The future of forage conservation

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Introduction

The Organizing Committee of this Conference has invited me to elaborate on this demanding and challenging topic. Already to have accepted the invitation appears to be presumptuous because nobody has the power to look into the future.

However, we all are living in an era with many uncertainties and without reliable orientation for the future. Numerous of the old certainties are not valid any longer. Questions like: How do we feed the growing world population? How do we produce sufficient energy? How do we limit global warming to an acceptable level? – are asked with increasing pressure and discussed internationally, but satisfying solutions are not in sight, which are accepted by the international policy, and realizable.

Simple answers are not there anyway due to the massive impact of these problems and their resolution. But what is already clear today is: we all must be prepared for bigger changes than the generations before us and for new challenges to research and development. This also applies to such a special research field which is forage conservation.

To acquire orientation, it is crucial to summarize and urgently re-evaluate our knowledge. What portion of it is fit for the future and what we need in terms of gain of knowledge can only be determined out by a critical and simultaneously constructive discussion process. The attempt to contribute thereto can be the only aim of my presentation, not more.

In the following I would like to explain my view as to why we need to preserve more feed by silage making than in the past and how we can improve the current preservation methods and technologies.

Forage conservation and the problem of methane emission

It is commonly accepted that one of the pre-requirements for the high productivity in cattle farming in the developed regions of the temperate climate zone was the introduction and utilization of efficient methods of forage conservation. The proportion of conserved forages significantly increased in relation to the total yearly feed production, and feed quality has markedly improved during the last 50 years.

In Central and Northern Europe as well as in some parts of North America, this was achieved by replacing hay by silage and by using improved technologies of ensiling grasses and legumes. The spread of growing silage maize in cooler regions then before brought also a further big progress. Today, there is even competition between different silage sources and grassed pasture, which, formerly, had been considered superior in terms of quality and costs. Dairy herds with an average milk yield of 8,000 kg per cow and year, and even more, are kept indoors throughout the year and fed on silage as sole roughage source because this seems to be the only way to meet their very high quality requirements.

From a historical perspective, forage conservation has served one fundamental function – to ensure adequate nutrition of animals also in seasons without or with limited plant growth. There are hardly any regions on the globe in which fresh pasture feed is available throughout the year at constant volume and quality. The alternation is more typical between seasons with and – more or less – without vegetation, between summer and winter, or between wet and dry seasons. Animal production, on the contrary, is a continuous process that requires a constant supply of feed in quantity and quality. Animals do have requirements for maintenance, and only feed intake exceeding this will lead in performance. Each day, on which the genetically and physiologically determined performance potential is not fully used due to insufficient nutrition, will ultimately result in losses in productivity.

Thus, forage conservation resolves the discrepancy between continuity in feed demand and discontinuity in vegetation. It therefore ensures the supply of feed based on demand throughout the year. Moreover, only the conservation of forages enables the fixation of optimal quality which would otherwise change during the course of vegetation. This makes it possible to fully exploit the performance potential of animals throughout the year. Therefore, we must conclude that forage conservation and storage is an essential issue.

Nevertheless, public funding for research in forage conservation has dramatically declined during the last decades in many European countries although there is still a lot to do. Institutes of a high international reputation were closed, and in others was the experienced staff drastically reduced. Existing knowledge could not be passed on to the next generation so that know-how for future use was lost.

However, there are still research needs in forage conservation even in developed countries. In this regard it may be reminded of the frequently occurring, serious problems with food hygiene in the globalized world, which are often caused by hygienic problem of fed silages (Fenlon, 1988; Roberts, 1988; Pahlow et al. 2003; Driehuis and te Giffel, 2009). Even more important is there the need for improvements in emerging nations and developing countries. In these countries is the low level in animal performance often caused by shortages of suitable technologies for forage conservation and therefore a too low extent of storage of feed.

On the other hand, currently there has been enormous financial support for research projects on methane emissions from ruminants in numerous institutes across the globe. Beside carbon dioxide, methane is known to be the most relevant trace gas regarding climate change and contributes to the greenhouse effect. Its emissions should possibly be limited in the interest of limiting global warming.

But methane emissions by ruminants and its potential consequences have been widely known for long. The public, and thereby politics seem to have been become aware of it during the last few years only. Beside astonished realization of the facts, questions have arisen as to whether how much methane is produced by ruminants, if this emission can be reduced, and if not, if we can still afford to keep cattle, sheep and goats? These questions shall be answered by results from ongoing research activities obviously.

However, on the basis of numerous experimental data, which have been available for decades, it is already well possible to take a scientifically sound standpoint on this topic. The formation of methane is an undesired but unavoidable special characteristic of the ruminant´s digestive system. Methane production results in energy loss. On average, 7-9% of ingested gross energy is lost (Schiemann *et al*., 1971).

Trials have frequently been conducted which aimed at reducing ruminal methanogenesis by special feed additives or by diet formulation. As far as feed additives are concerned (e.g. ionophores like monensin), it has been shown that their effects are limited to the first days of administration and that thereafter methane emission reached pre-trial level soon (Kirchgeßner *et al*. 1995). New ideas, approaches and concepts for the control of rumen fermentation by chemical additives (Takahashi, 2010) or bacterial additives (Davis, 2010) still remains largely a matter of speculation. As of yet, no results from animal trials supporting these hypotheses have been published that showed a sustainable reduction in methane emission by additives of any type without affecting animal health or performance. Thus, a solution of the problem by using feed additives is not to be expected in the near future.

The possibilities to influence methane emissions by diet formulation can be evaluated by using regression equations describing the relationship between nutrients and methane formation. The evaluation of the most comprehensive data collection (337 metabolic trials in cattle using 3 to 12 animals per diet, 5 days balance period and about 1,500 data sets) resulted in the following multiple regression equation (Jentsch *et al*., 2009):

$$m = 1.32\ x_1 - 0.56\ x_2 + 1.68\ x_3 + 2.78\ x_4 \qquad r^2 = 0.858$$

where m is the methane energy [J] and x_1 to x_4 are the apparent digestible nutrient fractions [g]: x_1 crude protein, x_2 crude fat, x_3 starch + sugar (≈ NFC) and x_4 N-free organic residue (≈ NDF). It is obvious that the content of cell wall substances (NDF), which are typical for diets for ruminants, has the biggest impact on methane formation. Rations containing high non-fibre carbohydrates (NFC) concentration require high inclusion rates of grain and are therefore not a viable option. The same data sets were used to describe the relationship between dry matter intake by cattle and their methane production (Piatkowsky *et al*., 2010):

$$M = 32.76 - 0.384\ x \qquad r^2 = 0.224$$

where M is the methane weight [g/kg DM] and x the feed intake [DM g/kg live weight]. Taking into consideration typical feed intake figures, methane emissions by different cattle categories can be calculated as well as methane emission as a function of milk yield (Table 1).

Table 1: Methane emmission from cattle

(Piatkowski e al., 2010)

Performance	Methane	
	g/kg DM intake	g/kg Milk
Dairy cows		
Maintinance	28.3	
4000 kg milk/year	24.8	29.5
6000 kg milk/year	23.0	22.0
8000 kg milk/year	21.8	17.4
10000 kg milk/year	20.7	14.6
Heifers		
200 - 300 kg	25.7	
300 - 400 kg	24.7	
Beef cattle		
250 - 350 kg	25.7	
350 - 450 kg	25.0	
450 - 550 kg	25.9	

It can be concluded therefrom that – regardless of how and where on our globe ruminants are kept and fed – at least 2.1 to 2.6% of the ingested DM is converted into methane, and emitted. Increasing performance leads to reduced emission per kg ingested DM and per kg produced milk and beef. Cattle which do not perform due to insufficient feed supply take in low amounts of feed and consequently emit low amounts of methane per animal and day. But these methane emissions are not only unproductive, they are also extremely high (2.8%), if related to ingested DM.

This is the range which covers the magnitude of methane emissions from a given number of cattle and their consumption of plant biomass. Simultaneously, this suggests the limits within which emission can be influenced. More possibilities are not available, and will not become available in the near future. Therefore, one is tempted to conclude that the number of cattle – as well as of sheep and goat for which the same relationships and emission rates per kg ingested DM are applicable – should be drastically reduced. To consume less food of animal origin, for the sake of the earth´s climate, is currently a real request announced in public. Particularly for food products from ruminants is this request entirely unrealistic.

Apart from the fact that the population in emerging or developing countries cannot be denied higher consumption of animal products as a consequence of increasing living standard, the vast portion of agriculturally exploitable land in the world is grassland. Data presented in Table 2 (taken from the Statistical Yearbook of the FAO) show that two thirds of this are pastures. In Brazil, even about 75% of the total land which is utilizable for agricultural purposes is grassland.

Table 2: Grassland as proportion of the total agricultural area

(FAO Statistical Yearbook 2010)

	World		Brazil	
	Area Million ha	Proportion %	Area Million ha	Proportion %
Arable land	1381	28	61	23
Permanent crop	146	3	8	3
Pastures	3357	**69**	196	**74**
Total agricultural area	4884	100	265	100

Naturally, the vast acreage of grassland is less productive than is arable land. However, its yield cannot be abandoned, neither today, nor in the future in prospect of further increasing world population. Grass can only contribute to feeding mankind by its utilization by ruminants. Therefore, maintaining a similarly numerous cattle stock as we have today can hardly be avoided in the future.

Data from statistical publications of the FAO are summarized in Table 3 and show cattle and buffalo numbers in the world and present countries in which at least 50 million animal of this category are kept already today.

Table 3 : Number of big ruminants

(FAO Statistical Yearbook 2010)

Countries	**Cattle and buffaloes** (Million heads)		
	1999-2001	2007	2009
India	286	280	279
Brazil	171	201	206
China	125	105	116
USA	98	97	95
Pakistan	45	59	63
Argentina	49	51	51
Ethiopia	35	45	51
World	**1479**	**1540**	**1571**
	100	104	106

Also during the last decade a further increase in cattle stock could be observed. The least that should be achieved is to stop this trend. The increasing demand for food of animal origin which is caused by the steady growth of the world´s population can and must be met by improving animal performance. Concurrently, this is the only realistic way of reducing methane

emission per kg product. An even higher aim would be to increase performance to such an extent that the number of ruminants and the amount of methane emitted by them could be reduced.

The relationship between methane emission and milk yield has been described earlier (Kirchgeßner *et al*., 1995). It can be concluded from figure 1, and also from data presented in Table 1, that the biggest effect can be achieved by increasing the animal's yield at nowadays low performance levels whereas the contribution to further reducing emissions can be neglected at already high milk yields.

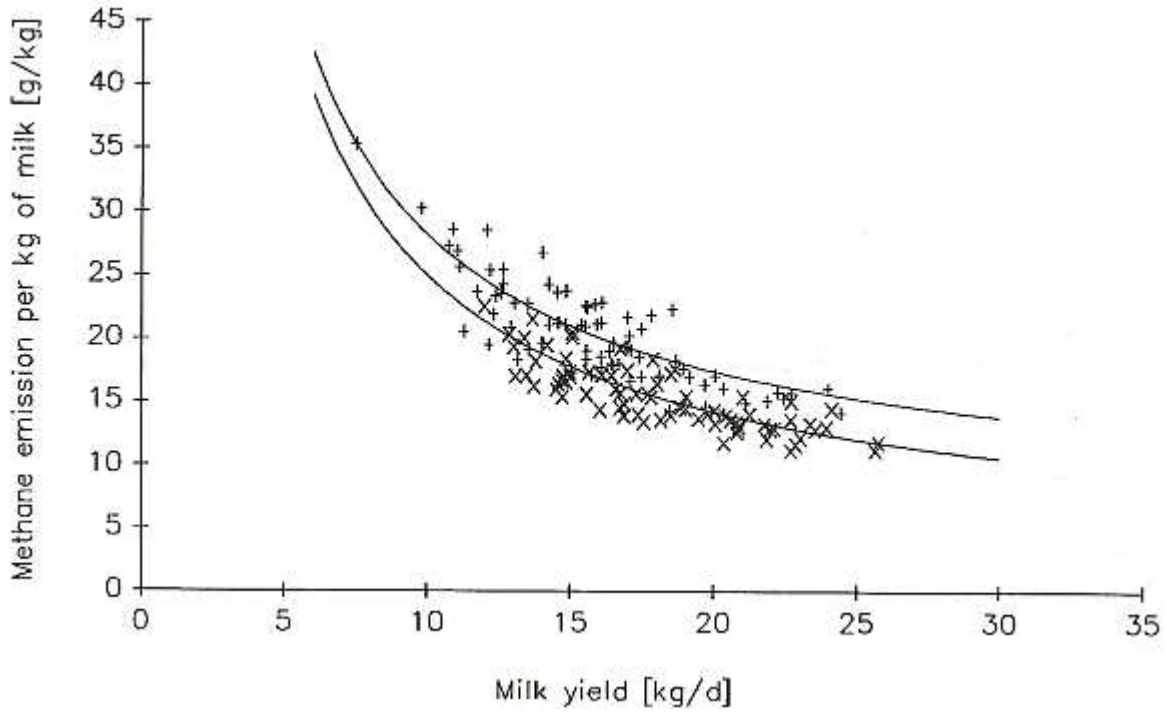

Figure 1: Methane emission per kg of produced milk as affected by performance level (adapted from Kirchgeßner *et. al*., 1995)

Among countries having very big ruminant populations, and especially in among developing countries, there are many with extremely low performance level in animal production and, thus, high potential for performance increases, which would ultimately lead to significant reductions in methane emissions. One of the most effective measures that can be taken for improvements is the implementation of an efficient feed store management. Consequently, the development and implementation of improved technologies for feed conservation, which are adapted to country-specific climatic and socio-economic conditions, becomes an important task of general climate policy.

Further challenges to forage conservation have arisen during the last few years by the increasing use of agriculturally produced plant biomass for energy production. Both, the production of bioethanol and of biogas are continuous biological processes, which, in analogy to animal production, require storage of plant biomass.

As far as moist grains are concerned, the energy saving preservation technology of anaerobic storage needs to be taken into consideration. If whole-plant maize, maize stover, whole-plant cereals, biomass from grasses and legumes as well as sugar beet and possibly also sugarcane in future are addressed for production of biogas, conservation by making silage is unavoidable.

Only as silage can forages be used as substratum for biogas production. In addition to the necessity to make these materials storable, plant biomass also for this utilization needs to be produced at a defined and constant quality. Fermentation in the silo can be considered, at least to a certain degree, the first phase of the whole process of biogas production which subsequently continues in the fermenter until the fermentable organic matter is fully degraded to methane and carbon dioxide. Quality requirements upon silages are similar to those for animal feeding, but not identical in all quality traits.

Production of electricity, heat and fuels from biomass is desired in the future to significantly contribute to the overall production of renewable energies in order to replace fossil sources, thereby relieving the atmosphere of carbon dioxide formed from them. Forage conservation must, and can, bear its crucial share to climate-neutral energy production by providing suitably prepared plant biomass on demand. Also for this purpose must forage conservation be carried out at a larger scale in the future, and the best technologies for that must be developed.

Hay-crop silages and the problem of fermentation quality

The aim of all technologies and procedures in forage conservation is to maintain the highest possible feeding value of the grown forage in terms of quantity and quality at reasonable economic input. Wherever climatic conditions permit the regular production of "field-dried hay" without any problems in a short period of time, this preservation technology represents the least cost method. If made properly, nutrient loss does not necessarily need to be higher and feed quality lower than that of ensiled biomass.

As this is not applicable to other regions of the world hay making was replaced by producing „hay-crop silages". This change has led to marked improvements, and its very likely further expansion in the future will be of additional benefit. Furthermore, the utilization of whole-crop maize, whole-crop cereals, and possibly also of sugar cane, for feeding purposes and energy production is linked to the preservation technology of ensiling. The extended use of such crops in the form of silage will, in any case, lead to extension of silage making. Therefore it seems rewarding to have a closer look at the potential of this method of forage conservation, and the still future demand for research and development which is worth to reflect on.

Wilkinson, Bolsen and Lin (2003) carefully analyzed and evaluated the history of silage and silage making. In their summary, they distinguished between three categories of regions and countries, respectively, which differ in current situation and developmental potential in silage production:

- „Europe and North America, where silage making is well established"…and with…"a need for new technologies and inputs to constrain costs of silage production"…and probably..."some replacement of perennial grass silages with silages made from corn, whole-crop cereals and forage legumes."

- "Some temperate and tropical areas, where silage currently supplies a small proportion of nutrients (e.g. Australia, New Zealand and Latin America), there will probably be increase in silage production to capitalize on the advantages of a silage system in producing a more even seasonal supply of nutrients… compared with grazing or hay systems."

- "Tropical and subtropical livestock production…where…the potential of silage … is, as yet, largely unrealized"… and where …"will be a continued requirement to harvest

material of reasonable nutritional value and to maintain that feeding value and reduce losses during the storage and feeding periods."

For each of these situations ensiling technologies and strategies are to be searched for, which are suitable for the specific conditions in the respective countries. In this regard, experience from developed countries can be made use of, but it is unlikely that all of it is directly applicable in tropical and subtropical regions.

In the following, technologies and strategies are described that have been developed in Europe and North America. Thereafter, it will be discussed as to whether those might be suitable for other regions. Finally, conclusions are drawn on required research and development activities in particular for tropical and subtropical areas.

The main problem of ensiling grass and legumes in temperate regions is to ensure good fermentation quality of the silage despite changing whether conditions. Good fermentation quality is needed to ensure low fermentation losses, high feed intake and good hygienic status of the silage.

It is well established that the behaviour of a crop, when subjected to silage fermentation, depends on the substratum supply for lactic acid bacteria. The required amount of water soluble and thus fermentable carbohydrates (WSC) is related to buffering capacity (BC) of the herbage. Therefore, in order to characterize the ensilability of a given crop, the ratio between WSC and BC is calculated. The WSC/BC ratio has been suggested to express the acidification potential of the herbage.

Buffering capacity is characterised here – on the contrary to Playne and McDonald (see McDonald *et al*., 1991) – by the amount of lactic acid which is required to acidify the crop to pH of 4.0 (Weissbach, 1967). The practical advantage of this procedure is that the parameters WSC and BC have the same dimensions (e.g. g/kg DM). If so, the ratio between the two reflects how many times of the standardized lactic acid demand does the herbage contain in fermentable carbohydrates.

Legumes very often have a low content of WSC but, simultaneously, contain higher concentrations of buffering substances than found in grasses. As opposed to what is frequently assumed BC is not primarily affected by the protein content of the herbage but mainly by the alkalinity of its mineral components. The evaluation of data from 52 plant species of different taxonomic families resulted in the following equation (Weissbach, 1998):

$$BC = 0.092\ x_1 + 0.442\ x_2 - 19.5\ (5.88 - x_3)\ r^2 = 0.842$$

where BC is the buffering capacity as meq/100 g DM, x_1 is the nitrogen content [meq/100 g DM], x_2 is the ash alkalinity [meq/100 g DM] and x_3 is the pH of the herbage.
This equation also takes into consideration the effect of high concentrations of free organic acids, which may occur at high levels in some tropical species (McDonald *et al*., 1991).

The susceptibility of clostridia to acid increases with decreasing water activity in their environment (Table 4). Thus, bad fermentation can be avoided despite of a low WSC/BC ratio by pre-wilting the herbage. The lower WSC/ BC is the more the DM must be increased.

Table 4: Critical pH values of silages

(Weissbach, 1968)

DM content %	Water activity a_w	pH required for stabilty of silage
15	0.985	4.10
20	0.980	4.20
25	0.975	4.35
30	0.971	4.45
35	0.966	4.60
40	0.961	4.75
45	0.956	4.85
50	0.952	5.00

Figure 2 demonstrates different frequency ranges of bad fermentation to be expected at given WSC/BC ratio and DM content.

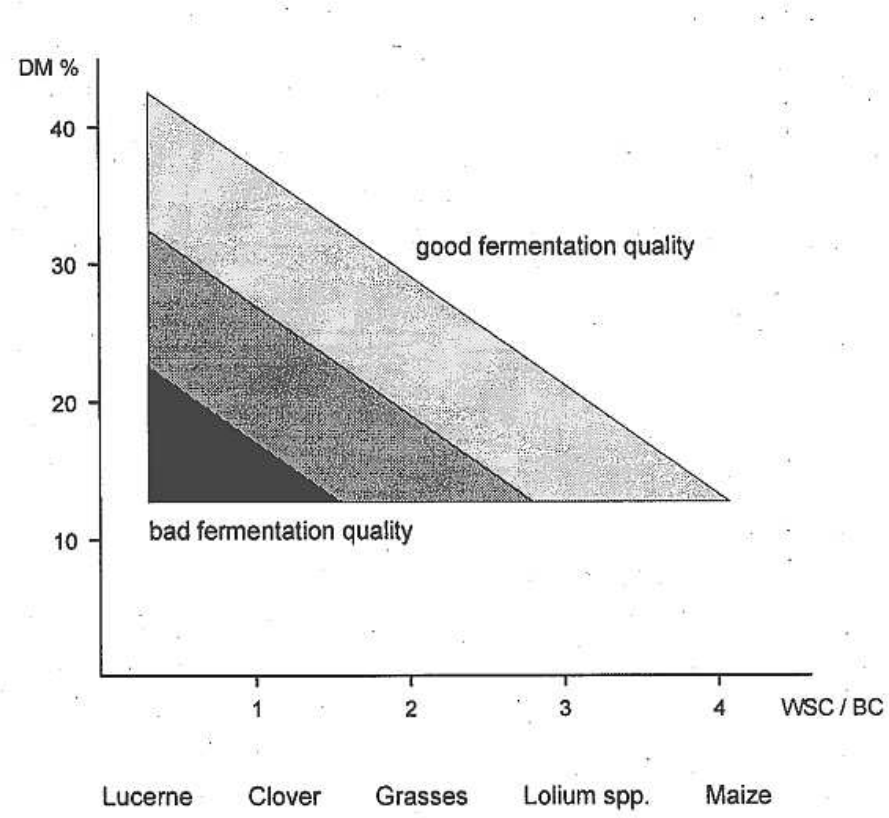

Figure 2: Frequency of bad fermentation (butyric acid containing silages) as affected by WSC/BC ratio and DM

The minimum DM content (DM_{min}), which is required to compensate for substratum deficiency (upper edge of the triagle), increases with decreasing WSC/BC ratio and can be calculated by the following equation (Weissbach *et al.,* 1974):

$$DM_{min}\ [\%] = 45 - 8\ WSC/BC$$

The fermentability of a given crop refers to its ensilability as far as the two parameters WSC/BC ratio and DM are concerned. In order to characterize fermentability, the two parameters DM and WSC/BC according to a proposal of L. Schmidt (see Weissbach and Honig, 1996) can be also combined to one parameter, which is named the "fermentability coefficient" (FC):

$$FC = DM\ [\%] + 8\ WSC/BC$$

Herbages with FC < 35 are considered difficult-to-ensile, whereas those with FC > 45 are referred to as easy-to-ensile.

It has been shown that ensuring the minimal DM content (DM_{min}), as described by the equation above, is not always sufficient to consistently inhibit butyric acid fermentation. The crop to be ensiled additionally needs to contain a certain concentration of nitrate (Hein and Weissbach, 1977; Spoelstra, 1985; Kaiser and Weiß, 1997; Weissbach *et al*. 1993; Weissbach, 1996). Nitrate is converted into nitrite during the early stages of fermentation, thereby inhibiting clostridial development until pH has reached the critical level. The minimal required nitrate concentration has been discussed controversially (Kaiser *et al*. 2002; Kaiser *et al*. 2005; Kaiser *et al*., 2009; Pahlow, 2002; Kaiser *et al*. 2009; Weissbach and Honig, 1996; Weissbach, 1998). However, based on experimental data from numerous ensiling trials with herbage from very different plant species, a minimal content of nitrate of 1 g/kg DM has proven to be sufficient under most conditions. Alternatively, an epiphytic lactic acid bacteria (LAB) count of at least 10^5 cfu/g fresh forage can compensate for a lack of nitrate and support a good fermentation quality.

In contrast, it has been shown that butyric acid free silage can be produced frequently even if the crops had DM concentrations lower than DM_{min} and did not contain significant amounts of nitrate and high LAB counts. For some plant species it was proven that the causal agents for this observation were secondary plant metabolites (Weissbach, 1998). Apparently is the susceptibility of clostridia to low pH values also affected by the simultaneous presence of bacterial inhibitors. These inhibitors prevent the degradation of lactate at later stages of fermentation.

Based on the two protective effects, namely

- the presence of nitrate (and nitrite, respectively) or high populations of efficient epiphytic LAB at the beginning of the fermentation process and

- the presence of specific inhibitors which protect silage against clostridial activity during the later stages of fermentation and the further storage

strategies can be derived concerning the control of the fermentation process by the use of silage additives.

Table 5 summarizes data on ensilability of the most important silage crops in Europe. Due to higher WSC/BC ratios, rye grasses (*Lolium* species) are easier to ensile than all other grass species, which are easier to ensile than legumes. Whole-crop cereals and maize (*Zea mays*) are generally easy to ensile. In the most unfavourable conditions, a DM_{min} of about 30 % is needed for rye grasses, 35% for red clover (*Trifolium pratense*) and for all other grasses, and 40 % for Lucerne (*Medicago sativa*).

Table 5: Ensilability parameters of silage crops as expected under normal conditions

Crop resp. / Sward type	Cut No. resp. / Maturity stage	N supply level	DM %	g/kg DM WSC	g/kg DM BC	WSC/BC	DM_{min} g/kg	FC unwilted (DM as cut)	FC wilted (DM 30 %)
Grasses									
Lolium dominated swards									
	Primary growth	low	18	220	55	4.0	< 20	50	62
		moderate	18	180	55	3.3	< 20	44	56
		high	18	160	55	2.9	22	41	53
	Re-growthes	low	22	140	55	2.5	25	42	50
		moderate	22	120	55	2.2	28	39	47
		high	22	100	55	1.8	30	37	45
Other grass swards									
	Primary growth	low	18	120	50	2.4	26	37	49
		moderate	18	100	50	2.0	29	34	46
		high	18	80	50	1.6	32	31	43
	Re-growthes	low	22	100	50	2.0	29	38	46
		moderate	22	90	50	1.8	31	36	44
		high	22	70	50	1.4	34	33	41
Legumes									
Red clover	all cuts		20	100	70	1.4	34	31	41
Lucerne	all cuts		20	60	80	0.8	39	26	36
Whole-crop cereals									
Barley	Milk stage		30	140	40	3.5	< 20	58	
	Dough stage		40	70	35	2.0	29	56	
Wheat	Milk stage		30	120	40	3.0	21	54	
	Dough stage		40	60	35	1.7	31	54	
Maize	Milk stage		25	190	35	5.4	< 20	68	
	Dough stage, early		30	130	32	4.1	13	63	
	Dough stage, full		35	80	30	2.7	24	56	

WSC = water soluble carbohydrates; BC = buffering capacity
DM_{min} = DM minimum; FC = fermentability coefficient

In practice, the DM content varies in a rather wide range during the harvest of a pre-wilted crop and during filling the same silo. The higher the intended average wilting degree, the higher this variation range will be. The recommended strategy is to maintain the DM within a certain range. The lower limit of this range (DM_{min}) is determined by WSC/BC, the upper limit depends on the ensiling technology and the quality of sealing the silo. For bunker and pit silos, a DM_{max} of 45% should not be substantially exceeded. Thus, specific crops require different ranges of DM variation, wherein the wilting degree should be fluctuating ideally. For bales, DM_{max} should be set 60 %, whereas for tower silos, DM_{max} should set based on stacking height (lower section: 60%, middle section: 45 %, upper section: 30%).

The primary aim of the use of silage additives to ensure good fermentation quality is the alleviation of a too low wilting degree and, if required, of the lack of nitrate. Proven chemical silages additives (organic acids and salts thereof, as well as neutral reacting preservatives, including sodium nitrite and hexamine) should possess the strength which equals that of an

increase in crop DM by at least 10%. Inoculants, mainly of the homofermentative type, should be as efficient so that the DM at ensiling can be 5% lower than the DM_{min}. Considering these facts, the resulting crop specific DM ranges at ensiling, which should be adhered to, can be derived. Table 6 shows the recommended ranges for ensiling in bunker and pit silos.

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Table 6: Strategy of making wilted hay-crop silage

Silage additive	DM content [%] to be aimed at	
	Available range DM_{min} … DM_{max}	Width of the available range
***Lolium* dominated grass swards**		
without	30…45	15
homolactic inoculant	25…45	20
chemical additive	20…45	25
Other grass swards and red clover		
without	35…45	10
homolactic inoculant	30…45	15
chemical additive	25…45	20
Lucerne		
without	40…45	5
homolactic inoculant	35…45	10
chemical additive	30…45	15

By strategically using silage additives, it is possible to significantly extend the technologically advisable DM range, and to vastly suppress undesired fermentation pathways. However, the costs for silages additives, especially for chemical products, are rather high as, for consistency of effect, the required application rate depends on the moistest batch of crop which is brought into the silo.

Recent developments in harvesting technology have enabled the use of „precision farming“ tools also in silage production (Savoie and Shinners, 2009). This has opened up possibilities for the control of silage additive application strictly based on real demand. Choppers are nowadays equipped with sensors which measure throughput and DM content on a real-time basis as well as with on-line controlled silage additive applicators. For each of the chemical silage additive types can crop-specific mathematical functions be created, which permit additive application based on DM. This in turn leads to a significant decrease in additive costs since, on average of the whole silo, only the dosage is used which is required for a given DM content.

Exemplarily, Table 7 shows the expected effects for the ensiling of grass with a liquid chemical additive, composed of sodium nitrite and hexamethylene tetramine. This additive is normally applied at 3 l/t and its effect is equal to increasing DM level by 14% (Weissbach *et al*., 1989). The minimal dosage of this silage additive, which is constantly applied by using the on-line controlled equipment, supplies sufficient sodium nitrite to inhibit clostrial activity during the early fermentation phase also in nitrate-free forage.

Table 7: Mean requirement of a chemical silage additive with DM controlled application

Degree of wilting	DM content of the grass that enters the silo [%]			Mean application of silage additive for the whole silo, litres/t FM
	Mean content within the whole Silo	Variation during filling the silo		
		Range	Width of range	
Without	18	16 … 20	4	3.0
Very slihgtly	25	20 … 30	10	2.5
Slightly	30	22 … 35	13	1.8
Moderately	35	25 … 45	20	1.2
Rather heavy	40	28 … 58	30	1.0

What recommendations can be derived from this body of knowledge and state-of-the- art technology for other regions, e.g. Brazil?

There have been published comprehensive reviews (Nussio, 2005; Adesogan, 2009) as well as numerous individual articles by different research groups on the problems, challenges and experiences of silages production in tropical and subtropical regions (Cezario *et al*. 2009; Martens et al. 2009; Parvin *et al.*, 2009a; Parvin *et al.*, 2009b). Warm-season grasses are the backbone of the tropical forages. As reported by Ribeiro et al. (2009), grass silage production in Brazil is mainly based on the genera *Brachiaria* and *Panikum*, whereby *Brachiaria* species alone represent 85% of the cultivated grassland.

It is well known that these warm-season-grasses, in comparison to temperate grasses, are much lower in WSC and protein, much higher in ADF and NDF and, consequently, substantially lower in digestibility (Adesogan, 2009). However, systematic research seems to be still lacking on chemical composition, digestibility and fermentability of these grasses as affected by plant species, season, level of fertilization, stage of vegetation (maturity). But such information is absolutely necessary to be able to derive optimal cultivation and utilization regimes and strategies for conservation as well.

Experiments, in which individual plant species were cultivated on experimental plots (see e.g. Ribeiro et al., 2009), are a good start, but it is not sufficient to chemically analyze the crop – or even only the silage, as it was done in the cited publication. In fact, such experiments must also aim at different stages and maturity, and should preferably be combined with digestibility studies in sheep. This information should be used in the prediction of the effects of stage of maturity and cutting frequency on nutritive value.

The basic principle of ensiling strategies for grasses in the tropics and subtropics can, as in Europe, only be the combination of pre-wilting and silage additive use. The necessity to wilt already originates from the demand to prevent effluent production, and the loss of nutrients caused by it. In addition, wilting will be necessary to ensure Silages of good fermentation quality. How much the crops need to be wilted to inhibit butyric acid fermentation is likely to be derivable from the same relationships that are known for European crop species. The required DM_{min} depends on the WSC/BC ratio. This approach is certainly applicable also to warm season grasses. On the contrary, not applicable will be the European threshold values for DM_{min}, or even

the recommendations on minimal sugar content as percentage of fresh matter, as has been done in the past.

Regarding the usability of silage additives to compensate for low fermentability, it is strongly recommended in all ensiling trials to analyze the fresh crop for DM, WSC, BC, nitrate and, preferably, also for epiphytic lactic acid bacteria count. This is the precondition to decide whether the additive in question had the chance to show positive effects. Moreover, single laboratory ensiling experiments are not sufficient to evaluate the efficacy of a given silage additive. The factors affecting fermentation quality are too complex, and many factors are not controllable so that the validity of the results of only a few studies is too weak. It should be enforced that a minimum of 5 independent trials using the same species and the same additive be conducted in order to be able to draw sound conclusions.

Adesogan (2009) forcefully pointed at the need to distinguish between low and high input farming systems in the tropics. Both, the aim and the justifiable input differ significantly. Against this background, the use of the cheaper commercial inoculants will be more advisable than chemical silage additives for low-input systems in many cases.

Under such conditions even the use of simple and cheap methods like the inoculation with „previously fermented juice“(PFJ) can be a reasonable option (Oshima *et al*., 1997a; Oshima *et al*., 1997b; Nishino and Uchida, 1999; Yu *et al*., 2009). This method is characterized by the cultivation of epiphytic microorganisms in a plant extract prepared from the crop to be later on ensiled. The diluted plant extract is supplemented by molasses or sucrose and incubated for 2-3 days at 30°C. This suspension containing vital microorganisms (probably mainly LAB) is subsequently added to the crop and used as a starter of silage fermentation. However, it might be even more successful to use samples from good silages (which were made with successful inoculation) for the preparation of PFJ as “self made inoculants”. Research also in this field could be worthwhile.

Maize silages and the problem of aerobic instability

The increasing cultivation of forage maize and its use for silage production offer chances to increase silage production and feed inventories in many warm countries. Recommendations from Europe and North America regarding this crop and specific ensiling technologies can be directly applied. Wherever necessary can those be also adapted very well to low-input farming systems.

Forage maize is generally easy to ensile. Its fermentability coefficient is always higher than 45, and many mistakes must be simultaneously made to produce a maize with silage bad fermentation quality. Maize always contains much more WSC in relation to its BC, and also the epiphytic LAB counts are very high in most cases.

However, the surplus of WSC creates a completely different quality problem. WSC which are not utilized for lactic acid production serve as substrate for yeasts. During anaerobic storage will yeasts thrive on utilizing sugar to produce ethanol. Upon subsequent exposure to air, yeasts switch over to respiratory metabolism and excessive cell multiplication linked with head generation. Subsequently, lactic acid is degraded so that pH increases, thereby creating environmental conditions which allow other undesirable microorganisms to develop. Silages made from forage maize, but also those produced from sorghum and whole-crop cereals, tend to be susceptible to aerobic spoilage, which is associated with dramatic losses in nutrients as well as with the deterioration of hygienic quality. During the last years, it was shown that even spores of the obligate anaerobic clostridia were found at very high numbers in the upper layers of silages which underwent aerobic deterioration (Driehuis and te Giffel, 2005; Tabacco and Borreani, 2009).

These processes are well studies and documented (Pahlow and Muck, 2009). The surplus of fermentable carbohydrates creates the predisposition of silage from maize and sorghum to aerobic deterioration. Mainly yeasts create the aerobic spoiling and air ingress during storage and after silo opening initiate this undesirable process. To avoid the impact of oxygen, or at least to reduce it, is the pre-requirement for any efficient ensiling technology. Technical measures, which lead to improvements regarding this aspect, are also highly economical as a rule (Muck and Homes, 2005; Bernardes *et al*., 2009; Holmes and Bolsen, 2009; Muck and Homes 2009).

Even though, the particularly high risk of aerobic instability in these crops remains, and measures need to be taken to minimize it. Unfortunately, there is no reliable prediction of the aerobic stability of a given silage possible as of yet. However, what is well known is the inhibiting effect of high concentrations of undissociated acetic acid on yeasts and its beneficial effect on aerobic stability. Figure 3 presents the result of an evaluation of numerous experimental data.

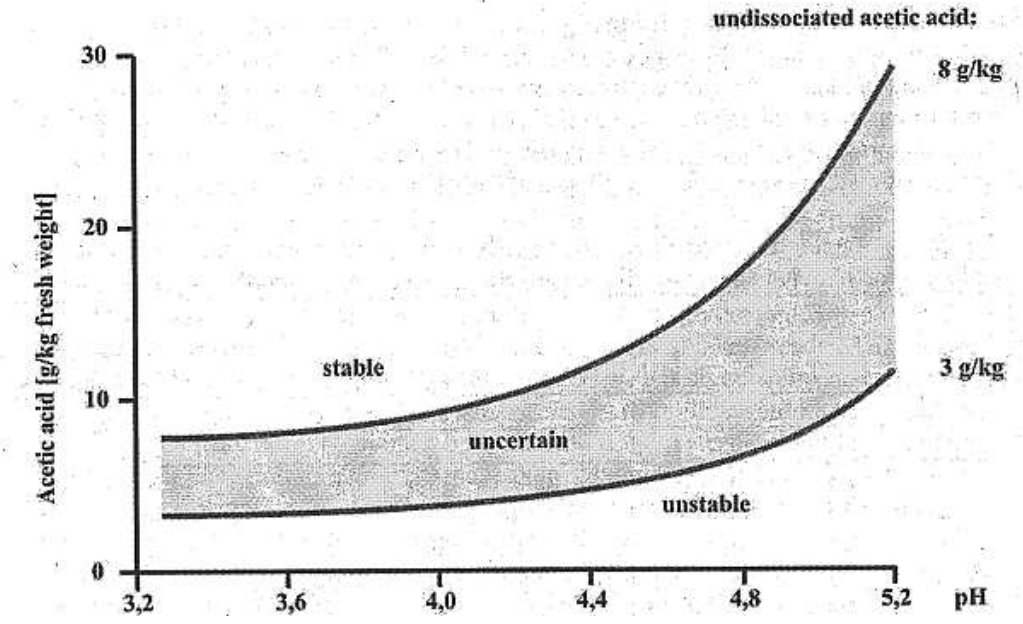

Figure 3: Risk of aerobic instability as influenced by acetic acid and pH (Wolthusen *et al*., 1989)

Data clearly demonstrate that silages containing less than 3 g/kg FM are mostly unstable, whereas those having more than 8 g/kg FM of undissociated acetic acid are almost always stable. As known, the proportion of undissociated acid (α) depends on pH according to the following equation:

$$\alpha = \frac{[H^+]}{[H^+] + D}$$

where $[H^+]$ is the concentration of hydrogen ions [mol/L] and D the dissociation constant, which is 1.76×10^{-5} for acetic acid. Consequently, to secure aerobic stability, the two criteria must be met, namely sufficiently high acetic acid content and sufficiently low pH.

It can be concluded from Figure 3 that there is still a wide range of undissociated acetic acid concentration (3 - 8 g/kg FM) in which the behavior of the silage upon exposure to air cannot be predicted. Thus, there must be additional factors which affect aerobic stability. Further research into this phenomenon is crucial. With the exception of maize and sorghum, there should be considered secondary plant metabolites and their derivatives which may exert an inhibitory effect on yeasts. This effect is known for Lucerne, but the chemical nature of these compounds still remains to be elucidated. Systematic studies on European wild plants revealed that not only silage from lucerne is resistant to aerobic spoilage, but also such from 5 additional legumes and numerous other dicodylic species did not deteriorate at air contact (Weissbach, 1999). It should therefore focus be placed on the experimental question as to whether these effects can be found in tropical and subtropical plant species and to make use of that.

As far as the suppression of yeasts by increased acetic acid concentration is concerned, there was a major breakthrough achieved in the end of the 1990ies. It could be demonstrated that inoculation of crops with specifically selected strains of the heterofermentative species *Lactobacillus buchneri* resulted in elevated acetic acid concentrations and higher aerobic stability of silages (Driehuis *et al*., 1996; Driehuis *et al*. 1999). Lactate is subjected to secondary fermentation and converted into acetate. Somewhat later the metabolic pathway was elucidated regarding the formation of acetate. The formed hydrogen is utilized to produce 1,2-propanediol (Oude Elferink *et al.*,1999; Oude Elfering *et al.,* 2001) (Figure 4).

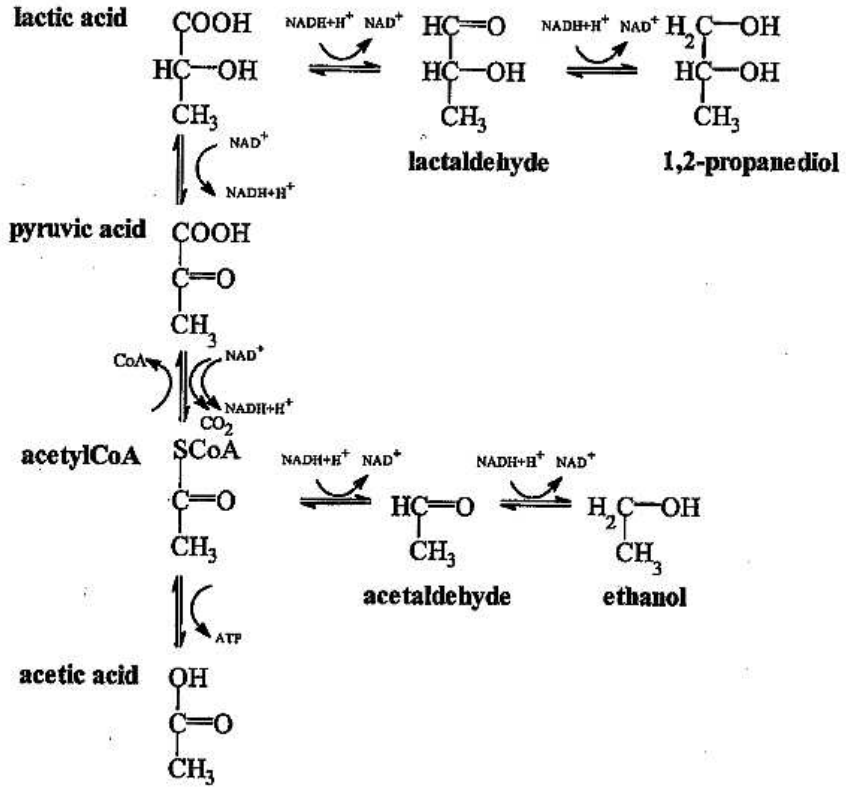

Figure 4: Proposed pathway for anaerobic degradation of lactic acid by *Lactobacillus buchneri* into equimolar amounts of 1,2-propanediol and acetic acid and trace amounts of ethanol

Further on, it was shown that 1,2-propanediol is metabolized by the naturally occurring species *Lactobacillus diolivorans* to give 1-propanol and propionic acid at later stages of silage fermentation (Krooneman *et al*., 2002). It is well documented that propionic acid is a more potent fungal inhibitor than acetic acid. The formation of this fermentation acid also contributes

to stabilizing the silage. In addition to this, it has to be noted that the described biochemical reactions result in the accumulation of two compounds which have higher energy contents per g than the acids lactic and acetic acids.

During the last few years, different researchers have tested different *L. buchneri* strains, which were shown to be very efficient in improving aerobic stability (Bannemann *et al*., 2009; Brüsemeister *et al*, 2009a; Brüsemeister *et al*, 2009b). In the meantime, evidence has been provided that inoculation with this type of bacteria can lead to acetic acid concentrations which may be higher than tolerated by small and large ruminants. Excessive amounts of acetic acid are suspected to reduce feed intake (Eisner *et al.*, 2006). Even though such potentially negative effects are unlikely to be of practical relevance in temperate regions, it should be studied as to whether these effects and the potential risk associated with it may occur in the tropics and subtropics. Under the prevailing storage temperatures there, which can be higher than those in Europe and North America, the process of lactate degradation by *L. buchneri* may lead to higher contents of acetic acid as desired.

On the contrary to hay-crop silages is the use of homofermentative inoculants in maize and sorghum neither necessary nor advisable. Repeatedly postulated positive effects have not been consistent, or its magnitude has been marginal. Quite the contrary was observed. Stimulation of homolactic fermentation resulted in significant decreases in aerobic stability of these types of silages.

The opinions about the best concept of inoculation of silages expressed by silage specialists have been controversial although the body of evidence is unequivocal (Pahlow *et al*., 2003; Kung, Jr. *et al*. 2003; Kung Jr., 2009). Davies (2010) opposed to the use of heterofermentative LAB and stated that the production of acetic acid leads to the formation of CO_2, and that energy is lost which cannot be used by the ruminant. Moreover, the higher acetic acid concentration he assumed to detrimentally affect methane production in the rumen if more acetic acid instead of lactic acid enters this part of the digestive tract.

However, these postulates are not substantive. The released CO_2, which is produced as a co-product of acetic acid forming in the silo, originates from photosynthesis and therefore is not loading the atmosphere. Considering this loss of biomass is even indirectly advantageous since for each kg of DM that is lost during fermentation, as much as at least 3 kg of DM can be saved during feed-out upon exposure to air, which may otherwise be degraded during the process of aerobic deterioration (Tabacco *et al*., 2011). Moreoever, the metabolic end products of the heterolactic pathway are not only composed of acetate, but also of the energetically more valuable compounds 1,2-propanediol, 1-Propanol and propionic acid. Potentially, the energy value per g of the silage DM is even increased. Unfortunately, the volatile compounds which are lost during oven drying are sometimes not or incomplete determined. This in turn results in an incorrect calculated, too low nutritional value of silages.

Another problem, which just very recently became obvious, is also associated with volatile fermentation end-products. There have been reports from commercial farms on odd-smelling maize silages which are not taken in well by dairy cows, or silages are even refused. Analyses of samples taken on farms as well as numerous studies at laboratory scale could shed light on the causal agents. The odd smell was associated with the spontaneous formation of esters of fermentation products (Weiß *et. al.*, 2009 a; Weiß *et. al.*, 2009 b).

By using GC-MS and a special GC analysis a number of highly volatile substances could be identified. The highest concentrations were consistently found for ethyl lactate and ethyl acetate. The content of these esters was mainly influenced by the concentration of ethanol and only to a smaller extent by the concentrations of the organic acids. The higher ethanol level, the more ethyl esters of the respective acids were found. As a consequence, if ester accumulation is to be reduced, then ethanol forming must be lowered.

Mitloehner et al. (2009) also reported on studies into volatile organic compounds (VOC) including esters emitted from open-face silage piles. The purpose of these investigations was to check as to whether and which VOC from dairy farms might be released into the atmosphere and could be a source of ground level ozone formation. But no qualitative and quantitative data and no relations between ester formation and silage properties were given in this article.

Table 8 below summarizes the results of a lab-scale ensiling trial on sorghum (Weiß and Auerbach, 2011), in which the effect of different additive types was studied on ester accumulation. Although *L. buchneri* could reduce the levels of ethanol and forming of ethyl lactate if compared with untreated silages and those treated with a homofermentative *L. plantarum* additive, only the combination of sodium benzoate and potassium sorbate in the tested chemical additive dramatically restricted ethanol fermentation as well as the formation of ethyl esters of lactate and acetate. These findings are supported by Kleinschmidt *et. al.* (2005), who also reported on the inhibition of yeasts and ethanol formation in silages caused by chemical additives.

Table 8: Fermentation pattern of sorhum silage made with different additives
(Weiß and Auerbach, 2011)

Treatment (DM = 26 %)	pH	g/kg DMc				mg/ kg DMc	
		Lactic acid	Acetic acid	Ethanol	1.2-Proane-diol	Ehtyl acetate	Ethyl lactate
Control	3.8	4.0	2.7	3.4	1.3	120	467
L. plantarum	3.8	3.8	2.2	2.9	0.3	123	463
L. buchneri	3.8	2.5	4.6	1.8	3.6	128	237
Benzate/Sorbate*	3.7	2.4	2.8	0.8	1.2	44	33

* Liquid preparation containing sodium benzoate and potassium sorbate
DMc = DM corrected for volatile organic compounds

Sugarcane silages and the problem of volatile compounds

Sugarcane belongs to the highest yielding crops and is used already today for feeding to some extend (Nussio, 2005). Not only the whole plant is used, but also sugarcane tops, which accrue as by-product during harvest of the crop for sugar production. Obviously, this crop possess the potential of being used for feeding to a higher extend in the future, thereby enabling a more efficient and seasonal even supply of feed for ruminants throughout the year.

An increased use of sugarcane would be easier if efficient silage making technology would be available. Therefore, several studies on ensiling sugarcane were carried out (Kung, Jr. and Stanley, 1982; Pedroso *et al*., 2002; Pedroso *et al*., 2005; Avila *et al*., 2009; Muraro *et al*., 2009; Nussio *et al*., 2009a; Nussio *et al*., 2009b; Pinto *et al*., 2009). But the results were contradictory. Although positive results were reported from feeding of sugarcane silages to heifers (Nussio, 2005) and also to dairy cows (Queiroz *et al*., 2005) the experiences with ensiling losses and the measured nutritive value of silages were in contrast to that. Kung, Jr. and Stanley (1982) even concluded that „sugarcane did not lend itself to ensiling because of large dry matter losses …“

Obviously, the high sugar surplus is the problem of silage making here. Sugarcane contains much more WSC than can be converted into lactic acid. Thus, the vast proportion is subjected to utilization by yeasts. Very high gaseous fermentation losses and an even higher total DM loss have been frequently reported (Pedroso *et al*., 2005; Nussio *et al*., 2009a; Nussio *et al*., 2009b). However, the total DM loss was not associated with effluent seepage, as only low amounts were produced. The reason for the remarkable difference between total DM loss and gaseous loss remained unclear.

What was considered even more important was the dramatic decline in DM content and nutritive value with progressing fermentation. Concentrations of the fiber fractions like ADF and NDF increased during the course of fermentation, and the *in vitro* as well as *in vivo* digestibility measured with sheep was reduced. The more mature sugarcane and the higher its sucrose content, the higher was the loss in nutritive value of the silages.

All these negative observations on ensiled sugarcane, however, are likely to be caused only by volatile organic compounds (VOC), which are contained in the silage but were not or not sufficiently accounted for. As ethanol content can be extremely high in sugarcane silage, the impact of this methodological error is particularly prominent and leads to biased and unrealistic results.

The fact that silages contain VOC is well known (McDonald and Dewar, 1960) and the methods to account for them in DM determination have a long history in silage research (Cherny and Cherny, 2003). Over decades, DM determination by employing the „corrected toluene distillation method" according to Dewar and McDonald (1961) was considered the standard method. The correction was at first only directed on acids which were transferred into the distillate, later on also alcohols were also taken into consideration. Extensive studies were then carried out to obtain the "true CM content" by the use of chemical methods for determination of the water content like Karl Fischer titration or gas chromatography (Porter and Barton, 1997; Porter and Murray, 2001). It has been quite surprising to European silage specialists to notice that the VOC are not considered in the procedure of determination of the nutritive value of silages by AOAC methods which are followed also in some other countries (e.g. Pedroso et al., 2005).

It is accepted that routine toluene distillation is not a viable option any more due to health protection issues and costs. Moreover, there are additional principal reasons which render this method inadequate. All results obtained by this method have never been compatible with oven-drying, to which all other laboratory analyses have been related to (e.g. to express the nutrient contents given on a total DM basis). This applies even if all VOC which were transferred into the distillate would have been determined and considered. The reasoning behind this is that silage is not composed of only solid and liquid substances, but it also contains absorbed CO_2 which is totally only released if the sample is subjected to high temperatures during oven drying or toluene distillation. From the results of an extended study with different kinds of silage carried out by Berg, 1971 (re-evaluated and cited in: Weissbach, 2005) it could be proven that this absorbed CO_2 achieves a noticeable amount and is closely related to DM content. Consequently, the equation:

$$\text{(Silage fresh weight)} - \text{(Water)} = \text{DM}$$

is false. The calculated difference between silage fresh matter and weight of water is, thus, always slightly higher than the real DM. Therefore, toluene distillation cannot serve as reference for simplified analytical methods, as was proposed by e. g. Haigh (1995) and cited in: Cherny and Cherny (2003). This also applies to all methods based on chemical determination of the water content and proposals for DM correction based on them.

The only feasible method, which is in full agreement with the current state of knowledge, must include the determination of all VOC from silages and the addition of the volatile proportion of them to the DM measured by oven-drying. In doing this the specific volatility of each individual VOC must be taken into account and subsequently their volatile proportions calculated. These volatility coefficients were determined by employing a standardized procedure of oven drying (pre-drying of the sample at 60-70°C, followed by final drying at 105 °C for 3 hours) (Weissbach and Strubelt, 2008a-c; Weissbach, 2009a). The following equations have been proposed to correct the DM for the loss of volatiles during oven-drying for these drying conditions.

Maize silages

$$DM_c = DM_n + 0.95\ FA + 0.08\ LA + 0.77\ PD + 1.00\ AL$$

Hay crop silages

$$DM_c = DM_n + (1.05 - 0.059\ pH)\ FA + 0.08\ LA + 0.77\ PD + 0.87\ BD + 1.00\ AL$$

Sugar beet silages

$$DM_c = DM_n + 0.95\ FA + 0.08\ LA + 1.00\ AL$$

where DM_c is the corrected DM, DM_n is the uncorrected DM, FA is the sum of volatile fatty acids (C_2 …C_6), LA is lactic acid, PD is 1,2-propanediol, BD is 2,3-butanediol and AL is the sum of all other alcohols (C_1 … C_4). All these parameters are to be used in the equations with the dimension g per kg fresh matter. The equation on silages from forage maize can be also used for such from sorghum and whole-crop cereals, and that on sugar beet should be also suitable for sugarcane.

As a consequence of correcting the DM content, all other analytical parameters, which are expressed as part of the DM, need to be corrected as well. Those of them which are directly measured in the pre-dried sample and are usually expressed as percent of DM_n (e. g. ash, ADF or NDF) must be multiplied by the quotient DM_n/DM_c. Difference fractions (e. g. OM or NDS = neutral detergent solubles) have to be calculated once more by using the figures expressed as percent of DM_c. The same applies to the calculation of the *in vitro* or *in situ* digestibility of such fractions to which the VOC belong (e.g. digestibility of DM or digestibility of OM). As an example, the dried residue of the IVTDM test, given as part of DM_n, has to be multiplied by DM_n/DM_c. The difference between 100 and this number is then the real IVTDM.

The article of Kung and Stanley (1982) contains experimental results on sugarcane silages, which were harvested at different stages of maturity (6, 9, 12, 15 und 24 months of growth), as well as on a maize silage. Silages made from sugarcane after 6, 12 and 24 months of growth and the maize silage were tested in digestibility trials with sheep. Fortunately, this article provides all of the needed data to enable subsequent re-calculation based on corrected DM. Data summarized in Tables 9-11 compare the results based on uncorrected and corrected DM.

Table 9: Composition of sugarcane silage with and without VOC correction calculated from experimental data published by Kung, Jr. and Stanley (1982)

Herbage and stage of maturity	DM content, %			Ethanol		ADF	
	Fresh herbage DM	Silage not corrected DMn	Silage corrected DMc	Silage not corrected g/kg DMn	Silage corrected g/kg DMc	Silage not corrected g/kg DMn	Silage corrected g/kg DMc
Corn	33.4	33.1	34.0	8	7	308	299
Sugarcane							
6 mo	22.3	18.1	20.5	75	68	434	395
12 mo	29.0	20.4	24.0	155	131	441	375
24 mo	31.5	22.4	26.6	175	147	443	372

DMn = not corrected for VOC; DMc = corrected for VOC

With increasing age of the sugarcane, DM increases due to accumulation of sucrose. The DM of the silages decreases mainly as a result of ethanolic fermentation, what can be explained by dramatic mass losses. Whenever ethanol is formed, 49% of the mass disappears (based on monosaccharides) (McDonald *et al*., 1991). Fermentation leads to decreased amount of DM, and the content of all components in the dry matter, which are not affected by fermentation, e.g. ADF, increases. The magnitude of this increase is lower if the content is calculated based on DM_c (Table 9).

In digestibility trials, DM intake increases due to correction of silage DM, while DM excretion remains unchanged, leading to increased DM digestibility. In the sugarcane silage of 24 months of age reaches the difference between corrected and non-corrected digestibility of DM about 10 percent units (Table 10).

Table 10: Digestibility of sugarcane silage with and without VOC correction calculated from experimental data published by Kung, Jr. and Stanley (1982)

Herbage and stage of maturity	Digestibility of DM %		Digestibility of energy %		TDN % of DM	
	not corrected	corrected	not corrected	corrected	not corrected	corrected*
Corn	61.4	**62.5**	67.6	**68.4**	62.3	**63.9**
Sugarcane						
6 mo	49.5	**54.0**	57.6	**62.3**	51.6	**60.8**
12 mo	47.3	**55.2**	58.5	**66.7**	48.1	**65.2**
24 mo	41.4	**50.8**	49.5	**60.6**	41.5	**61.3**

* TDN corrected with regard to DM and energy

In the calculation of nutritive value it still needs to be considered that during ethanolic fermentation about 97% of the gross energy of glucose or fructose is maintained in the metabolic end-product, the ethanol. Ethanol, which is included in the corrected DM, is not only fully digestible, but also contains much more energy per g than do other components of digestible OM.

It was attempted in this data evaluation to incorporate the high energy value of ethanol. The following assumptions were made: gross energy of ethanol is 7.12 kcal/g, gross energy of volatilized fatty and lactic acids 3,50 kcal/g and the average gross energy of the total of other components of digestible organic matter is 4.17 kcal/g (Schiemann *et al.*, 1971; Jentsch e*t al.*, 1969). Accordingly, 7.12 kcal/g ethanol and 3,50 kcal/g acids were added to gross energy (GE) and digestible energy (DE) (Table 10).

A rather unconventional approach was chosen in order to take account of the high energy content of ethanol in the calculation of TDN. In analogy to digestible fat, whose concentration is multiplied by 2.25 when calculating TDN, the ethanol as part of the digestible carbohydrates was multiplied by 1.71 g per g (7.12/4.17 = 1.71). In this way, one can get to a TDN figure which is not only DM-corrected but also energy-corrected. The TDN figures given in Table 10 are obtained by this calculation. The difference between corrected and non-corrected TDN achieves 20 percent units, where 10 are coming from higher digestibility of DM_c and about 10 units from the higher energy content of the digestible DM_c.

This evaluation supposes that the energy of ethanol is utilized like the energy of other nutrients. Based on our current physiological knowledge there is not any doubt that the ethanol will remain unchanged when passing through the rumen and the rumen wall, and that its energy will be then utilized in intermediary metabolism of the animal like that of other absorbed nutrients. Jentsch *et al.* (1969) found an energy utilization rate of 72% for ethanol in pigs, which is quite normal in comparison to other nutrients like, e.g., glucose or lactic acid, while the energy of acetic acid was less effective used (about 60%).

The calculations performed here led to substantial higher values for the energetic feeding value of sugarcane silages than was suggested before. Although the tested maize silage was not of best possible quality, the sugarcane silages - on average - achieved the same level of energetic feeding value as did the maize silage. This may explain why with sugarcane silages in the mentioned feeding experiments much better results were obtained then from the data on its apparent nutritive value could have been expected (Nussio, 2005; Queiroz *et al.*, 2005).

This conclusion is supported by the energy contents of the silages (Table 11). If the correction were done the digestible energy of sugarcane silages reaches the same level as the tested maize silage did.

Table 11: Energy content of sugarcane silage with and without VOC correction calculated from experimental data published by Kung, Jr. and Stanley (1982)

Herbage and stage of maturity	Gross energy kcal/g DM		Digestible energy kcal/g DM		Methane forming potential litres**/kg DM	
	not corrected	corrected*	not corrected	corrected*	not corrected	corrected
Corn	4.74	**4.73**	3.20	**3.24**	279	**271**
Sugarcane						
6 mo	4.92	**5.04**	2.83	**3.14**	276	**251**
12 mo	4.78	**5.07**	2.80	**3.38**	324	**276**
24 mo	4.62	**4.97**	2.29	**3.01**	321	**270**

* correted for DM and energy of VOC

** volume at standard temperature and pressure

In Table 11 also the values of the methane forming potential of these silages are given for the case that sugarcane silage is to be used as substratum for biogas production. These numbers were calculated by using a method which has been established during the last years and described (Weissbach, 2008; 2009a; 2009b; 2009c; 2009d; 2009f: 2009e).

The method is based on the assumption that the content of true digestible OM, which was measured in sheep fed at maintenance level, normally can be used as a measure of the biogas forming potential of a crop. The true digestible OM is regarded here as the "fermentable organic matter" (FOM). From the measured contents of apparent digestible OM, 60 g per kg DM_c as metabolic faecal fraction were subtracted in order to get to the content of true digestible OM.

The contributions of the individual chemical compounds to biogas formation were calculated by using stoichiometric equations, like that of Buswell and Mueller (1952) for the nitrogen-free-compounds:

$$C_aH_bO_c + \left(a - \frac{b}{4} - \frac{c}{2}\right)H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right)CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4}\right)CO_2$$

An analogous equation for N-containing compounds was formulated by Boyle (1976). For instance, the stoichiometric methane forming potential is 393 L per kg sucrose and 730 L per kg ethanol according to this equation. As the result of extensive calculations on the basis of the chemical composition of the respective crop, the following equations have been deduced for predicting the methane forming potential:

Maize silage: MFP = 0.420 FOM

Sugarcane silage: MFP = 0.400 FOM + 0.34 AL

Sugar beet silage: MFP = 0.375 FOM + 0.32 AL

where MFP is the "methane forming potential" [litres/kg DM_c], FOM is the fermentable organic matter [g/kg DM_c] and AL is the sum of all alcohols [g/kg DM_c]. The MFP is given as gas volume at standard temperature and pressure.

As can be seen in the last column of Table 11, MFP is similar between all 4 tested silages (approximately 270 Liter methane per kg DM_c). It can be concluded from this finding that fermented sugarcane produces as much methane as maize silage, and that this does not depend on the extent of conversion of sugar into ethanol.

However, if MFP was related to the non-corrected DM (see second last column in Table 11), then the results were markedly biased and indicated an seeming increase in MFP by 19% due to increasing sugar transformation into ethanol. This seeming increase has been observed in many laboratory batch trials on biogas production in which correction of DM for the loss of VOC was not carried out. It is easy to recognize that DM correction is also a crucial pre-requirement in the evaluation of biogas yield and the possibilities to influence it.

A recently published microbiological study has attracted significant attention. This article described the capability of certain *Lactobacillus buchneri* strains of producing ferulate esterase (Nserenko *et al*., 2007), thereby generating hope to be able to increase cell wall digestibility of maize and grass silages by the use of these bacteria as inoculant. Other scientists also focused on this topic (Berzahi, 2009; Brüsemeister *et al*., 2009a; Brüsemeister *et al*., 2009b; Kung, 2009; Nussio et al., 2009; Santos *et al.*, 2009; Spielbauer *et al*., 2009). Summarizing the results it must be stated that the expected effect on digestibility of NDF was inconsistent and its extent marginal. Also a colonizing within the digestive tract when inoculated silage was fed could not be found (Harman et al., 2009). However, the already well known positive effects of *L. buchneri* on aerobic stability have been confirmed also for these strains.

Another study aimed at improving biogas yield of grass and maize silage by using a favored *L. buchneri* strain (Ruser *et al.,* 2009). As could be seen in table 11, the effects on gas yield primarily depend on if and how comprehensive DM was corrected for the loss of VOC during drying. In order to be able to undoubtedly relate the higher biogas yield to improved cell wall digestibility, it should be excluded that the observed differences were caused by differences in fermentation pattern of the tested silages. This, in turn, renders the full analysis of the silages for all relevant VOC and the subsequent correction of DM. Pronounced improvements in biogas yield by inoculation of silages with *L. buchneri* strains can already be explained entirely by increasing aerobic stability, which reduces aerobic biomass losses. This has been demonstrated in numerous trials (Banemann *et al*., 2009).

As shown above, it is well possible to produce valuable silages from sugarcane with low energy losses, to be used in the feeding of ruminants and as substratum for biogas production. However, the question of how to design the ensiling technology and procedures for each specific use has not been answered yet, and remains to be addressed in further research activities. Also in this regard, high expectations and hopes were expressed about the potential and commercial use of *L. buchneri*-type inoculants (Nusssio *et al.,* 2009a and 2009b; Muraro *et al.,* 2009) to inhibit the growth of yeasts and ethanolic fermentation. Novel bacteria strains have been searched and tested for, which would eventually exert a specific suppressing effect on yeasts (Avila *et al.*, 2009; Pinto *et al.,* 2009) or whose antifungal effect could be attained especially in certain sugarcane varieties. All these attempts have not demonstrated promising results, and even more importantly, the basic problem of excessive WSC surplus in this crop could not be solved, which was likely to be expected.

It appears meaningful, if at all possible, to use the existing body of research data and re-evaluate them after DM correction for the loss of VOC during drying. Furthermore, additional studies are to be carried out which include the determination of all relevant silage parameters. Based on these experiences, novel concepts regarding technological developments can be proposed, thoroughly tested and, finally, implemented. Many questions still remain open, and the answers to them can only be given by specifically-designed trials. These questions are:

- How does untreated sugarcane silage behave under practical conditions if it is produced by employing technologically best ensiling measures (chop length and quality, compaction, air exclusion) as is done with maize?

- How is the aerobic stability of such sugarcane silage after sufficiently long fermentation and storage length (e.g. 6 months)?

- How is the acceptance and feed intake of such sugarcane silage by animals despite high ethanol concentrations?

- Does the use of *L. buchneri*-type inoculants really lead to benefits, how much acetic acid is produced during extended periods of storage and how does this affect feed intake?

- Are there any advantages of using antimycotic chemical additives that preserve the sugar in sugarcane silage and concurrently ensure high aerobic stability, and do positive effects pay for the cost of this type of additive?

It also needs to be asked as to whether energy production from whole-crop sugarcane does have an economically chance in the future. In comparison with the use of sugarcane for bioethanol production not only the sucrose yield would be utilized but the total plant biomass as

far as fermentable. Which requirements would then need to be met by the sugarcane silage, and which ensiling technology offers the most profitable solution?

Not very long ago, the use of sugar beet as substratum for biogas production was initiated in Germany (Wagner *et al.*, 2009). Also this crop cannot be stored without special technologies and must be ensiled if it is intended to use it continuously throughout the year. The best technology has not been determined yet, and different options are currently in discussion and testing. Mainly two concepts are followed.

The first preservation option is to crush the sugar beets and let them ferment spontaneously and uncontrolled. We do not see any constraints to the unavoidably occurring conversion of sucrose into ethanol by yeasts during extended fermentation periods since the MFP of the sucrose is almost fully retained in the fermentation end-product ethanol. However, there is still the challenge of providing cost-efficient inventory capacity for anaerobic storage. The disadvantage of sugar beets, if compared with sugarcane, is the production of excessive volumes of effluent, which further increases the costs for storage capacity. One solution to this problem may be the storage of whole beets in plastic tubes. Whole beets release significantly less effluent than do crushed beets. The needed processing of the whole beet for biogas production will be done just prior to the feeding into the biogas fermenter. The second option is that of chemical preservation of whole or crushed beets. The use of inoculants we do not consider for a viable approach in the preservation of such sugar-rich plant biomass.

Exemplarily, Table 12 and 13 shows the results of a study on the effects of a chemical additive on fermentation pattern, fermentation losses and biogas production parameters (Thaysen and Auerbach, 2011).

Table 12: Effect of a chemical additive on silage fermentation in sugar beet

(Thaysen and Auerbach, 2010)

	DMc	g/kg DMc				FOM	MFP
	%	Sugar	Lactic acid	Acetic acid	Ethanol	g/kg DMc	L/kg DMc
Fresh beet	25.0	732			0		352
Silage from whole beet							
Control	20.7	289	77	28	162	920	403
Benzoate/Sorbate*	24.0	641	24	21	12	927	352
Silage from crushed beet							
Control	21.2	271	78	31	171	912	402
Benzoate/Sorbate*	24.2	455	66	40	9	924	350

* Liquid preparation containing sodium benzoate and potassium sorbate

DMc = DM corrected for volatile organic compounds

MFP = methane forming potential

Untreated sugar beet markedly lost DM due to the degradation of sugar. However, the recovered DM had a substantially higher MFP since ethanol levels were elevated. In the contrary, in the treated sugar beet silage ethanolic fermentation was almost completely suppressed, thereby maintaining most of the sugars.

Table 13: Effect of a chemical additive on fermentation losses in ensiling sugar beet (Thaysen and Auerbach, 2010)

Treatment	Losses during fermentation, %			
	DMc		MFP	
	Mean	SD	Mean	SD
Ensiling of whole beet				
Control	**21.0**	8.1	**9.0**	7.5
Benzoate/Sorbate*	**7.6**	4.3	**7.1**	4.8
Ensiling of crushed beet				
Control	**20.3**	3.4	**8.3**	2.9
Benzoate/Sorbate*	**6.4**	1.3	**5.7**	0.9

* Liquid preparation containing sodium benzoate and potassium sorbate
DMc = DM corrected for volatile organic compounds
MFP = methane forming potential

Fermentation losses were determined by balancing input and output of corrected DM and by balancing the MFP of fresh beet and beet silage. MFP was calculated from the contents of FOM in fresh beet and in beet silage considering the ethanol content of the silages and using the equation shown above.

The DM losses which were mainly caused by CO_2 release during ethanolic fermentation amounted to more than 20 % in untreated silages and was substantially reduced by the chemical additive. Because of high energy content of the ethanol the losses of MFP were much lower and only little decreased by additive treatment. From this results, it can be stated that regarding recovery of energy both options of ensiling crops with high sugar contents can be accepted.

Conclusions

Forage conservation in general and silage production in particular presents an extremely important topic of high actual priority. Sufficient feeding of the world´s growing human population in all regions requires the best possible productive use of agricultural land resources, the reduction of losses of grown biomass and its highly efficient utilization.

This holds true for all regions of the world, but in emerging countries contributing significantly to the global agricultural production, there are huge possibilities to increasing productivity, which still have not been turned into reality. In many developing countries, efficient subsistence farming structures must be set up which are adapted to the socio-economic conditions.

All this is not possible without keeping ruminants. How many animals are needed and how much of climate-damaging methane is emitted depends on the performance level of the animals, which, in turn, is affected by the quality of feed inventory management.

A novel challenge to the agricultural industry is posed by the increasing use of plant biomass as renewable energy source and there demand for substratum supply. Also for this purpose, low-loss conservation and subsequent storage of biomass is crucial.

Consequently, forage production and conservation must be increased and improved by employing suitable technologies. Further research is to be carried out on silage production. This applies particularly to tropical and subtropical regions, in which silage production has not been used so far to the possible and needed extend, respectively.

An intensified international exchange of opinions and experiences in forage conservation is fruitful and useful, but the direct transfer of technologies from temperate climates seems limited. Solutions leading to their broad use under practical conditions must be developed for specific conditions, and probably for specific countries. This ultimately creates the demand for systematic research and extension programs on forage conservation and their financial support.

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