Aerobic spoilage of silage: part one – cause, extent and risk factors

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Dry matter losses associated with silage have been estimated to be as high as £2,500 million (€2,880 million) across the EU, individual losses ranging from just 10% to a huge 70%.

Even a 20% loss is worth nearly £7,000 for a UK farmer with a typical 1,000 tonne clamp of grass silage at 30% DM (valued at £115/te DM).

For a maize silage at 30% DM and £100/t DM, a 20% DM loss equates to £6,000 for a 1,000t clamp.

Variable losses can occur at several stages during the ensiling process, their relative importance depending on the crop and dry matter (DM) ensiled at.

For instance, you would expect fermentation and effluent losses to be higher when ensiling at low DM and field losses and aerobic spoilage to be more important at high DM (Fig. 1).

In the UK, the DM of grass silage, the main forage crop, has increased gradually over the years and now averages over 30%.

With more high DM crops such as maize and whole crop cereals, aerobic losses have become a much bigger issue here.

Silage DM (%)	Temperature rise above ambient (°C) 5	10	15	20	25
20	1.6	3.2	-	-	-
30	1.2	2.3	3.5	-	-
50	0.7	1.5	2.2	2.9	3.7

Table 1. Daily DM loss (%) at different grass silage dry matters (Honig,1990).

At these higher DMs the biggest potential losses are aerobic losses which begin as soon as a crop is cut and continue after ensiling until any oxygen trapped in the clamp initially is used up by plant enzymes, which remain active for a while after ensiling, and a wide range of aerobic micro-organisms associated with the fresh crop.

This can take from a few hours to several days, depending on the crop and the speed and efficiency of ensiling.

The longer air is present, the bigger the delay in fermentation starting and the less sugars will be available, as well as there being an increase in yeast numbers, making the silage potentially more unstable at feedout.

Aerobic activity (respiration) produces heat and temperatures above 50°C have been measured in the top layers of a clamp when it is being filled, a sure indication of poor consolidation as you should not see more than a 5-10°C increase above ambient. Prolonged high temperatures (above 45°C) will damage proteins, making them unavailable, and have a detrimental effect on the lactic acid bacteria needed for a successful fermentation.

Not all heat arises from aerobic activity; fermentation also results in some heat being produced in the bulk of the clamp, often rising to above 35°C then decreasing gradually, although clamps can remain above 30°C for months as silage acts as a heat sink.

Aerobic spoilage at feedout, resulting mainly from yeast and mould activities, is by far the biggest potential contributor to overall DM losses. It is the most digestible nutrients that are lost too so what is left has a lower digestibility and ME.

Digestible energy loss can be 1.5 to 2 times the loss of DM. Protein availability may also be affected.

Aerobic spoilage leads to:

- High DM losses.
- Loss of lactic acid which can destabilise the fermentation.
- Reduced nutritional value.
- Reduced palatability.
- Potential production of mycotoxins.

Aerobic deterioration is seen as heating, a pH increase (due to a reduction in the concentration of fermentation acids as well as ammonia production) and the appearance of visible moulding and a musty smell.

Heating is the first indication but may not be immediately obvious on the face itself as it often dissipates quickly in wet, windy or cold weather. But deeper within the clamp the heat is trapped, causing a temperature rise and accelerating spoilage.

The highest temperatures will be 0.5 to 1 metre behind the face. A clamp with a temperature of 25°C at the face may be over 50°C just one metre further back.

It is often difficult to appreciate just how much DM has been lost from a clamp because most of the loss is invisible carbon dioxide (CO_2) gas with the remaining visibly spoilt 'mouldy' silage representing a relatively small fraction of what was there originally. Some work by

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Fig. 1. The effect of DM on the partitioning of maize silage DM losses.

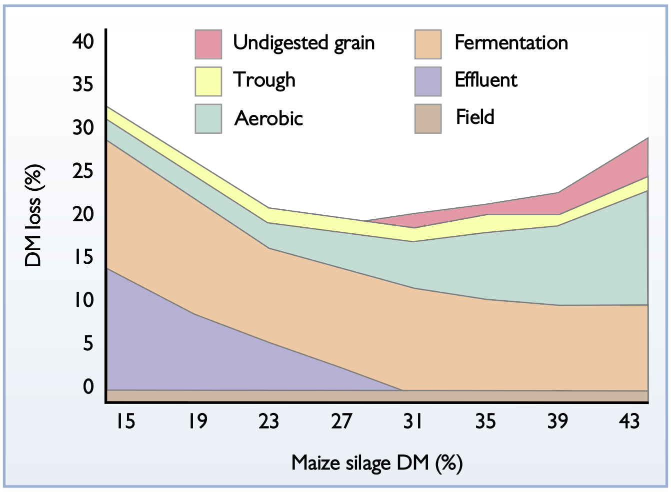
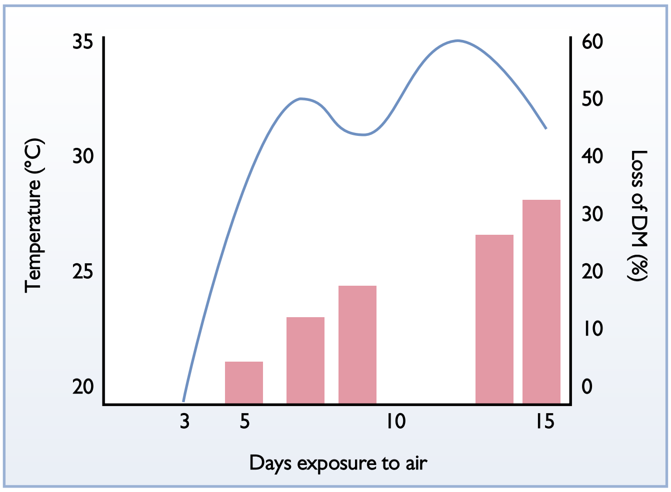


Fig. 2. Heating and DM loss in maize silage (Wilkinson, 2005).



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Honig (Table 1) demonstrates how large these losses can be and how the silage DM affects them.

Feeding heated and/or mouldy silage leads to a significant reduction in animal performance. In one UK study, a 27% DM grass silage heated up to 34°C over a period of six days with a pH increase from 3.8 to 5.8 (60% loss of lactic acid).

This resulted in DM and energy losses of 13.6% and 1 MJ/kg DM respectively, which represents a potential loss of 46 litres of milk per tonne of silage.

Similarly, Bolsen et al., (2002) demonstrated the negative effect of including spoiled maize silage in cattle rations. As the inclusion rate increased, DM intakes fell progressively from 7.95kg/day with 100% good silage to 6.66kg/day with 75% spoiled silage in the ration.

In most cases it is the fungi (yeasts and moulds) that are primarily responsible for aerobic spoilage with acetic acid bacteria and Bacillus spp. having a role in some situations.

When the temperature of heating silages is monitored, you often see two temperature peaks, the first due to yeast activity and the second, moulds (Fig. 2).

Fermentation: $\underset{\text{sugar}}{C_6H_{12}O_6} \longrightarrow \underset{\text{ethanol}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2}$

Fig. 3. Fermentation.

Respiration: $\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \textbf{heat}$

Fig. 4. Respiration.

Yeasts

Yeasts initiate the spoilage process in most crops. Most are tolerant of low pH, some growing at less than pH 3, and they can grow in the presence (aerobic) or absence (anaerobic) of oxygen.

They use up any oxygen trapped initially in the forage, multiplying rapidly and reducing the sugars available for lactic fermentation. Once the air is used up their numbers tend to remain fairly stable during the fermentation stage, waiting for access to oxygen to allow them to begin multiplying rapidly again.

Under anaerobic conditions they ferment a fairly restricted range of carbohydrate substrates to ethanol and carbon dioxide (Fig. 3). This only generates a small amount of energy for the cells and, with more competitive bacteria present, their numbers do not usually increase.

The carbon dioxide produced represents a 49% loss of DM and ethanol does not aid acidification.

In the presence of air, they switch to an oxidative metabolism (respiration) which allows them to utilise a much wider range of substrates, including some fermentation acids (Fig. 4).

Respiration produces about 20 times more energy than fermentation so cell growth and replication are much faster. However, there is a complete loss of DM from the clamp.

About half of the 500 or so yeast species are able to utilise lactic acid, loss of which can destabilise the fermentation, allowing a secondary butyric fermentation to occur.

The substrates are oxidised to carbon dioxide and water with the generation of a large amount of heat.

Temperature increase and carbon dioxide production are both directly correlated with DM loss.

Yeasts will also oxidise amino acids, releasing ammonia which further increases the pH.

On fresh crops yeast numbers may be as low as 10 per gram forage but in spoiled silage can increase to over 10^9 (1,000,000,000). Silages with yeast counts of more than 10^5 (100,000) per gram are generally at a higher risk of aerobic spoilage at feedout.

Moulds

Although yeasts initiate aerobic deterioration, it is moulds that do the most damage as they grow very fast and can utilise a much wider range of substrates, leading to significant losses of both DM and nutritional value. Some also produce mycotoxins.

Moulds generally become active after the yeasts, preferring a slightly higher pH. Their growth is favoured by a pH above 5, a moisture content above about 15%, a humidity above 70% and temperature above about 15°C. They require oxygen for growth, surviving as spores in anaerobic conditions.

Patches of mould growth are very visible, often being highly coloured, and in some cases 'mushrooms' may even be seen, especially on the shoulders where compaction is less.

Great care needs to be taken when handling mouldy silages as they are associated with a number of human diseases, for example 'farmers lung'. Some moulds produce mycotoxins which are associated with production, fertility and health problems. Ideally, mouldy silage should be discarded and certainly never fed to prime stock.

Bacteria

Bacteria tend to have a smaller role in aerobic spoilage, although aerobic, thermotolerant proteolytic Bacillus species may become active in the later stages of deterioration when the temperature is already high and the pH above 5. In some maize silages, however, acetic acid bacteria (AAB) are believed to initiate aerobic deterioration, with yeasts following on soon after.

Normally AAB oxidise ethanol to acetic acid but in its absence can utilise acetic acid and lactic acid.

The conversion of ethanol to acetic acid does not result in a significant pH change but the further breakdown of acetic and lactic acids results in a large pH increase (Fig. 5)

The increase in pH that occurs in deteriorating silage allows other bacteria, such as clostridia and listeria, to become active again, reducing the nutritional value of the silage still further and with potential hazards for stock.

Clostridia are highly undesirable, their activities destabilising the fermentation, breaking down proteins and producing potentially harmful metabolites. They are inhibited by low pH and high DM and they only grow in the absence of air, surviving in spore form when it is present.

They are not normally associated with aerobic spoilage but deterioration near the surface can cause a pH increase deeper in the silage mass where the oxygen concentration is low enough to allow clostridia spores to germinate.

Listeria monocytogenes is the listeria species generally associated with silage. They can survive for long periods in silage below pH 3.8 provided oxygen is present but are killed rapidly at pH 4.2 in its absence.

Numbers can increase rapidly above about pH 4.5 in the presence of a low level of oxygen. They also prefer wetter silage, conditions on the surface of bales under the wrap, being ideal. They can cause severe health problems in both humans and animals – they are responsible for 'silage eye' in cattle and listeriosis in sheep.

Gas movement

Air penetration into the silage mass is dependent on the density of the silage which in turn depends on a number of inter-related factors such as crop DM and maturity, chop length and compaction. With a 350g/kg DM silage, increasing wet density from 500 to 800kg/m^3 would reduce porosity by 50%.

Air exchange will continue as long as the clamp remains open. Carbon dioxide is more dense than oxygen so it escapes at the bottom, causing more air to be drawn in at the top. Similarly, rising hot air draws more air in at the bottom.

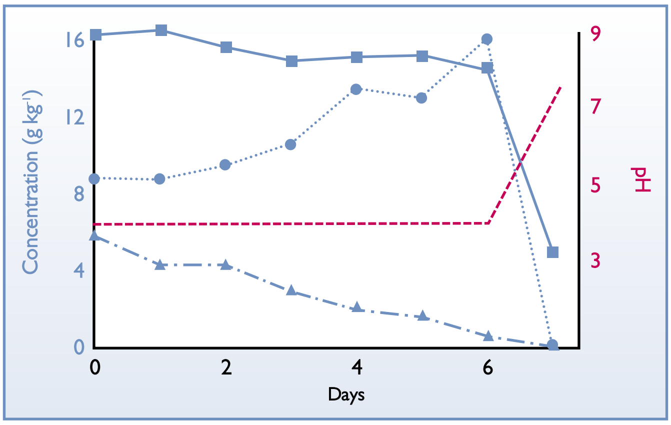
Initial air to forage ratios of up to 4 to 1 in newly filled clamps have been quoted, but even in a poorly consolidated clamp, provided it is sealed properly, any trapped oxygen should be used up in within a couple of hours at most due to respiration by plant enzymes and aerobic microorganisms.

It is at feedout when the silage is exposed to air again that the effect of poor consolidation is seen. The more porous the silage mass, the easier and further the air will penetrate.

Some crops are more difficult to compact, the differences being more apparent at lower levels of compaction. At 35% DM there is little air penetration at 300kgDM/m^3 with any crop but at 200kgDM/m^3 (more typical for clamps) there are large differences, maize being by far the worst with grass lowest and lucerne in between.

Without doubt, good consolidation will reduce DM losses significantly as shown in one experiment with lucerne where increasing silage density from 160 to 350kg DM/m^3 halved DM losses from 20% to just 10%.

Fig. 5. Changes in the pH (---) and concentration of lactic acid (–■–), acetic acid (··●··) and ethanol (··▲··) in maize silage during exposure to air.



Susceptible silages

Although much research has been conducted into the subject it is still not possible to predict with any certainty whether a silage will be aerobically unstable.

There are, however, several factors that would appear to increase the risk:

- Crops, such as maize, that tend to have high numbers of yeasts already present on the standing crop, giving them a head start.
- Silages with a yeast count higher than 100,000/g, especially if they are lactate utilising yeasts.
- Silages with high residual sugars, for example high DM, enzyme treated, restricted fermentation, or a high starch level.
- Wilted silages, especially if prolonged and/or under poor conditions as yeasts multiply during wilting and high DM silages are more difficult to compact.
- High DM crops as their restricted fermentation results in higher residual sugars and they are more difficult to consolidate, especially if longer chop.
- Enzyme treated silages as residual sugars are often higher. Also, if no inoculant is used the extra sugars may promote yeast growth.
- Well fermented silages with a high percentage of lactic acid. The pattern of fermentation is more important than the extent for determining aerobic stability as it is the products of a poor fermentation, for example acetic, propionic and butyric acids and ammonia, that make poorly fermented silages stable
- Silage bales as they are usually made from higher DM crops, less densely packed than clamps, even with chopped forage, and have a high surface area to volume ratio (outer 10cm represents 30% of bale volume).
- Silages being fed in a TMR as the mixing action of the wagon aerates the silage resulting in increased DM losses in the feed trough.

Ambient temperature has a significant effect on aerobic stability, warm weather encouraging microbial activity so any silages being fed during warm weather, especially if humid too, will spoil faster. Silage pH is not directly correlated with aerobic stability.

Aerobic spoilage can result in very high DM losses and changes to the remaining silage that impact negatively on animal production, fertility and health. Many interlinking factors are involved in determining the speed and extent of spoilage. ■

References are available from the author on request.

Part 2 of this article, which will be published in the next issue of International Dairy Topics, will look at ways of reducing the risk of spoilage.