Chapter 2

Principles of silage preservation

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In this chapter

The authors

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The Key Issues

- The key to producing a well-preserved silage is an anaerobic fermentation dominated by lactic acid bacteria (LAB).
- A good fermentation requires sufficient water soluble carbohydrate (WSC) content to produce enough lactic acid to overcome the buffering capacity of the forage and reduce pH to an adequate level for preservation.
- Shorter chop length increases rate of release of fermentation substrates and improves compaction.
- Effective wilting will improve the fermentation, by concentrating available WSC and restricting activity of undesirable bacteria, and reduce effluent losses.
- Wilt as rapidly as possible to avoid excessive respiration losses in the field and in the early stages of storage.
- Compact well and seal effectively to create an anaerobic (air-free) environment. This will minimise losses during storage.
- Once the silo is opened and the silage is exposed to air, aerobic spoilage will commence. Management during feedout will influence the extent of aerobic spoilage.

Section 2.0

Introduction

An acid fermentation occurs when forages of sufficiently high moisture content are stored under anaerobic conditions. During fermentation, bacteria convert plant sugars, water soluble carbohydrates (WSCs), to fermentation acids and other compounds. Ideally, this fermentation produces mainly lactic acid and in sufficient quantity to quickly reduce pH. At low pH, acid conditions prevent further microbial activity and spoilage.

The final pH achieved in a well-preserved silage depends on the WSC and dry matter (DM) content of the forage at time of ensiling. The final pH may be as low as 3.8-4.2, but could exceed 5.0 in heavily wilted silages, particularly those produced from legumes (see Chapter 12, Table 12.3).

The silage will not deteriorate as long as anaerobic conditions are maintained. In other words, the nutrients in the silage are preserved while the silo or bale remains sealed.

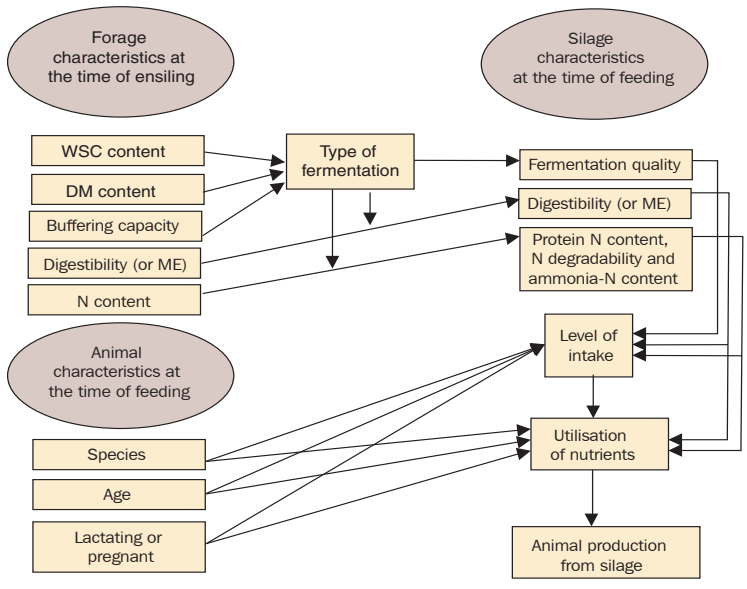
silage – the fermented product resulting from the anaerobic fermentation of sugars in forage

aerobic – in the presence of air (specifically oxygen)

anaerobic – without air (specifically oxygen)

Figure 2.1

Effect of forage characteristics and quality on silage quality and animal production.



The rate and efficiency of the fermentation process, the products of fermentation, and the fermentation quality of the resultant silage depend on several factors, the most important being the composition of the parent material at the time of ensiling and the species of bacteria that dominate the fermentation.

The quality of the silage produced depends on its nutritive value – digestibility, ME, protein and mineral content – combined with its fermentation quality (see Figure 2.1). Poorly fermented silage may result in inferior animal production due to unpalatability and poor utilisation of dietary nitrogen (crude protein).

Losses in quality can occur throughout the silage-making process. The level of loss will depend on:

- the physical and chemical properties of the forage at the time of harvest and ensiling;
- wilting conditions and the extent of wilting;
- the harvesting process;
- the efficiency of the fermentation process;
- maintenance of anaerobic conditions during storage; and
- management during feedout.

Section 2.1

Parent forage composition

The composition of the parent forage at ensiling has a major influence on the silage fermentation. The most important components are DM content, WSC content and buffering capacity (BC).

2.1.1

Dry matter content

The DM content of the parent forage at ensiling can affect the quantity of effluent lost from the silage during storage, the growth of bacteria in the silage and the ease of compaction which, in turn, affects the exclusion of air from the silo or bale.

Effluent

During the early stages of the ensiling process, as the cell structure breaks down due to compaction and the action of plant enzymes and microbial activity, fluids are released from within the cells. If the forage is stored at low DM content – in particular unwilted, direct-cut pastures or forages containing 'free' water from rainfall or dew – surplus moisture (including soluble compounds) will flow out of the silo as silage effluent.

The quantity of effluent produced is directly related to the DM content of the forage ensiled and the extent of compaction of the silage. Effluent flow falls as DM content increases (see Figure 2.2), and stops when the DM content reaches about 30%. As a result, wilting is an effective management strategy for reducing effluent losses.

Effluent flow is slightly greater for finer chopped compared to long chop forage.

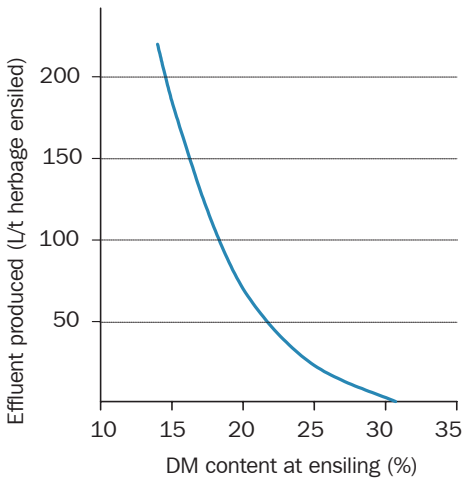
Silage effluent contains WSCs, protein, minerals and fermentation products, so it represents a significant loss of nutrients. The loss of WSCs will reduce the quantity available for the silage fermentation.

Silage effluent is also a serious environmental pollutant if it enters waterways. It has a very high biological oxygen demand (BOD), in the order of 12,000 to 83,000 mg/L. In the UK, silage BOD levels have been estimated to be about 200 times higher than those of untreated domestic sewerage.

Effluent (from various sources) contaminating water systems is receiving increasing attention from the various State environmental protection authorities. In many European countries, landowners face prosecution if silage effluent enters water systems.

Although some silage additives can be used to reduce the amount of silage effluent produced (see Chapter 7), wilting is the most effective way to prevent effluent production.

Figure 2.2



Effect of forage DM content at ensiling on effluent losses from silage.

Source: Adapted from Bastiman (1976)

Growth of silage micro-organisms

The DM content of the forage directly affects bacterial activity during the fermentation phase. The activity of all silage bacteria slows as forage DM content increases and as silage pH decreases. Bacterial activity stops at a higher pH as forage DM content increases. Therefore, wilted silages have a higher final silage pH.

When fermentation is restricted by falling pH, some of the WSC may be left unfermented. Residual WSCs can cause the silage to be more aerobically unstable, resulting in greater losses during feedout (see Chapter 10, Section 10.2.1).

Bacteria vary in their preferred conditions for optimum growth, especially moisture content (or water activity). Clostridia, one of the main bacteria responsible for silage spoilage, are particularly sensitive and require low DM conditions to flourish. Wilting to a DM content >30% usually restricts clostridial growth and favours the preferred lactic acid bacteria (LAB).

When forages are wilted, the concentration of WSCs on a fresh crop basis increases (see Section 2.1.2). This also favours the growth of LAB and improved silage fermentation quality.

The micro-organisms important to silage production are discussed in detail in Section 2.3.

Compaction and silage density

If forage DM content is too high at ensiling, it is more difficult to achieve adequate compaction. When silage density is low, more oxygen remains in the silo at ensiling and there is increased air infiltration when the silage is opened for feeding. Increased exposure to oxygen in the early stages of the ensiling process leads to increased respiration and loss of DM and energy.

Additional information on storage and feedout losses is provided in Section 2.5, Section 9.8 of Chapter 9 and Chapter 10.

Information on optimum DM content of various forages at ensiling is provided in Chapter 4, Table 4.1; Chapter 5, Table 5.2; and Chapter 6, Section 6.4.1.

2.1.2

Water soluble carbohydrate (WSC) content

Effective ensiling relies on the fermentation of WSCs to lactic acid by LAB. WSC content in the parent forage should be >2.5%, on a fresh forage basis, for good silage fermentation. If WSCs are <2.5%, the forage should be wilted (see Appendix 2.A1, Figure 2A.1) or a silage additive used to reduce the risk of a poor fermentation (see Chapter 7, Section 7.4).

The main non-structural carbohydrates in temperate grasses are glucose, fructose, sucrose and fructans. Fructans are the most important storage carbohydrates. These and other sugars, present in small quantities in plants, are soluble in cold water and are collectively referred to as WSCs.

The WSC contents of temperate legumes, tropical grasses and tropical legumes are lower than that of temperate grasses. The main sugars in temperate legumes are fructose, glucose and sucrose.

The principal storage carbohydrate in temperate legume forages is starch, rather than fructans – starch is insoluble in cold water. In cereal crops WSC contents are high at the vegetative stage of growth, but as grain filling progresses WSC content falls and starch content increases.

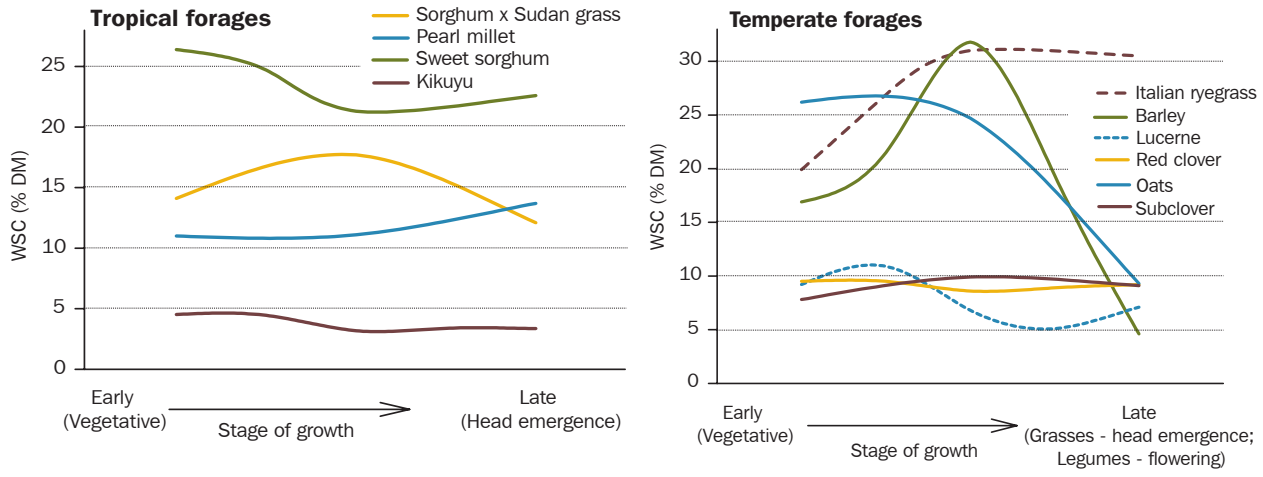
Most naturally occurring LAB are unable to ferment starch. Therefore, starch is not a satisfactory substrate for LAB growth, unless there is some breakdown (hydrolysis) by plant enzymes (amylase) or acid hydrolysis during the fermentation to convert starch to WSCs. In addition, most LAB cannot ferment hemicellulose (a component of the plant fibre fraction), but some hydrolysis of hemicellulose occurs (due to the action of plant enzymes and silage acids) releasing sugars for fermentation.

Although a number of other factors influence the WSCs of forages, species differences (Appendix 2.A1, Table 2A.1) and stage of growth have the greatest effect. The trends for changes in WSC content at different stages of growth are illustrated in Figure 2.3. (More details for crops and pasture species can be found in Chapters 4 and 5.)

The effects of growth stage tend to be greatest with temperate grasses and cereal crops.

Figure 2.3

Influence of stage of growth at harvest on the WSC content of different forages.



Sources: McDonald et al. (1991); Kaiser (various studies, unpublished data)

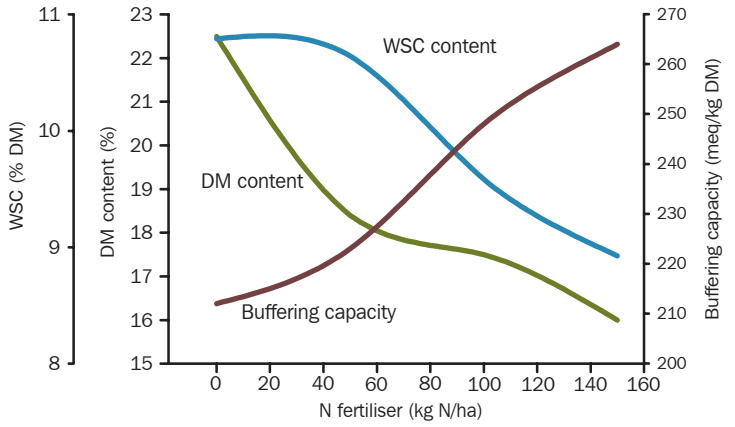
Other factors influencing WSC content include:

Cultivar: There is evidence of significant variation in WSC between cultivars in some grass species. Some plant breeders are selecting for higher WSC content.

Weather conditions: Low light intensity, cloudy weather and high rainfall during crop growth can reduce WSC content.

Figure 2.4

Effect of N fertiliser on WSC and DM content, and buffering capacity of ryegrass.



Source: Adapted from OKiely et al. (1997)

Time of day: On sunny days, WSC content usually increases during the day, until mid afternoon. For this reason some advisers have recommended mowing of crops and pastures mid afternoon. However, the variation in WSC content during the day is considerably less than that due to species and stage of growth. Furthermore, any advantage in WSC content could be lost by slower wilting and higher respiration when forage is cut later in the day (see Chapter 6, Section 6.2).

N fertiliser application: Application of nitrogen fertiliser can reduce WSC and DM content, and increase buffering capacity (see Section 2.1.3). This is highlighted in a study with perennial ryegrass (see Figure 2.4). Consequently, nitrogen fertiliser application is not recommended within four weeks of harvest for most crops, in most situations. The exception is short regrowth crops, such as kikuyu and other tropical grasses during their peak growth periods.

Crops receiving high rates of nitrogen fertiliser must be adequately wilted (see Chapter 4, Section 4.3.2).

2.1.3

Buffering capacity (BC)

All forages contain chemical compounds, called buffers, which resist changes in pH. Most of the BC of forage depends upon the content of organic acids and their salts, with proteins contributing to about 10-20% of BC. In silage production, these buffers neutralise some of the silage acids as they are produced, restricting and delaying the decline in pH, and providing an opportunity for the growth of undesirable bacteria. Therefore, there is an increased risk of a poor fermentation when ensiling forages with a high BC.

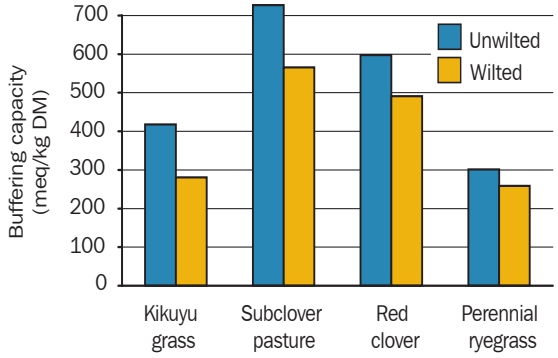
The main factors influencing the BC of forages are:

Species: The BC of forages varies between species (see Table 2A.2, in Appendix 2.A2), with legumes having higher BCs than grasses. Some summer forage crops, in particular maize, have a very low BC, while some broadleaf weeds can have a very high BC.

Stage of growth: There is evidence with a number of pasture and forage crop species that BC declines with advancing crop maturity.

Figure 2.5

Influence of wilting on the buffering capacity of various forages under favourable weather conditions.



Source: Playne and McDonald (1966); Dawson et al. (1999); Kaiser (various studies, unpublished data)

N fertiliser application: The application of nitrogen fertiliser can increase BC (see Figure 2.4).

Wilting: BC is sometimes reduced when forage is wilted (see Figure 2.5), although this may not occur where wilting conditions are unfavourable and there is an ineffective wilt. The reduced BC has been attributed to a reduction in the organic acid content of the forage.

2.1.4

Assessing the ensilability of forages

The ensilability of a forage, or the likelihood of producing a silage with a good lactic acid fermentation, can be assessed by taking account of its DM content, WSC content and BC. Forages with a high WSC content and low BC are relatively easy to ensile successfully. On the other hand, forages with a low WSC content and high BC are more difficult to ensile, particularly if the DM content is also low. In these circumstances, the crop needs to be wilted to DM targets to achieve minimum WSC in the fresh crop (see Section 2.1.2 and Figure 2A.1 in Appendix 2.A1).

Table 2.1 shows the ensilability of a number of common crops, pastures and weeds.

To take account of the three factors influencing the ensilability of forages – DM, WSC and BC – European researchers have developed a *fermentability coefficient,* which can be calculated for each forage. They have identified a minimum score, above which there is a high probability of a good lactic fermentation under European conditions. At this stage, critical scores have not been developed for forages under Australian conditions.

Even if the ensilability of a forage is poor, there are strategies that can be used to increase the probability of a good fermentation. Wilting (see Section 2.2.1 and Chapter 6) and silage additives (see Chapter 7) are effective 'tools' for improving the ensilability of difficult forages.

Table 2.1

*The ensilability of various crops and pasture species.**

Buffering capacity	**WSC content (% DM basis)**		
(meq. NaOH/kg DM)	High (>20%)	Medium (12-20%)	Low (<12%)
Low (<350)	Sweet sorghum	Maize, grain sorghum, winter cereals (heading), perennial ryegrass, lupins	Cocksfoot
Medium (350-550)		Italian ryegrass, peas, sunflowers	Medics, arrowleaf clover, lucerne, white clover, sainfoin, kikuyu grass, other tropical grasses, millets, forage sorghum
High (>550)		Capeweed, variegated thistle	Immature oats, subclover, balansa clover, red clover, berseem clover, vetch, tropical legumes, Paterson's curse

Very easily ensiled

Easily ensiled

Moderately easy to ensile

Difficult to ensile successfully without wilting or silage additives

** Some species with a wide range in WSC or BC may appear in more than one category – see Appendices 2.A1 and 2.A2 for mean values and ranges.*

WSC content and BC of a species is modified by the stage of growth, N fertiliser application and weather conditions.

Section 2.2

The silage preservation process

2.2.1

Aerobic phase

The aerobic phase commences when the forage is cut. It includes the wilting period and the time between sealing and when anaerobic conditions are achieved within the silo (see Figure 2.7). Changes in forage composition are mainly due to the action of plant enzymes. Early in this phase enzymes break down more complex carbohydrates (fructans, starch and hemicellulose), releasing simple sugars (WSCs). Plant enzymes continue to use WSCs for the process of respiration until either all the substrate (WSCs) or available oxygen has been used. Plant enzymes will also continue to break down (degrade) protein to various non-protein N compounds – peptides, amino acids, amides and ammonia – the process of proteolysis.

Respiration

Respiration is undesirable because it results in a loss of DM, energy (ME) and available WSCs required by LAB for fermentation. Although some respiration is unavoidable, good silage-making practice will minimise these losses (see Sections 2.5.1 and 2.5.2, and Chapter 6).

During respiration, WSCs are converted to carbon dioxide and water, with energy released in the form of heat. Heat production is the first sign of respiration.

WSC + oxygen → carbon dioxide + water + heat (16MJ/kg WSC)

Because the process is oxygen-dependent, respiration ceases once anaerobic conditions are established in the silo or bale.

The extent of aerobic respiration will depend on a number of factors, including characteristics of the forage, the length of wilt, wilting conditions, the time between harvest and compaction and sealing, and the degree of compaction achieved. Two of the most important factors affecting the rate of respiration are forage DM content and temperature (see Figure 2.6). Respiration rate is quite low once forage DM reaches 50-60%, but at all DM levels respiration increases with temperature.

Management factors that affect the time taken to achieve anaerobic conditions – the time taken to fill and seal the bunker or bale, and the degree of compaction – are also important (see Chapter 9, Section 9.4). However, even in a well-sealed silo, the temperature rise increases as silage density falls, especially when DM content is high (see Figure 2.8).

If the aerobic phase continues for a prolonged period after sealing, the sealing is inadequate or a hole develops in the plastic, allowing air into the silo, aerobic micro-organisms (yeasts and moulds) will grow. This results in increased DM and energy losses due to spoilage in the silo and also during the feedout phase (see Section 2.5.3 and Chapter 10).

During the aerobic phase plant enzymes:

Break down WSCs to carbon dioxide and water, and release of heat = respiration.

Break down proteins to various forms of soluble non-protein nitrogen (NPN) = proteolysis.

Respiration rate:

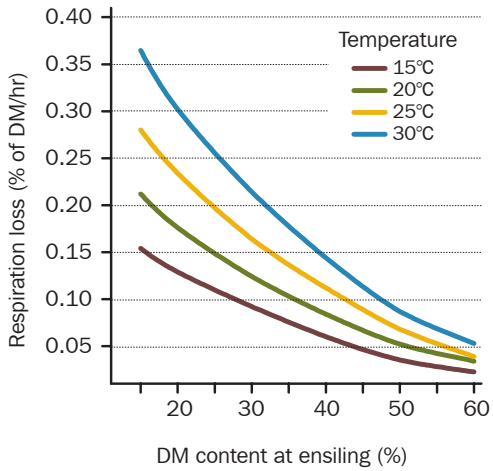
- is highest in leafy forages;
- is greater for legumes than grasses;
- decreases with increasing forage DM content; and
- is greater at higher ambient temperatures.

Respiration depends on the availability of oxygen, so is greater:

- with poorly compacted silages;
- when filling is slow; and
- when sealing is delayed.

Figure 2.6

Respiration losses from cut grass in the field.



Source: Adapted from Honig (1980)

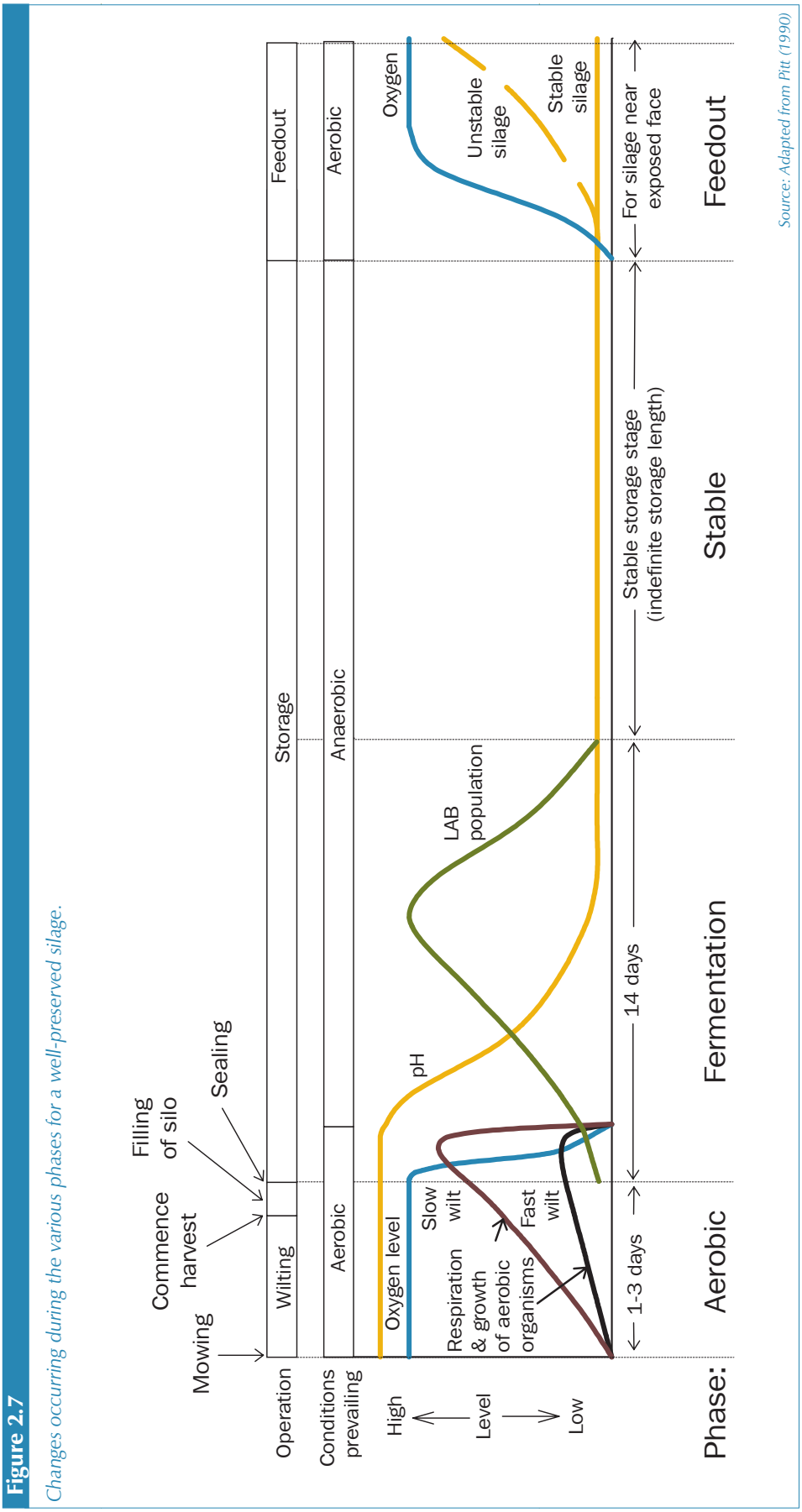


Figure 2.7

Changes occurring during the various phases for a well-preserved silage.

Source: Adapted from Pitt (1990)

If the respiration is allowed to continue for a prolonged period, a large amount of heat will be produced. The temperature within the silo or bale can become quite high, resulting in heat damage of the protein and a reduction in digestibility due to a browning reaction (also known as Maillard reaction or caramelisation).

Heat-damaged silages have a pleasant, sweet, burnt sugar aroma and are quite palatable to livestock, provided moulds are not present. However, the digestibility of heat-damaged silage is very low and it is usually only suitable for maintenance feeding. There is a significant drop in quality because the excessive heat binds the protein and amino acids to the hemicellulose fraction, increasing the indigestible fibre and acid detergent insoluble nitrogen (ADIN) content (see latter section of Chapter 12, Section 12.4.4).

Silages with a DM content ≥50% are most susceptible to heat damage. Digestibility will be reduced if the temperature in the silo rises above 50°C.

Proteolysis

Proteolysis is undesirable because ruminant livestock are not able to use degraded protein as efficiently in the rumen (see Chapter 12, Section 12.4.4).

The extent to which proteolysis occurs during wilting varies considerably, and does not appear to be related to either plant species or nitrogen content.

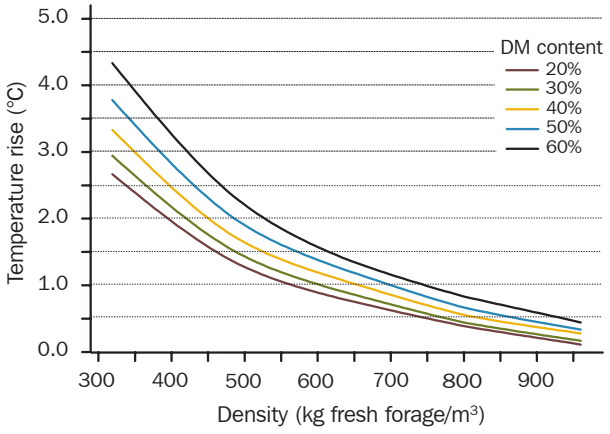
If wilting is achieved quickly there appears to be very little increase in the amount of degraded protein within the forage. However, slow, extended wilts have been shown to increase protein breakdown (see Table 2.2).

Although respiration and proteolysis occur more rapidly at higher temperatures the rate of wilting also increases, with a more rapid wilting usually resulting in less proteolysis and loss of WSCs. Greatest losses will occur when temperatures are high, but rain and humid conditions cause wilting rate to be slow.

Enzymic proteolysis can continue in the ensiled material for several days. Production of fermentation acids will eventually stop the action of the enzymes. For this reason, proteolysis occurs more rapidly in freshly ensiled forage and declines as pH declines. Achieving a rapid lactic acid fermentation will result in less degraded protein in the silage.

Figure 2.8

Effect of forage density and DM content on temperature rise in a well-sealed bun.



Source: Adapted from Pitt (1983)

Increased wilting rate leads to:

- reduced respiration of WSC;
- reduced loss of energy and DM;
- increased WSC available for fermentation;
- better fermentation;
- reduced proteolysis during wilting; and
- reduced proteolysis in the silo due to more rapid decline in pH.

Table 2.2

The effect of wilting on the major nitrogen components of ryegrass/clover forage.

Rate of wilt	Length of wilt (hours)	DM content (%)	Protein-N (% total N)	Ammonia-N (% total N)
Unwilted	0	17.3	92.5	0.12
Rapid	6	34.9	87.7	0.11
Rapid	48	46.2	83.2	0.21
Slow	48	19.9	75.2	0.26
Slow	144	37.5	68.9	2.61

Source: Carpintero et al. (1979)

Types of silage

The composition of the ensiled forage and the subsequent fermentation will determine the type of silage produced. Silages produced under Australian conditions can be broadly classified into five main types:

Lactate silages

- fermentation is dominated by LAB;
- WSCs are primarily converted to lactic acid;
- have a pleasant, acidic and sometimes sweet smell;
- pH values are generally low (3.8-4.2), except in heavily wilted silages where the fermentation is restricted; and
- contain high lactic acid levels relative to other organic acids.

Acetate silages

- fermentation may be dominated by enterobacteria;
- more likely to occur when unwilted, or lightly wilted, low DM forage is ensiled;
- WSCs are primarily converted to acetic acid;
- typified by a sour, vinegar smell;
- pH values are higher than those of lactate silages at the same DM content; and
- DM and energy losses can be significant.

Clostridial silages

- fermentation is dominated by clostridia;
- more likely to occur when unwilted, or lightly wilted, low DM forage is ensiled;
- WSCs and lactic acid are converted to butyric and acetic acid;
- characterised by low lactic acid levels and high pH;
- proteins and amino acids are extensively degraded;
- ammonia-N levels are high as a proportion of total N;
- DM and energy losses can be significant (silages are unpalatable to livestock and the utilisation of the N in these silages is poor); and
- clostridial silages are not common in Australia.

Wilted silages

- fermentation is dominated by LAB;
- fermentation is restricted because of the high DM content (>30%). Less WSC are converted to lactic acid. pH values are higher than those of lactate silages;
- residual, unfermented WSC levels can be high, but vary due to length and extent of wilting;
- very dry forages are harder to compact, especially if chop length is long; there is a greater risk of yeast and mould growth because oxygen levels in the pit or bale are high in poorly compacted silages; and
- higher residual WSC, poor compaction and carry-over yeast and mould spores can make these silages more aerobically unstable.

Silages with additives

- the characteristics and type of fermentation observed varies with additive type. Chapter 7 gives further information on the types of additives available and their use.

A more detailed description of the appearance and aroma of various silages is contained in Chapter 12, Section 12.3.

2.2.2

Fermentation phase

The anaerobic fermentation phase commences once anaerobic conditions are achieved within the silo (see Figure 2.7). During this phase, acids are produced, lowering the silage pH and preventing further microbial activity, and so preserving the silage. The silage will not deteriorate until exposed to oxygen. A slow fermentation increases DM and energy losses, and reduces the palatability of the silage.

The silage quality and fermentation products are determined by the forage characteristics and which micro-organisms dominate.

After the fermentation phase commences there is a short period, about one day, when breakdown of cell walls and the release of fermentation substrates by plant enzymes continue. Bacteria then begin to multiply rapidly, increasing to a population of about 1 billion (10^9) per gram of fresh forage. These silage bacteria ferment WSCs, converting them to acids and other products. Ideally, LAB dominate the fermentation, but enterobacteria and clostridia may be dominant in some silages. Aerobic yeasts can also be present.

This phase may be dominated, in the early stages, by enterobacteria. These bacteria ferment WSCs, producing mainly acetic acid, with lesser quantities of lactic acid. Ethanol, 2,3-butanediol and carbon dioxide are also produced and DM and energy is lost.

In well-fermented silages, as lactic acid is produced the pH drops, enterobacteria cease growing, and LAB quickly begin to dominate the fermentation. If the decline in pH is slow, enterobacteria may continue to dominate the fermentation, and produce an acetate silage.

LAB ferment WSCs to lactic acid, with only very small quantities of other compounds being produced (see Appendix 2.A3). Fermentation dominated by LAB is preferred because lactic acid production is the most efficient chemical pathway. The decline in pH is rapid and there are only very small fermentation losses of DM and energy.

The proportion of lactic acid to other compounds produced will depend on the relative activity of homofermentative and heterofermentative LAB (see Section 2.3.1). Providing sufficient WSC are available, fermentation will continue until a pH of about 4 is achieved. Lower pH values have been observed in silages produced in Australia from forages with high levels of WSC and low buffering capacity, such as maize and forage sorghums. In drier silages, the fermentation is inhibited and the ultimate pH achieved is higher, and can exceed pH 5 in heavily wilted silage (see Chapter 12, Table 12.3).

Clostridial silages result if insufficient lactic acid is produced or it is produced too slowly. Clostridia require moist conditions to thrive and are not usually a problem in silages wilted to >30% DM content.

If the population of clostridia increases, a secondary fermentation can occur. Clostridia ferment WSC, lactic acid, and protein to produce butyric, propionic and acetic acid, and ammonia-N (NH_3-N) plus a number of other intermediate compounds (see Appendix 2.A3, Table 2A.4).

As the secondary fermentation proceeds, the pH rises. Final pH will be higher than for a lactic acid fermentation and depends on the final products of the fermentation. This is because the acids produced are weaker than lactic acid, and the ammonia-N has a buffering effect against these acids.

Table 2.3

Fermentation characteristics for a range of silages in the United States and Europe.

	Lucerne silage[2] (30-35% DM)	Lucerne silage[2] (45-55% DM)	Grass silage[2] (25-35% DM)	Maize silage[1] (25-35% DM)	Maize silage[2] (35-45% DM)
pH	4.3-4.5	4.7-5.0	4.3-4.7	3.8	3.7-4.2
Lactic acid (% DM)	7-8	2-4	6-10	4.9	4-7
Acetic acid (% DM)	2-3	0.5-2.0	1-3	1.4	1-3
Propionic acid (% DM)	<0.5	<0.1	<0.1	N/A	<0.1
Butyric acid (% DM)	<0.5	0	<0.5	0.25	0
Ethanol (% DM)	0.5-1.0	0.5	0.5-1.0	1.9	1-3
Ammonia-N (% total N)	10-15	<12	8-12	5.4	5-7

Source: [1]Adapted from Andrieu (1976), mean of 42 varieties; [2]Kung (2001), expected range.

Fermentation losses of DM and energy, and degradation of protein can be substantial. Clostridial silages have a rancid odour and are unpalatable to livestock.

If anaerobic yeasts are present in the forage they will ferment WSC to ethanol (see Section 2.3.4). DM is lost due to the production of carbon dioxide, but the loss of energy is not significant. Growth of yeasts is undesirable because they deplete WSCs that would otherwise be available for LAB. Other yeasts present also break down lactic acid produced by the LAB.

The fermentation characteristics for a range of silages are outlined in Table 2.3. Remember, the ideal pH of a silage is heavily influenced by the DM content of the forage. Where DM content is high, the fermentation is inhibited, resulting in higher pH values and the quantity of fermentation end products is lower.

The quality of the silage fermentation directly affects the production from animals fed that silage. Some examples of poorly fermented silages are given in Table 2.4. The level of ammonia-N (as a % of total nitrogen) in conjunction with pH are good indicators of silage fermentation quality (see Chapter 12, Section 12.4.5).

Without supplementation, poorly fermented silages will only support relatively low rates of production compared to well-preserved silages (see Table 2.5).

Once the fermentation phase is completed, the silage then enters a stable phase. Provided that oxygen is excluded, there will be little or no change to a lactate silage during this period.

Table 2.5

Effect of silage fermentation quality on liveweight gain (kg/day) in beef cattle.

Number of experiments	Silage fermentation quality	
	Poor	Good
36	0.27	0.50

Note: Silages produced from the same parent fodder. Good fermentation was achieved by either wilting or using a silage additive.

Source: Kaiser (1984).

Table 2.4

Composition of several silages which have undergone a poor fermentation.

	Ryegrass[1]	Cocksfoot[1]	Lucerne[1]	Kikuyu[2]	Pasture[2]	Maize[2]
Type of silage	acetate	clostridial	acetate	acetate	acetate	aerobically spoiled
Silage DM (%)	17.4	16.2	13.1	18.3	19.1	29.5
pH	5.4	5.4	7.0	5.2	4.7	6.1
Lactic acid (% DM)	trace	0.1	1.3	1.5	1.5	<0.1
Acetic acid (% DM)	11.6	3.7	11.4	4.2	4.8	<0.1
Propionic acid (% DM)	1.4	1.5	0.8	trace	0.6	trace
Butyric acid (% DM)	2.3	3.6	0.8	trace	<0.1	trace
Ammonia-N (% total N)	20.5	32.3	29.2	16.2	16.2	6.0

Source: [1] McDonald et al. (1991); [2] Kaiser et al. (1995)

2.2.3

Feedout phase

When silage is exposed to air, aerobic organisms that have been dormant during the anaerobic phase multiply (see Figure 2.7). Their activity will eventually decompose the silage. The first sign that aerobic spoilage has begun is heating of the silage at the feeding face. Experiments with silages undergoing aerobic spoilage have shown that the temperature may rise to 50°C or higher. A laboratory test would also show a rise in the pH.

This process is sometimes incorrectly referred to as 'secondary fermentation'. In fact, it is an aerobic process, more correctly referred to as 'aerobic deterioration' or 'aerobic spoilage'.

The substrates used early in the aerobic spoilage process are lactic and acetic acid, and any residual WSCs. Their relative importance as substrates depends on the type of fermentation. Unfermented WSC levels are usually higher in wilted silages where fermentation has been inhibited. Figure 2.9 shows the relationship between wilting, residual WSC in the silage and aerobic stability (time taken to commence heating).

The breakdown of proteins and amino acids to ammonia also contributes to a pH rise.

The main organisms involved in aerobic spoilage are listed on this page. It is interesting to note that some strains of LAB are able to ferment lactic acid under aerobic conditions and may play a role in the aerobic spoilage process.

Later in the aerobic spoilage process mould activity breaks down and metabolises cellulose and other plant cell wall components.

Biochemical changes

The first biochemical changes during aerobic spoilage can be summarised as:

Substrates		*Products*		*Outcomes*
lactic acid	→	CO_2	→	rising temperature
acetic acid		water		and pH; mould
residual WSCs		heat		growth commences; silage deterioration

Spoilage organisms

The common genera of the main micro-organisms involved in aerobic spoilage are:

Yeasts: *Pichia, Hansenula, Candida* (acid-utilising)
Torulopsis, Saccharomyces (sugar-utilising)

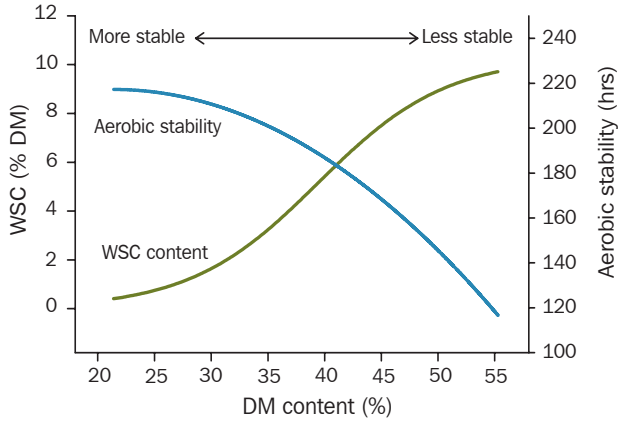
Moulds: *Monascus, Geotrichum, Byssochlamys, Mucor, Aspergillus*, Penicillium*, Fusarium**

Bacteria: *Bacillus,* some LAB, *Acetobacter* (acetic acid bacteria)

* Some species are capable of producing mycotoxins that can be harmful to livestock.

Figure 2.9

Effect of wilting on residual unfermented sugar content and subsequent aerobic stability of pasture silages.*



** Aerobic stability is the number of hours taken to reach 1°C above ambient temperature.*

Source: Adapted from Wyss (1999)

Aerobic spoilage can result in significant losses, which increase with time of exposure to air. DM losses can exceed 30% and quality losses can be significant. Not only is silage intake often depressed, animals may reject hot, spoiled silage.

The importance of air penetration and rate of feedout for silages of varying aerobic stability is highlighted in Figure 2.10. Air penetration is greater in poorly compacted silages and where there is greater disturbance of the silage face. The results shown in Figure 2.10 demonstrate that a reduction in air penetration and an increase in feedout rate can significantly reduce temperature rise, particularly with unstable silage.

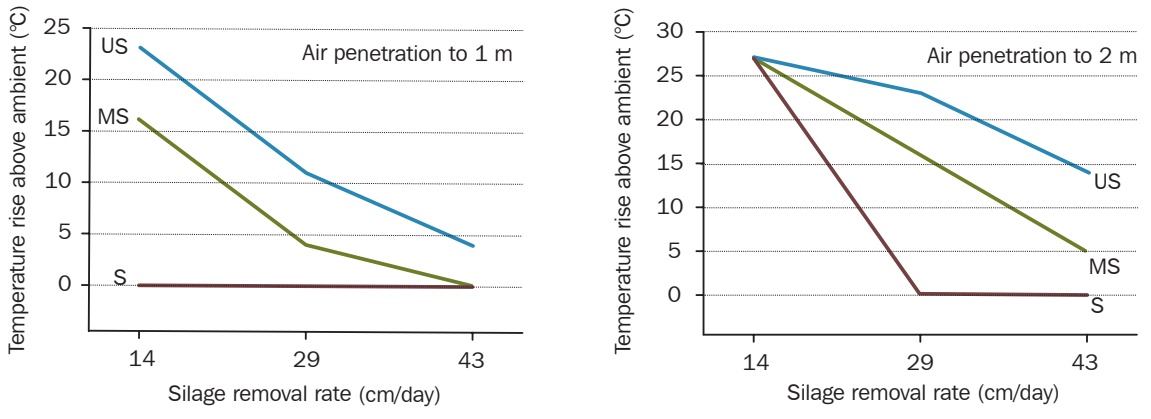
Chapter 10, Section 10.2.1, gives the losses in nutritive value in this study and more details on the effects of feedout management on aerobic spoilage.

The time between when the silage is first exposed to air and when spoilage commences at the exposed face varies from a few hours to several days. A large number of factors can reduce the susceptibility of a silage to aerobic spoilage. The key management factors are:

- rapid wilt, harvest and seal without delay;
- good compaction (low silage porosity) to reduce the air available for the aerobic organisms responsible for spoilage, and to minimise air penetration into the exposed face during feeding;
- sufficiently rapid feedout to minimise the time of exposure to air; and
- minimum disturbance of the silage face during feedout to reduce the rate of air penetration.

Figure 2.10

Effects of silage stability, depth of air penetration and rate of feedout on the temperature of the silage at the time of unloading from the silo. Average DM content of silages, approximately 35%.



US: Unstable – stable for only 1 day. MS: Moderate – stable for 3 days. S: Stable – stable for 7 days. Source: Derived from Honig et al. (1999)

Factors influencing the aerobic stability of silage

Silage factors

- **Composition.** Silages with high levels of fermentable carbohydrates, including WSCs, remaining after the fermentation (e.g. wilted silages), tend to be less stable.
- **Fermentation quality.** Silages which have a poorer fermentation quality and higher levels of volatile fatty acids (acetic, propionic and butyric) tend to be more stable. Silages can be more susceptible to aerobic spoilage where homofermentative LAB have dominated.
- **Porosity.** Silage stability declines as air infiltration increases. The susceptibility of a silage to air infiltration is influenced by the physical characteristics of the silage, silage density (kg/m^3)and DM content.
- **DM content.** Wilted silages can be more susceptible to aerobic spoilage due to higher levels of residual WSC, and greater difficulty in achieving adequate compaction. There is, however, some evidence that susceptibility to aerobic spoilage is less once DM exceeds 50%.
- **Population of aerobic spoilage organisms.** An extended aerobic stage at the commencement of the ensiling process, or air entry during storage, allows aerobic organisms to proliferate. They remain dormant during the anaerobic storage phase, until the silage is opened.

Feedout factors

- **Ambient temperature.** Silages tend to be more susceptible to aerobic spoilage during warmer weather.
- **Feedout rate.** Slow feedout of silage or bales from the feeding face increases aerobic spoilage. This is one of the most important factors influencing aerobic spoilage.
- **Management of the feeding face.** Excessive disturbance of the face during removal of silage increases air penetration, increasing the spoilage rate.
- **Mixing prior to feeding.** Mechanical processing of silage in a feedout wagon, mixer wagon or bale chopper increases aeration and can increase aerobic spoilage.

Section 2.3

Silage micro-organisms

2.3.1

Lactic acid bacteria (LAB)

Homofermentative LAB convert WSC to lactic acid only.

Heterofermentative LAB convert WSC to lactic acid plus acetic acid and other compounds (see Appendix 2.A3).

Bacteria belonging to this group convert WSC to lactic acid and other fermentation products. LAB are classified as either homofermentative or heterofermentative (see Appendix 2.A4, Table 2A.5).

Domination of the fermentation by homofermentative LAB leads to a more efficient utilisation of available WSC and a more rapid decline in pH with less loss of DM or energy. In forages with low WSC content, achieving a successful fermentation may be dependent on homofermentative LAB dominating the fermentation.

The population of LAB is low on growing crops and pastures, and is concentrated on dead and damaged plant tissue. Studies with chopped silage show that the population increases rapidly between mowing and delivery to the silage pit or bunker. Damage to the plant tissue releases nutrients and minerals and is suggested as a possible reason for this rapid increase in bacteria numbers. Some studies have shown that LAB numbers also increase rapidly during the wilting phase, although this is not always the case.

Commercial bacterial inoculants usually contain cultures of homofermentative LAB bacteria to improve the rate and efficiency of fermentation (see Chapter 7, Section 7.4.3). However, recent information indicates that production of some acetic acid may improve aerobic stability of the silage upon opening. This would be an advantage in warm Australian conditions, particularly for maize silage, which is inherently unstable. This suggests that some heterofermentative LAB may be desirable during fermentation. Further studies are required to confirm this.

2.3.2

Clostridia

Clostridia are classified as either saccharolytic or proteolytic according to whether the main substrate they ferment is WSCs and lactic acid or protein, respectively, although some species possess both saccharolytic and proteolytic activity (see Table 2A.6 in Appendix 2.A4).

Clostridia require a neutral pH (about 7.0) and moist conditions for optimal growth. As pH falls during an effective lactic acid fermentation, clostridia become less able to compete, until their growth is completely inhibited. Wilting to a DM content greater than 30% severely restricts clostridial growth.

2.3.3

Enterobacteria

These bacteria prefer a neutral pH (about 7.0) and warm conditions for optimal growth. The warm Australian conditions are ideal for enterobacteria to flourish early in the fermentation phase. In low WSC forages (e.g. tropical grasses), where pH drops slowly, these bacteria can dominate the fermentation. If they dominate, an acetate silage will be produced with a pH of about 5.0. Below this level the growth rate of enterobacteria is inhibited.

Levels of enterobacteria are low on crops and pasture, and decline during wilting. However, numbers can increase rapidly during the first few days of the fermentation and compete with LAB for available WSC. In most silages, they are only likely to be significant during the early stages of fermentation, before pH starts to decline significantly.

The main products of their fermentation process are acetic acid, lactic acid and CO_2, and increased ammonia-N levels due to the degradation of protein. Although some acetic acid production may improve aerobic stability, DM and energy losses can be significant if the fermentation is prolonged and enterobacteria are dominant. The resulting silage is also less palatable to stock.

How clostridia affects silage

Clostridia adversely affect silage preservation because:

- they compete with LAB for WSC needed to produce lactic acid;
- saccharolytic clostridia degrade WSC and lactic acid to butyric acid. This raises silage pH;
- proteolytic clostridia degrade proteins and amino acids to ammonia, amines and volatile fatty acids, reducing the utilisation of silage nitrogen by livestock;
- clostridia activity increases fermentation losses of DM and energy; and
- clostridia activity reduces silage palatability and lowers the nutritive value of the silage through the loss of energy and degradation of protein.

2.3.4

Yeasts and moulds

Yeasts and moulds are classed as fungi. Most require oxygen to grow and multiply, although a number of yeasts can grow and multiply in anaerobic conditions. Yeasts and moulds can grow over a wide range in pH (3.0-8.0) and temperature (0-40ºC). They do not contribute to silage preservation and are responsible for spoilage during the initial aerobic phase after ensiling and during feedout (see Sections 2.5.2 and 2.5.3).

Yeasts are common in soil and it is believed that contamination with soil during mechanical operations will increase numbers on the cut forage. They multiply on damaged plant tissue, with numbers usually increasing during wilting. Yeasts and moulds also multiply during the initial aerobic phase after ensiling.

Fermentation phase

Anaerobic yeasts begin to multiply when anaerobic conditions have been achieved after ensiling. They compete directly with LAB for WSC, which they ferment primarily to ethanol. Other yeasts, less able to ferment WSC, use lactic acid. Yeast activity is eventually inhibited by the increasing concentration of lactic and acetic acids.

Because it is easy to see, mould growth is an indicator of the presence and distribution of oxygen in the silo or bale at sealing. Growth can be spread throughout poorly compacted silages or appear in clumps in silages that contain air pockets at the time of sealing. In well-compacted silages, without air pockets, any mould growth is limited to the surface of the silo or bale. Surface mould growth can be eliminated with effective sealing. Because drier silages are harder to compact, they usually contain more mould growth. Further description of mould growth is provided in Chapter 9, Appendices 9.A1 and 9.A2.

Feedout phase

When the silage is exposed to air during feedout, the growth of yeasts is the primary cause of aerobic deterioration. Mould growth begins later. Silages that contain significant numbers of yeast and mould spores, carrying over from the initial aerobic phase, tend to be less stable.

Yeasts and moulds initially use residual WSC, lactic acid, other organic acids and ethanol for growth. The silage begins to deteriorate in the same way that composting occurs, with yeast and mould growth causing a rise in temperature and pH, loss of DM and energy, and reduction in silage palatability. As the decay processes continue, the moulds break down some of the structural carbohydrates in the silage.

2.3.5

Potentially harmful micro-organisms

There is no evidence to support the misconception that silage feeding has significantly greater animal health risks than feeding other forms of conserved forage. Reports of animal health problems associated with silage feeding are not common.

Animal health issues are only covered briefly in this publication. Producers who are concerned about health risks associated with the feeding of silage should seek veterinary advice.

The potential health risks most likely to be associated with feeding silage to livestock are caused by listeria (listeriosis), moulds and *Clostridium botulinum* (botulism). The risks of health problems caused by listeria and moulds can be almost eliminated by good silage-making practices, particularly effective compaction and sealing. Poor silage-making practices *may* increase animal health risks. However, the main issue is that poor practices will *always* result in significant economic penalties from increased DM and quality losses.

Listeria: Listeriosis is an infection caused by the bacteria *Listeria monocytogenes*. Listeria can cause abortions (usually in late pregnancy), brain damage ('circling disease') in sheep, or even death. Listeriosis is more common in animals with weakened immune systems – particularly new-born and pregnant stock. Sheep are inherently more susceptible than cattle.

Listeria require aerobic conditions to grow and multiply, but are able to survive under anaerobic conditions. They are intolerant of acidic conditions and, under anaerobic conditions, activity is severely restricted below a pH of about 5.5. Therefore, listeriosis is generally only associated with poor quality silages – inadequate air exclusion, poor sealing and limited fermentation (high pH). European studies have found the incidence of listeriosis is marginally more common with baled silages, where adequate compaction and air exclusion are more difficult to achieve, there is a greater surface to volume ratio and the fermentation is limited.

If listeria are present they are usually in the surface spoilage layer. If this layer is removed prior to feeding, the risk of listerosis is reduced. The most effective strategy to avoid listeriosis is effective sealing.

Moulds: Some moulds are capable of producing toxins, which if eaten, can be fatal to livestock. Inhaled mould spores are also capable of causing allergic reactions in humans – asthma and farmer's lung.

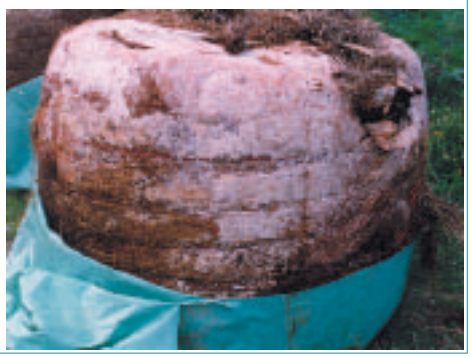
Moulds require aerobic conditions for growth. In well-made silages – rapid filling and compaction of the silo, good air exclusion and adequate sealing – any mould growth is limited and confined to the surface of the silo or bale.

If mould is observed, and potential animal health risk is a concern, take the following precautions:

- Remove the mouldy material prior to feeding, if possible.
- Feed sufficient silage to allow livestock to avoid eating the mould. Because it is unpalatable, stock will generally not eat mouldy silage, if given a choice.
- Avoid feeding the silage to very hungry livestock and to pregnant animals. Feeding mouldy silage is more likely to lead to animal health problems when it is used for drought feeding.

Plate 2.1

Mould is an indication of aerobic spoilage. The extent of mould growth in this bale is probably the result of inadequate wrapping, poor quality plastic or damage to the plastic seal.



Photograph: F. Mickan

Most authorities consider the risk to livestock from mouldy silage to be minimal and no greater than the risks associated with feeding mouldy hay. Reports of livestock deaths from either source are not common. There is no evidence to suggest that colour of the mould is any indication of toxicity.

Botulism: The disease caused by the bacteria *Clostridium botulinum*. When the carcases of dead animals are ensiled, these bacteria multiply and produce a toxin. Although the incidence is very low, eating contaminated silage or hay causes death very quickly.

The most common sources are probably rats, snakes and other small animals picked up during harvest. As a precaution, remains of dead livestock should be removed prior to sowing a silage crop or locking up pasture. Vermin that burrow into and nest in silos and bales, and then die may also be a source of contamination.

Section 2.4

Chop length

The chop length of the ensiled forage can affect the rate and extent of silage fermentation, the extent of losses during storage and animal production.

Reducing the length of chop causes more physical damage to plant cells, releasing WSCs more rapidly for the silage micro-organisms. This allows the fermentation to develop more rapidly and the LAB to ferment more WSC to lactic acid. The pH will decline more rapidly, with a reduced loss of DM and energy, and less degradation of the protein fraction.

For forages with low levels of WSC, such as legumes or tropical grasses, a finer chop length will assist in the production of more acid, which will, in turn, assist successful preservation. As well as making WSCs more available, short chopping increases bacterial activity in wilted silages by releasing moisture from the cells. This increases the amount of WSC fermented to lactic acid. The effect of chop length on the silage fermentation, as indicated by rate of pH decline, for a wilted lucerne silage is clearly demonstrated in Figure 2.11.

Reducing the chop length makes the silage easier to compact and reduces the amount of trapped oxygen in the silo. As a result, losses due to aerobic respiration and the risk of mould growth are lower (see Section 2.5.2 and Chapter 9). The advantage of a finer chop length is greater for silages that are difficult to compact, e.g. heavily wilted forage and grasses compared to legumes. However, finer chopped, low DM silages produce more effluent, at the same DM content, due to the release of moisture from damaged cells (see Section 2.1.1 and Chapter 9).

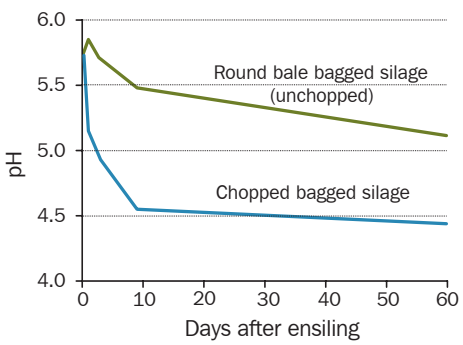
The effects of reducing chop length

Reducing chop length:

- increases the rate at which fermentation occurs;
- reduces fermentation losses of DM and energy, and degradation of the protein fraction;
- increases the chances of a successful fermentation in forages with low WSC content;
- increases amount of lactic acid produced in wilted silages;
- can result in a lower silage pH;
- reduces the volume of forage transported at harvest, and storage space required;
- makes compaction of the forage in the silo easier; and
- can increase effluent production in low DM content silages.

Silage intake by livestock has also been shown to increase with short versus long forage chop length in a number of studies. This is particularly so with sheep compared to cattle, and with young compared to older livestock. Increased voluntary intake improves animal production in almost all cases. The effects of chop length on animal production are discussed in Chapters 13, Section 13.2.5; Chapter 14, Section 14.2.5; and Chapter 15, Section 15.2.5.

Figure 2.11



Effect of chop length on the pH of lucerne silages with a DM content of 39%.

Source: Nicholson et al. (1991)

Section 2.5

Losses

Even in well-managed systems, losses of DM and energy will occur during silage making, storage and feeding. The type and extent of the losses are influenced by a number of factors:

- crop type and composition;
- weather conditions;
- silage system; and
- management.

In practice, the most important factor influencing losses is management – poor management can substantially increase losses, greatly reducing the efficiency of the conservation process.

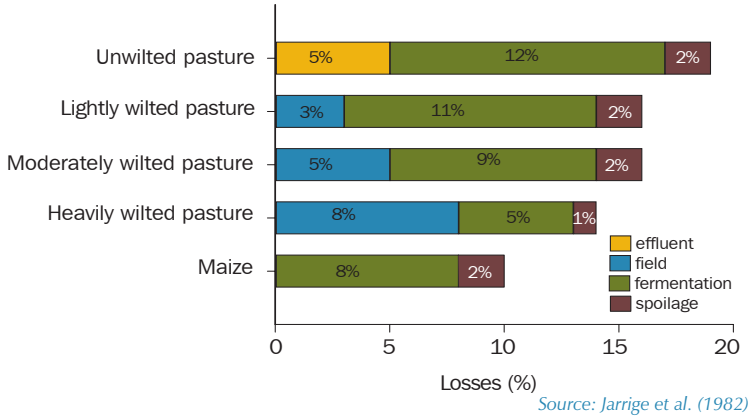
There is often considerable debate concerning the level of losses that can occur during the ensiling process. One source of confusion is whether the losses quoted are 'typical' losses observed on-farm or losses that occur with good management. Clearly, the on-farm losses are highly variable and reflect the standard of management. So it is recommended that the latter be adopted as the benchmark that producers should target. This should also be the basis for any economic appraisal of silage, although a sensitivity analysis to determine the penalty of greater losses due to poor management can be very informative (see Chapter 11, Section 11.2.4).

As there are few Australian studies on losses occurring at various stages of the ensiling process, data from Europe and the United States have to be used. Loss estimates vary considerably, and there is some concern as to whether DM losses have been over-estimated in some studies due to failure to adequately account for the volatile compounds in silage when calculating DM losses (see Chapter 12, Section 12.4.1).

The sources of DM and energy losses during the ensiling and feedout process are illustrated in Figure 2.12 and Table 2.6. The source of losses varies between silage systems and can be seen to be strongly

Figure 2.12

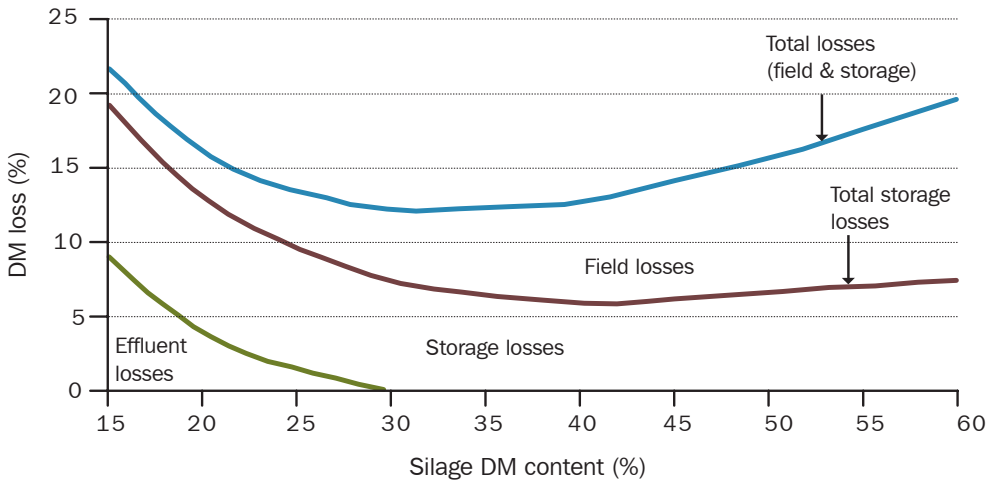
Typical DM losses from a chopped silage system with bunker storage.



Source: Jarrige et al. (1982)

Figure 2.13

Estimated DM losses during harvesting and storage of pasture silage under Australian conditions with good management.



Source: Data from various sources – Hoglund (1964); Wilkinson (1981, 1988); Jarrige et al. (1982); McDonald et al. (1991); Wilkins et al. (1999)

influenced by wilting (see also Figure 2.13). The data in Figures 2.12 and 2.13 indicate that, with good management, it should be possible to keep DM losses to 12-16% in a wilted silage system.

In a direct-cut maize silage system, where field losses are minimal, DM losses should be kept to about 10%.

With good management, quality losses during the ensiling process will be minimal. With poor management, DM losses can be considerably higher than those illustrated, and silage quality will suffer.

Energy losses are usually less than DM losses. This is because some of the fermentation products in silage have a higher energy value than the substrates from which they are produced and the gross energy content of silage is usually higher than that of the parent forage. Energy losses at various stages of the ensiling process are listed in Table 2.6, and have been classified as unavoidable or avoidable. The avoidable categories can be eliminated with good management. According to this European work energy losses need be no higher than 7%.

Losses during the ensiling process

DM losses:

The quantity of forage lost (on a DM basis) at various stages of the ensiling process:

$$\text{DM loss (\%)} = \frac{\text{Initial forage weight (kg)} - \text{Final forage weight (kg)}}{\text{Initial forage weight (kg)}} \times 100$$

Note: Some publications refer to DM recovery = 100 DM loss (%)

Quality losses:

The loss of nutrients present in the initial forage. Most commonly applied to changes in digestibility, energy or the nitrogen fraction during the ensiling process, and loss of WSC during wilting.

The relative importance of field and storage losses varies with the degree of wilting and the DM content at ensiling (see Figures 2.12 and 2.13). Figure 2.13 shows the expected DM losses in the production of pasture silage, under Australian conditions, given good management. The data in Figure 2.13 are a composite of results from various overseas studies – there are no Australian data, a deficiency that needs to be addressed in future research. Total losses are likely to be lowest in the DM range of 30-40% when rapid wilting is achieved.

Table 2.6

Energy losses during ensiling and factors responsible for these losses.

Process	Classified as	Approximate losses (%)	Factors responsible
Effluent *or* Field losses by wilting	Unavoidable for most crops and pastures	5 to >7 *or* 2 to >5	DM content of forage at ensiling Weather, technique, management, crop/pasture (type and yield)
Harvesting losses	Unavoidable but manageable	1 to 5	DM content, crop/pasture type, number of mechanical operations
Residual respiration	Unavoidable	1 to 2	Plant enzymes
Fermentation	Unavoidable	2 to 4	Micro-organisms
Secondary (clostridial) fermentation	Avoidable	0 to >5	Crop/pasture type, environment in silo, DM content
Aerobic spoilage during storage (including surface waste)	Avoidable	0 to >10	Filling time, density, silo type and size, sealing, crop/pasture type
Aerobic spoilage (heating) during feedout	Avoidable	0 to >10	As for aerobic spoilage above. DM content of silage, unloading technique, weather
Total		7 to >40	

Source: Based on Zimmer (1980)

2.5.1

Field and harvesting losses

Field losses include the DM lost during various mechanised operations in the field (mowing, tedding and raking), during harvest and transport to the storage site, and due to the activity of plant enzymes. Table 2.7 outlines the various components of field losses. The extent of these losses and management strategies to reduce them are covered in more detail in Chapters 6 and 8.

Of the field losses in Table 2.7, the physical losses due to mechanical handling should be minimal, and will reflect the standard of management of the field and transport operations. Forage left in the paddock may be utilised with post-harvest grazing. If grazing is an option, items 1, 4, 6 and 8 in Table 2.7 account for little loss to the system.

Direct harvested crops, such as maize, have considerably lower field losses (<1%, see Figure 2.12) than wilted crops because there is less time for respiration and fewer handling operations.

Respiration and proteolysis can account for significant DM and quality losses, particularly during wilting (see Section 2.2.1). The quality losses will mean reduced forage digestibility and ME content and increased protein degradation. Some respiratory loss during wilting is unavoidable, but can be minimised (to about 2%) by rapid wilting.

As Figure 2.13 shows, field losses increase with forage DM content. The longer wilting period associated with higher DM content increases the susceptibility of the crop to respiration losses. At the same time the higher DM forage is susceptible to greater mechanical losses during various handling operations, particularly as DM content increases above 35 to 40%.

Table 2.7

Sources of field losses during silage making.

Operation or source of loss	Type of loss	Reason	Management solutions
Mowing	1. DM	Cut too high, sections of paddock uncut	Graze paddock after harvest to utilise uncut forage
Tedding	2. DM, quality	Damage to forage, with some loss of leaf	Avoid tedding crops that are too dry (over-wilting), especially legumes
Wilting	3. DM, quality	Respiration of WSC and degradation of protein by plant enzymes	Increase rate of wilting but some loss unavoidable
Raking	4. DM	Cut material not all raked into windrow	Graze paddock after harvest to utilise residual forage
	5. DM, quality	Damage to forage, with some loss of leaf	Avoid over-wilting and raking crop when too dry (especially legumes)
Harvesting of direct cut crops	6. DM	Some crop uncut and left in paddock	Graze paddock after harvest to utilise uncut forage
	7. DM, quality*	Some loss of chopped forage when blown into truck/cart	Minimal if using an experienced forage harvester operator. Graze paddock after harvest.
Harvesting wilted forage (windrows)	8. DM	Windrow not all picked up	Graze paddock after harvest to utilise cut forage
	9. DM, quality*	Some loss of chopped forage when blown into truck/cart	Avoid harvesting small, light windrows. Minimal if using an experienced forage harvester operator. Graze paddock after harvest.
Transport to storage	10. DM	Loss of forage from truck during transportation	Avoid overloading truck/cart and avoid harvesting crop that is too dry. Covering may be an option but probably not practical.

* *Quality losses may not occur on all occasions.*

2.5.2

Storage losses

Table 2.8 summarises the sources of DM and quality losses during storage. They are:

- effluent;
- respiration and aerobic fermentation while oxygen remains in the silo or bale (or if the seal is damaged); and
- the silage fermentation.

These losses are strongly influenced by the DM content at which the forage is ensiled. The effluent losses decline rapidly as DM content increases to 30% (see Figure 2.2). Respiration and fermentation losses decline as DM content reaches 35-45% and then slowly increase (see Figure 2.13).

Effluent losses are influenced by forage DM content, chop length, and the degree of compaction or silage density. Some additives (e.g. molasses, acids and enzymes) will increase effluent production (see Chapter 7), but the most important factor is forage DM content at ensiling (see Section 2.1.1). Chapter 9 covers the effect of management on silage effluent production more fully.

As described in Section 2.2.1, losses due to respiration of WSC by plant enzymes and fermentation by aerobic micro-organisms will continue until anaerobic conditions are achieved within the silo or bale. Heating of the freshly harvested forage in the silo or bale is an indication of respiratory losses. Some heating and losses due to respiration are unavoidable (see Table 2.6).

Direct losses of WSC represent only part of the quality loss. Heat build-up within the silo or bale as a result of respiration can further reduce digestibility and damage to the protein fraction (see Section 2.2.1 and Chapter 12, Section 12.4.4). Chapter 9, Section 9.4, covers management strategies to reduce these losses – rapid filling, good compaction or bale density, and effective sealing (without delay).

While oxygen is present during the early stages of the storage period, aerobic bacteria, yeasts and moulds will continue to grow. Where sealing is inadequate or the seal is damaged during storage, air entry will allow these organisms to grow. The growth of aerobic organisms will result in silage decay and the development of a

Table 2.8

Sources of losses during silage making.

Source of loss	Type of loss	Reason	Management solutions
Effluent losses:	DM, quality	Forage ensiled at too low a DM content (<30%).	Wilt mown crops and pastures, harvest direct cut crops at a later stage of maturity.
Aerobic losses:			
Respiration	DM, quality	Presence of air resulting in loss of WSC due to activity of plant enzymes (invisible in-silo losses)	Avoid ensiling at too high a DM content. Fill silo rapidly, compact and seal well as soon as possible. Some loss unavoidable.
Inedible waste silage	DM, quality	Presence of air for longer period will result in visible inedible waste (rotten and mouldy silage) due to growth of aerobic bacteria, yeasts and moulds.	As above, and maintain an air-tight seal throughout the storage period. Check regularly for damage to the seal and repair immediately.
Fermentation losses:	DM, quality	Fermentation of WSC. Losses minimal with a homofermentative lactic acid fermentation, and little or no quality loss. Losses of DM and quality higher with poor (including secondary) fermentations.	Promote desired LAB fermentation, wilt or use additives as required, as well as good silage-making practices.

surface waste layer, mouldy silage and pockets of rotten silage.

Some loss of DM and energy during the anaerobic fermentation of WSC to lactic acid and other products is unavoidable. However, if the fermentation is dominated by homofermentative LAB, the losses are small (see Appendix 2.A3). Higher losses will occur if heterofermentative LAB play a significant role in the fermentation. The greatest fermentation losses will occur if clostridia or enterobacteria dominate the fermentation.

2.5.3

Feedout losses

Losses during feedout have two sources – aerobic spoilage or heating, and wastage of silage by animals (see Table 2.9). Effective management of the feedout process can avoid most of these losses.

Once exposed to air, silage at or close to the feeding face commences to deteriorate as yeasts, moulds and aerobic bacteria become active. Heating is usually the first noticeable sign of aerobic spoilage of the silage stack or bale (see Section 2.2.3). Chapter 10 covers more fully management strategies that reduce these losses.

Crop type, DM content, silage density, the type of fermentation, the quantity of residual spores present from the initial aerobic phase, ambient temperature during feeding, rate of feedout, and silage removal technique can all affect the stability of the silage after opening. Silage additives can influence aerobic stability (see Chapter 7, Section 7.7).

Wastage of silage during feedout is difficult to estimate and few studies have been conducted. In poorly managed feeding systems, wastage is likely to reach 30-50% of silage DM fed. These losses will be influenced by:

- quantity of silage offered to livestock – if the silage is not consumed within a reasonable time then losses will increase (irregular feeding intervals or overfeeding should be avoided);
- measures taken to prevent animals from walking, camping, urinating and defecating on the silage; and
- wet weather (trampling losses are likely to be higher when silage is fed on the ground).

Animals are also likely to reject silage that is hot (aerobically spoiled), mouldy or rotten. These losses, resulting from rejection by animals, have been accounted for earlier as components of storage losses or aerobic spoilage.

Table 2.9

Sources of losses during the feedout of silage.

Source of loss	Type of loss	Reason	Management solutions
Aerobic spoilage (heating)	DM, quality	Silage unstable and heats on exposure to air. Due to growth of aerobic micro-organisms, and results in significant DM and quality losses. Aerobically spoiled silage is unpalatable. Intake is depressed.	Silages vary in susceptibility, and tend to be more unstable when fed out during warm weather. Good management at ensiling is important. Rapid rate of feedout is essential, with minimum disturbance of the silage face.
Wastage during feeding	DM	Animals drop, trample and foul silage. Overfeeding is likely to increase losses.	Silage fed on the ground is most susceptible. Losses are reduced by using suitable feed barriers, feeders, feed troughs and feed pads.

Section 2.6

Appendices

2.A1

WSC content of various forages

Calculating WSC content on a fresh basis:

$$\text{WSC (\% fresh basis)} = \frac{\text{WSC (\% DM basis)} \times \text{DM content (\%)}}{100}$$

So, for a silage with a WSC content of 10.7% (DM basis) and a 36% DM content:

$$\text{WSC (\% fresh basis)} = \frac{10.7 \times 36}{100} = 3.9\%$$

Figure 2A.1

Target DM content required to exceed the critical level of 2.5% WSC in the fresh crop, for crops with varying WSC content (% DM).

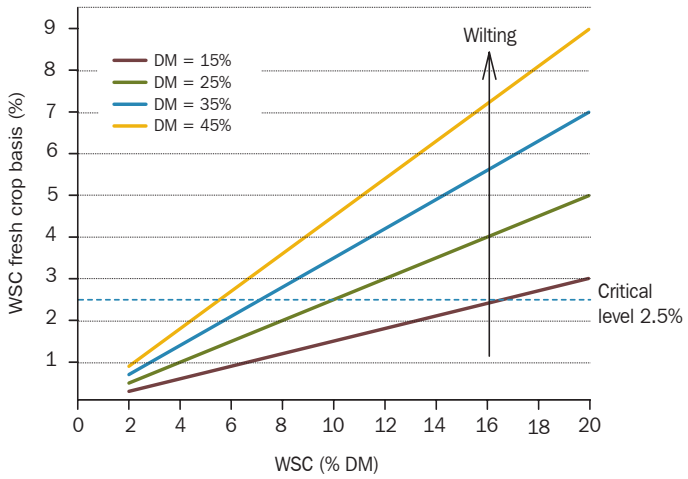


Table 2A.1

WSC content (% DM) of a range of unwilted forages.

Species	Range	Mean
Temperate grasses:		
Italian ryegrass[1]	7.5-31.5	18.1
Perennial ryegrass[1,2]	4.6-34.1	19.6
Timothy[1]	5.3-19.9	11.0
Meadow fescue[1]	3.5-26.3	9.6
Cocksfoot[1]	5.0-19.1	7.9
Cereals:		
Barley[1]	4.6-31.8	19.3
Oats[2]	7.7-35.0	20.1
Maize[1]	5.0-33.0	17.4
Grain sorghum[3]	3.5-7.3	4.4
Temperate legumes:		
Subclovers[2,4]	6.3-13.7	10.2
Medics[2]	4.2-10.6	6.6
Balansa clover[2]	5.8-14.1	10.9
Arrowleaf clover[2]	9.9-12.0	11.1
Red clover[1]	5.3-10.8	7.8
Lucerne[1]	4.5-11.6	7.2
Berseem clover[2]	6.4-12.1	9.2
White clover[1]	5.1-9.1	6.7
Sainfoin[5]	6.8-8.4	7.6
Vetch (common and purple)[2]	3.9-9.2	6.6
Peas[2]	8.6-15.8	12.3
Lupins (albus)[6]	15.3-16.5	15.9

Species	Range	Mean
Tropical grasses:		
Kikuyu grass[7]	2.3-6.8	4.5
Setaria[8,9]	3.5-6.2	4.8
Rhodes grass[8]	2.7-3.2	3.0
Signal grass[9]	8.6	–
Napier grass[9]	9.9	–
Guinea grass/green panic[9]	3.0	–
Paspalum[10]	2.7-3.4	–
Tropical legumes:		
Lablab[11]	4.6-5.6	5.1
Desmodium[12]	4.8	–
Siratro[12]	5.9	–
Lotononis[12]	9.9	–
Other forages:		
Sunflowers[1]	10.3-21.3	16.0
Japanese millet[4]	7.0-9.0	8.0
Forage pennisetum[4]	7.8-13.7	10.4
Sudan grass[3]	7.4-15.9	10.1
Forage sorghum x Sudan grass[3, 4]	6.1-17.7	9.8
Sweet sorghum[3,4]	11.4-35.7	24.1
Dual purpose sorghum (grain/grazing)[3,4]	5.1-18.3	10.7
Broadleaf weeds:		
Capeweed[4]	17.2	–
Variegated thistle[4]	14.7	–
Paterson's curse[4]	11.9	–

Sources: [1] Kaiser, 1984; [2] Dear et al. (unpublished); [3] Cole et al. (1996); [4] Kaiser (unpublished); [5] Hill (1999); [6] Jones et al. (1999); [7] Kaiser et al. (2000b); [8] Catchpoole (1965); [9] Aminah et al. (2000); [10] Catchpoole and Henzell (1971); [11] Morris and Levitt (1968); [12] Catchpoole (1970)

2.A2

Buffering capacity of various forages

Table 2A.2

Buffering capacities (meq/kg DM) of a range of unwilted forages.

Forage type	Range	Mean
Temperate grasses:		
Cocksfoot[1]	209-438	302
Italian ryegrass[1]	265-589	386
Perennial ryegrass[1,2]	231-428	313
Cereals:		
Maize[1]	149-351	236
Oats – immature vegetative[1]	732-779	756
Oats – heading[1,2]	213-453	308
Temperate legumes:		
Subclovers[1,2]	420-877	647
Subclover/annual grasses[1]	383-656	506
Medics[2]	496-720	614
Balansa clover[2]	487-623	576
Arrowleaf clover[2]	484-588	548
Red clover[1]	491-617	562
Lucerne[1]	297-595	505
Berseem clover[2]	638-790	696
White clover[1]	512	–
Sainfoin[3]	467-539	496
Vetch (common and purple)[2]	504-616	549
Peas[2]	328-502	415
Lupins (albus)[4]	304-338	321

Forage type	Range	Mean
Tropical grasses and legumes:		
Kikuyu grass[5]	225-496	351
Rhodes grass[6]	435	–
Stylo[6]	469	–
Siratro[6]	621	–
Other forages:		
Japanese millet[7]	343-682	519
Forage pennisetum[7]	315-520	393
Forage sorghum x Sudan grass[7]	333-532	416
Sweet sorghum[7]	258-419	322
Broadleaf weeds:		
Capeweed[1]	1,082	–
Variegated thistle[1]	682	–
Paterson's curse[1]	1,013	–

Source: [1] Kaiser (1984); [2] Dear et al. (unpublished); [3] Hill (1999); [4] Jones et al. (1999); [5] Kaiser et al. (2000b); [6] McDonald et al. (1991); [7] Kaiser (unpublished)

2.A3

Biochemical pathways, and energy and DM losses that occur during silage fermentation

Table 2A.3

The main chemical pathways that occur during a LAB fermentation.

Reaction	Fermentation type*	DM loss (%)	Energy loss (%)
glucose → 2 lactic acid	homolactic	0	0.7
fructose → 2 lactic acid	homolactic	0	0.7
pentose → lactic acid + acetic acid	homolactic and heterolactic	0	–
glucose → 2 lactic acid + ethanol + CO_2	heterolactic	24.0	1.7
3 fructose + H_2O → lactic acid + 2 mannitol + acetic acid + CO_2	heterolactic	4.8	1.0
2 fructose + glucose + H_2O → lactic acid + 2 mannitol + acetic acid + CO_2	heterolactic	4.8	–

** Homolactic – fermentation is dominated by homofermentative LAB*
Heterolactic – fermentation is dominated by heterofermentative LAB

Source: McGechan (1990) from Roberts (1995)

Table 2A.4

The main fermentation pathways which occur during a clostridial fermentation.

Reaction
glucose → butyric acid + 2 CO_2 + 2 H_2
2 lactic acid → butyric acid + 2 CO_2 + 2 H_2
3 alanine → 2 propionic acid + acetic acid + 2 CO_2 + 3 NH_3
alanine + 2 glycine → 3 acetic acid + CO_2 + 3 NH_3
lysine → cadaverine + CO_2
valine → isobutyric acid + NH_3
leucine → isobutyric acid + NH_3

Source: Adapted from McGechan (1990) from Roberts (1995)

2.A4

Species of lactic acid bacteria (LAB) and clostridia found in silage

Table 2A.5

Some important species of lactic acid bacteria found in silage.

Homofermentative	Heterofermentative
Lactobacillus acidophilus	*Lactobacillus brevis*
L. casei	*L. buchneri*
L. coryniformis	*L. cellobiosus*
L. curvatus	*L. fermentum*
L. dulbrueckii	*L. viridescens*
L. leichmannii	*Leuconostoc mesenteroides*
L. plantarum	
L. salivarius	
Pediococcus acidilactici	
P. damnosus	
P. pentosaceus	
Enterococcus faecalis	
E. faecium	
Lactococcus lactis	
Streptococcus bovis	

Source: McDonald et al. (1991); Ross (unpublished data)

Table 2A.6

Classification of main clostridia found in silage.

Lactate fermenters (saccharolytic)	Amino acid fermenters (proteolytic)	Others
Clostridium butyricum	*C. bifermentans*	*C. perfingens**
C. paraputrificum	*C. sporogenes*	*C. sphenoides**
C. tyrobutyricum		

** Ferment both WSCs and protein.*

Source: Adapted from McDonald et al. (1991)