


FEEDLOT DESIGN AND CONSTRUCTION

32. Silage storage

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Introduction

Silage is forage (e.g. pastures, cereals or legumes) cut at high moisture content (typically 40–70%) and stored in an oxygen free (anaerobic) environment. Anaerobic storage promotes fermentation and the production of lactic acid. A pH of 4.0–4.5 preserves the forage.

Poorly fermented silage has lower nutrient value and palatability and produces unpleasant odours. Critical processes for good quality silage include

- Timing of harvest (stage of forage maturity, moisture content).
- Harvesting method (inoculants, grain conditioning, chop length).
- Filling, packing and sealing of silage storage system.
- Storage system management.

Design objectives

Silage storage systems should be designed and constructed to

- Be located in the controlled drainage area (CDA) of the feedlot and near the feed processing and preparation area.
- Provide sufficient slope to allow rainfall and silage effluent to drain away from the storage site.
- Be structurally sound and long lasting.
- Provide safe access for people and machinery during filing and removal.
- Provide an airtight storage system as quickly as possible after harvesting and ensiling.
- Maintain an airtight seal until feeding out starts.
- Provide sufficient storage capacity for expected feedlot demand, considering seasonal and regional availability and ability to maintain silage quality during storage.
- Promote sound economic inventory control.

Mandatory requirements

Design choices

Silage characteristics

Optimum dry matter (DM) content for ensiling. Table 1 indicates recommended DM content ranges for a variety of crops/pastures for either bunker or bale silage storage.

Table 1. Recommended dry matter content ranges for bunker, stack and bale silage (Kaiser et al. 2003)

Crop type (growth stage when to cut)	Bunker/stack (DM%)	Bale* (DM%)
Pastures (vegetative to very early heading)		
– long chopped	30–35	40–50
– precision chopped	35–40	
Lucerne (bud less than 10% flowered)		
– long chopped	33–35	40–50
– precision chopped	33–45	
Other pasture (early to mid-flowering)		
– long chopped	33–35	40–50
– precision chopped	35–45	
Whole crop cereals (vegetative stage) – oats, barley, wheat, triticale		
– flag leaf to boot stage	33–40	38–50
Whole crop cereals (direct harvested) – barley, wheat, triticale		
– late milk to soft dough stage	33–40	38–50
Maize		
– precision chopped	33–36	
Summer forages – sweet sorghum, millet		
– long chopped	30–35	35–45
– precision chopped	30–40	
Brassicas	33–35	38–45

** Large rectangular bales could be increased by 5-10% DM. If too dry, fermentation may not occur and it greatly increases the risk to moulding if plastic seal is punctured.*

Density – As silage densities are highly variable, storage and feed budgeting calculations should be based on on site measurements. Typical densities for wilted pastures and maize are 590kg/m^3 and 690kg/m^3, respectively. Bulk density increases with the depth of silage in the bunker or stack. Table 2 shows typical values for DM, wet and dry density and particle size for hay and maize silage over a large range of bunkers.

Table 2. Dry matter content and densities from hay and maize silage (Kaiser et al 2003)

Characteristic	* Hay crop silage		** Maize silage	
	Average	Range	Average	Range
DM content (%)	42	24–67	34	25–46
Wet density (kg/m^3)	590	210–980	690	370–960
DM density (kg/m^3)	237	106–434	232	125–378
Average particle size (mm)	11.7	6.9–31.2	10.9	7.1–17.3

** Data based on 87 bunkers/stacks from Wisconsin, United States, mainly lucerne.*

*** Data based on 81 bunkers/stacks from Wisconsin, United States.*

An above ground stack with no side walls. Note stack lay out on compacted earthen pad.

Hillside pits excavated into the side of the slope. The natural slope provides adequate drainage for the open end of the pit.

A pit excavated into gently sloping site. Cut soil material has been used to raise height of the embankment, but contains rocks.

Storage systems

Silage can be stored above ground (horizontal or vertical), or in hillside pits (horizontal). The most common methods at a feedlot include hillside pits, above ground bunkers, in ground pits or trenches and stack and bale silage.

The system used will depend on cost, area available, topography, equipment available, expertise and personal preference.

Whatever the method used, the main functions are to exclude air during the ensiling process, prevent air from entering the silage during storage and minimise losses and quality problems during feeding out.

Modern technologies, such as inoculants, preservatives and oxygen-impermeable covers, can greatly reduce surface losses - irrespective of storage method.

Above ground stack (bun)

Silage stacks are for short term storage. The silage is placed on top of the ground, then compacted and covered. As there are no side walls, the height of the stack is limited and the surface area to volume ratio is higher. The greater surface area increases potential spoilage.

Stacks should be located in an area with a slight slope for drainage and away from trees to minimise potential damage from falling limbs and birds. The stack width should fit the size of the plastic cover to be used. For example, a plastic cover of 13 x 33m will allow a pile width of 9–10m to be sealed by burying, or overlapping, the edges of the sheet.

Advantages

- No material construction costs.
- Easily sealed using a grader blade or front end loader bucket.
- Removing silage from the face minimises loose silage, reducing air penetration into the bun.
- Size of bun can be adjusted to suit rate of feeding.
- Multiple separate buns can promote quality and better inventory control.

Disadvantages

- High surface area to volume ratio, thus larger area to cover and greater chance of surface spoilage.
- Can be a workplace health and safety issue for tractor operators during stack formation and compaction.
- Not suitable for long term storage, unless the cover is protected from sunlight exposure (UV degradation).

Hillside pits

Hillside pits are usually dug into the sides or tops of hills, or high embankments, with the ‘down hill’ end open for drainage and pit access. The surrounding earth provides the side walls of the storage. Earth walls should be sloped to prevent caving in and to enable adequate silage packing. Where soil is unstable, the walls may need to be lined with concrete or untreated timber.

A convenient width for unloading with a tractor and front end loader is 7m (small feedlot) to 15m (large feedlot).

Advantages

- Suitable for long and short term storage.
- Lower risk of water entry compared to in ground pits.
- Reduced area to cover compared to above ground storage with no walls.
- Can be replicated by sharing a common wall on either side.

Disadvantages

- Earth walls may become unstable if rocks or loose soil are encountered.
- Location must be planned to avoid problems with water run-off.
- Direct contact with soil generates risks of clostridia and mycotoxins.
- During unloading, any rocks picked up will damage feed mixing equipment.

Bunker storage

Bunker storages are permanent structures constructed above ground and are commonly used in flat areas. Above ground walls are constructed using concrete, earth, steel or timber and braced with timber or concrete buttresses.

Timber contacting silage should not be treated with preservatives and silage acids will corrode concrete or steel over time. Round bales lined with plastic have also been used for bunker storage walls, but this is typically a temporary solution.

Bunker storages are rectangular in shape and are open at one or both ends. Most have earth floors, but concrete flooring provides all weather access. Bunker storages must have adequate drainage.

The height and width of the structure will depend on the daily silage usage, based on the removal of the required amount of silage per day from the silage face. Generally, about 0.3-0.5m depth of silage needs to be removed from the face each time and the full face of the pit should be traversed every one or two days to minimise spoilage in the exposed face.

The height of the silage in the pit should not be higher than the extended bucket of the front end loader removing the silage in case the loader overturns, or gets buried if the silage face collapses.

Advantages

- Can be built in areas where the soil type is rocky or has a high water table.
- Is reasonably inexpensive to construct (with earth floors).
- Can be replicated by sharing a common wall on either side.

Disadvantages

- Concrete floor bunkers are expensive to construct.
- Poor compaction, or an uneven surface, can lead to water pooling where the cover meets the side walls.
- Earth walls must have stable slopes.
- Requires regular maintenance (e.g. cleaning walls, weed control and re-surfacing the base).
- Losses or wastage from silage can be caught on walls.

An above ground bunker stack with vertical concrete walls and end wall.

An above ground bunker storage with pre-cast concrete panels laid against the earth embankment. These bunkers are located next to the commodity shed for easy access.

Above ground bunker storage with gravel base and compacted clay walls. The embankments are graded to the end of the storage and the top centres are overlaid with plastic to reduce erosion from stormwater run-off.

A hillside pit with near vertical walls and covered with soil. The soil type here provides a stable and durable side wall – which may not always be the case.

Open-ended, above ground bunker with compacted gravel base and clay walls. The walls are trimmed to the design batter and base to the design grade. A flat sloping end face allows water to drain from top of wall to ground level without eroding the face.

Stretchable bag/bale storage

Stretchable bag/bale storage systems are typically temporary and used for making haylage (wilted forage that is stored at higher dry matter, see Table 1). The forage is compacted, as it is forced into a plastic cover, bag, wrap or tube which is then sealed to exclude oxygen to assist the fermentation process.

These heavyweight plastic bags are available in various diameters and lengths and offer a range of storage capacities.

Advantages

- Greatest flexibility with the storage location.
- Low capital requirement.
- Low labour requirement.
- Stronger wrapping achieved, as the bales can be wrapped multiple times.
- Relatively small face is exposed when a bale(s) is retrieved, which reduces aerobic spoilage.

Disadvantages

- Specialised wrapping machine is required.
- Spoilage can be large if care is not taken to adequately seal out oxygen during the wrapping process and during storage.
- Not suitable for long term storage, unless the cover is protected from sunlight exposure (UV degradation) and predator damage.
- Disposal of used plastic may present problems.
- Preparation costs are high due to the cost of the plastic required to seal the forage.

Location on site

At feedlots, most silage storage facilities are permanently located. General site considerations are discussed in *Section 2 – Feedlot site layout* and *Section 28 – Feed preparation and storage*. Additional factors are outlined below.

Accessibility

The storage site is usually located close to the feed processing facility/commodity shed to minimise the distance and time to travel to and from the site during feeding out.

Sufficient space, with appropriate truck turn arounds, is needed to unload delivery trucks and to transfer silage to the feed processing area.

Above or below ground constraints

Sites with above or below ground constraints should be avoided. For example, overhead powerlines pose a hazard to machinery during placement of forage and feedout. Falling limbs and bird damage to the plastic covers may be more prevalent near trees.

Topography and drainage

For bunker storages, sites with a uniform natural slope of about 2% will help to minimise the cost of earthworks, as this will direct leachate to the drainage system of the controlled drainage area.

Sites with a low gradient can be more difficult (and expensive) to design and install adequate drainage.

Stormwater run-off should be diverted away from silage storage structures. A cut-off trench should be dug around any free standing stack to collect and divert water.

Geotechnical

The physical properties of the soil at the site should be assessed to determine the suitability of the material for base and embankment construction. Further information about material suitability for protection of groundwater and trafficability can be found in *Section 17 - Pen and road surfaces* and *Section 12 – Holding pond design.* Correctly compacted clay soils (and concrete floors) can limit leachate seepage.

There should be a sufficient depth of soil to accommodate excavation (cut and fill and borrowing) requirements if any storage embankments are needed.

Groundwater protection

Storage facilities should be situated to prevent contamination of groundwater by silage leachate.

Surface water protection and flooding

Storage facilities should be situated so that silage leachate poses no risk to surface water quality and riverine ecosystems. Silage leachate contains water soluble carbohydrates, proteins, minerals and fermentation products (i.e. nutrients) and can yield a high biological oxygen demand (in the order of 12,000–83,000mg/L). The quantity of leachate produced is a function of the dry matter content of the forage ensiled, particle size of chop and the extent of compaction.

Construction

Correctly constructed storage facilities will allow better compression and sealing of silage, significantly improving quality, reducing wastage and improving storage life, while having low maintenance costs.

Materials

Various materials and construction techniques can be used to construct silage storage facilities.

Common materials for construction of side walls include concrete (pre-formed or fabricated on site), timber (e.g. railway sleepers) and earth embankments. The wall is usually reinforced, or supported by posts (e.g. steel or timber) or earth. Silage leachate is extremely corrosive and can damage concrete and steel. Adding silicon or silicate to concrete can help to protect against acidity and pitting. Asphalt may be more corrosion resistant than concrete.

The floor or base of pits and bunkers is usually compacted soil or gravel. A concrete floor reduces contamination from air and soil and reduces wastage when feeding out—but is also the most expensive option. The floor should be impermeable to prevent leachate from contaminating groundwater and should extend out beyond the bunker walls.

The gravel pavement should have a thickness of 200–300mm to support typical vehicle loadings (e.g. semi-trailer, telescopic/front end loaders) and facilitate access after wet weather.

Hillside pit with near vertical walls. Side walls that are too steep may collapse on impact of machinery, or from erosion when empty.

Rocks and tree roots in this earth bunker wall could contaminate silage and damage plastic covers.

The walls and floor of a bunker storage must be able to withstand the pressure of the compacted silage and impact of machinery during placement and feedout. A durable all-weather surface can withstand heavy point loadings and the impacts of machinery dry-steering, as well as resist corrosion from leachate.

Concrete floors need to be laid properly to ensure liquid cannot pass through - with expansion joints sealed with a flexible compound. A concrete floor should be 125–150mm thick and reinforced by 32MPa concrete to support the size and type of vehicles used and for durability.

Wall geometry

Sloping bunker walls, rather than vertical, allow more efficient compaction of forage at the edges and will increase compaction with depth.

Earth walls must be stable under all conditions of construction and operation. Some natural slopes with marginal stability can fail with relatively minor works, such as excavation or removal of vegetation.

The top and end face of earth walls should be capped by gravel to about 150mm to minimise erosion.

The chosen slope ratio will depend on the following

- Soil types and strength parameters.
- Soil layering – changes in geology of the site (e.g. soft layers).
- External loads – roads.
- Construction – the construction technique, schedule and any safety issues.
- Erosion control – particularly where sand, non-plastic silt and dispersive clays are used as embankment fill materials or found in cut slopes.

Earth walls may collapse or subside if the slope is too steep. Slope stability analysis should be carried out by a qualified and experienced geotechnical engineer.

Earth walls should be compacted using suitable soils and the wall slope (batter) cut from the compacted earthen embankment.

Most pre-cast concrete bunker walls are tapered with the bottom wider than the top for strength. Concrete walls should be reinforced according to Australian Standard AS3600-Concrete Structures and erected according to AS3850- 2003 Tilt-up concrete construction.

Table 3 provides typical floor (base) and wall construction slopes for earth, gravel and concrete silage storages. A steeper floor is required for earth floor storages to ensure leachate drains.

Table 3. Typical floor and wall construction slopes for silage storages

Floor type	Suggested slope (horizontal to vertical)
Earth floor	50:1 (2%)
Gravel/Concrete floor	100: 1 (1%)
Wall type	
Earth walls - compacted clay	1:1 (45^0) – 1:2 (65^0)
Concrete walls	1:1 (45^0) – vertical

The top of walls should drain to the feedout face with end wall bunkers or to both directions with open bunkers. The top of the wall should be graded with an even longitudinal slope of 1% (gravel) to 2% (earth) to cater for run-off from the plastic cover. The end face of the bunker wall is a steep slope that can erode and will need to be protected from erosion that may be caused by the run-off.

End wall

Bunker storages may be constructed with or without an end wall.

Advantages of an end wall include

- The ability to construct the storage into a hill.
- Forage can be delivered from the closed end and the sides.
- The walls can be driven over when the bunker is filled at that level.

Disadvantages include

- Safety concerns when working near the top of walls (e.g. tipping into the empty bunker).
- Difficulties in lengthening the bunker, if desired.

Advantages of no end wall include

- Can be filled and/or unloaded from either end.
- Self-unloading wagons can be pulled through the structure if the bunker is filled with a single product in a short period of time.
- Bunker can be lengthened more easily.

However, water can accumulate at the feedout face as the floor slopes towards one feedout face.

Drainage

The floor of a bunker storage or stack should be constructed to a finished height of 200–300mm above the surrounding natural surface level to prevent extraneous stormwater entering the storage site. The floor should be sloped towards the feedout face and collection drain with a gradient of about 1:100 and no cross fall.

Capturing and diverting leachate away from the entrance to the storage will reduce the incidence of soil and/or mud being trafficked into the storage site and contaminating the silage. A narrow (0.3–0.5m) drain should be constructed along the full width of the storage site (downslope end) to capture and direct effluent into a catch drain.

Silage stacks on the ground also require a sealed surface, with leachate directed to a collection point and correctly contained. A shallow drain around the stack will help prevent water run-off from the pad entering the stack.

Run-off from the silage cover should be prevented from flowing between the silage and bunker walls by heaping the silage above the top of the wall and by ensuring the cover extends on to the side and end walls. Run-off is directed along the top of the wall and along its length. The silage pile should be sloped towards the feed-out face of the bunker so that water flows over the plastic and onto the ground. However, this may not be necessary if there is good side slope drainage.

A poorly drained bunker floor allows leachate to remain in the bunker area. The soft floor allows ruts from machinery – exacerbating the problem.

Geometry

Review aspects of both filling and inventory management before selecting the size and number of structures to construct.

Long, deep, narrow pits are preferred over short, wide, shallow storages because these are easier to fill and compact progressively and minimise exposure to air when feeding out.

The target removal rate should be to a depth of at least 0.15m/day, increasing to 0.30m/day for unstable silages, such as maize. Removing 0.15–0.30m/day minimises aerobic spoilage, as silage is removed from the bunker, or stack, and the complete face of the silage bunker should be traversed at this depth every one or two days.

To correctly size the storage

1. Determine the quantity of silage that will be fed from the pile each day (in kilograms).
2. Determine the cross-sectional area of the feed-out face or pile by dividing the quantity of silage that will be fed from the pile each day by the density of the silage (kg/m^3) multiplied by the rate of removal (0.15m) and the number of days to transverse the face.
3. The surface area can then be used to determine a suitable width and height for the bunker or stack. For example, divide the cross sectional area by the average depth to obtain the average width.

Calculating the cross-sectional area of the feed-out face to be removed per day is outlined below.

$$\text{Area of feeding face (m}^2) = \frac{\text{Quantity of silage fed per day (kg fresh weight)}}{\text{Silage density (kg/m}^3) \times \text{Rate of removal (m/day)}}$$

For chopped silage, the bunker or stack must be at least 1.8 times the width of the machinery used to compact the silage to ensure the centre can be compacted.

Constructing several smaller pits rather than one large one can increase flexibility of silage storage, improve quality and promote good inventory control.

The top of this silage has been shaped to shed water. Whole and split tyres firmly hold the plastic cover along the length of the bunker. Note the drainage line along the top of the side wall.

The design of above ground silage stacks is similar to that of bunker structures, but the depth of the silage mass is restricted. At heights above about 3m, the base needs to be extended or the bun made longer. Selection of bun shape determines the formula for calculating capacity. Typically, buns are constructed as rectangles or trapezoids. The approach for calculating capacity and dimensions for a rectangle is the same as for the bunker.

Sealing and covering

The compacted forage must be given an air-tight seal as soon as practicable after harvesting and this must remain airtight until the bunker or stack is opened. Poor sealing results in degraded silage (with mould, nutrient loss, heating and odour), increased loss and the potential development of poisonous microtoxins.

After compaction, the top of the silage should be shaped to shed water.

Covering during bun/pit filling and compaction significantly reduces formation of a cap (a layer of degraded silage on the outside of bun/pit). Combination covers such as Silostop™ (an oxygen-impermeable film), protected by heavy UV-resistant shade cloth or plastic, are ideal for sealing silage and preventing oxygen penetration during ensiling and feedout.

Covers should be weighted down using tyres, tyre beads or sand bags, rather than soil that could contaminate the silage with clostridia bacteria and mycotoxins.

Forage in pits should be stacked higher than the sides and the cover should extend and be secured over the sides.

Old silage covers may be used to create 'sausages' containing dirt, sand or small gravel and these can be laid in overlapping rows along the edges of the cover and in rows across the surface of the cover.

Tyres are commonly used to hold down plastic tightly against the silage and are easier to handle. Tyre sidewalls are lighter and easier to handle than whole tyres and do not collect rain, insects, spiders, vermin or snakes. When an oxygen-impermeable film is not used, tyres need to be laid so they touch one another to seal the plastic to the silage and minimise air spaces.

Covers should be inspected regularly and any holes repaired using specifically designed tape. The edges of a bunker storage must be kept sealed, as shrinkage leaves a space along the walls.

Walls, floors and drainage channels of bunkers should be cleaned when the bunker is empty and any cracks, corrosion or other faults mended before refilling.

Safety

Signage should be used to alert people of the dangers of approaching the storage (e.g. steep earth walls that may collapse after silage removal, limited visibility of the machinery operator when stacking/compacting or removing silage and falling hay bales).

Safety rails along the tops of bunker back walls will reduce the risk of machinery wheels dropping off the edge when rolling silage.

Any excavation during construction of silage storages can create safety issues for the machinery operators and workers. Check with Workcover or the relevant State authority to ensure the proposed design, construction and management of the silage storage complies with State and Commonwealth regulations.

Packing silage too high in the pit can lead to a front end loader overtipping or being buried when removing silage for day-to-day feeding.

Tyre sidewalls used randomly to hold down plastic do not hold water or harbour vermin.

Silage pits should be situated in the CDA so that leachate can be directed and retained in the effluent drainage system.

Quick tips

- A range of systems for storing silage have advantages and disadvantages - and wide ranging capital costs.
- Select the system based on cost, available area, topography, available equipment, volume of silage to be used, expertise and personal preference.
- Access (traffic flow, unload/feed-out) and site suitability (topography/drainage, soil type) are key site selection factors. Permanent structures are costly to relocate.
- Allow additional area for potential expansion.
- Floors of bunker storages or pits need to be graded and compacted for good drainage and constructed to minimise risk of silage leachate contaminating groundwater.
- Earth walls must be stable under all conditions of construction and operation. Seek professional advice from a suitably qualified geotechnical engineer to guarantee the structural integrity of the proposed design, especially those involving above ground concrete or earth walls.
- Long, deep, narrow pits are recommended compared to short, wide, shallow storages because they are easier to fill and compact progressively - and minimise exposure to air when feeding out.
- Determine the width of the bunker or pit by calculating the cross-sectional area of the feed-out face and design height of the pile.
- After filling and compaction, shape the top of the silage in a bunker to shed water after the silage has settled and been covered.
- Weigh down plastic covers over the top of the pile with tyres, tyre side walls or sand bags to seal the silage. Tyre sidewalls are lighter and easier to handle than whole tyres.
- Bury the edges of covers on stacks in the ground to ensure an air-tight seal.
- Slope the length of earth embankments to the open end of the bunker or pit to direct stormwater run-off away from the pile. Erosion control may be required where dispersive clays are used, as embankment fill materials or found in cut slopes.

Further reading

Dairy Australia Online Publications – Pastures, Forages and Crops Section *http://www.dairyaustralia.com.au/Animals-feed-and-environment/Feeding-and-nutrition/Pastures-forages-and-crops.aspx* (accessed 10-10-2012)

Kaiser, A.G. et al. 2003, Successful Silage, New South Wales Department of Primary Industries, Orange, New South Wales, ISBN 0734715835.

Standards Australia, 2009, AS3600-Concrete Structures

Standards Australia 2003, AS3850- 2003 Tilt-up concrete construction

Successful Silage Manual – Appendix 9 discusses how to diagnose and rectify spoilage losses in forage harvested and baled silages

University of Wisconsin Extension Services provides several downloads (PDF and MS PowerPoint presentations) with information on harvesting and storing forages. *http://www.uwex.edu/ces/crops/uwforage/storage.htm* (accessed 10-10-2012)