of volatiles during sample drying according to the following equation [4]:

$$DM_c\left[g/kgFM\right] = DM_n + 0.95\left(FA\right) + 0.08\left(LA\right) + 1.00\left(AL\right)\left[g/kgFM\right] \qquad \text{(Eq. 1)}$$

where DM_c is corrected DM, DM_n is not corrected DM, FM is fresh matter, FA is the sum of volatile fatty acids (C_2 to C_6), LA is lactic acid and AL is the sum of all mono- and bivalent alcohols (C_1 to C_4). The values for the parameters XA, SOIL and ADF_{org} which are normally based on uncorrected DM (DM_n) were multiplied with the quotient of DM_n/DM_c:

$$XA_{Silage}\left[g/kgDM_c\right] = \frac{DM_n}{DM_c} XA_{Silage}\left[g/kgDM_n\right] \qquad \text{(Eq. 2)}$$

Accordingly, the values for SOIL and ADF_{org} were corrected in the same way.
The concentration of OM must be derived from the following equation:

$$OM_{Silage}\left[g/kgDM_c\right] = 1000 - XA_{Silage}\left[g/kgDM_c\right] \qquad \text{(Eq. 3)}$$

For the prediction of DM losses (DML) and the losses of OM (OML) based on the changes in XA content, the following equations were deduced:

$$DML\left[\%\right] = 100\left(1 - \frac{XA_{Beets}\left[g/kgDM\right]}{XA_{Silage}\left[g/kgDM_c\right]}\right) \qquad \text{(Eq. 4)}$$

$$OML\left[\%\right] = 1000\frac{DML\left[\%\right]}{1000 - XA_{Beets}\left[g/kgDM\right]} \qquad \text{(Eq. 5)}$$

In this case, the XA content is used as internal marker. Accordingly, also the content of HCl-insoluble ash (SOIL) can be employed:

$$DML\left[\%\right] = 100\left(1 - \frac{SOIL_{Beets}\left[g/kgDM\right]}{SOIL_{Silage}\left[g/kgDM_c\right]}\right) \qquad \text{(Eq. 6)}$$

The transformation of DML into OML is done then in the same way like in case of the use of XA as marker by equation 5.

In order to be able to use these equations, the concentrations of XA and SOIL in the fresh, not ensiled sugar beets had to be known in addition to those from the silages. Data on these parameters from fresh beets were not available when the silages were analysed. As an alternative, the measured values for all fermentation end-products in the silage from the anaerobic section of the lagoon can be used to stoichiometrically calculate the magnitude of the expected fermentation losses, and by using these estimated values to conclude on the XA and SOIL contents of the fresh sugar beets.

Per each kg of produced acetic acid and ethanol, 733 g and 955 g, respectively, of CO_2 are formed. As the vast proportion of the volatile fatty acids is composed of acetic acid and ethanol represents the predominant proportion of the total alcohol content, these specific CO_2-formation rates can be applied to the sum parameters FA and AL. Therefore, the percentaged fermentation loss of DM (FL_{DM}) and OM (FL_{OM}) was calculated by using the following equations:

$$FL_{DM}\left[\%\right] = 100\frac{0.733\left(FA\right) + 0.995\left(AL\right)\left[g/kgFM\right]}{DM_c + 0.733\left(FA\right) + 0.955\left(AL\right)\left[g/kgFM\right]} \qquad \text{(Eq. 7)}$$

$$FL_{OM}\left[\%\right] = 1000\frac{FL_{DM}\left[\%\right]}{1000 - XA_{Beets}\left[g/kgDM\right]} \qquad \text{(Eq. 8)}$$

Based on the measured XA and SOIL contents, expected fermentation losses of DM can be used to calculate the XA and SOIL concentrations in the fresh sugar beets:

$$XA_{Beets}\left[g/kgDM\right] = 100\frac{XA_{Silage}\left[g/kgDM_c\right]}{100 + FL_{DM}\left[\%\right]} \qquad \text{(Eq. 9)}$$

$$SOIL_{Beets}\left[g/kgDM\right] = 100\frac{SOIL_{Silage}\left[g/kgDM_c\right]}{100 + FL_{DM}\left[\%\right]} \qquad \text{(Eq. 10)}$$

The content of fermentable organic matter (FOM) in sugar beet silages was calculated according to equation 11:

$$FOM\left[g/kgDM_c\right] = 991 - \left(XA\right) - 0.50\left(ADF_{org}\right)\left[g/kgDM_c\right] \qquad \text{(Eq. 11)}$$

and their methane forming potential (volume at standard temperature and pressure) determined by using equation 12 [5]:

$$Methane\left[l/kgDM_c\right] = 0.375\left(FOM\right) + 0.32\left(AL\right)\left[g/kgDM_c\right] \qquad \text{(Eq. 12)}$$

Results and discussion

Data on the concentrations of fermentation end-products based on fresh matter are summarized in **Table 1**. The most part of the sugar from the beets was fermented to mainly lactic acid, acetic acid and ethanol. The detected methanol originated from the degradation of pectins. Acids and alcohols other than those aforementioned were only measured at minute concentrations. All these substances are volatile to a certain extent, and their evaporation during the determination of DM results in a mis-

Table 1

Contents of fermentation end-products and sugar in the fresh matter (FM) of silage from pulpified sugar beets stored in an open ground basin

Probenahme-technik *Sampling technique*	**Schicht unter der Oberfläche** *Layer below the surface*	**Probenzahl** *Number of samples*	**pH**	**Milchsäure** *Lactic acid*	**Essigsäure** *Acetic acid*	**Propionsäure** *Propionic acid*	**Methanol** *Methanol*	**Ethanol** *Ethanol*	**Zucker** *Sugar*
				g/kg FM					
Stechproben vom Rand/*Core samples from edge*									
	0–5 cm	6	n. b.$^{3)}$	n. b.	n. b.	n. b.	n. b.	n. b.	n. b.
	0–20 cm	6	4.0	11.9	1.8	0.3	0.5	1.2	n. b.
	70 –90 cm	6	3.5	26.3	3.1	0.2	0.7	5.8	n. b.
Stechproben vom Zentrum/*Core samples from center*									
	0–50 cm	3	3.5	19.6	8.5	0.4	0.4	6.4	17.1
	50 –100 cm	3	3.3	28.0	8.5	0.2	0.9	11.0	19.7
	100–150 cm	6	3.3	34.9	8.9	0.1	1.1	13.6	35.5
	150–200 cm	6	3.3	33.9	9.0	0.1	1.0	10.9	43.7
Absaugproben/*Samples taken by suction*									
	Grund/*Bottom*$^{1)}$	6	3.3	21.8	10.5	0.1	1.0	12.3	45.0
	Grund/*Bottom*$^{2)}$	7	3.3	20.7	8.6	0.2	0.9	10.5	22.3

$^{1)}$ Mai/*May.* $^{2)}$ Februar bis August/*February to August.* $^{3)}$ n. b. = nicht bestimmt/*not determined.*

evaluation of the concentrations of DM and OM and all parameters whose dimensions are typically related to them.

In **Table 2**, the parameters DM_n and DM_c are given. Moreover, the measured contents of XA, SOIL and ADF_{org} per kg DM_c are compiled. In this table as well as in the following two tables, values represent the means ± standard deviation.

It has to be stated that there were pronounced differences in the parameters XA and SOIL and that they were strongly affected by sampling site and sampling technique. Moreover, there was found a close correlation between these two parameters. This correlation proves that XA content is primarily determined by fine earth components originating from residual

Table 2

Contents of crude ash (XA), HCl-insoluble ash (SOIL) and the organic proportion of ADF (ADF_{org}) in the corrected DM (DMc) of silage from pulpified sugar beets stored in an open ground basin

Probenahme-technik *Sampling technique*	**Schichttiefe unter der Oberfläche** *Layer below the surface*	**Probenzahl** *Number of samples*	**TS_n** *DM_n* %	**TS_k** *DM_c* %	**XA** *Crude ash*	**SAND** *SOIL*	**ADF_{org}** *ADF_{org}*
						g/kg TS_k g/kg DMc	
Stechproben vom Rand/*Core samples from edge*							
	0–5 cm	6	18.9	18.9	436 ± 30	386 ± $^{3)}$	442 ± 34
	0–20 cm	6	9.7	10.2	322 ± 40	260 ± 43	238 ± 13
	70–90 cm	6	8.5	9.7	187 ± 42	151 ± 40	118 ± 26
Stechproben vom Zentrum/*Core samples from center*							
	0–50 cm	3	18.5	20.2	221 ± 39	n. b.$^{4)}$	102 ± 20
	50–100 cm	3	18.8	21.1	161 ± 13	n. b.	82 ± 3
	100–150 cm	5	18.8	21.7	138 ± 13	102 ± 11	67 ± 7
	150–200 cm	5	18.4	20.8	117 ± 7	79 ± 6	61 ± 6
Absaugproben/*Samples taken by suction*							
	Grund/*Bottom*$^{1)}$	6	16.3	18.8	81 ± 11	45 ± 12	85 ± 2
	Grund/*Bottom*$^{2)}$	7	15.3	17.6	84 ± 34	n. b.	61 ± 5

$^{1)}$ Mai/*May.* $^{2)}$ Februar bis August/*February to August.* $^{3)}$ n = 2. $^{4)}$ n. b. = nicht bestimmt/*not determined.*

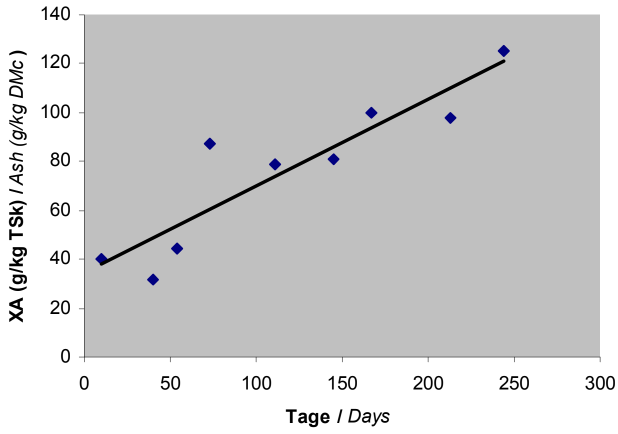
soil contamination after superficial cleaning of the beets. This close correlation between the two parameters enabled the recognition of single randomly extreme values. Thus, one of the 6 samples from each of the two lower layers could be identified as outlier and was therefore excluded from the evaluation of the data pool.

Furthermore, data in **Table 2** demonstrates that aerobic degradation of biomass – and surely also the evaporation of alcohols – from the layers near the surface led to graded increases in XA and SOIL contents. This increase applies also to the content of ADF_{org}. Thus, a contamination of the surface layer with mineral particles from outside (e. g. dust) during storage can reliably be excluded as the cause of the high XA and SOIL contents.

Samples which were retrieved by suction showed lower XA and SOIL contents than were found in the material that remained in the lagoon. This means that a separation process during silage removal by suction from the bottom of the lagoon had taken place. The evaluation of the analytical values of the monthly samples taken by suction revealed that lactic acid and alcohol levels decreased whereas XA content increased with progressing feed-out. For the XA content, this development is illustrated in **Figure 2**.

On account of this unavoidable separation of the material during removal from the lagoon, the XA and SOIL contents of the material obtained by suction cannot be used as reference for the determination of losses. In fact, only the XA and SOIL concentrations of the material that remained in the lagoon is to be used as reference. It is evident that the XA and SOIL values from the deepest of all analysed layers may be rather usable for this purpose. Regarding this layer it can be most surely assumed that the increase of XA and SOIL contents from fresh sugar beets to silage can be solely attributed to fermentation processes and are not caused by aerobic degradation of biomass or evaporation. The validity of this assumption can be checked by using the stoichiometrically calculated fermentation losses in this material layer. The evaluation criterion should be the best possible approach of the fermentation losses from using the marker method to that from stoichiometric calculation.

Fig. 2



Increase of ash content of silage made from pulpified sugar beets and taken out by suction from an open ground basin during the course of the year

Table 3 shows the results of the calculation of OM losses. Silages from 150 to 200 cm below the surface contained fermentation end-products (FA and AL) which, according to equation 7, correspond to DM losses of 8%. The mean concentrations of XA and SOIL were found to be 117 g and 79 g per kg DM_c, respectively, in this layer (see **Table 2**). Consequently, by using equations 9 and 10, the following figures for the fresh beets are obtained:

- XA_{Beets} = 108 g/kg DM and
- $SOIL_{Beets}$ = 73 g/kg DM.

If these concentrations are applied to all tested material layers and the analysed values for XA_{Silage} and $SOIL_{Silage}$, respectively, are put in equations 4, 5 and 6, then the results shown in **Table 3** on the determination of losses by the marker method are obtained.

In the lower section of **Table 3**, the expected fermentation losses are given which were obtained by stoichiometric calculations. Fermentation losses of DM were derived from the concentration of fermentation end-products by using equation 7. These values are converted to fermentation losses of OM by employing equation 8. For the last step in this evaluation procedure, the XA content of fresh sugar beets is required, for which 108 g/kg DM was already deduced. For the other two data sets regarding the material which was taken by suction, 74 and 77 g XA, respectively, per kg DM of fresh beets was assumed. These values were calculated (like the 108 g/kg DM for the material from the deepest layer) based on the concentration of fermentation end-products in the respective material retrieved by suction.

If the substantial standard deviations of the losses obtained by the marker method are taken into consideration, then the chosen reference values for XA and SOIL in the fresh sugar beets led to results which agree very well with the stoichiometrically calculated fermentation losses. The magnitude of these losses was substantiated by numerous mass balances from lab-scale experiments with sugar beets in gas-tight silos [2]. It is to be concluded that within the anaerobic section of the lagoon,

- about 10 % OM losses

can be expected. In all other sections which are more or less affected by the open surface significantly higher OM losses will be found. The calculated losses based on SOIL content support those based on XA content. By trend, these loss figures are even somewhat higher.

According to equation 11, the content of FOM was calculated by using XA and ADF_{org} concentrations in the silages. Subsequently FOM and AL were used in equation 12 to predict the methane forming potential (MFP). Data in **Table 4** summarize the results.

The MFP per kg OM of the material in the deeper silage layers supports data from other studies on sugar beet silages

Table 3

Estimation of conservation losses of silage from pulpified sugar beets in an open ground basin by using crude ash (XA) and SOIL contents as internal markers or by stoichiometric calculation from the contentrations of fermentation end-products

Probenahme-Technik ***Sampling technique***	**Schichttiefe unter der Oberfläche** ***Layer below the surface***	**Probenzahl** ***Number of samples***	**Verluste nach Markermethode/*Losses by marker method*** **XA als Marker/*Crude ash as marker*** **TS$_k$/*DM$_c$*** %	**oTS/*OM*** %	**SAND als Marker/*SOIL as marker*** **TS$_k$/*DM$_c$*** %	**oTS/*OM*** %
Stechproben vom Rand/*Core samples from edge*						
	0–5 cm	6	75 ± 2	84 ± 2		
	0–20 cm	6	66 ± 4	74 ± 5	71 ± 5	80 ± 5
	70–90 cm	6	40 ± 14	44 ± 16	48 ± 15	54 ± 17
Stechproben vom Zentrum/*Core samples from center*						
	0–50 cm	3	50 ± 9	56 ± 10		
	50–100 cm	3	33 ± 5	36 ± 6		
	100–150 cm	5	21 ± 7	24 ± 8	28 ± 7	31 ± 8
	150–200 cm	5	7 ± 5	8 ± 6	8 ± 7	9 ± 8
			Verluste nach der stöchiometrischen Berechnung aus dem Gehalt an Gärungsendprodukten ***Losses by stoichiometric calculation from the contentrations of fermentation end-products*** **TS$_k$/*DM$_c$*** %	**oTS/*OM*** %		
Stechproben vom Zentrum/*Core samples from center*						
	150–200 cm	6	8 ± 1	9 ± 1		
Absaugproben/*Samples taken by suction*						
	Grund/*Bottom*1)	6	10 ± 1	11 ± 1		
	Grund/*Bottom*2)	7	10 ± 2	11 ± 3		

1) Mai/*May*. 2) Februar bis August/*February to August*.

Table 4

Content of fermentable organic matter (FOM), total content of alcohols (AL) and methane forming potential of silage from pulpified sugar beets stored in an open ground basin

Probenahmetechnik ***Sampling technique***	**Schicht unter der Oberfläche** ***Layer below the surface***	**Probenzahl** ***Number of samples***	**FoTS/*FOM*** g/kg TS$_k$ *g/kg DMc*	**AL/*AL*** g/kg TS$_k$ *g/kg DMc*	**Methan/*Methane*** **l/kg oTS** ***l/kg OM***	**m^3/t FM** ***m^3/t FM***
Stechproben vom Rand/*Core samples from edge*						
	0–5 cm	6	335 ± 45	n. b.	222 ± 19	24 ± 5
	0–20 cm	6	550 ± 45	14 ± 7	298 ± 5	21 ± 4
	70–90 cm	6	745 ± 41	63 ± 22	319 ± 12	25 ± 10
Stechproben vom Zentrum/*Core samples from center*						
	0–50 cm	3	719 ± 49	39 ± 23	362 ± 12	57 ± 5
	50–100 cm	3	790 ± 14	59 ± 34	375 ± 13	66 ± 4
	100–150 cm	5	819 ± 14	76 ± 20	385 ± 7	72 ± 3
	150–200 cm	5	844 ± 6	59 ± 17	379 ± 5	70 ± 2
Absaugproben/*Samples taken by suction*						
	Grund/*Bottom*1)	6	868 ± 11	72 ± 5	368 ± 1	64 ± 3
	Grund/*Bottom*2)	7	877 ± 34	70 ± 23	385 ± 8	56 ± 11

1) Mai/*May*. 2) Februar bis August/*February to August*.

[2]. The MFP of the silage from the both lowest layers do not differ significantly so that these results can be summarized. On average of the 10 samples which were taken by core sampler 100 cm below the surface and used in the evaluation, MFP was determined to be

- 382 litres per kg OM.

The MFP markedly decreases in the upper layers. The stronger the material near the surface is subjected to aerobic biomass degradation and volatilization of organic compounds the lower is the MFP per kg OM.

The MFP based on fresh matter of the pulpified sugar beet silage even in the deeper layers of the lagoon revealed to be substantially lower (approximately 70 m^3/t) than that of silages stored in closed silos. This can be explained by the unavoidable influx of rain water.

Data in **Table 5** summarize the results on OM losses and on MFP per kg OM as affected by the depth of silage layer below the open surface. For fresh sugar beets, 360 litres methane per kg OM were taken from earlier studies [2, 5].

Table 5

Loss of OM and methane forming potential of OM of silage from pulpified sugar beets during storage in open silos within every single layer

	Schicht unter der Oberfläche ***Layer below the surface***	**Verlust an oTS** ***Loss of OM*** **%**	**Methanbildungspotenzial** ***Methane forming potential*** **m^3/kg oTS** ***m^3/kg OM***
Silage/*Silage*			
	0–50 cm	56	362
	50–100 cm	36	375
	100–150 cm	24	382
	> 150 cm	10	382
Frische Zuckerrüben/*Fresh sugar beets*			
			360

Table 6

Expected minimum of losses during storage of silage from pulpified sugar beets in silos with open surface

Füllstandshöhe ***Filling height***	**Verluste/*Losses* [%]**		
	oTS ***OM***	**MBP** ***Methane forming potential***	**Differenz** ***Difference***
Im Durchschnitt des ganzen Silos/*On average of the tolal silo*			
3 m	26.3	**22.5**	3.8
4 m	23.0	**18.8**	4.2
10 m	14.3	**9.2**	5.1
Im anaeroben Bereich 1)/*In the anaerobic region*			
	10.0	**4.5**	5.5

1) Tiefer als 1,5 m unter der offenen Oberfläche/*more than 1.5 m below the open surface.*

The values in **Table 5** enables the calculation of the losses of OM and MFP in sugar beet silage stored in lagoons and various other open storage reservoirs, depending on their dimensions and the filling heights. For this purpose, the filling heights of the total content of the reservoir has to be divided into layers of 0.5 m each, and the respective volume of each layer has to be calculated. The weighted arithmetic mean of the OM losses from all single layers according to their respective volume proportion permits the quantification of the total OM loss of the reservoir.

In order to obtain the losses of MFP, a MFP balance needs to be established for each of the layer. Based on the simplified assumption of a material density of 1kg/l, the use of the measured OM content/kg FM and the information in **Table 5** it is possible to calculate from how much sugar beet OM this layer was made of and how much MFP was contained therein. Subsequently, this amount of MFP needs to be compared with that which was present at the time of sampling, and finally the percentaged loss for each of the layers is calculated. The weighted arithmetic mean of the individual MFP losses for each layer based on their volumetric proportion of the total volume results in the total MFP loss of the storage system.

Such calculations were made for the studied lagoon with a filling heights of about 3 m after filling. Additionally, calculations were made for a lagoon with a filling heights of 4 m and an upright storage tank at an effective heights of 10 m. Results are given in **Table 6**.

The values in the table are referred to as “minimum losses“ because the losses in the peripheral areas of layers near the surface of a lagoon are higher than those calculated for the centre and because the presented study did also not cover the maximum storage length until the next harvest of sugar beets. The effects of these two factors are difficult to quantify. As to whether these can be partly compensated for by slightly lower losses in the silage, which was removed by suction during the first few months of storage, is possible but remains uncertain. Only for the silage mass which is deposited in the anaerobic sections of the reservoir (>1.5 m below the open surface) additional losses, e.g. due to extended storage length, can be excluded.

Conclusions

The storage of pulpified sugar beets as substrate for biogas production in open ground basins lined with plastic film offers substantial technological and economic advantages over other preservation methods for sugar beets that have been recommend so far. However, these benefits are accompanied by the acceptance of substantial conservation losses and reduce the potential methane yield per hectare. The magnitude of these losses are higher than frequently assumed and should be taken into consideration realistically in the future comparisons made between different technologies and different crops.

The higher conservation losses in open reservoirs as compared with gas-tight storage systems arise from the open surface. The losses in material layers which are unaffected by the open surface are low. These unavoidable losses amount to about 10 % of OM and 5 % of methane forming potential, and they are not affected by type of the storage system and storage length.

The most effective measure to reduce conservation losses in open reservoirs is to increase the filling heights. This similarly applies to ground basins and upright storage systems. Whether higher investments for storage systems are justified or not depends on the magnitude of economic benefits obtained by the achievable reduction in losses.

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Authors

Prof. Dr. agr. habil. Friedrich Weissbach is a freelance consultant for biogas production. 18107 Elmenhorst, e-mail: prof.f.weissbach@web.de

Dipl.-Ing. agr. Klaus Parr is the farm manager of Gut Dummerstorf GmbH, Wilhelm-Stahl-Allee 7, 18196 Dummerstorf, e-mail: klaus.parr@gut-dummerstorf.de

Dipl.-Ing. Uwe Reinsdorf and **Dr. agr. Christina Warnke-Gurgel** are employees of NAWARO BioEnergie Park Güstrow GmbH, Am Langen Bruch 1,18273 Güstrow, e-mail: Uwe_Reinsdorf@nawaro.ag; christina_warnke-gurgel@nawaro.ag

Dr. agr. Bernd Losand is staff member of the State Research Centre of Agriculture and Fisheries of Mecklenburg-West Pomerania, Wilhelm-Stahl-Allee 2, 18196 Dummerstorf, e-mail: b.losand@lfa.mvnet.de

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