Hay-crop silages and the problem of fermentation quality

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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 utilisation.

The vast portion of agriculturally exploitable land on the globe is grassland. But grass can only contribute to feeding mankind by its utilisation by ruminants. The efficiency of animal production depends on an even feed supply all the year round. Consequently, development of forage conservation presents an extremely important topic of high actual priority. 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.

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

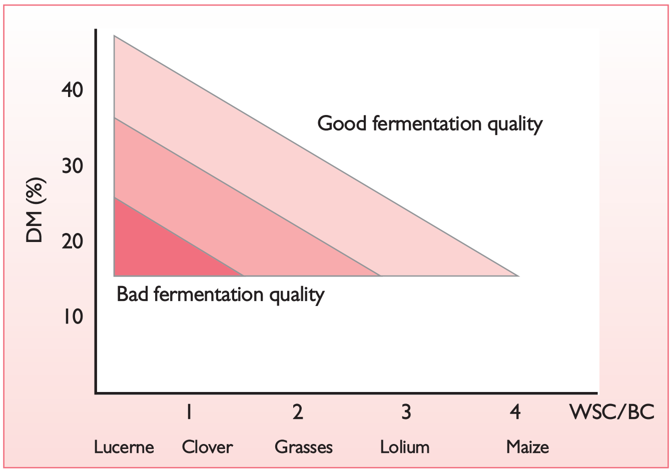

Fig. 1. Frequency of bad fermentation (butyric acid containing silages) as affected by WSC/BC ratio and DM.

need to be higher and feed quality lower than that of ensiled biomass.

As this is not applicable to all regions of the world hay making was replaced by producing 'hay-crop silages'. This change has led to marked improvements in European and North American countries, and its very likely further expansion in other parts of the world in the future will be of additional benefit.

Furthermore, the utilisation of whole-crop maize, whole-crop cereals, and possibly also of sugar cane in the future, for feeding purposes 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

Table 1. Critical pH values of silages (Weissbach 1968).

DM contents (%)	Water activity (a_w)	pH required for stability 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

this method of forage conservation, and the still future demand for research and development which is worth reflecting on.

Wilkinson, Bolsen and Lin (2003) carefully analysed 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 (for example, Australia, New Zealand and Latin America), there will probably be an increase in silage production to capitalise 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 unrealised 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 this article, 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.

Ensure good quality

The main problem of ensiling grass and legumes in temperate regions is to ensure good fermentation quality of the silage despite changing weather conditions. Good fermentation quality is needed to ensure low fermentation losses, high feed intake and good hygienic status of the silage. Silages of good fermentation quality are characterised by low numbers of Clostridia spores and the absence of butyric acid.

It is well established that the behaviour of a crop, when subjected to silage fermentation, depends on the substrate 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 characterise 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 McDonald et al. (1991) – by the amount of lactic acid which is required to acidify

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the crop to pH of 4.0. The practical advantage of this procedure is that the parameters WSC and BC have the same dimensions (for example g/kg DM).

If so, the ratio between the two reflects how many times of the standardised 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:

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

Where BC is the buffering capacity as meq/100g DM, x_1 is the nitrogen content [meq/100g DM], x_2 is the ash alkalinity [meq/100g 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.

The susceptibility of clostridia to acid increases with decreasing water activity in their environment (Table 1). Thus, bad fermentation can be avoided despite a low WSC/BC ratio by pre-wilting the herbage. The lower the WSC/ BC, the more the DM must be increased.

Fig. 1 demonstrates different frequency ranges of bad fermentation to be expected at given WSC/BC ratio and DM content.

The minimum DM content (DM_{min}), which is required to compensate for substrate deficiency (upper edge of the triangle), increases with decreasing WSC/BC ratio and can be calculated by the following equation:

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

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 characterise fermentability, the two parameters DM and WSC/BC 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.

Nitrate concentration

Nitrate is converted into nitrite during the early stages of fermentation, thereby inhibiting the development of clostridia until pH has reached the critical level. Based on experimental data from numerous ensiling trials with herbage from very different plant species, a minimal content of nitrate of one g/kg DM has proven to be sufficient under most conditions.

Alternatively, an epiphytic lactic acid bacteria (LAB) count of at least 10^5cfu/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 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.

Apparently the susceptibility of clostridia to low pH values is 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.
- 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 2 summarises 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 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 and for all other grasses, and 40% for Lucerne.

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 be 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 compensation of a too low wilting degree and, if required, the lack of nitrate.

Proven chemical silage 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}.

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Table 2. 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/ BC	DM_{min} (g/kg)	FC	
				WSC	BC			Un-wilted (DM as cut)	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-growth	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-growth	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	
Lucerne	all cuts		20	60	80	0.8	39	26	
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	<20	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

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Considering these facts, the resulting crop specific DM ranges at ensiling, which should be adhered to, can be derived. Table 3 shows the recommended ranges for ensiling in bunker and pit silos.

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 silage 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.

Precision farming

Recent developments in harvesting technology have also enabled the use of 'precision farming' tools in silage production. This has opened up possibilities for the control of silage additive application strictly based on real demand. Choppers can nowadays be 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 crop-specific mathematical functions can 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 really required for a given DM content. Table 4 shows the expected effects for the ensiling of grass with a liquid chemical additive, composed of sodium nitrite and hexamethylenetetramine. This additive is normally applied at 3 l/t and its effect is equal to increasing DM level by 14%.

The minimal dosage of this silage additive, which is constantly applied by using the on-line controlled equipment, supplies sufficient sodium nitrite to inhibit clostridial activity during the early fermentation phase also in nitrate-free forage.

Warm-season grasses

There have been published comprehensive reviews as well as numerous individual studies by different research groups on the problems, challenges and experiences of silage production in tropical and subtropical regions.

Warm-season grasses are the backbone of the tropical forages but their use in silage making is low so far.

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.

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 fertilisation and stage of vegetation (maturity). But such information is absolutely necessary to be able to derive optimal cultivation and utilisation regimes and strategies for conservation as well.

Consequently, more research work in this field is urgently needed and should be done.

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}. This can only be the result of systematic research programmes carried out in the respective region with the native plant species. The same applies to the suitability and the effect of silage additives.

With regard to the potential use of silage additives it should be distinguished between low and high input farming systems in the tropics. Both, the aim and the justifiable input can 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), as proposed by Oshima et al. (1997), can be a reasonable option. This method is characterised by the cultivation of epiphytic micro-organisms 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 micro-organisms (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 in this field could also be worthwhile. ■

Table 3. 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

Degree of wilting	DM content of the grass that enters the silo (%)		Mean application of silage additive for the whole silo (litres/tFM)
	Mean content within the whole silo	Variation during filling the silo	
Without	18	16-20	3.0
Very slightly	25	20-30	2.5
Slightly	30	22-35	1.8
Moderately	35	25-45	1.2
Rather heavy	40	28-58	1.0

Table 4. Mean requirement of a chemical silage additive with DM controlled application.